MH/NCN - 1031

Manitoba Hydro

EXHIBIT #
WUSKWATIM GENERATION
& TRANSMISSION PROJECT
CLEAN ENVIRONMENT COMMISSION

4/2/2004

Clarification of Wind Turbine Cold Weather Considerations: Manitoba Hydro Summary

There are cold weather issues which must be addressed when evaluating wind generation in climates such as that of Manitoba. These issues can largely be mitigated through the purchase of a cold-weather package. Manitoba Hydro is confident these issues can be accommodated and managed (i.e. backed-up) through the flexible operation of the Manitoba Hydro hydroelectric system and that wind generation is technically viable in Manitoba. Manitoba Hydro anticipates that wind generation ultimately will be economically and financially viable and thus includes 250MW of wind generation in its plans.

This page briefly summarizes cold-weather operation issues associated with wind turbine generators. A more thorough discussion is presented in the attached "Clarification of Cold Weather Considerations – Overview" and in the reference materials provided.

1. All wind generators have an operating and standstill (non-operating) minimum temperature limit. This limit is specified by the manufacturer and is required to ensure the safe and reliable operation of the equipment with acceptable loss of equipment life.
2. Typical minimum operating temperature of a utility-scaled wind turbine generator for the standard package without any special temperature package is -20°C with a standstill temperature of -30°C.
3. It is possible to decrease the operating temperature limit through the purchase of a cold weather package whereby the utility-scale wind turbine generator is typically capable of operating to -30°C and at standstill temperatures as low as -40°C. With additional measures, it is possible to decrease the temperature limit further.
4. Determination of the cost/benefit of a cold weather package must be analyzed on a site by site basis including factors such as 1) the cost of the cold-weather package; 2) the amount of the wind resource at the colder temperatures; and 3) the value of the need for availability of turbines at those temperatures. For operation below temperature of -30°C typically wind speeds are low and therefore performance at these temperatures likely would not improve the economics of the wind farm significantly, but would add a cost to the turbine itself.
5. Whether the wind farm is not producing electricity because of exceeding the minimum temperature limit or because of low wind speeds especially during cold temperatures, an external station service electrical supply is required for the wind farm. It is estimated that for the 99MW St. Leon Project, the wind facility would require 1 to 3 MW of station service supply from the Manitoba Hydro system during periods of low temperature when it is not operating.
6. At low temperatures, the air is denser and thus for the same wind speed more electricity can be generated by wind turbines. But this higher air density benefit is not sufficient to offset the lower wind speeds that tend to occur at low temperatures.

Despite the considerations necessary with respect to cold weather operation, Manitoba Hydro plans to develop or purchase 250MW of wind generation in Manitoba in the next 5-10 years. Manitoba Hydro intends to continue to pursue developments of wind energy and, with improved knowledge of the wind generation related system limitations and potential for the hydroelectric system to support and backup wind generation, will consider implementing additional capacity above the 250MW currently in the 2003/04 Resource Plan.

Manitoba Hydro 4/2/2004

Clarification of Wind Turbine Cold Weather Considerations - Overview

The following information provides background information regarding cold weather operation of utility-scale (1-2.5MW) wind turbines.

1. Utility-Scale Wind Turbine Cold Temperature Minimum Operating Limit:

All wind turbine manufacturers specify temperature operating limits for their equipment. One of these operating limits is a minimum ambient temperature below which operation is stopped and this is necessary due to the characteristics of the materials and lubricants used in the wind turbine. Materials and lubricants are designed to withstand temperatures within their specified ranges and when temperatures exceed those ranges, increased maintenance may be required, accelerated loss of equipment life will occur and damage to equipment may result.

2. Utility Scale Wind Turbine Minimum Operating/Standstill Temperatures:

Manufacturer's specified normal ambient minimum operating temperature of a typical utility scale turbine:

a. GE Turbine (1.5MW, 1.5S/SL):	-20°C
b. Vestas Turbine (1.8MW, V80/V90):	-20°C
c. NEGMicon Turbine (NM72/82, 1.65MW):	-20°C
d. MHI (Mitsubishi) (1MW, 1000/1000A):	-20°C
e. Enercon (all models ≥300kW)	-20°C
f. Gamesa (850kW, G52, 1.8MW,G80):	-20°C
g. Bonus (1.3MW,1.3):	-10°C

The standstill temperature refers to the temperature the turbine can withstand while not operating. This temperature reflects a limit on the turbine material's ability to withstand stress without exceeding normal or acceptable wear and tear. Most manufacturers' minimum specified standstill temperature is -30°C.

3. Utility Scale Wind Turbine Minimum Operating/Standstill Temperature with Cold Weather Package:

Manufacturer's specified minimum ambient operating/standstill temperature of a typical utility scale turbine with a Cold Weather Package:

	Operating	Standstill
a. GE Turbine (1.5MW, 1.5S/SL):	-30°C	-40°C
b. Vestas Turbine (1.8MW, V80/V90):	-30°C	-40°C
c. NEGMicon Turbine (NM72/82,1.65MW):	-30°C	-40°C
d. MHI (Mitsubishi) (1MW, 1000/1000A):	-40°C	N/A
e. Enercon (any product):	*	N/A
f. Gamesa (G52/G80):	-30°C	N/A
g. Bonus (1.3MW, 1.3):	*	N/A

* Bonus and Enercon evaluate operating temperature limits by project.

Typical Cold Weather Package:

a. Lubricant heaters (usually in gearbox)
b. Additional generator heaters
c. Control cabinet heaters
d. Nacelle space heaters

e. Ice detector
f. Heated anemometry
g. Special alloy ductile iron for hub and machine frame
h. Special alloy tower steel
i. Improved nacelle sealing
j. Low temperature lubricants
k. Anemometer and weather vane equipped with heaters

There are several cold weather packages for small wind turbine applications which are currently operating in northern regions. Examples of this are:

Yukon:	1 x Bonus 150kW installed in 1993 (-30°C, operating) 1 x 660kW Vestas V47 LT II installed in 1999 (-30°C, operating)
Alaska (Kotzebue)*:	10 x 66kW AOC 15/50 cold weather package (-40°C to 40°C, operating) 1 x 100kW Northwind (Northern Power Systems) (-46°C to 50°C, operating)

* These turbines are not available in utility scale versions.

4. Economics of Cold Weather Package:

According to Helimax, wind energy consultant for Manitoba Hydro, the cold-weather package costs typically range between 2.5 – 5% of the capital cost of the wind turbine. As an example, Vestas has provided a cost of $25,000/ turbine which for a 100MW wind farm, would cost an additional $1,650,000 for the cold weather package. Operating and maintenance (O&M) costs would also be slightly higher then for a normal operating temperature range.

As provided from Helimax, based on wind data from Manitoba Hydro's monitoring site near St.Leon, there were two days for the period of winter 2003/04 where the average ambient daily temperature fell below -30°C; these days were the Manitoba load peak for the year. The wind speeds during these low temperature days were relatively low (approximately 10% of maximum wind turbine capacity.) Additionally there were 10 separate days in the winter 2003/04 period where the ambient temperature was -30°C or below (for a 102 hours in total).

5. Station Service Requirements:

For example, utilizing the NEGMicon-NM82 turbine (the turbine chosen for the Bison wind farm at the St.Leon site), the station service requirements for the 1.5MW wind turbine during winter months (where temperatures require turbines to shutdown) is 47.35kW. Therefore for a large wind farm of 100MW (66 – 1.5MW turbines) this would equate to a winter station service size of 3.1MW.

7. Cold Climate Issues:

a. Low temperature: Affects materials, lubricants, electrical equipment and controls. During low temperatures, steel becomes more brittle resulting in its energy absorbing capacity and deformation being reduced which can result in failure. Additional stress on composite materials, i.e. blade materials, can result in microcracking in the material. Power applied to electrical equipment at cold temperatures can cause windings to suffer thermal shock and become damaged.

b. Icing:
This is the major operational issue as icing affects rotor performance, rotational stability, and instrumentation reliability. (Icing on the anemometers affects the reliability of the wind speed indication and leads to underestimation of wind speed at hub level.) There is also a safety issue as ice fragments can be propelled from the blades. Note that the St.Leon Area is within Manitoba's prime icing area.

A utility scale wind turbine in a cold climate faces specific operating limitations not encountered in more moderate climates. Although small turbines have operated successfully in artic conditions, the effects of cold climate operation are magnified by scale for large turbines since doubling the physical size quadruples the material stresses. It is generally uneconomic to build utility-scale wind turbines to operate < -30°C.

7. Current Research Initiatives

International Energy Agency (IEA) has implemented a new annex – Wind energy in Cold Climates to address the sites that have icing events or temperatures outside the normal operating conditions of standard wind turbines. Website: http://ardticwind.vtt.fi/

Reference Material

International Energy Agency – IEA (2003) State-of-the-Art of Wind Energy in Cold Climates, website: http://arcticwind.vtt.fi/

Renewable Energy Research Laboratory – (2000) Wind Energy: Cold Weather Issues, website: http://www.ecs.umass.edu/mie/labs/rerl/research/Cold_Weather_White_Paper.pdf

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NEGMicon product specification (2003), Item#C72/82-0124, NM72/82 Arctic Specification

GE product brochure (2003), 1.5sl/1.5s wind turbine

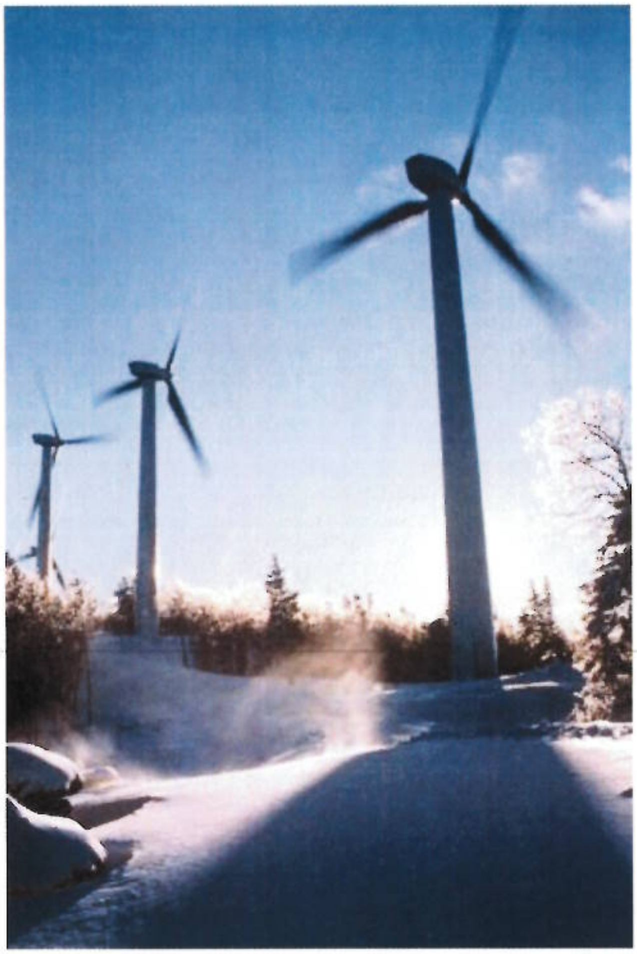
Northern Power Systems product overview (2003), NorthWind NW100/19 wind turbine

SaskPower Cypress Hill brochure (2003), Cypress Wind Power Facility, website: www.saskpower.com

Helimax Energy Ltd, memo to Manitoba Hydro on cold weather operation, March 17, 2003

Global Energy Concepts LLC, memo to Manitoba Hydro on cold weather operation, March 16, 2003.

Wind Energy: Cold Weather Issues



Presented by:
Antoine Lacroix
Dr. James F. Manwell

University of Massachusetts at Amherst
Renewable Energy Research Laboratory
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TABLE OF CONTENT

TABLE OF FIGURES

1. Introduction

As the environmental matters become more important and as the world is striving to find cleaner sources of energy, the portion of electricity that is wind generated is likely to increase substantially every year. However, harnessable winds are sometimes located where the climate is inclement for a substantial part of the year. Indeed, areas such as New England and the Mid-West have long been identified for their wind energy potential but partly because of harsh winter conditions, have not seen many wind farms being commissioned.

Until recently, most large-scale wind energy development took place in regions where cold weather was not a major concern, most notably California. More recently, wind energy development has begun to occur in colder regions. Thus, many developers and manufacturers are beginning to gain more cold weather operating experience. Much of that information is not publicly available and in any case, not all of the issues that have been encountered have been completely resolved. The wind farm developer is therefore confronted with a lack of information when planning wind farms in a cold weather environment.

This paper provides an overview of the issues affecting wind turbine operations in cold weather with a special emphasis given on atmospheric conditions prevailing in the Northeast United States. The first section describes previous and more recent wind energy projects in cold weather areas. In the second section, environmental elements most likely to impact on the operation of wind turbines in cold weather are introduced: low temperatures, icing and snow. It also presents various climatic situations and their specific behavior in cold weather. The third section suggests some solutions to problems identified in the previous section. In addition, this paper suggests ideas of further research on the operation of wind turbines in cold climate. It also identifies organizations interested by similar issues whose cooperation would be beneficial.

2. Previous Experience

The first wind turbine to be grid-connected in America was built more than fifty years ago in Vermont. It was located on Grandpa's Knob near Rutland and began feeding the grid for the first time in October 1941 (Putnam, 1948). It is interesting to note that early in the design process, the concern about cold weather, especially icing was very present. Indeed, the selection of Grandpa's Knob was based on the fact that a lower elevation mountain would represent a reduced risk of heavy ice accumulation. The designers wanted to eliminate any possibility of structural failure, which would have resulted in the end of the project. So the choice of Grandpa's Knob was made in spite of superior wind resources available on mountains with higher elevation. The next attempts at grid-connected wind turbines in New England were made during the 1980's in New Hampshire and Vermont at Crotched Mountain and Mt. Equinox respectively. It is fair to say that the difficult winter conditions are partly responsible for their short duration. Note, for example, the accumulation of ice on the turbine shown in figures 1 and 2. During these years, however, some experience was acquired in small wind energy conversion systems. This type of machinery was often installed to provide power for scientific camps, communication relays or meteorological stations in Antarctica and other desolated areas.

More recently, wind turbines have been installed in areas where cold weather conditions exist. In the Midwest, especially in Minnesota and Iowa, glaze ice and snow can be expected (AWEA, 2000). In Vermont, a wind farm has been built in a mountainous domain where rime ice is likely to occur. Europeans have installed wind farms in Scandinavia, the highlands of Germany, Austria and the Alps (Seifert and Tammelin, 1996). Conditions like rime and cold temperatures are likely to be found in these regions. A series of conferences were held in Finland to address these issues and other aspects of wind energy in cold weather such as resource assessment.

3. Cold Weather Issues

There are three general issues important to the operation of wind turbines in cold weather. These issues could be classified under three categories:

- the impact of low temperatures on the physical properties of materials
- the ice accretion on structures and surfaces
- the presence of snow in the vicinity of a wind turbine

Cold weather operation of wind turbines require that these issues be examined in the design or at least in the phase preceding the installation of the turbines in their working environment. Not doing so would mean prolonged period of inactivity required for safety purposes or because turbines inability to perform satisfactorily.

3.1 Low Temperatures

Low temperatures affect the different materials used in the fabrication of wind turbines, usually adversely. Structural elements such as steel and composite material all see their mechanical properties changed by low temperatures. Steel becomes more brittle; its energy absorbing capacity and deformation prior to failure are both reduced. Composite materials, due to unequal shrinkage of their fiber/matrix components, will be subjected to a residual stress. If this stress is sufficient, it can result in microcracking in the material. These microcracks reduce both the stiffness and the impermeability of the material, which can contribute to the deterioration process (Dutta and Hui, 1997).

Low temperatures can also damage the electrical equipment such as generators, yaw drive motors and transformers. When power is applied to these machines after they have been standing in the cold for a long period, the windings can suffer from a thermal shock and become damaged.

Gearboxes, hydraulic couplers and dampers suffer from long exposure to cold weather. As the temperature goes down, the viscosity of the lubricants and hydraulic fluids increases up to a point where at -40° F, a chunk of heavy gear oil could be used to pound nails (Diemand, 1990). Damage to gears will occur in the very first seconds of operation where oil is very thick and cannot freely circulate. In addition, due to an increase in internal friction, the power transmission capacity of the gearbox is reduced when the oil viscosity has not reached an acceptable level.

Seals, cushions and other rubber parts loose flexibility at low temperatures. This may not necessarily result in part failure but can cause a general decline in performance. A typical rubber part can see its stiffness augmented by a factor of 8 at a temperature of -40°F (Brugada, 1989). Brittleness also increases which changes impact resistance and makes the part prone to cracking (Brugada, 1989).

3.2 Icing

Icing represents the most important threat to the integrity of wind turbines in cold weather. Based on the duration of inoperative wind measuring equipment at one surveyed mountain in western Massachusetts, it was determined that icing weather can occur as much as 15% of the time between the months of December and March (Kirchhoff, 1999). Wind turbines must therefore be able to sustain at least limited icing without incurring damage preventing normal operation. Furthermore, it is advisable that power production be maintained in moderate icing for the following reasons:

- To minimize downtime period and benefit from the more favorable winter winds
- To keep the rotor turning and therefore limit the ice growth to leading edge part of the blade that is likely fitted with some ice protection equipment

The icing likely to form on wind turbine blades is of two kinds: glaze and rime. Glaze ice is the result of liquid precipitation striking surfaces at temperatures below the freezing point. Glaze is rather transparent, hard and attaches well to surfaces. It is the type of icing encountered during ice storms. New England and especially Massachusetts is an area of high occurrence for glaze storms as confirmed in Figure 3. A study covering a period of fifty years of glaze precipitation in the United States conducted by Tattelman and Gringorten supports this claim. They have established the probability of an ice storm of thickness greater or equal than 0.63 cm for the Pennsylvania, New York and New England regions during one year to be 0.88, i.e. almost once per year.

Rime ice occurs when surfaces below the freezing point are exposed to clouds or fog composed of supercooled water droplets. Its white and opaque appearance is caused by the presence of air bubbles trapped inside. Rime ice is of primary importance in high elevation locations such as hills or mountaintops. Figure 1 and 2 show how severely can a wind turbine be affected by rime ice.

Figure 1. Severe rime ice accretion on a US Windpower 56-100 turbine installed on Mt. Equinox Vt. Note the magnitude and extent of the ice coverage. (University of Illinois at Urbana-Champaign, Dept. of Aeronautical and Astronautical Eng.)

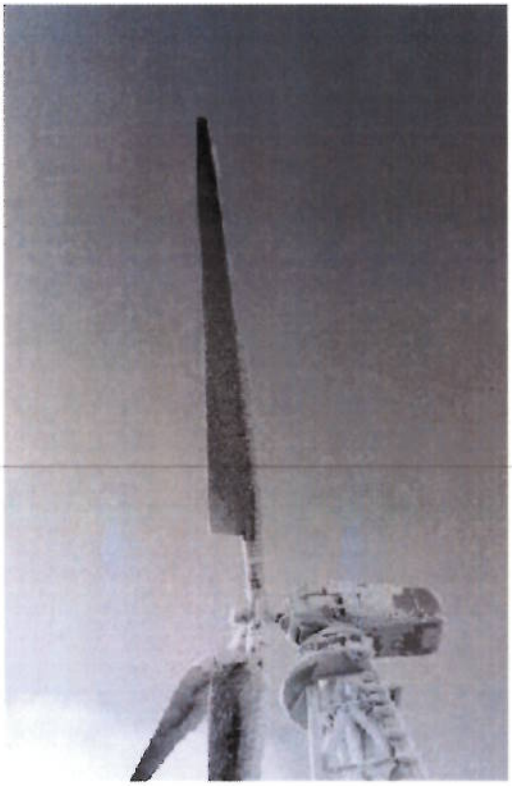

Figure 2. Same as Figure 1 showing a close-up view of the rotor and nacelle. (University of Illinois at Urbana-Champaign, Dept. of Aeronautical and Astronautical Eng)

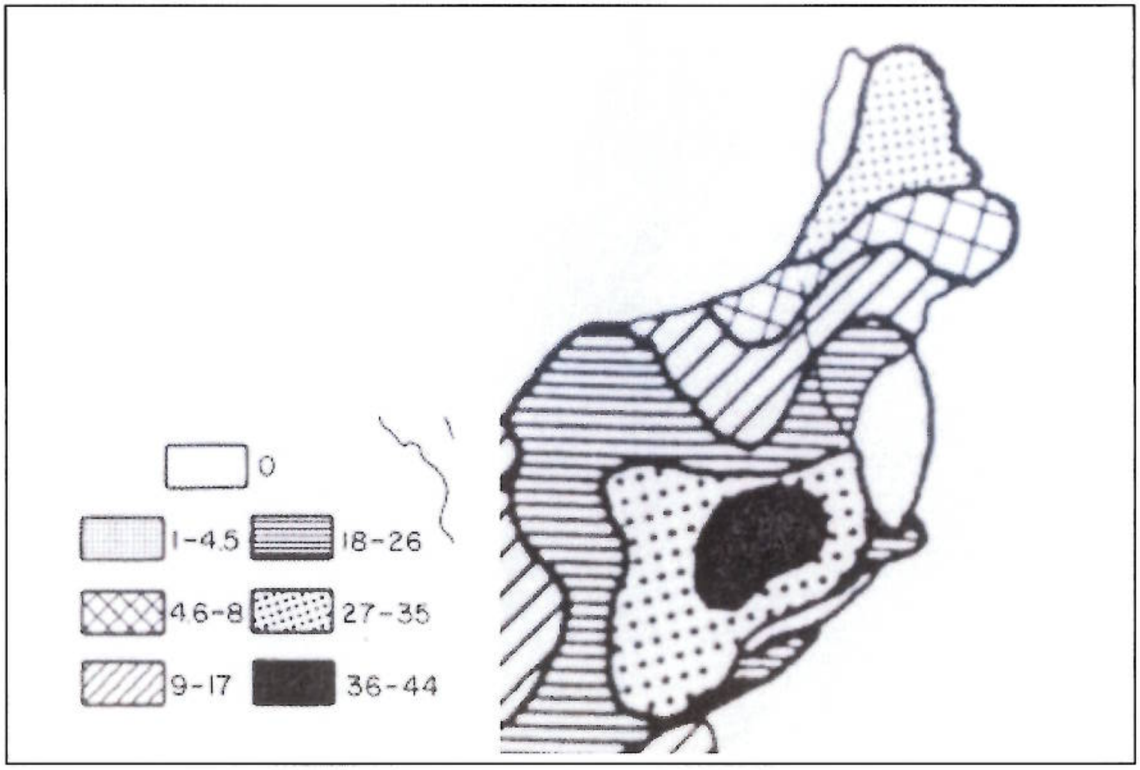

Figure 3. Total number of glaze storms, without regard to ice thickness, observed during the 9-year period of the Association of American Railroads study (undated) (Adapted from Bennett, 1959)

Ice collects on both the rotating and non-rotating surfaces. The most adverse effect of icing occurs on the rotor itself. Its consequences on the rotor are the following:

- Interfere with the deployment of speed limiting devices such as tip flaps or movable blade tip
- Increase the static load on the rotor
- Change the dynamic balance of the rotor, thereby accelerating fatigue
- Reduce the energy capture by altering the aerodynamic profile of the rotor
- Ice fragments can be propelled and represent a safety hazard for population and property in the vicinity of wind turbines. Larger chunk can also strike the rotor and damage it.

Ice also accumulates on fixed structures such as nacelles, towers and ladder, making periodic maintenance more difficult by preventing easy access to turbine components. It can interfere with the normal functioning of pitch control and orientation mechanisms. Finally, the presence of ice on structural elements increases both the static loading and the wind loading due to an augmentation in surface area.

3.3 Snow

Due to its very low specific gravity, snow is easily carried by wind. It can infiltrate almost any unprotected openings where an airflow can find its way. Wind turbine nacelles, i.e. the housings that contain the gearbox and the generator, are not necessarily airtight compartments. In fact, they incorporate many openings in order to provide a supply of fresh air for cooling purposes. Hence, snow can accumulate inside the nacelle and damage the equipment. This could prove very detrimental for the electrical machinery. On the other hand, snow could also obstruct these openings and prevent normal circulation of air. It is suggested to use deflectors or baffles in order to keep these openings free of obstruction.

3.4 Climatic Type

3.4.1 Polar Weather

Locations where wind turbines have supplied energy for many years are the remote sites of Arctic and Antarctica. Small units are used to power radio relay stations, expedition base and navigational aids. The abundant wind supply makes them ideal and very cost-effective sources of energy for these areas. The climatic conditions are more characterized by the extreme low temperatures than by precipitation of any kind. Therefore, the major meteorological concern associated with the polar weather is the severity of the low temperatures that generally degrades the stiffness and toughness properties of materials.

3.4.2 High Elevations

In the Northeastern U.S., the most suitable sites for wind turbines are frequently mountains or ridgetops. These also are areas where wind turbines are more susceptible to rime ice due to the relative proximity of low-level clouds. Bailey (1990) suggests that during cold weather at altitude about 2300 ft, rime ice can be expected approximately 10% of the time. This figure jumps to 20% for altitude above 3000 ft.

3.4.3 Lower Elevations

The type of meteorological hazard most likely to happen at lower elevations is glaze ice. Bailey (1990) suggests that glaze ice events are of short duration and light in intensity but the January of 1998 northeast ice storm proved otherwise. One could only observe the magnitude of the damages inflicted to trees and power lines. It could also suggest that the weather patterns are changing and become more dependent on global meteorological phenomena.

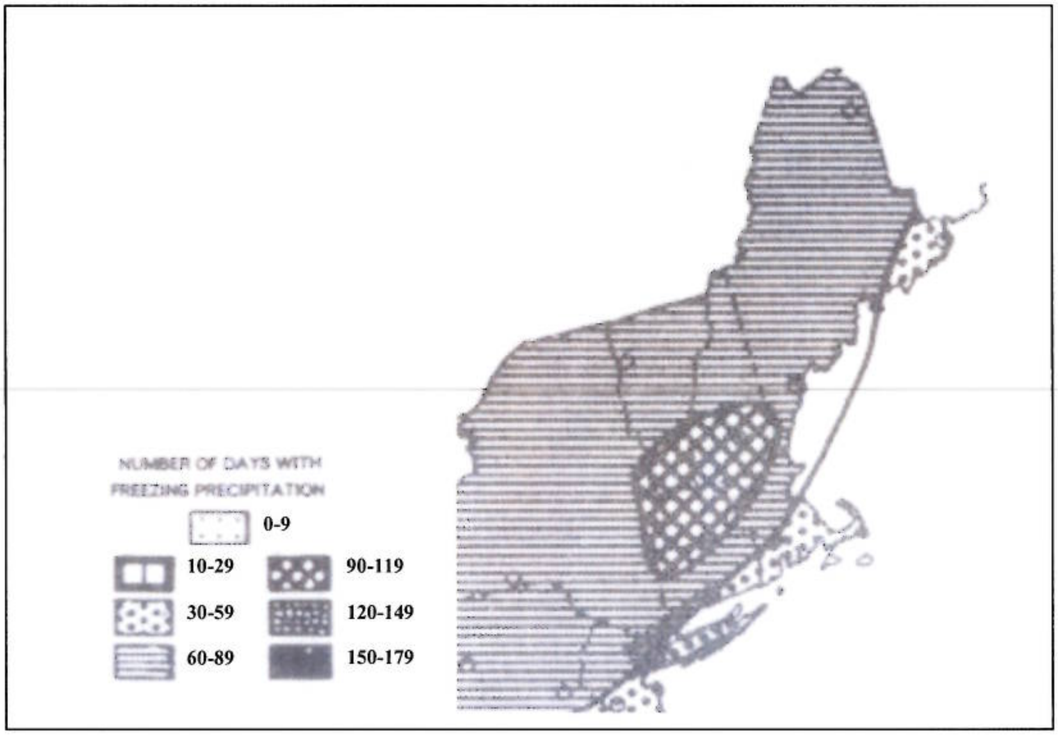

Figure 4. Total number of days with freezing rain or drizzle in the 10-yea period from 1939 to 1948. Based on data from 95 Weather Bureau stations (Adapted from Bennett, 1959)

4. Proposed Solutions

Some solutions are already known for cold weather wind turbine operations. In fact, they are the same as any other cold weather engineering applications. This is especially true for materials and other elements whose low temperature behavior is well understood. For instance, the service conditions of a steel tower will determine the type alloy used in its fabrication. This is similar for lubricants; the application it will serve and the outside temperature will dictate the choice of a specific lubricant.

4.1 Low temperatures

Metals have found applications in low temperatures for many years now. For instance, it is well documented that alloys such as nickel and aluminum improve the strength of steel at low temperatures. Aluminum itself is also very suitable for these applications. Composite materials are fairly new and have not found low temperatures widespread applications. Dutta (1989) indicates that technologies that have done well in warmer climate sometimes behaved disastrously in low temperatures. His investigations of composite materials in low temperatures do not suggest a way to prevent unequal shrinkage and residual stress inside the fiber/matrix element. One way to prevent this would be to use fiber and matrix that exhibit similar thermal expansion coefficients.

Preventing thermal shocks on electrical machinery windings could be accomplished by locating heaters inside the nacelle. Prior to turbine activation, these heaters could be operated to provide quick warm up and allow windings to reach an operational temperature.

Heating elements, used as is or with a circulating oil pump, could be added to gearboxes in order to improve the viscosity of the lubricants. A lower viscosity lubricant could be used to facilitate the cold start but this could offer less protection when the normal operating temperature is reached. Another suggestion would be to slowly start the turbine drivetrain and do not apply full torque until a safe lubricant temperature is reached. This could prove to be very impractical considering normal wind turbine start up procedures, however.

Selection of appropriate rubber will insure that seals and other rubber parts retain their elasticity and prevent their brittleness at low temperatures. It is suggested to use special nitride rubber or fluorosilicone materials (Soundunsaari and Mikkonen, 1989).

4.2 Icing

Wind turbine icing has received a lot of attention in the recent years. As wind energy was developing in Scandinavia and in the highlands of Germany, icing was quickly identified as an area of uncertainty. Hence, research has been undertaken to identify and model the type of icing wind turbines would be subjected to. Efforts have also been done in the area of icing prevention technologies. They can be classified in two categories: active and passive.

Passive icing prevention methods rely on the physical properties of the blade surfaces to prevent ice accumulation. An example of passive icing prevention is the application of an anti-adhesive coating on the blade such as teflon. Another approach takes advantage of the heat absorbing capacity of dark colored surfaces and consists in the use of black coated blades. This technique was used on the eleven wind turbines that were erected in Searsburg VT in the summer of 1997.

Figure 5. Searsburg turbines use black blades to prevent ice accumulation. Note the layer of ice along the blade leading edge. (National Renewable Energy Laboratory)

Active de-icing methods have also been investigated. They come directly to us from the aeronautical industry. They consist of thermal, chemical and impulse de-icing. In thermal de-icing, electrical elements, similar to the one found on the rear window of a car, can be used to warm and melt the ice accumulation off the blades. Existing research in wind turbine active icing prevention has focused on thermal de-icing. Based on early work in Europe, Jasinski et al. (1998) indicate that thermal anti-icing requires an amount of heater power equal to at least 25% of the turbine maximum rated power. Recent work conducted in Europe indicates that the early estimate in anti-icing power requirement can be revised down. They now claim that the power requirement ranges between 6 to 12% of the output for 1000 to 220 kW turbines respectively.

In a comprehensive wind turbine icing prevention approach, sensors that could detect the build-up of ice on the rotor could be considered. Such devices already exist for the aeronautical industry. They consist of detection sensors and a control unit. The control unit processes signals received from the sensors and activates the ice removal mechanisms. A similar system could be adapted to work on wind turbines and insure automatic de-icing operations.

5. Recommendations

Wind turbines installed in New England should have demonstrated capabilities to operate and/or survive under cold weather conditions. This includes low temperatures, icing and snow. Studies to monitor the impact of these factors, especially icing, on the operations of wind turbines should be undertaken.

Representative of Massachusetts should participate in international activities regarding the identification and amelioration of cold weather related problems on wind turbine operations. Members of the Massachusetts energy community should establish working relations with groups and organizations already involved in cold weather issues. These include:
CRREL –The U.S. Army Cold Regions Research and Engineering Laboratory; Hanover, N.H.

Wind turbine operators
Green Mountain Power – The Vermont utility operates a 7.5 MW windfarm near Searsburg VT since 1997.

IREQ – Hydro-Québec Research Institute; Varennes, Québec

European nations that are involved in wind energy research:
JOULE III Wind Energy in Cold Climate (WECO) Project, co-funded by the European Commission – The BOREAS Conferences

VTT Energy - The leading institute in research on wind energy in Finland
FMI Energy – The Finnish Meteorological Institute
DEWI – Deutsches Windenergie-Institut

Additional research should be carried out on icing and its effects on wind turbine operations. The following subjects could be of interest:

- The long term effect of icing, especially on blade fatigue

- Is the blade more prone to collect ice when at rest or when running, the answer could be different whether glaze or rime ice is involved
- The ice collection pattern, is it similar to aircraft icing or is it more random in shape?
- What part of the blade is more prone to icing, the root or the tip?
- What is the energy loss associated with icing?

So far, the research in icing seems to have focused on rime ice. This is due maybe because this is a better understood phenomena and also this is the sort of icing occurring where icing on wind turbine is a concern and where research has begun on this subject. Available weather data suggest that this is not necessarily the type of icing most likely to occur in the lower elevations of New England. Therefore, documenting glaze ice on how it forms, its occurrences throughout New England and its impact on the utilities among others, is something that seems valuable to undertake.

An investigative effort could be done in the area of ice monitoring. For instance, the anemometer stations could also be fitted with icing detectors to evaluate the duration of each icing episode and the total number of hours during a season. Although there are different types of ice detectors available, their general operating principle is the same: they sense a change in properties resulting from an accumulation of ice. Some work by detecting the frequency variation in a sonic or vibratory wave while others monitor the capacitance between metal strips. The Rosemount ice detector uses the frequency shift principle (Ryerson, 1988). Researchers from CRREL have used it to study the ice growth on the summit of two New England mountains.

6. Conclusion

The most favorable areas for the production of wind energy are often located where the climatic conditions are severe and unpredictable. In order to improve the performance of wind turbine in this environment, some issues need to be examined carefully.

The issue of low temperatures can be addressed by making sure that the turbine is designed appropriately. The technology is available and has been used for other applications of engineering in cold weather. A problem like icing deserves further investigation. Work in the areas of ice detection, prevention and removal could significantly improve the dependability of wind turbines in cold weather.

Other groups in North America & Europe operate wind turbines in conditions similar to New England. Some have accomplished work in areas that are compatible with our objectives. Cooperation with these organizations is suggested. This would contribute to improve our level of expertise and inform us of the evolution of the technology.

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Cypress Wind Power Facility

Generating capacity	5.9 MW
Mean annual output	20 million kW.h
Mean annual wind speed	32 kilometres/hour
Wind turbine characteristics	
Manufacturer and model	Vestas V47 – 660
Rated output	660 kW
Rotor diameter	47 metres
Blade length	23 metres
Number of blades	3
Rotor speed	28.5 revolutions/minute
Generator speed	1800 revolutions/minute
Operational wind speed	15 - 90 kilometres/hour
Steel support towers	
Height	50 metres
Diameter at base	3.8 metres
Diameter at top	2 metres
Foundations	
Depth	7.6 metres
Diameter	4.4 metres
Anchor bolts	
Number of anchor bolts	80
Length	7.9 metres
Diameter	35 millimetres

Glossary

Kilowatt (kW)

A unit of bulk power: 1,000 watts.

Kilowatt hour (kW.h)

A unit of bulk energy: 1,000 watt hours. The measurement is generally used for billing residential customers.

Megawatt (MW)

A unit of bulk power: 1,000 kilowatts. The unit generally used to describe the ouput of a commercial generator.

Kilovolt (kV)

A unit of pressure, or push, of an electric current: 1,000 volts.

POWERING SASKATCHEWAN

History of the Facility

An initial wind resource assessment in 1993/94 identified the area around Gull Lake as one of the windiest locations in Saskatchewan. More recently, computer modeling of the wind regime in southwestern Saskatchewan and other relevant information for siting wind plants identified several candidate sites for wind power development.

Four of these sites were chosen as preferable locations and evaluated for six months with wind monitoring towers. Based on the resulting wind data and an assessment of grid interconnection costs, the Cypress site was chosen for the project.

SaskPower carried out an environmental assessment and in July 2002, construction began at SaskPower's Cypress Wind Power Facility. At peak capacity, the facility can generate up to 5.9 MW of electricity, utilizing nine wind turbine generators.

The Cypress Wind Power Facility is an important part of SaskPower's plans to help meet the province's growing energy needs while minimizing our impact on the environment.

Our Commitment to Safety

Safety is a top priority at SaskPower and the responsibility for doing business safely is shared by employees across the corporation.

Our Commitment to Environmental Responsibility

Wind power generation represents an exciting opportunity for SaskPower to harness the power of prairie winds, providing electricity without generating greenhouse gas emissions. Electricity from wind power is clean, renewable and inexhaustible.

SaskPower continues to work to minimize the environmental impacts associated with the generation and delivery of electrical energy to our customers. We are committed to sharing the long-term responsibility of a clean, safe and biologically diverse environment for future generations.

ISO 14001 Registered

We achieved a significant environmental milestone in 2000 when we became the first electric utility in Canada and the first major business headquartered in Saskatchewan to achieve corporate-wide ISO 14001 registration, an international measure of excellence. This leading environmental management system will enable us to better assess and control the environmental aspects of our business.

SaskPower

saskpower.com

CYPRESS
WIND POWER FACILITY

SaskPower

WELCOME TO SASKPOWER

The location for the Cypress Wind Power Facility was chosen based on wind characteristics of the area, as well as proximity to the electrical grid, road access and land availability.

Control and Transmission

Each of the nine wind turbines at the Cypress Wind Power Facility is connected via an underground cable to overhead 25 kV distribution lines, which connect to the province-wide electrical grid. Since the wind power is fed into SaskPower's overall power supply, there is a seamless flow of electricity to homes and businesses, no matter how strong the wind is blowing.

This is the second wind power project in the province. We also purchase electricity from the SunBridge Wind Power Project, a partnership between SaskPower, Suncor Energy Inc. and Enbridge Inc. Together, these facilities produce 17 MW of green power, which is enough to serve about 7,000 Saskatchewan homes.

Cypress Generating Capacity

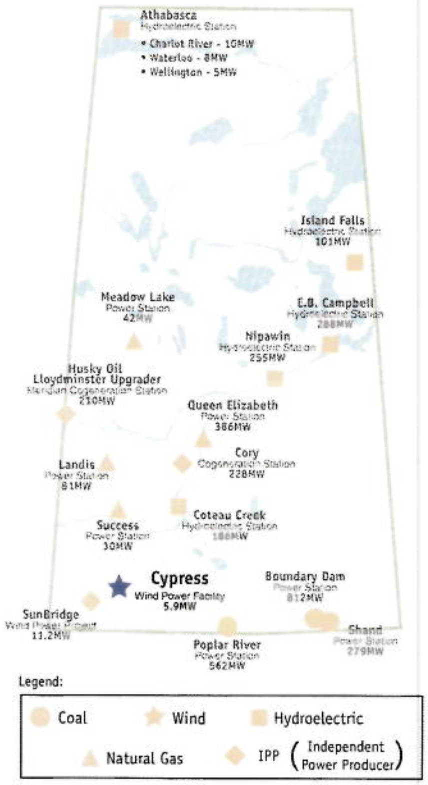
At peak output, the nine Cypress turbines are able to produce 5.9 MW of electricity.

The towers are 50 metres high – equivalent to the height of a 12-storey building. Each turbine blade is 23 metres long, with a rotor diameter of 47 metres, or approximately half the length of a football field.

Location

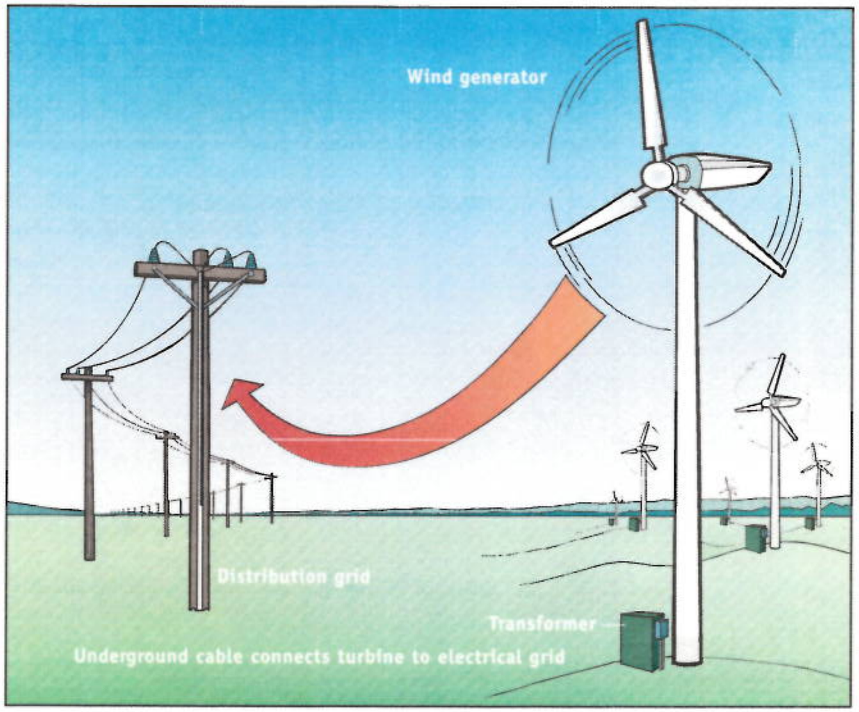
The Cypress Wind Power Facility is located approximately 12 kilometres southwest of Gull Lake.

SaskPower Generation Sources



SaskPower generation - net capacity	**3,050 MW**
Independent power producers - net capacity	**450 MW**
Total generation in Saskatchewan - net capacity	**3,500 MW**

HOW A WIND TURBINE WORKS



How A Wind Turbine Works

Wind turbines capture the kinetic energy available from wind and convert it into electrical energy. Large blades mounted on tall towers rotate a shaft connected to a gearbox and generator to produce electricity.

A wind turbine 250 metres from a residence produces no more sound than a home refrigerator. Turbines usually operate with wind speeds between 15 and 90 kilometres per hour. They cease operating when temperatures fall below -30C.

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NORTHERN
POWER SYSTEMS
power without limits

PRODUCT OVERVIEW

Northern's NorthWind 100/19 wind turbine provides cost-effective, highly reliable renewable energy in demanding environments.

The NorthWind NW100/19™
Simplicity by Design

Designed specifically for extreme weather in remote village power and distributed generation applications, the NW100/19 is a state of the art, utility-scale wind turbine. Northern Power Systems has drawn on 25 years of experience to engineer a wind turbine that provides cost-effective, highly reliable renewable energy in demanding environments.

Designed to meet the needs of small utilities and independent power producers, the NW100/19 has the following features:

Simplicity

High reliability and low maintenance were the focus in developing the NW100/19. The design integrates industry proven robust components with innovative design features to maximize wind energy capture in severe and remote locations. The turbine features a minimum of moving parts and vulnerable subsystems to deliver high system availability. The uncomplicated rotor design allows safe, efficient turbine operation.

- Direct drive generator eliminates the drivetrain gearbox
- Dual fail-safe disk brake and electrodynamic braking system eliminates blade brakes

Serviceability

All service activities can occur within the tubular tower or nacelle housing, providing complete protection from severe weather conditions. Designated work areas provide ample room to perform service activities.

Power Quality

The most common generator utilized in the wind industry is a gear driven asynchronous (induction) generator. Induction generators must be connected to a stable voltage source for excitation and reactive power (VAR) support. While large power grids can easily provide this support, power quality and system stability is compromised in distributed generation and village systems where the power grid is typically "soft and unbalanced."

NPS has solved this issue with the NW100/19. Our synchronous, variable speed direct drive generator

www.northernpower.com

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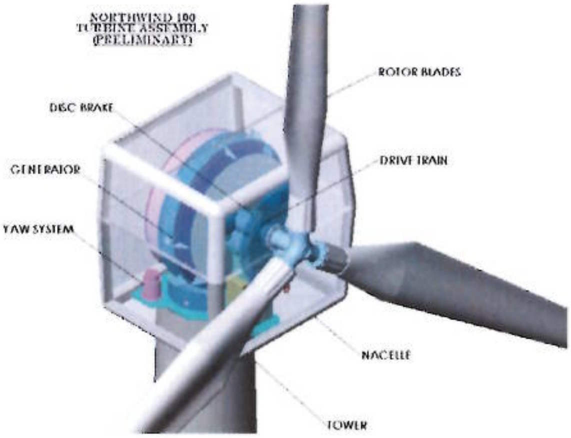
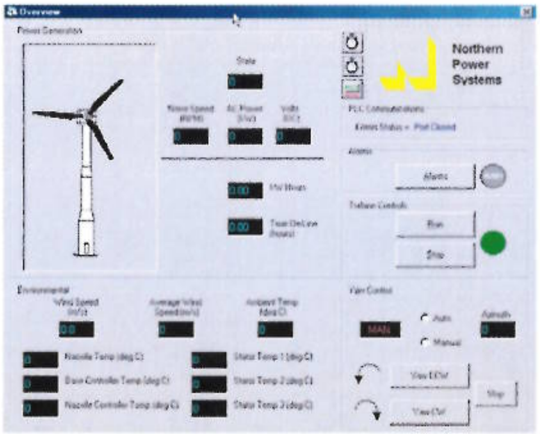




and integrated power converter increases energy capture, while eliminating current in-rush during control transitions. This turbine can be connected to large power grids and remote wind-diesel configurations without inducing surges, effectively providing grid support rather than compromising it.

System Description

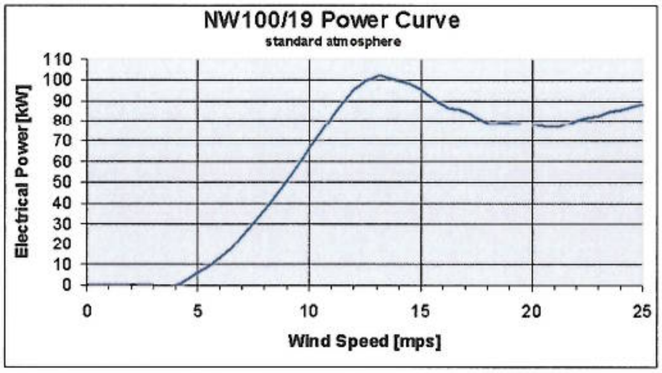
The variable speed, stall controlled turbine rotor assembly consists of three fiberglass reinforced plastic (FRP) blades bolted to a rigid hub, which mounts directly to the generator shaft. This simple, robust design eliminates the need for rotating blade tips, blade pitch systems, and speed increasing gearboxes.

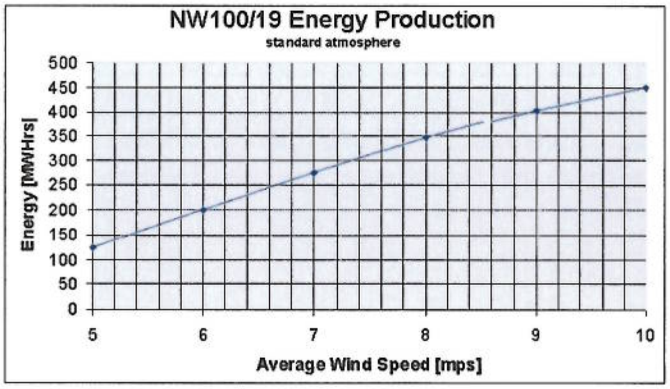
Using a state-of-the-art airfoil design increases the blade's aerodynamic efficiency and renders them insensitive to surface roughness caused by dirt build-up and insects. The advanced FRP-resin infusion molding process ensures a high-quality blade while the root connection guarantees it will meet extreme temperature requirements.

The direct drive generator is a salient pole synchronous machine designed specifically for high reliability applications. Electrical output of the generator is converted to high quality AC power that can be synchronized to conventional or weak isolated grids. The advanced power conversion system also eliminates the inrush currents and poor power factor of conventional wind turbines. The output complies with IEEE 519-1992 power quality specifications.

The variable speed direct drive generator/converter system is tuned to operate the rotor at the peak performance coefficient, and also allows stall point rotor control to contend with wide variation in air density found in the target applications.

The safety system consists of a spring applied, pressure released disk brake mounted on the generator shaft for emergency conditions, and an electrodynamic brake system that provides both normal shutdown and emergency braking backup functions.





NW100/19 Technical Specifications

Design Specifications

Turbine Class	IEC WTGS Class I
Design Life	30 year
Design Standards	In Accordance with IEC 1400-1

Performance

Nominal Power Rating	100 kW
Rated Wind Speed	13 m/s (29mph)
Cut-In Wind Speed	4 m/s (9mph)
Cut-Out Wind Speed	25 m/s (56mph)
Survival Wind Speed	70 m/s (157mph)

General Configuration

Rotation Axis	Horizontal
Orientation	Upwind
Yaw Control	Active
Number of Blades	3
Hub Type	Rigid
Drive Train	Direct Drive
Power Regulation	Stall

Rotor

Diameter	19.1 m
Swept Area	284 m2
Speed Range	45-69 RPM
Speed @ rated power	68.5 RPM
Structural Configuration	Flange Mounted Blades, Rigid Hub
Power Regulation	Variable Speed Stall
Rotor Rotation	Clockwise (Viewed from Upwind)
Pitch Angle	-0.75° @ tip, nominal
Coning	0°

Blades

Airfoil	S819, S820, S821 Series
Material	Fiberglass Reinforced Plastic (FRP)
Lightning Protection	Standard Integrated System

Drive Train

Configuration	Variable Speed Direct Drive
Tilt Angle	4°
Generator Type	Salient Pole Synchronous
Insulation Class	NEMA H
Generating Speed	45-69 RPM
Generator Rating	100 kW w/ 1.15 Service Factor
Generator Output	575 VAC
Speed Control	IGBT Controller

Grid Connection

Grid Voltage	480 VAC std: 380-30kW available
Grid Frequencies	50/60 Hz

Braking Systems

Mechanical Brake	Main Shaft Disc Brake w/ Dual Spring Applied Calipers
Electro-Dynamic Brake	Parking and emergency backup

Yaw System

Type	Active Upwind
Damping system	Adjustable Friction
Yaw Drive	Electrically Driven Planetary Gearbox
Yaw Bearing	Slew Ring

Tower

Type	Tubular
Hub Height	25/30/35 m (82/98/115 ft)
Material	Steel
Corrosion Protection	Marine Paint

Service Environment

Tower	Fully Enclosed, Ladder Way
Nacelle	Fully Enclosed

Controller

Type	Northern WTGS-100 Controller, Microprocessor-based
Functions	Complete Supervisory Control and Data Acquisition
Remote Control/ Monitoring Software	Integrated SmartView™ Access
Power Electronics	IGBT Pulse Width Modulation (PWM) Converter
Power Quality	IEEE 519-1992

Environmental Specifications

Temperature Operating Range	-46°C to 50°C (-50°F to 122°F)
Lightning Protection	In Accordance with IEC 61024-1
Icing	Ice cover to 30 mm (1 in)
Seismic Loading	Zone 4

Packages available for specific site condition such as coastal environment.

Masses

Rotor	761 Kg (1 680 lbs)
Nacelle (excluding rotor)	6325 Kg (13 950 lbs)
Tower (25m)	6500 Kg (14 330 lbs)

Northern Power reserves the right to alter turbine specifications at any time.

Northern Power Systems designs, builds and installs ultra-reliable electric power system solutions for industrial, commercial and government customers worldwide. Since our founding in 1974, we have installed over 800 systems in 40 countries on all seven continents.

Headquarters:
Northern Power Systems
182 Mad River Park
Waitsfield, VT 05673 USA
Phone: 877-496-2955
Fax: 802-496-2953

California Office:
Northern Power Systems
33 New Montgomery Street,
Suite 1280
San Francisco, CA 94105 USA
Phone: 415-543-6110
Fax: 415-543-6105

www.northernpower.com

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Development

The NW100/19 turbine was developed by NPS with support from cooperating agencies within the U.S. government, including the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); the Department of Energy (DOE); and the DOE-funded National Renewable Energy Laboratory (NREL). Siemens-Westinghouse acted as a subcontractor to NPS in developing the innovative direct drive generator subsystem.

Turbine certification testing is being carried out at the National Renewable Energy Laboratories National Wind Test Site at Rocky Flats, CO. This testing is near completion and will result in a Type Testing Conformity Statement, which validates the turbine safety systems and structural design. Turbine testing also includes Type Characteristic Measurements that prove the performance and acoustic signature of the turbine.

NPS wind turbines at the South Pole and the Antarctic coast have operated in more extreme conditions than any other turbines, including winds to 198 mph (88.5 m/s) and temperatures to -112°F (-80°C.) This experience gained in harsh, remote conditions has been incorporated into key NW100/19 design decisions affecting configuration, materials selection, performance characteristics, and deployment procedures.

For further information contact:

Lawrence Mott
Northern Power Systems
Waitsfield, VT 05673
(802) 496-2955 x-239
lmott@northernpower.com

State-of-the-art of wind energy in cold climates

WIND ENERGY IN COLD CLIMATES

T. Laakso, H. Holttinen, G. Ronsten,
L.Tallhaug, R. Horbaty, I. Baring-Gould,
A. Lacroix, E. Peltola, B. Tammelin

April, 2003

ABSTRACT

Wind turbines in cold climates refer to sites that have either icing events or low temperatures outside the operational limits of standard wind turbines. International Energy Agency, IEA R&D Wind has started a new annex, Wind Energy in Cold Climates. This is an international collaboration on gathering and providing information about wind turbine icing and low temperature operation. The goal is to monitor reliability of standard and adapted technology and establish guidelines for applying wind power in cold climates. In this report, the state-of-the-art of arctic wind energy is presented: knowledge on climatic conditions and resources, technical solutions in use and operational experience of wind turbines in cold climates.

CONTENTS

1 INTRODUCTION

In 2001, the International Energy Agency (IEA) R&D Wind Programme started a new annex, number XIX, called Wind Energy in Cold Climates. This international collaboration between the participating countries has as objectives to gather operational experience of wind turbines and measurement campaigns in icing or cold climates to enable a better understanding of turbine operation under there conditions. The goal is to formulate site categories based on climatological conditions and site infrastructure and then link the wind turbine technologies and operational strategies to these categories. This will give guidelines to operators and manufacturers operating wind turbines in cold climates.

Information is gathered and disseminated on the project website http://arcticwind.vtt.fi/.

The operating agent of the annex is Technical Research Centre of Finland VTT and participating institutes are FOI/FFA from Sweden, Kjeller Vindteknikk from Norway, Risø National Laboratories from Denmark, the National Renewable Energy Laboratory (NREL) from the USA, ENCO from Switzerland and Natural Resources Canada [1].

At the moment there are a relatively small number of wind power projects in the cold climate, however this global market segment is estimated to be substantial, although no real market assessment has yet to be performed. There does seem to be lack of information regarding the operational experience and exact climatic conditions relevant to sites in cold climates, especially when risk of icing is concerned.

In addition, when siting wind turbines in cold climates, the assessment of the climatic conditions, their impact on turbine production and economy (reliability, O&M costs) have to be made (Fig. 1). Generally information about the average and minimum temperatures on perspective sites is usually available however icing frequency is more difficult to obtain. Current IEA and other international standards simply state that standard methodologies do not hold for sites outside of normal operating conditions and thus projects in these areas are often carried out with inadequate knowledge on icing and other extreme weather conditions.

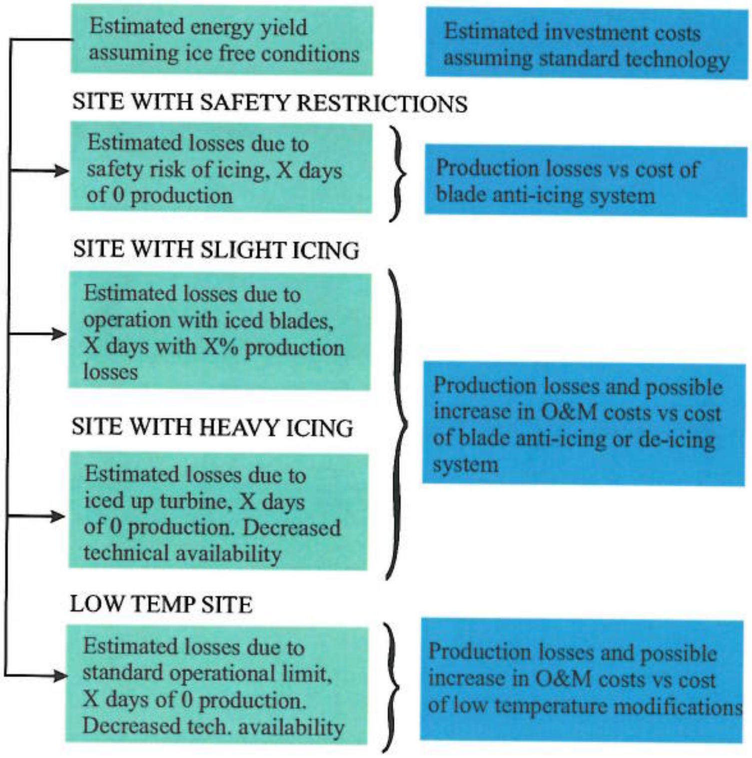


Figure 1. Assessment of sites in cold climates: there are sites in very low temperatures but dry climate with no icing events. Icing is most frequent just below 0°C. Some sites have to consider all the cases above.

2 WIND TURBINES IN COLD CLIMATES

There are already several sites with either existing or projected wind parks in cold climates: Northern and Central Europe, Northern America and Asia (China and Russia). All together approximately 500 MW (Fig.2).

The following describes operational experience reported by the permanent members of the IEA Annex on wind turbine operation in cold climates.

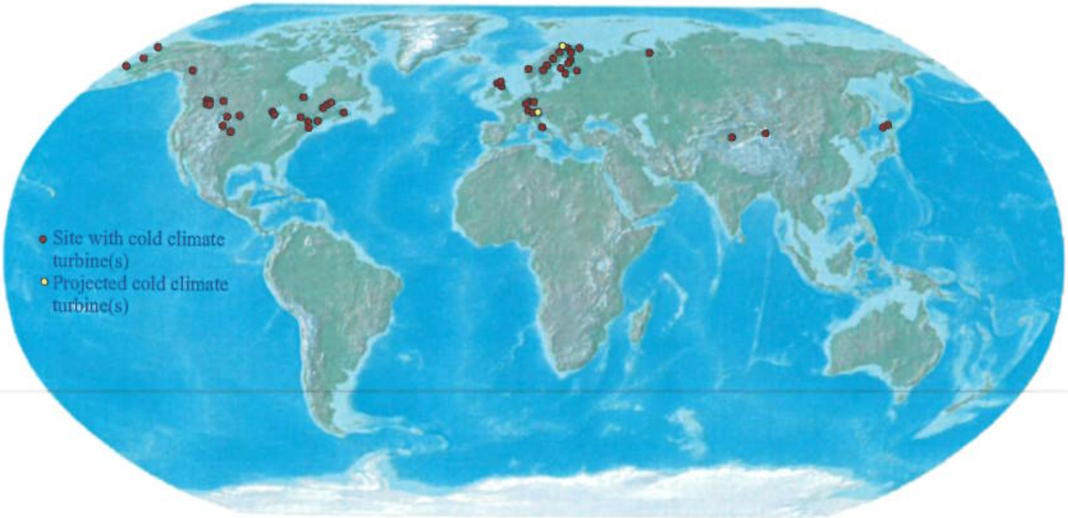


Figure 2. Locations of operating wind turbines in cold climate sites [2,3,4,5,6,7].

2.1 NORTHERN EUROPE

In Scandinavia there are existing sites in Finland and the mountains of Sweden and Norway. In Scandinavia icing is occasional on the coastline, and severe icing conditions occur in high altitudes regularly. Temperatures may fall below –20 °C often in higher altitudes and few times during the winter on coastal areas. Due to the combination of very good wind conditions, severe icing and low temperatures on arctic fell tops, arctic modifications for turbines have been developed [12]. Though designed for arctic conditions blade heating systems have been installed also to milder icing conditions [9].

In the Lapland region of Finland icing is severe, with rime icing conditions up to 200 hours a month making wind turbine usage without adapted technology impossible. Icing is most harsh between November and February and occurs most often in a temperature range of 0°C--7°C. [8] There is two find farms in Finnish Lapland Olostunturi-fjell and Lammasoaivi, both in Northwest Lapland. Olostunturi-fjell wind farm consists of five Bonus Mk IV 600kW wind turbines and Lammasoaivi contains one Bonus Mk IV 600 kW and two Bonus Mk III 450 kW turbines. All turbines are equipped with an ice prevention system called the JE-System. Manufacturer of the JE-Blade heating systems is Kemijoki Arctic Technology OY. Apart from Lapland, wind turbines in Finland locate in coastal areas and in the southern archipelago where they also experience occasional and moderate icing. Cold climate versions of the standard turbines are used in these projects but blade heating systems have not been utilised extensively. An exception is the wind farm at Pori, located along the western coast of Finland (N 61.3°, E 21.2°) where the four turbines that are located next to a busy road were equipped with blade heating systems to improve road safety. The entire Pori wind farm consists of 9 wind turbines of which eight have nominal power of 1 MW and one 2 MW. The wind turbine supplier was Bonus Energy A/S and the turbines use the JE-System blade heating technology. Icing occurs occasionally at Pori, most often at temperatures just below freezing (0°C--3°C). [9]

According to the Finnish wind turbine statistics nearly every site in Finland reports down time due to icing or low temperatures during the winter. [21]

Norway has a long shoreline facing the warm waters of the eastern part of the north Atlantic ocean currents. Low pressure systems forming in the polar jet stream areas over the warm Atlantic waters move eastward and ensure high wind speeds and a mild climate along the Norwegian coast. Well exposed Islands and ridges along the coast are well suited for wind energy. Compared to other areas in the world at the same latitude, the temperatures in wintertime are relatively high. At North Cape (71°), -4°C is the lowest monthly average temperature at sea level.

In cloud icing occur frequently above a certain altitude all along the coastline. From experience with wind monitoring programs, it seems as the frequency of icing is more dependent of altitude then latitude. The wind turbines located at Havøygavlen (Latitude 71° and 275 m above sea level) do not have heated blades.

In Sweden the prevailing winds are from the South West. Consequently the northern part of Sweden generally takes shelter from severe icing conditions behind the mountains of Norway. Icing of wind turbines still experienced, particularly in the area of Jämtland where the Norwegian mountains provide less shelter. Occasionally Sweden experience cold easterly winds flowing off of the unfrozen Baltic Sea creating severe icing over large areas. Such an event in December of 2002 caused turbines without blade heating systems to be put out of operation for several weeks.

The combination of low temperatures, below -50 in the northern Sweden, and low solar radiation during the winter months limit the ability to de-ice structures that are iced during extreme weather. Structures that have been iced up may stay iced for long periods.

Occurrences of super-cooled rain are common in Sweden and a severe case was recorded at temperatures below -10 as far south as Stockholm on Feb 6, 2003. Frequent in cloud icing will also impact all operators of large offshore wind turbines in the Baltic. In addition, the annual return of the sea ice along the coastline, lakes and northern seas will create a significant challenge for the designer of offshore wind turbine foundations.

As part of a voluntary national program the incidents of problems related to operating wind turbines in cold climate have been reported and entered into a database. 92 impact reports were received for 2000, 2001, and 2002 reporting approximately 8000 hours of missed production.

2.2 CENTRAL EUROPE

In a recent paper by Tammelin et. al., ref. 19, an analyses showed that icing conditions exists in much larger regions of Europe than earlier has been expected by the wind power community. The analysis also found that in central Europe icing and low temperatures deteriorate wind energy production at elevated sites, which unfortunately also provide good wind conditions. Areas where low operating temperatures and icing has been recorded centre on the Alps, Apennines and other mountainous areas. [19]

Heavy icing and a high number of icing days is observed at sites like the Apennines in Italy. As an example the Acqua Sruzza test site in Italy, at same latitudes as Napoli, experiences heavy icing occasionally. The amount of icing experienced at that site would lead to a significant production loses with standard wind turbines. [19]

Icing and low temperatures are also experienced frequently in mountainous regions of Southern France, in the Alps, and in the Albs in southern Germany.

Icing has also been recorded to deteriorate wind energy production of several wind farms at the high altitudes in Scotland mountains.

In Switzerland several projects have been carried out in icing and in low temperature climates. Wind turbines that experience icing and low temperatures are located at high altitudes, generally from 1300 to 3000 metre above the sea level. Typically sites below 2000 metre above sea level experience only light icing and sites with higher altitude are prone to heavy icing and low temperatures. Important experience on the use of wind energy under climatically extreme conditions will be gained from the 800 kW plant on the Guetsch near Andermatt (2300 m above sea-level) which was commissioned in spring 2002. This is the first wind turbine in Switzerland that uses adapted technology to protect it against icing and low temperatures. Further projects such as St.Moritz (2200 m above sea-level) as well as Crêt Meuron (1300 m above sea-level), will increase the knowledge about wind energy production in alpine region and harsh climatic conditions.

In Europe there is a growing and identified interest to erect more wind turbines at sites in which the wind turbines will be prone to icing. [19]

2.3 NORTHERN AMERICA

Wind farms are being installed in three general climatic regimes effected by cold weather. In the north central region, such as the 200 MW wind plants in the Lake Benton, Minnesota area, snowfall and cold temperatures are common but turbine icing is uncommon due to the low humidity. Additionally along the eastern coast of the US and Canada, and specifically the north east such as the 6 MW plant in Searsburg, Vermont, turbines are located on low altitude mountain ridges or in coastal regimes where icing is frequent. Depending on the location and altitude, cloud or rime icing is common. The last clarification of sites are along the arctic coast, such as the 0.8 MW plant located in Kotzebue Alaska and specific units in northern Canada. These sites experience icing, cold temperatures and high density air flows.

In Canada, one can say with confidence that all turbines installed, except maybe the ones immediately located on the East and West coasts that benefit from the ocean effect, will be exposed to temperatures below –20°C at one time or another during the year.

Atmospheric in-cloud icing is encountered on the elevations of British Columbia, Yukon and, to a lesser extent, in the Appalachian domain of the East coast. Freezing precipitation on the other hand is more likely to occur in Central and Eastern Canada.

2.4 ASIA

In China turbines are generally located on sites where winter humidity is typically low, but temperature may drop below –20 °C, and diurnal temperature changes may be as high as 40 °C.

3 KNOWLEDGE ON CLIMATIC CONDITIONS

Generally information about the average and minimum temperatures at a site is usually available however icing frequency is more difficult to obtain, and projects are often carried out with inadequate knowledge on icing conditions.

To assess the consequences of icing and the required modifications to standard wind turbines, information on the frequency of icing events and the duration of ice on different parts of the wind turbines, such as the blades, anemometers, nacelle, and tower are needed. Icing can also effect wind resource estimation due to the occasional icing of anemometers during a measuring campaign, which can be difficult to detect.

According to statistics on Finnish coast, icing can be 5 times as frequent at 100 meters above ground level as at 50 m. Direct measurements of icing are very rare and improvement of ice sensors is still needed. Also, development of models to be used in estimating the amount of icing days on a specific site are still needed. This is especially true for mountainous areas where the local terrain effects can be difficult to assess in modelling. Measurements of the conditions further than 1 km away may also not give enough information about a specific site in question.

Icing occurs at temperatures below 0 °C when there is humidity in the air. The type, amount and density of ice depend on both meteorological conditions and on the dimensions and type of structure (moving/static). There are also different icing climates, such as cloud icing, when small water droplets in the cloud impact and freeze on the surface of structures, or cold and extreme low temperature icing. This is demonstrated in Fig.3, which shows examples of two different sites in Finland: Pori is a coastal site in Southern Finland and Olostunturi is a site with heavy icing in the arctic fells of Northern Finland [8,9].

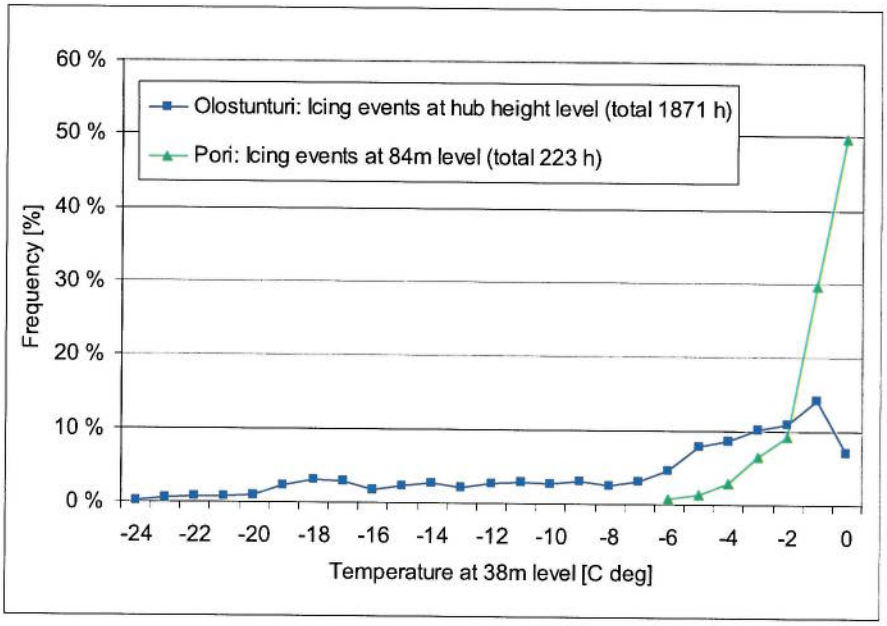


Figure 3. Temperatures during icing events. Two different sites in Finland with annual mean temperatures of 0.3 °C (Olos) and 7.1 °C (Pori).

3.1 MEASUREMENTS

Proper measurement of climatic and icing conditions in extreme climates is not as simple as purchasing the right sensor. Before any sensor can be connected to a data acquisition system one has to find a suitable set of cables, connectors and cable ties. In extreme cases simply using weather and UV-resistant equipment is not sufficient, everything must also be specified for low temperature usage. Currently, modern sensors, such as ultra-sonic anemometers and data acquisition networks can be connected via fibre optical cables. However, fibre cables for cold climate operation need to be adopted for such use by, for example, using non-freezing gel that is pumped into conduits surrounding the interior cables to prevent water ingress and subsequent ice formation. One such example is described in ref [17]. The gel will also protect a cable against breaking if exposed to unforeseen external loads by a maintenance crews, or reindeers; and the movement when cable attachments are deteriorating. Cable attachments will occasionally break and standard weather resistant cable ties are not sufficient in cold climates. Generally weather resistant Nylon 12 cable ties should be used in cold climate and/or high moisture conditions. . A similar reasoning can be applied to connectors.

Instruments for cold climate measurements, including humidity, temperature, wind speed, wind direction, precipitation and radiation, have to be properly heated under icing conditions to maintain their accuracy (Fig. 3). Instruments, more or less suitable for cold climate measurements, are continuously being developed and evaluated by manufacturers and users [11]. Depending on the required accuracy and in standard conditions, the exact location of an instrument might be required to adhere to IEA recommended practices or standards, which ensure proper mounting including sufficient distances to surrounding objects. IEA recommended practices are not available for icing conditions, one is typically recommended to stay away from such events, like ice storms, which is one reason for the creation of this IEA Annex.

Figure 4. Ice free anemometer in severe icing conditions.(Photo, VTT)

3.1.1 Wind conditions

In the field of wind energy a properly acquired wind speed is of outmost importance. There are three basic categories of needed accuracy when measuring wind speed in flat terrain. In resource estimation accuracy requirements are around ± 5%, the accuracy level of European Wind Atlas [42]. Standard IEC 61400-1 gives an accuracy requirement for anemometer used in power performance testing of ±2% [34]. For wind turbine control a lower anemometer accuracy is needed, commonly±3% however an even lower accuracy level may be acceptable. [51-53]. Many different types of anemometers are available with wide degrees of accuracy, down to below 2% for calibrated anemometers. Specific requirements are defined for different conditions by several national and international standard.

In addition, accurate wind speed measurements in complex terrain have other difficult and do not need the uncertainty introduced by improperly heated or mounted wind velocity sensors.

Up until this point not much attention has been paid to icing of the wind gauges in the wind energy sector even though anemometers and vanes are very sensitive to icing. This is surprising given the importance of wind speed measurement in siting and system control. Tests have repeatedly shown that a small amount of ice reduces measured wind speed significantly and large ice accretions may stop the anemometer entirely. For example, a small amount of rime ice on the cups and shaft of an anemometer may lead to underestimation in wind speed of about 30 % at wind speed of 10 m/s. The level of underestimation depends on severity of icing conditions. [Refs. 23-26]. This decrease is more insidious as, without other monitoring equipment, there is no way to determine if a given anemometer is reading an accurate wind measurement. This may lead to an underestimation of the wind speed or the failure of a turbine to shut down in a high wind event.

Although many different ice mitigation methods have been investigated, the most common solution for accurate measurement in icing climate is the use of a heated anemometers and wind vanes. Instruments suitable for cold and icing climate are available and new devices are actively being developed and evaluated by manufacturers and users [11].

Access to an electricity grid is generally required in order to heat the sensors, which need to be properly heated to maintain their accuracy; solar panels will not suffice as power requirements up to 1500 W are needed. Where no electricity grid is available, alternative measurement setups should be considered. One such alternative is the use of propeller type anemometers. The Swiss Federal Institute for Snow and Avalanche Research has been employing propeller type anemometers in the Jura mountains with good experience. In severe icing conditions and temperatures below 0°C with high humidity their propeller type anemometers have provided reasonable data more than 98% of the time.

Icing and high winds also cause higher loads on masts and measurement booms. In these regions wind measurements are often performed at lower levels, 30 m instead of 50 m for example. As a result, it may be difficult to extrapolate measurement results to the hub height of a future wind turbine. If electricity grid access is available SODARs suitable for harsh climates may become an option. Experience with SODAR units in Switzerland have demonstrated that the technology may be used in harsh climates, but careful oversight of the equipment is necessary and it should it is likely not applicable for long term measurement programs.

If cup or propeller type anemometers are used, the anemometer's cup shaft and post should be heated in order to prevent ice from accumulating and impacting measurement quality.

Attention must be paid also to the positioning of the anemometer and wind vane in icing conditions. In severe icing conditions the accuracy gained through heating is quickly lost if neighbouring objects such as booms and masts are allowed to collect ice. Therefore surrounding objects need to be heated as well. When used for wind turbine control, considerations may also be needed to the change in wake and turbulence on top of nacelle under different icing conditions even if a heated anemometer is used.

References 19 and 31 provide reviews of anemometers suitable for the use in icing climates. As part of the "Wind Energy Production in Cold Climate" (WECO) project, funded in part by the European Union, several research institutions are currently conducting operational tests on a number of anemometers and wind measurement options for icing climates. As presented by Tammelin et. al. at the BOREAS IV conference [22] the annual market for ice-free sensors only in Europe is estimated to be some 11 million Euro.

3.1.2 Icing conditions

Detection of ice is similarly complex. Traditional ice-detectors used to be extremely unreliable however this technology has improved considerably, as has knowledge about the occurrence and conditions of ice. In addition to improved technology research, commercial organisations are also conducting and sharing extensive research on ice accretion due to temperature, humidity, radiation, wind direction, wind speed and precipitation.

Currently there are several types of ice detectors on the market and are mainly manufactured for aviation and meteorological purposes. [19] Principles of operation of ice detectors, some specific icing sensors and other ad hock approaches that have been used in research projects are presented in this text.

Finnish company Labko Oy has two versions of ice detectors to offer, LID (Labko Ice Detector) 3200 and LID 3500. The working principle of the both models is that a longitudinal wire waves is transmitted into an non magnetic wire with piezoelectric transducers. Solid ice attenuates the signal more than water or other non solid substances. This attenuation can be monitored and used in icing indication [27].

The Instrumar Limited ice sensor IM101 function through measurement of the surface electrical impedance and temperature of a proprietary ceramic probe. This data is combined to sense the surface conditions of the probe. A default icing window is programmed into each device and when the parameters fall within this window, an "icing" signal is triggered. The IM101 has an internal solid state switch that is closed when icing is detected and remains closed for a set period of time. This closure may be used to turn on/off low power devices directly, or as input to a controller. It can be used for controlling devices such as alarms, event recorders, or heaters. [28]

Goodrich Deicing Systems offer the Model 0871LH1 ice detector. The sensor works on the principle of magnetostriction. A detection probe vibrates ultrasonically at a resonant frequency of 40 kHz. The mass of the ice collecting on the probe causes the resonant frequency to decrease. A frequency decrease equivalent to 0.508 mm (0.020 inch) of ice thickness triggers an ice signal for a 60-second duration. At the same time, the detector undergoes a self-deicing cycle that removes the ice from the probe. Another icing event detected within that 60 seconds resets the timer to zero and the ice signal remains activated for an additional 60 seconds [39].

One interesting possibility is the use of dew point detector, which is designed to operate in below zero temperatures, as an ice detector i.e. one has to decide a limit for the relative humidity e.g. 97% and assume that when temperature is lower than zero icing occurs. The use such a dew point measurement as an ice detector was studied at the Pori site in Finland [9] and is discussed in greater detail in the paper by Makkonen et al. [29]. One of the main issues identified in the report is more general, there is no absolute reference for calibrating ice detectors because even the most up-to-date ice detectors are not 100% accurate.

For wind turbine applications it is possible to identify icing using one heated and one standard anemometers looking at the difference in wind speed, however a few questions arise. How much slower should the unheated anemometer read compared to the heated one to be interpreted as an icing signal? Is it possible to avoid false alarms caused by wakes on top of wind turbine nacelle by careful placing of the anemometer? When a standard unheated anemometer freezes it may take a long time before the anemometer is ice-free again, ref. [30], which can make determining the actual icing time difficult. This method however enables the estimation of energy losses that a wind turbine would experience at that specific site in icing conditions, especially if unheated anemometers are to be used for turbine control.

In an experiment on measuring icing in Northern Canada two heated and one unheated anemometers were used to measure the actual wind speed, icing time and sublimation time of ice. ref. [33] One of the heated anemometers was kept ice-free and the other was heated after every occasion when the wind speed of that anemometer showed a 15% lower value than the anemometer that was kept ice free. The unheated anemometer was allowed to ice naturally. Results showed that it is possible to estimate the icing time that a wind turbine would experience in an icing climate. It was also demonstrated that one could estimate of actual icing time with this method.

Production power of the wind turbine compared to the presumed production power according to the nacelle anemometer may also provide a guide of icing since a turbine with ice on the blades will produce less compared to the power curve. However it is still unclear what conclusions can be made due to ongoing issues such as how small should the power degradations be and how quickly after the beginning of the icing can such a method be used. In Finland if the turbine is located in a remote site and no visual observations are possible, reduced power production is often interpreted as an "anemometer error" when the cause of such error is icing.

Automatic visibility sensors may also be used as an ice detector however the entire instrument especially the lenses, must be heated in low temperatures and icing climate to ensure appropriate operation of the device.

3.1.3 Measurement of other meteorological parameters

It is known that temperature measurements are impacted by their surroundings, vegetation and design of the radiation shield. The performance of thermometers in icing conditions has also been studied extensively. Results of those studies have shown that errors of several degrees are possible when thermometers not designed for icing conditions are used in icing climates. An ice layer on a thermometer or on a radiation shield insulates the probe from the surrounding air and causes delays and dampening errors to the temperature measurements. In worst case the closed measurement conditions of the air inside the radiation shield may continue until the ice has melted. [31]

In icing climates the radiation shields for thermocouples should be heated or the instrument protected from being covered in ice. Thermometer itself should be designed for icing and low temperature operation. [31]

Measuring humidity reliably in icing and low temperatures climate is also a nontrivial task. Humidity sensors and dew point detectors should be placed with the same carefulness as temperature sensors. As described above the improper use of the radiation shield could impact the temperature measurement, in which the calculation of dew point is based. Standard hygrometers designed for temperatures over 0°C will give unreliable results at low temperatures. [31]

Instruments for cold climate measurements, including humidity, temperature, wind speed, wind direction, precipitation and radiation, have to be properly designed and heated under icing conditions to maintain their accuracy (Fig. 4). Instruments that are suitable for cold climate measurements are continuously being developed and evaluated by manufacturers and users [11].

3.2 MODELLING

Models for predicting local weather events including wind and icing estimates are being developed and improved continuously. The major factor limiting the progress of modelling is the calculation capacity of computers, which is too low to enable accurate weather predictions in a reasonable time. Commercial computer programs and models for calculating ice induced loads are available. Models for calculating shapes and masses of ice build up and blade heating demand in certain icing conditions have also been developed for wind turbines. Before wind turbine icing research took hold the aerospace industry had developed computer programs that model leading edge icing of aircraft wings. In the late 1970's power companies also developed models to calculate ice loads on electricity grids in severe icing conditions. Two models, TURBICE and LEWICE, that are used in calculating ice masses and blade heating demands in different icing conditions are described in this section. In addition, the basis of methods that are used to calculate different types of icing from standard meteorological observations is presented.

Of the various models that have been developed, two basic categories, physical and empirical, have been distinguished based on the different standpoints, backgrounds and the different physical properties of different icing phenomenon.

3.2.1 Physical Models

Physical icing and meteorological models are quite detailed and require specific definition of meteorological parameters including the water content of the air, droplet size, wind speeds, and temperature. When modelling the ice accretion on wind turbine blade or power line, one has to also know accurately the shape and size of the object under consideration. Detailed models are computationally demanding and have therefore been improved together with the technological improvements of computers.

As a separate category, full physical meteorological models can also be used to predict icing events. For instance meso-scale models (MM5, MC2 and others) have the physical basis to be extended to determine icing events. These models, generally used in regional weather prediction, can be used to predict upcoming icing events or to provide a general prediction of the likelihood of such events for specific projects under consideration.

3.2.2 Empirical/Statistical Models

Empirical and statistical models are based on historical data. Icing rate caused by in-cloud icing at a certain site may be quantified first by data from the nearest meteorological station. With cloud height, cloud cover and temperature data together with site elevation it is possible to estimate the frequency of icing that site is likely to experience.

Knowledge of icing events has increased and more meteorological and topographical parameters have been added to the empirical models. Parameters such as temperature (air, object, wet-bulb and dew point), wind direction, wind speed, cloud height, cloud cover, the humidity profile, precipitation, regional topography, local topography, object size, shape and material composite and solar radiation have been added to more sophisticated models. The outcome has been that these models can now also provide information about the amount and rate of icing instead of just the frequency of icing events.

3.2.3 Icing Types and Description of Calculation Methods

In-cloud icing is considered to occur if the height of cloud base is less than the site elevation and the temperature at the site is below zero.

Empirical and statistical models have been modified because accurate cloud base observations are made at mainly airports. Modelling results can be improved, by using statistical relation between weather situations and cloud position (cloud base height and horizontal location/extent). By using statistical values of droplet size, wind speed, direction, and object size and shape, the amount of icing can be calculated. The mass of a accumulated ice accretion may also be estimated with this method.

Calculations using full physical models with meteorological and topographical parameters, particle size, concentration, momentum, heat balance and object shape change may provide more accurate results depending on the accuracy of the initial parameters. Full scale physical models require large calculation capacities.

Freezing precipitation occurs when it is raining and wet-bulb temperature lies below zero.

Empirical and statistical models calculate icing frequency and amount from precipitation intensity, duration, wind speed, mean air temperature, object size, shape and an empirical correction factor.

As with in-could icing calculations using full physical models it is possible to model freezing precipitation with the same input data described above. This method also has the same drawbacks, they are computationally intensive.

Frost occurs when the surface temperature of an object drops below the frost or dew point temperature due to radiation heat transfer. The amount and type of frost are given as an equation of temperature ratios, empiric correction factor and humidity.

Wet snow and sleet is formed from dry snow when at lower elevations there is a strong enough positive heat flux from the environment to melt the surface of dry snowflakes. [43]

3.2.4 Icing rate

The rate of icing is dependent on the flux of particles (concentration times velocity) in the projection area of an object with respect to the wind direction. Due to the different size and therefore different inertia of particles, some of them will collide with an object while other smaller ones, which have less inertia, follow the air stream and pass the object. Some particles also bounce when colliding with an object and thus will not increase the total ice mass. Also depending on the heat flux form the surface to the surroundings, colliding particles freeze at their impact spot, rime ice, or form a thin water film on the surface of an object, glaze ice. Different icing process also leads to different density of ice formation. In general, due to its complexity and the many process parameters a physical icing model that would apply to all icing processes still needs to be developed. Physical descriptions, including heat transfer, of different icing processes are presented in detail in ref. [44-49].

3.2.5 TURBICE and LEWICE

Small amounts of ice on wind turbine blades deteriorate their aerodynamic performance and thus dramatically reduce the power generated by the turbine. Furthermore, large ice accretions may cause turbine vibrations and structural failure. Ice pieces are also hazardous when they shed off the turbine blades with high velocity.

As introduced previously, two software models have been developed that can be used to analyse ice formation, TURBICE and LEWICE.

TURBICE

This numerical model simulates ice accretion, amount and ice shapes on wind turbine blades. It has been under development at the Technical Research Centre of Finland (VTT) since 1991.

The model accretes ice on a two-dimensional airfoil section in a potential flow field directed perpendicular to the airfoil axis. The numerical solution for the potential flow follows the commonly used "panel" method. Droplet trajectories are integrated from the steady-state equation of motion, using droplet drag coefficients of Langmuir and

Blodgett (1946) and Beard and Pruppacher (1969). The integration begins ten chord lengths upstream of the airfoil section, and is carried out using a fifth-order Runge-Kutta scheme with an adaptive step-size control. The impact point is determined by linear interpolation between the 600 coordinate points, which define the airfoil section.

The model simulates both rime and glaze icing. All angles of attack experienced by a wind turbine blade may also be calculated. The model can also simulate icing when the blade is heated.

TURBICE simulations have been compared and verified with data from icing wind tunnel experiments for aircraft wind sections and from a field study of natural wind turbine icing. Simulations have shown good agreement with actual data. [54]

In the development of the blade heating technology TURBICE simulations have been utilised in the determination of the impingement area of water droplets on blade surface and in determination of blade heating power needed in different icing conditions. Results have enabled the optimisation of the necessary heating power and has been utilised in the positioning of a blade-heating element.

LEWICE

Another software that can be used for ice accretion and heating demand is Lewice 2.0. Lewice [40] was developed by the icing branch at the NASA Glenn Research Center in Cleveland, Ohio. It is an ice accretion prediction code that applies a time stepping procedure to calculate the shape of an ice accretion. Lewice does not predict the degradation in aerodynamic performances due to icing rather it evaluates the thermodynamics of the freezing process that occurs when supercooled droplets impinge on a body. Its primary use is for evaluating icing on aircraft but has been adapted to work on other applications.

The particle trajectories and impingement points on the body are calculated from a potential flow solution that is produced by the Douglas Hess-Smith 2-D panel code included in Lewice. Alternately and if specified, the flow solution can be obtained from a grid generator and grid-based flow solver or read in as a solution file from this flow solver. Notwithstanding the method used, the flow solution determines the distribution of liquid water impinging on the body, which then serves as input to the icing thermodynamic code. The ice growth rate on the surface body is calculated from the icing model that was first developed by Messinger [40, 41]. This is an iterative process by which an ice thickness is added to a body through the ice growth rate. This procedure is repeated for a specific time duration.

Lewice can model both dry and wet (glaze) ice growth. In addition to simulating the ice accretion, Lewice 2.0 incorporates a thermal anti-icing function. It works in conjunction with the ice accretion routine and calculates the power density required to prevent the formation of ice on the body. Two anti-icing modes are possible: running wet and evaporative. They will be further defined later in the text. The heat source for the anti-icing capability can be specified as being electrothermal or hot air.

In the current application, Lewice is used primarily to obtain anti-icing values. It can also generate data about droplet trajectories, collection efficiencies, impingement limits, energy and mass balances, ice accretion shape and thickness. Since potential flow cannot model stall or post-stall behaviour, the calculations are valid for unstalled rotor regions only.

3.3 MAPS

An icing map of Europe has been developed in order to estimate the areas in which icing may endanger wind energy production. First versions of the European Icing Map and Frost map were produced in WECO EU project [19,20,50], presented in Figure 5.

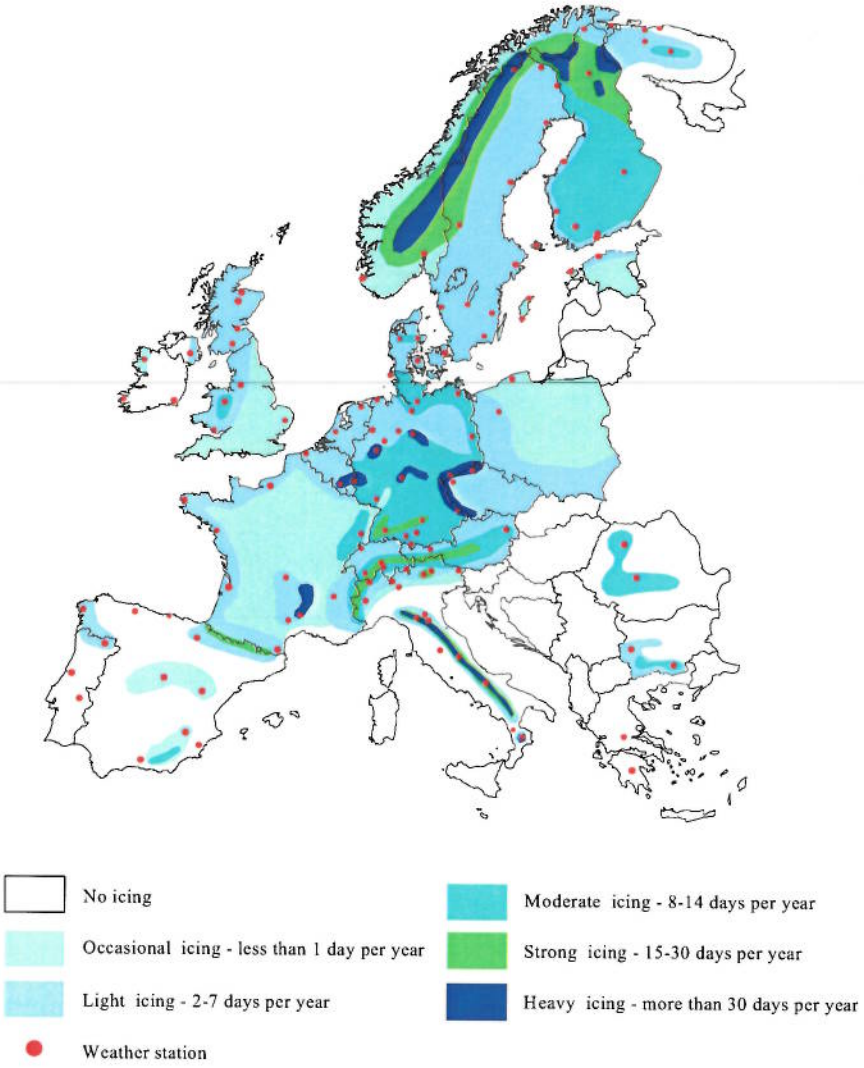


Figure 5. Icing map of Europe. [19]

An updated versions of the European Icing Map are currently under development in the framework of the EU project ICETOOLS project. However, a tool for estimating the number of icing days and icing intensity at a given site is still missing.

Due to the local topography, variations in icing severity and intensity may vary greatly within short distances and therefore icing maps, such as in Figure 5, cannot be interpreted as exact and must be used in connection with local topographical information and, if possible, with measurement statistics.

A more exact icing map for the British Isles where the effect of terrain has been taken into account is presented in Figure 6. . The icing map was produced by first examining the number of icing days at 0 m, 250 m and 500 m elevations above sea level at nine meteorological measurements stations shown in the figure. Those three levels were interpolated to cover the entire land mass. Local and detailed estimation of the number of icing days was then interpolated and extrapolated by using the previous three levels and digital terrain models. The result is a clear picture of areas were icing could be faced. [50] Due to the local climatic conditions and low number of weather stations used in the production of the map, the actual number of icing days experienced at some site may differ from the amount presented in the map.

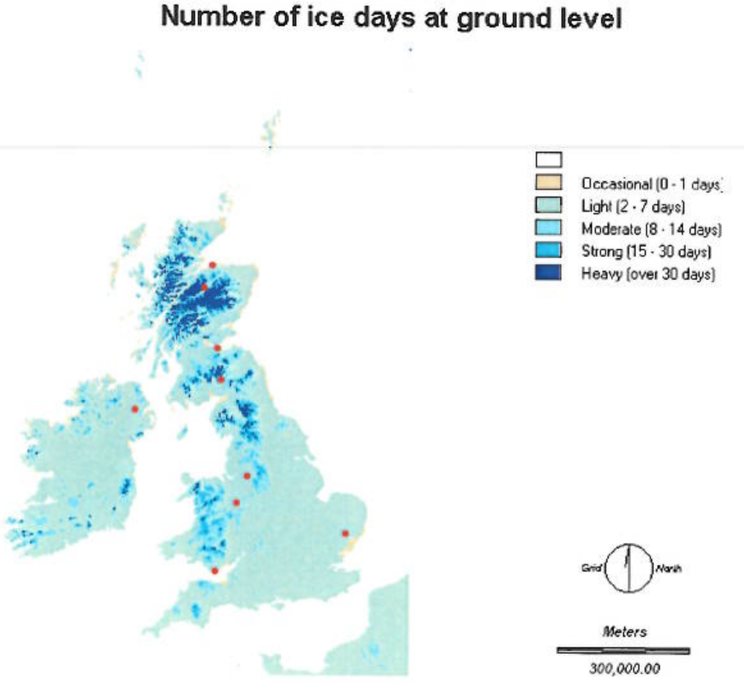


Figure 6. Annual number of in-cloud icing days in the UK and Ireland at ground level and the weather stations used in calculation [50].

Icing map of Switzerland is presented in figure 7. As with all such maps the severity and intensity of icing may vary greatly with short distance and the map in Figure 7 should be interpreted as indicative only.

Map for the average number days with freezing precipitation during a year in Canada is presented in Figure 8.

Similar general maps of this nature are generally available from the weather service agencies of most countries in northern and southern countries.

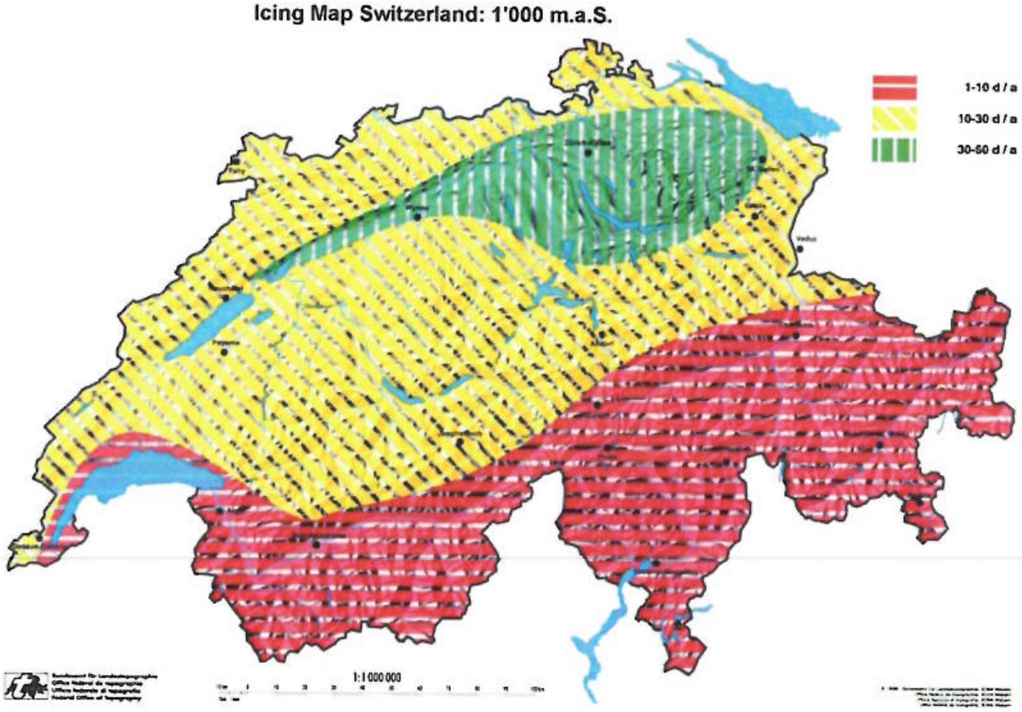


Figure 7. Icing map of Switzerland for 1000 m.a.s.l

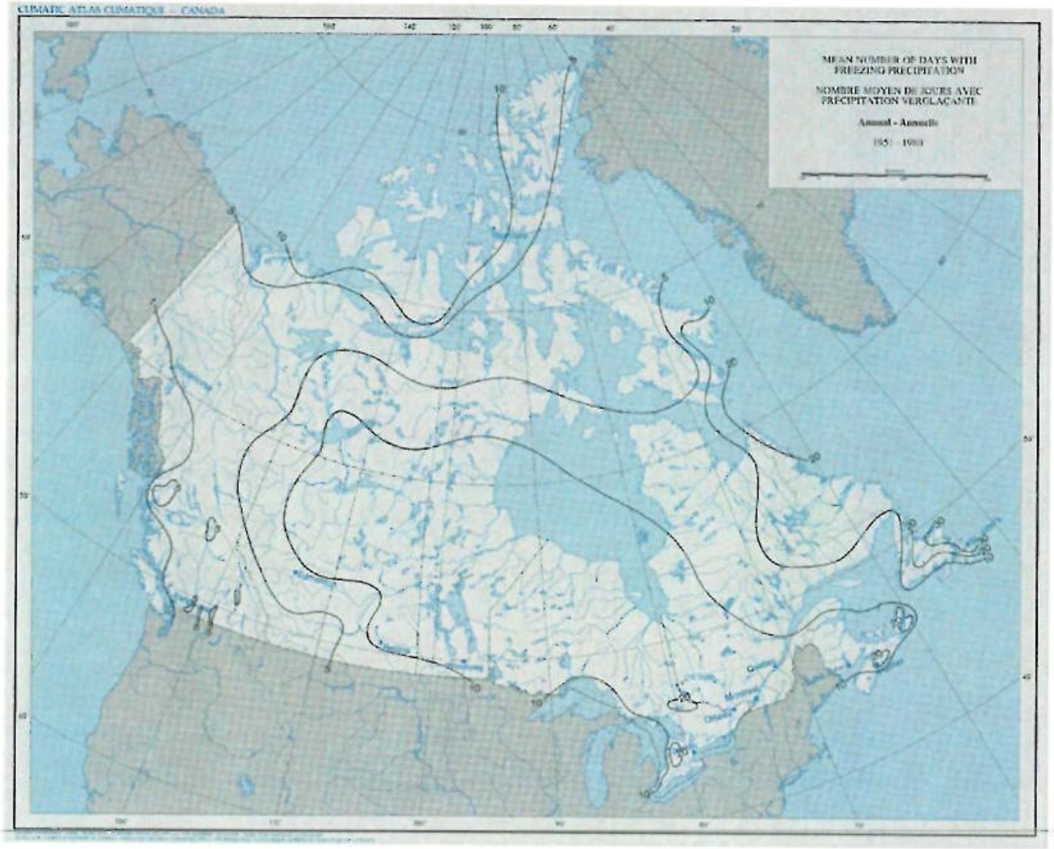


Figure 8. Mean number of days with freezing rain during one year in Canada between 1951-1980. Map from National Archives & Data Management Branch of the Meteorological Service of Canada.

4 TECHNICAL SOLUTIONS IN USE

There are a wide array of solutions that have been used to reduce the impact of cold weather and ice events on wind turbine design and operation. The following section of this document reviews current experience.

4.1 TECHNICAL SOLUTIONS FOR ICING

4.1.1 Sensors/Instruments

A variety of heated wind sensors, as discussed in greater depth earlier in this paper, are available, tested and used at sites where icing is frequent [11].

Currently some manufacturers also use anemometers to indicate weather turbines are functioning correctly. Using the anticipated production power, calculated from the wind speed, compared to actual production power. If the difference is large enough an alarm is given. Also ice-induced vibrations may cause vibration sensor alarms. In both cases turbine are shut down.

4.1.2 Blades

Blade heating may be necessary or profitable at sites that experience frequent icing or have high safety requirements such as proximity to roads. The break-even cost of such a heating system depends on lost energy production due to icing and the price of electricity. Therefore when the financial benefits of a blade heating system are evaluated, icing time, severity of icing and wind resources need to be known. Blade heating system may also be required as a safety precaution in connection to the planning or permission granting process. One of the limitations of blade heating systems is their energy consumption, which can be quite high. A simple approach to estimate the break-even conditions has been developed by Peltola et. al. [12].

A number of different approaches for the blade heating have been presented, developed and tested but current practice indicates that in heavy icing conditions the outer surfaces of the blades need to be heated in order to achieve satisfactory results.

At present there are some commercially available blade heating options available. The Finnish blade heating system, where carbon fibre elements are mounted to the blades near the surface, has the widest operating experience, from 18 turbines at various sites, with a total of nearly 100 operating winters [12].

One low power consumption method for heavy icing environments is the use of pneumatic deicing system that works with the rapid expansion of inflatable membranes within the blades. A similar system has been in use on some small and regional aircrafts for several years. Experience from wind turbines however is lacking.

In sites where icing is slight, infrequent and the icing periods are followed by temperature rising above 0 °C or areas of high winter solar intensity, blades coated with black paint may be sufficient. Stopping the turbine and circulating heated air inside the blades may be adequate in slight icing conditions. A method that uses blower and heater to circulate hot air inside the turbine blade is under the development in Switzerland. First experiences from this method will be available at the spring 2003. This however is likely a valid option in light icing environments. Stopping the wind turbine when icing starts may also be a sufficient solution in such environments. However, this method does require ice detectors.

There have been a number of other proposed solutions, like blade-heating systems based on microwave technology but to date they have not been successfully implemented.

Turbine Safety

Turbines, with or without blade heating systems, pose a risk in the form of thrown ice. Irrespective of whether the turbines are equipped with blade heating systems, warning signs should be used. Signs should be located at least 150m from turbine in all directions. Reference 19 provides a method to estimate the risk that results from ice fragments that are thrown off a wind turbine. An example of a warning sign is shown in Figure 9.

Figure 9. Warning against shedding ice fragments at Tauernwindpark in Austria. Photo from http://www.tauernwind.com.

4.1.3 Other components

Turbines that are modified for severe icing climate must also cope with snow and the freezing of moisture in the gearbox, yaw system or other components. Without properly sealing the nacelle, it may fill with drifting snow as has been experienced in Lapland and the Alps. Gearboxes and yaw systems need to be heated and kept free of ice, as do any disk breaks or separators.

4.2 TECHNICAL SOLUTIONS FOR COLD CLIMATES

Little specific information is available about material properties and lubricants for cold climates in specific relation to their application in wind energy systems. Most available information comes in the form of reports citing field experiences from projects in cold climates. There are however some common areas of concern that are expressed repeatedly in the area of turbine materials and lubricants.

Most turbine manufactures offer products or upgrades to products for cold environments. All information indicates that the use of these upgrades is required for successful unit operation in these climates.

4.2.1 Materials and lubricants

The use of cold resistant steel in all structural members with welds does not increase the costs significantly. Standard hot-dip galvanized bolts have proven adequate in low temperatures [15].

Recent testing at the National Wind Technology Centre, USA, has looked at the cyclic loading of wind turbine blade root studs at ambient and extreme cold temperatures, -45° to -51° C (-50° to -60° F). Testing considered 4140 steel root studs, a Vinyl Ester / E-glass laminate with an epoxy annulus to pot the root stud inserts into the fibreglass. In the limited tests "all of the cold temperature samples tested exceeded the life of the room temperature control group, though none of the cold temperature samples exhibited any evidence of superior construction over the room temperature samples" [16]. These tests, one of the few being conducted specifically to look at issues related to wind turbine construction, show that operation in cold temperatures do not always result in damage, but may actually improve the performance of the system.

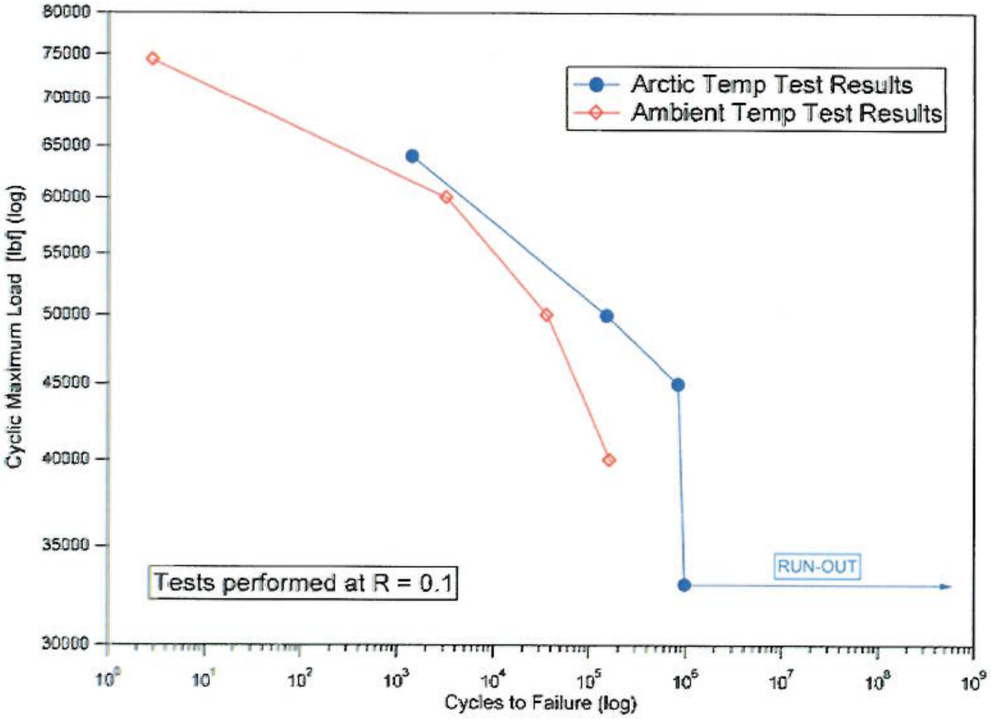


Figure 10. Cyclic fatigue pull tests on blade studs conducted at NREL comparing studs at standard(20°C) and arctic(-48°C) temperatures.

Lubrication: In the area of lubrication and hydraulic oils, similar practical work has been conducted though few scientifically based reports are available. In all cases synthetic lubricants that are rated for cold temperatures should be used. All manufactures recommend specific lubricants based on their particular turbine design. In most cases these lubricants have been tested but the operator is encouraged to obtain specific certifications prior to their use.

4.2.2 Heating of components

At the present moment surface heated gearboxes and gearboxes with immersed heaters with constant oil circulation, generator heaters and also heaters for the cabins containing control electronics are used to avoid cold related problems. [15,32]. Especially important is the protection of control electronics against moisture and condensation at sites where low temperatures during the winter is frequent.

4.3 OPERATIONAL SOLUTIONS FOR COLD CLIMATES

Wind turbine manufacturers recommend that, even the turbines that are equipped with cold weather package should be stopped at temperatures below -30°C. At some sites this would lead to significant amount of annual energy loss. Possible solution might be to allow the turbine to operate at partial load where the stresses would stay below the design limit.

An additional concern with the operation of wind turbines in cold climates is that low temperature air masses have a much higher air density. This can overpower wind turbine generators and has been known to brake gearboxes or turbine main shafts. Measuring temperature and disabling the wind turbines during extreme low temperatures have been used to reduce the chance of such failures.

4.4 O&M CONSTRAINTS

Turbines may locate at remote sites and the access to the sites may be difficult or even impossible part of the winter. It is possible that the access to site may be limited to motor sledge and light repair instruments. It is therefore outmost important that basic tools that enable light repairs such as wrenches, hammers, power drills etc. are kept at site. Also working conditions due to humidity, high wind speed, snowing or icing may prevent maintenance during wintertime. Basic operation and maintenance should also include the maintenance of cold climate modifications.

5 OPERATIONAL EXPERIENCE

5.1 OPERATIONAL EXPERIENCE IN ICING CONDITIONS

Icing of the blades causes production losses for wind turbines. This is the case even with slight icing as the aerodynamic properties of the blade are sensitive to minor changes in the blade profile and roughness. Heavy icing can result in a total stop of the turbine. The duration of ice on the blades can be considerably longer than the time of icing conditions. Downtimes of several weeks with a single icing incident have been reported in Southern Germany.

On the other hand, glaze ice accretion has been shown to cause overproduction due to delayed stall on passive pitch controlled wind turbines [57]. In most cases this will be detected by the wind turbine controller resulting in a turbine shutdown. Any operation over rated power causes additional damage to the components and will result in a shorter life of the generators, bearing and gear boxes.

The structural loads of a turbine may increase significantly due to icing of the blades, due to either aerodynamic and mass induced forces. In addition, ice usually sheds from the blades unevenly resulting in further loading on the turbine [10] due to the mass imbalance, especially if it is allowed to operate. These forces result in two basic load types; extreme loads and fatigue loads, depending on the turbines structural design and the icing event. A properly designed control system should address issues of extreme loads, irrespective of their origin and since other extreme load causes, such as a single failing blade pitch mechanism, typically result in higher loads, the extreme load cases caused by ice are unlikely to drive turbine design. Fatigue loading is similarly influenced by aerodynamic and mass induced forces. The physical influence of the latter is relatively easy to estimate but the knowledge regarding the frequency of such occurrences is scarce, especially for specific sites. Fatigue loading caused by aerodynamic forces, such as those caused by mere rime ice accretion, are likely to be underestimated by today's international recommendations. [58]

Ice thrown off the blade may also pose a safety risk even in areas where icing is infrequent, specifically when the turbines are situated close to the public, such as road and skiing resorts.

Ice shedding off the tower or the nacelle can also pose a similar though a more limited risk than ice that sheds of blades. Risk is higher especially for the service personnel. Cases where icing of the yaw gear has resulted in the damage of yawing motor have been recorded in Finland.

Icing also affects wind sensors, both in resource estimation and controlling the turbine. A wind turbine with an iced control anemometer may not start even in strong winds, which results in production losses. Increased loads are caused if a pitch control system is based on information of an iced anemometer. Iced wind vane may lead to operation in misaligned yaw or a production stop due to the misalignment.

5.2 OPERATIONAL EXPERIENCE IN LOW TEMPERATURES

Low temperatures effect on materials and in wind turbines primarily on glass fibre structures, plastics, steel and lubricants. Wrong lubrication oils and greases have been recorded to damage bearings and gearboxes during low temperature operation. Low temperature and condensation have also damaged control electronics.

Standard hydraulic oils become highly viscous at low temperatures. Modification of standard hydraulic system may also not be limited to the specific oil, modification of the tubes, valves and equipment associated with the hydraulic system may also be required. Due to high viscosity of standard oils in low temperatures or different properties of cold temperature oils, turbine start-up may be delayed to higher wind speeds which will impact overall turbine performance.

When going to very low temperatures, the need for cold weather or weather resistant materials extends for both the steel and plastics used in the system fabrication but also wires and other turbine parts not considered in most system impact assessments. Wires for which the insulation becomes brittle may fracture, leading to shorting, has caused many problems in turbines that have been designed for cold climates. Every piece of equipment, even the most trivial, must be assessed for flexibility and usability at extreme temperatures.

Also service and monitoring under difficult conditions has to be taken into account. This may result in increased O&M costs or extended downtime of the turbine.

Another factor that has been identified is the increased system loading due to the high density of cold air masses. It is not uncommon to have (stall controlled) turbines produce over 20% rated capacity due to the air density. Several cases of generator overheating have been reported in Canada and Finland caused by overproduction due to high air density [13]. This leads to production losses and probably has lead to generator failures [14]. Impacts on the gearbox and breaking systems will likewise need to be considered as the higher loading conditions will impact unit life. However, due to the complexity of these systems, specific tests and the impact of cold temperatures on these subsystems have not generally been carried out.

5.3 COUNTRY OPERATIONAL EXPEREANCE

5.3.1 Finland

At Olostunturi, the site described in detailed in section 2.1),in northern Finland standard power performance measurements were carried out for a single turbine and the performance was found to be according to the manufacturers power curve when icing situations were edited out. During the harshest icing periods the performance did not follow the manufacturers power curve. In some extreme icing cases the blade heating power was found to be too low. In addition to that in some cases the run back water on the blade during icing and blade heating was found to freeze after it had passed the heated area of the blade. During the falls and springs the blade heating system was able to keep the performance of the turbine at normal operating levels. The winter of 2000 to 2001 the blade heating system used 43674 kWh, which corresponds to 3.6% of the turbine's annual production in 2000. The used heating energy grew due to the problems with ice detectors, which led to the blade heating equipment receiving more power then was needed. Nevertheless wind energy conversion at sites like Olosturturi without a blade heating systems would be impossible and unprofitable due to turbine down time.

Similar power performance measurements, as at Olostunturi, were carried out at Pori, also described in section 2.1 between 1999 and 2001. In-cloud icing was observed to be seven times as frequent at the 84m level as compared to 62m. This strongly suggests that icing becomes a more important issue to coastal wind parks at sites like Pori when the dimensions of the wind turbines increase. However, the winters during the measurement period were milder than average and icing was only observed occasionally. The blade heating system was used for 10 minutes every night to avoid ice build-ups on blades. Main reason to install a blade heating system to a wind turbine at sites like Pori is for safety of public.

In Pori, lighting frequency is higher than in Northern Finland and lighting strikes to the blade heating elements have been registered although damage to the ice prevention system could not be detected.

Power consumption of the Pori ice prevention system was measured to be 1% of the turbine's annual production. The maximum heating power of the turbines is 6% of the nominal power of the turbines.

Reported down times due to icing and low temperatures in Finland between 1996-2001 are presented in Table 1 and Table 2 respectively.

Table 1. Reported down times due to icing in Finland 1996-2001. [21]

FINLAND	1996		1997		1998		1999		2000		2001	
	Hours	Turbines	Hours	Turbines	Hours	Turbines	Hours	Turbines	Hours	Turbines	Hours	Turbines
Lapland	119	2							159	8	5	1
Åland	12	1	55	5	23	3	49	9	7	3	44	3
Bay of Bothnia	858	4	372	5	98	2	532	7	573	7	4143	15
Sea of Bothnia	219	5	68	4	75	2					38	1
Gulf of Finland												
Total	1208	12	495	14	196	7	581	16	739	18	4230	20
Total number of turbines		19		21		29		38		61		61
Share of the total down time of the turbines that reported icing during the year	45 %		21 %		9 %		12 %		9 %		26 %	

Table 2. Reported down time due to low temperature in Finland 1997-2001. [21]

FINLAND	1997		1998		1999		2000		2001	
	Hours	Turbines	Hours	Turbines	Hours	Turbines	Hours	Turbines	Hours	Turbines
Lapland					450	3	32	1	100	6
Åland			1	1						
Bay of Bothnia	28	1	890	4	2477	8	72	1	706	4
Sea of Bothnia	60	4	397	4	699	4	100	2	1733	7
Gulf of Finland										
Total	88	5	1288	9	3626	15	204	4	2539	17
Total number of turbines		21		29		38		61		61
Share of the operational hours of the turbines that reported low temperatures during the year	0 %		2 %		3 %		1 %		2 %	

Icing retards more wind energy production than low temperatures in Finland (Table 1 and Table 2). There are several reasons for this difference, such as that low temperatures operation was taken into account in the design process of most turbines operating in Finland. In addition, the majority of Finland's wind turbines are located in coastal areas and thus do not often experience very low temperatures. Icing however is recorded regularly throughout the entire country.

5.3.2 Sweden

As part of a national program, monthly operational statistics from most wind turbine owners having obtained investment subsidies have been collected for more than 10 years. Data from 622 wind turbines, totalling 345 MW dispersed nationally, were available by the end of 2002 [55]. More recently, the average capacity of installed units has increased from 867 kW in 2001 to 882 kW in 2002. The total energy production also increased from the 2001 amount of 609 GWA by 23%. Figure 11 shows the location and impact of reported cold climate incident reports during 2000-2002.

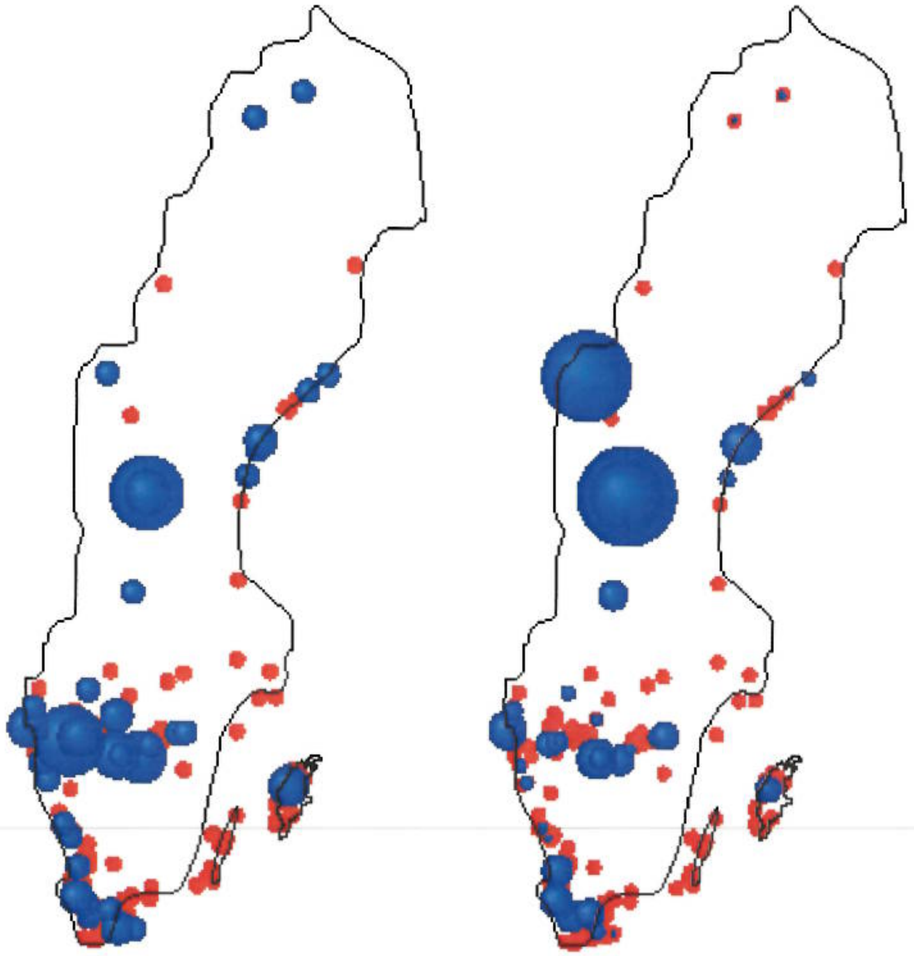


Figure 11. The location of 565 out of at least 622 wind turbines is shown (red). Cold climate reports have been submitted from 47 turbines (blue). Left: Distribution of 92 reported incidents of cold climate type during 2000-2002. Right: Distribution of 8022 reported incident hours of cold climate type during 2000-2002. Size of the circle represents the number of reports and incident hours respectively.

The Swedish statistical incident database contains a total of 1337 records reported to have occurred in between 1998-01-31 to 2002-12-31 resulting in a total downtime of 161,523 hours. 92 incidents (7%) are related to cold climate resulting in 8022 (5%) lost production hours. Of the total for cold climates, the reported low temperature downtime totalled 669 hours (8%) while the equivalent for icing events was 7353 h (92%). The number of unrecorded ice cases can safely be assumed to be overwhelming due to manual reporting in combination with an inherent lack of technology and methods to reliably and automatically detect ice. Automatic energy reporting has been applied in recent years [56] and covers, by end of 2002, 65% of the installed units. It is not clear whether automatic reporting will increase or decrease the willingness of wind turbine operators to submit cold climate incident reports once manual reporting is no longer mandatory.

Data collected through the mandatory reports show that number of incidents of cold climate reporting are increasing, figure 12.

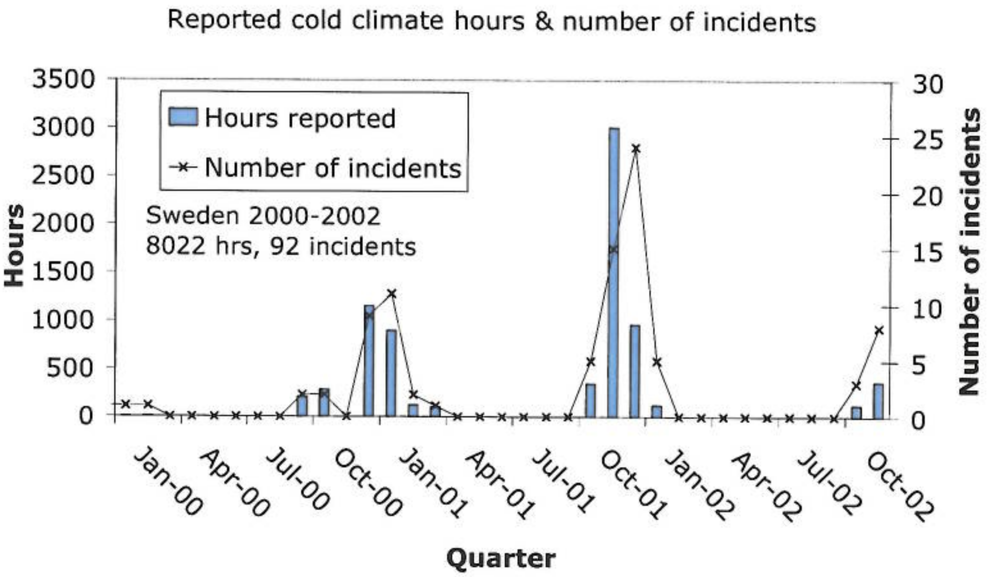


Figure 12. Monthly number of reported cold climate downtime and number of incidents.

An assumed reason for the increasing number of reported cold climate related incidents is the fact that wind turbines were built recently in areas with more extreme cold climate conditions, Figure 13.

The various causes of incidents are shown for ice and low temperature in Figure 14 and Figure 15 respectively.

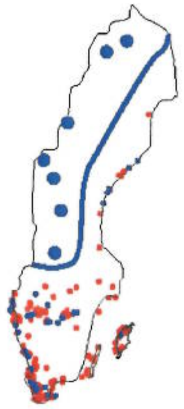
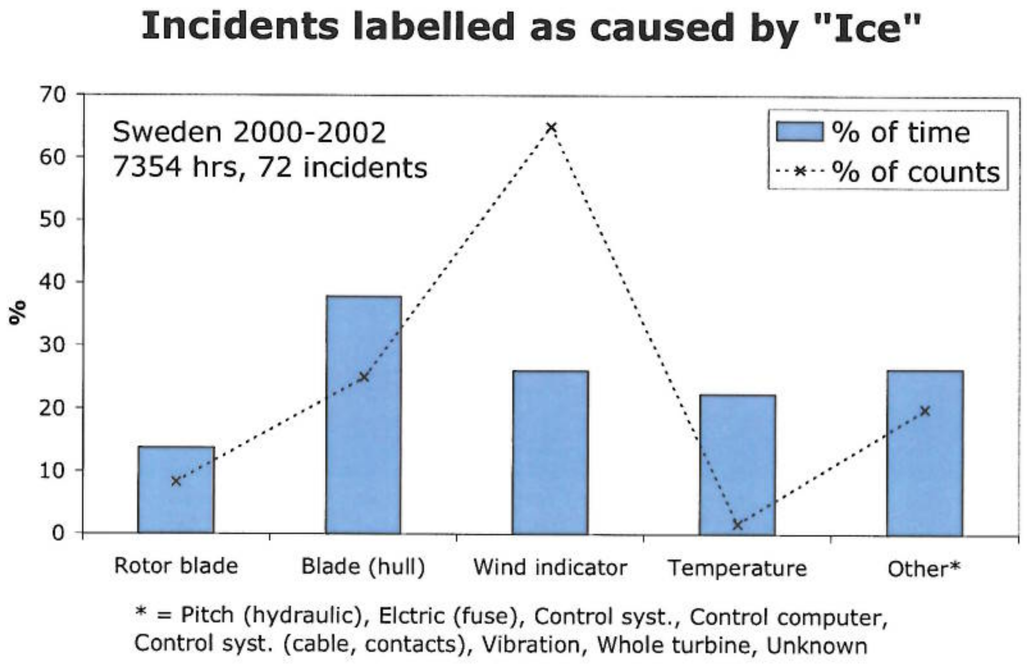


Figure 13. Main cold climate region.



* = Pitch (hydraulic), Elctric (fuse), Control syst., Control computer, Control syst. (cable, contacts), Vibration, Whole turbine, Unknown

Figure 15. Cause of incidents due to ice.

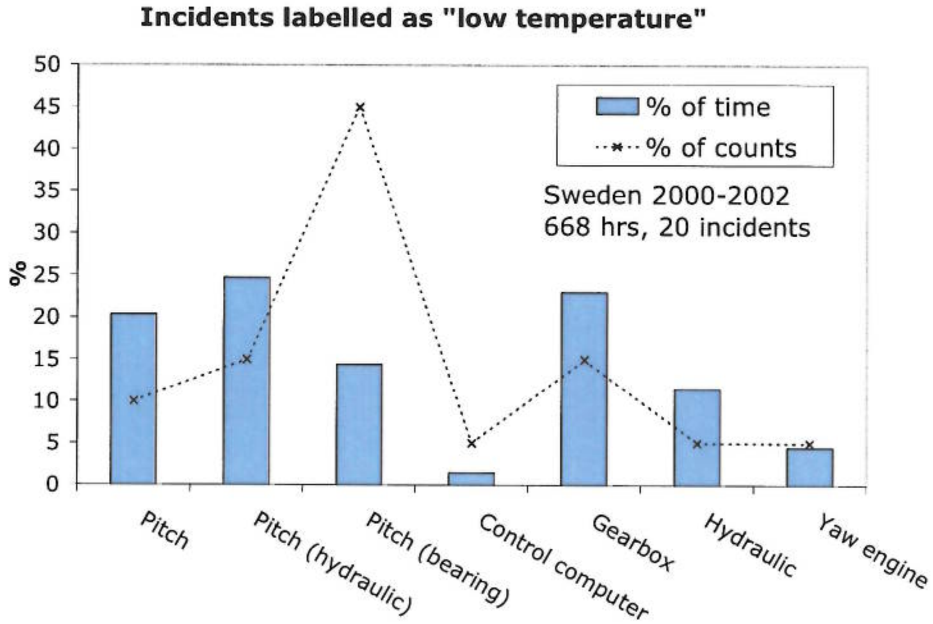


Figure 14. Cause of incidents due to low temperature.

There are 16 (3 with unknown co-ordinates) wind turbines located within the main cold climate region shown above. These are shown in table 3:

Table 3. Wind turbine types within cold climate region

#	Manufacturer	Model	Rated power [kW]	Control
10	NEG Micon	NM 900/52	900/200	stall, 2 speed
1	NEG Micon	NM 750/48	750/200	stall, 2 speed
1	NEG Micon	750kW	750/175	stall, 2 speed
1*	NEG Micon	NM72C/1500	1500/400	active stall, 2 speed
2	Bonus	Mk IV	600/120	stall, 2 speed
1 (2*)	Vestas	V52-850	850	pitch, variable speed
1	Vestas	V66-105	1750	pitch, variable speed
0 (1)	Nordex	600kW	600/125	stall, 2 speed
19 **(Total # of wind turbines)**				

* not included in national statistics

The geographical listing, from south to north, as well as 1st date of operation are shown in Table 4:

Table 4. Geographical listing, from south to north, and 1st date of operation, of present wind turbines within the main cold climate region.

#	Location	Date	Manufacturer	Model	
1	Äppelbo	00-12-17	NEG Micon	NM 900/52	
0* (1)	Rodovålen 1	98-10-21	Nordex	600 kW	
1	Rodovålen 2	98-10-07	Bonus	Mk IV, 600 kW	
1	Rodovålen 3	98-10-23	NEG Micon	750 kW	
1	Rodovålen	03-01-01	Vestas	V52-850	
1	Bydalen	02-09-04	NEG Micon	NM 750/48	
1	Gråsjön, Kall	00-11-08	Vestas	V66-105	
3	Klimpfjäll	01-01-16	NEG Micon	NM 900/52	
1	Suorva	98-10-13	Bonus	Mk IV	
6	Viscaria, Kiruna	01-09-18	NEG Micon	NM 900/52	
1**	Digerberget	02-01-01	NEG Micon	NM72C/1500	
1**	Almåsa, Krokom		?	Vestas	V52-850
1**	Vallrun, Krokom		?	Vestas	V52-850
19 (Total # of wind turbines)					

* replaced by a V52-850 not yet included in national operational statistics
** turbines not yet included in national operational statistics

Prolonged reduced, as well as absent, wind energy production from wind turbines due to ice have been observed on several occasions. One such example can be detected in the operational statistics from the southernmost wind turbine listed above; Äppelbo. Figure 16 shows the monthly energy production from the Äppelbo turbine divided by the average ditto from two identical wind turbines located in the southern part of the country. The energy output in December 2002 can be seen to hit a record low due to ice. The turbine does not have heated blades.

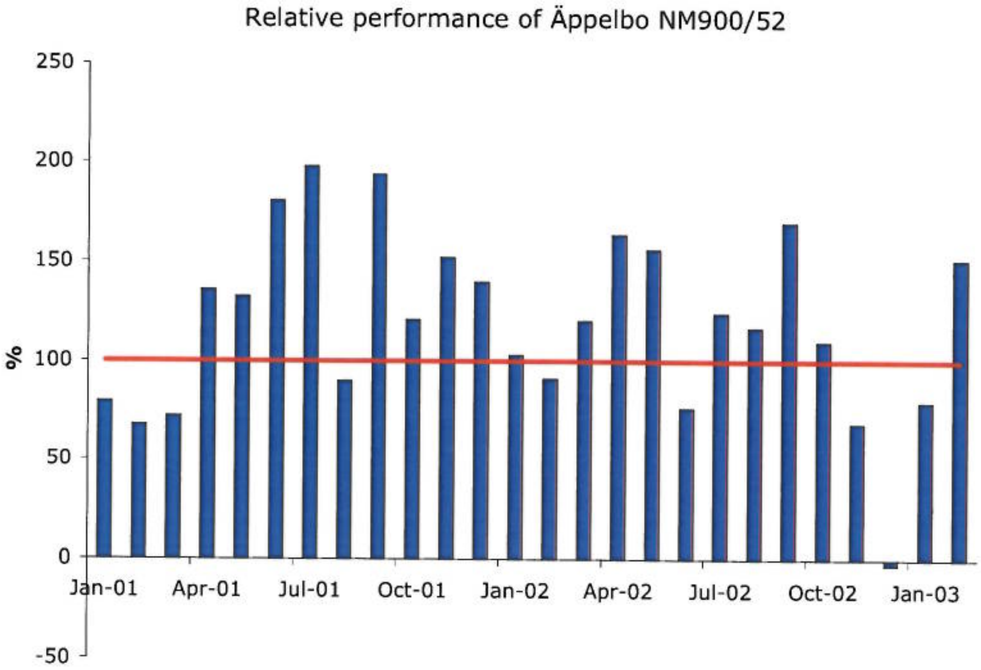


Figure 16. Monthly energy production from the Äppelbo turbine divided by the average ditto from two identical wind turbines located in the southern part of the country.

Access to offshore sites in southern Sweden has been limited during the past winter due to ice, as the cost of an ice-breaking vessel is prohibitive. Figure 17 shows such an example. The wind farm is close but yet so far away.

Figure 17. Access to offshore wind farms in southern Sweden has been limited due to ice.

The past winter, 2002/2003, ice build-ups on wind turbine blades have been reported from Gotland and the northern part of the country. An example of such an occurrence is shown in Figure 18. The wind was calm and production losses were small in this particular case. The risk of being hit by a piece of ice being shed from a starting wind turbine is small but shall not be neglected. The aerodynamic drag of a flying piece of ice need to be included in risk zone calculations, as this rightfully will reduce the size of the affected risk zone.

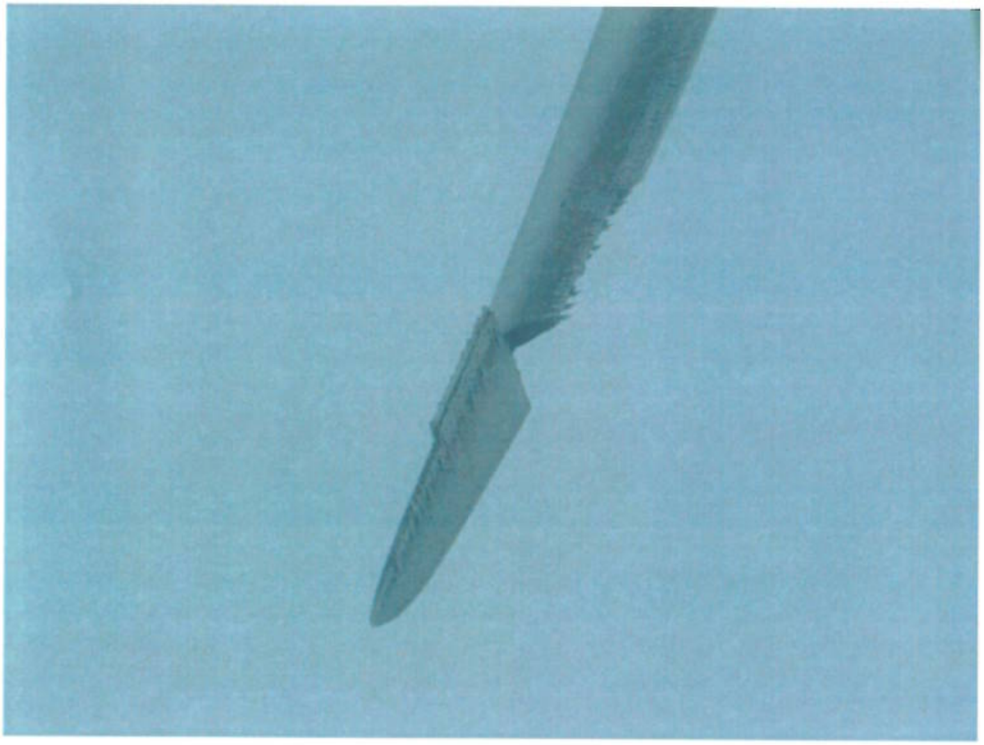


Figure 18. Ice build-up on a wind turbine blade during winter of 2002/2003.

5.3.3 Norway

Norway has a long shoreline facing the warm waters of the eastern part of the north Atlantic ocean currents. Low pressure systems forming in the polar jet stream areas over the warm Atlantic waters move eastward and ensure high wind speeds and a mild climate along the Norwegian coast. Well exposed Islands and ridges along the coast are well suited for wind energy. Compared to other areas in the world at the same latitude, the temperatures in wintertime are relatively high. At North Cape (71°), -4°C is the lowest monthly average temperature at sea level.

Norway does not have a centralized system for collection of operational experience from wind farms. Numbers for downtime due to icing or low temperature are therefore not available.

So far 2003, 97 MW of wind power, have been located at low altitudes. The latest wind farm Havøygavlen is located at Latitude 71° and 275 m above sea level. Even though it is the northern most wind farm in the world, the site is not considered arctic. The average winter (January) temperature is about -6 °C. The wind farm was installed autumn 2002, and little operational experience exists. According to the operator, very little icing has been reported so far. Only some minor problems with batteries and oil possibly due to low temperature have been reported.

Nord-Trøndelag Elektrisitetsverk has experience with operation of wind turbines since 1990. Their wind turbines are located in the middle of Norway, around latitude 65°. One Vestas V66 has been installed at 230 m above sea level, and a small wind farm is located at about 130 m above sea level. Since the installation of the wind turbines there has been no icing that would have resulted in operational interruption. After some years of usage the turbines were equipped with heating of the hydraulic oil to prevent problems related to restart in low temperatures.

Kvalheim Kraft owns a wind farm consisting of 5 Vestas 850 kW. They are located at Latitude 62° and about 410 m above sea level. The only arctic adaptation made is the use of heated sonic anemometers. Similar to the turbines at Havøygavlen, they have no arctic adjustments. No serious problems with low temperatures or icing have been experienced so far. Icing has been reported occasionally at the time of stand still of the turbines. It has been possible to start turbines with blades covered with ice by forced manual start. After the forced start ice has shed from the blades.

5.3.4 Switzerland

Switzerland has long experience of with wind energy site assessments in alpine areas. Such sites experience harsh climatic conditions such as low temperatures, high turbulence and extreme gusts.

In Switzerland several wind energy projects have been carried out in icing and in low temperature climate. Wind turbines that experience icing and low temperatures locate at high altitudes. Altitudes range from 1300 metre to 3000 metre above the sea level. Typically sites below 2000 metre above sea level experience light icing and sites with higher altitude are prone to heavy icing and low temperatures. Important experience on the use of wind energy under climatically extreme conditions will be gained, with the 800 kW plant on the Guetsch near Andermatt (2300 m above sea-level) which was commissioned in spring 2002. This is the first wind turbine in Switzerland that uses adapted technology because of icing and low temperatures. Further projects such as St.Moritz (2200 m above sea-level) as well as Crêt Meuron (1300 m above sea-level), will increase the knowledge about wind energy production in alpine region in harsh climatic conditions.

5.3.5 USA

Operational experience of wind turbines in cold and icing climates is limited and the private, unsubsidised nature of most installations make collecting data on system downtime difficult.

As stated previously wind turbines have being installed in three general climatic regimes effected by cold weather. In the north central region, such as the 200 MW wind plants in the Lake Benton, Minnesota area, snowfall and cold temperatures are common but turbine icing is uncommon due to the low humidity. Operators in these regions have not reported down time due to either cold temperatures or icing events. In the north-east and north west parts of the US, such as the 6 MW plant in Searsburg, Vermont, turbines are located on low altitude mountain ridges or in coastal regimes where icing is common, but is not usually sever at the elevations where wind turbines are installed. In most cases precipitation is in the form of snow, which does not impact turbine operation. The former company US Windpower conducted extensive tests of wind turbines on Mt. Equinox in central Vermont. This high altitude mountain ridge experienced sever rime ice and cold, humid air flows. All of the research from these sites, which were active in the mid to late 1980's was never made public. All other sites are at much lower elevations and thus do not experience the same rime ice conditions. The last clarification of sites are along the arctic coast, such as the 0.5 MW plant located in Kotzebue, Whales and St Paul Alaska. These sites do experience cold temperatures and high density air flows, but usually little icing due to the low humidity. Turbines installed in these areas are outfitted with cold weather packages, including oil heaters and special metal treatment. None of the turbines installed have included blade heating options, other then the use of black painted blades.

Of the sites outfitted with governmental supported monitoring systems, reports of downtime result more due to turbine maintenance in cold climates as compared to actual operational issues.

5.3.6 Canada

One operator in Canada has identified overproduction in cold temperatures has being its most significant cold weather issue. For a 600 kW Tacke machine located in Tiverton, Ontario, second-averaged power peaks of 950 kW were recorded in -20° C weather and the generator overheated and tripped out [13]. Also on a 65 kW Bonus machine located in Kuujjuaq (58° N), a 5-minute average power output of 89 kW was recorded [13].

Yukon Energy Corporation has a significant amount of experience in operating wind turbines in low temperatures and severe in-cloud icing environment. The company owns two turbines: one 150 kW Mark III Bonus and one 660 kW V47 Vestas in Haeckel Hill, Yukon (altitude 1430 meters). They were installed in 1993 and 2000 respectively [32]. Maissan [32] reports that low temperature steels, synthetic lubricants and heating systems for items like gearbox, generator and electrical cabinets have worked well. However, anemometers and aerial power lines proved to be adversely affected by in-cloud icing. In addition, problems were encountered with the ice detector that controls the heating strips installed on the first turbine. The ice detector was removed and the heating strips controlled manually. Another ice detector was installed but outside the control loop of the heating strips. It recorded approximately 800 hours of rime icing at the site [32].

Based on the experiences of Yukon Energy, Maissan identifies icing as probably the most significant issue. Yukon has experimented with a protective coating on their first turbine. They covered the blade surfaces with a black low adhesion type of paint. They noticed an improvement in turbine output. In addition to the more obvious solutions for cold weather climates, he recommends that turbines be fitted with full blade surface ice protection and wished that such a system had been available for the second turbine installed on Haeckel Hill. He also would like to see the operating temperature range reach down to -40°C [32].

6 EXISTING STANDARDS, REQUIREMENTS AND RECOMMENDATIONS

6.1 WIND TURBINES

Certifying wind turbines for cold and mountainous regions requires reliable procedures for the prediction of the amount of ice accretion during standstill and operation. International design standards take icing load cases into consideration in different ways. The IEC-61400-1 Wind Turbine Generator Systems - Part 1 Safety Requirements recommends to take ice loads into account but a special load case is not given and no minimum ice requirements are given for standard wind turbines [34]. Germanischer Lloyd requires that two icing cases for rotating parts and one for non-rotating parts must be considered when designing a wind turbine. For rotating parts the two cases are "all blades covered with ice" and "all but one blade iced over". For non-rotating parts icing of 30mm for all exposed parts must be taken into account. Simple formula for calculating the design ice loads is given. [35,36] The Danish Energy Agency gives it's recommendation for Offshore wind. Typical sea ice characteristics and formula for calculating static ice loads are given. The loads from dynamic sea ice behaviour are advised to be noticed, but no clear recommendation how to estimate those dynamic loads is given. Icing of the rotating parts follows the guidelines of Germanischer Lloyd. However at North Sea the design ice thickness is recommended to be increased from 30mm to 150mm due to the water spray for parts less than 20m from the water level. [37]

6.2 RESOURCE ESTIMATION AND POWER PERFORMANCE MEASUREMENTS

The IEC-61400-12 Wind Turbine Generator Systems - Part 12 Wind turbines power performance testing sets no requirements for equipments or data treatment used in power performance testing in low temperatures or in icing climate [38].

7 SUMMARY

Wind turbines have been and are located to such sites where turbines are exposed to such low temperatures outside the standard operational limit and to sites where turbines face icing, which retard energy production, at the winter time. Currently capacity of about 500MW locates on sites, which can be defined, as cold climate wind turbine sites. Such sites are often elevated from the surrounding landscape. Wind turbines have been recorded to operate in cold climate in Scandinavia, North America, Europe and Asia.

At the time of new investment site assessment is carried out. Low temperature and icing climate sets additional requirements for wind resource measurements. Selected measurement equipment should be designed for low temperature and icing climate use. Especially anemometer and wind vane should be selected with care. Already a small amount of ice may reduce measured wind speed significantly and large ice accretions may stop the entire anemometer. For example a small amount of rime on the cups and shaft of an anemometer may lead to underestimation of wind speed about 30 % at wind speed of 10 m/s. Lot of research has been done in this field and devices suitable for wind resource estimation in severe icing climate are available. In addition to the measurement instruments itself other parts of the measurement system should also be able to cope with low temperature and icing. Cables, connectors and cable ties specified for low temperature usage should be employed. Also heating for the boom of wind sensors in severe icing climates should be provided to avoid distorted results.

Extensive and reliable temperature data is commonly produced for weather forecasts. Such temperature recordings enable the estimation of extreme temperatures and duration of low temperature time. Icing measurements are however rare and are not included in standard meteorological measurement. It is possible to calculate estimation of in cloud icing from visibility observations, which include cloud base height measurements. These measurements are usually performed only at airports. Due to that coverage and accuracy of this method are only satisfactory. If icing is considered to deteriorate power production, it is advisable to add icing measurements to resource estimation measurements if such are carried out.

Several methods to detect icing are available. Ice detectors for meteorological measurements are available. It is also possible to measure icing indirectly with dew point detector. Since there is analogy between anemometer and a wind turbine, persistency of icing may be evaluated economically with a set-up of two anemometers, in which one is properly heated and the other is unheated. According to the current knowledge ice detectors are most suitable for icing time measurements and therefore also for controlling a possible heating devises.

Meteorologists have developed models for estimation of different type of atmospheric icing and the effects of icing and from other standpoint aviation industry has developed models to calculate weight and shape of ice accumulations on the leading edge of a wing. Those computer codes have been modified for wind turbines. Due to complexity of icing phenomenon and aerodynamics as well as current performance of modern personal computers, the development of more accurate models has been moderate. Maps to describe annual icing time have been developed but standardised method to calculate local icing time from meteorological measurements still lacks.

Technical solutions for wind turbines operating at low temperature or at icing climate are available. Low temperature specified materials and oils should be used if temperatures outside the standard limits are probable. Many turbine manufacturers have so called low temperature versions of their standard turbines. In addition to cold specified materials used, those turbines often are equipped with gearbox heaters. Some manufacturers have also developed adapted technology for icing climate. In addition to low temperature versions those turbines include measures against icing. Ice detectors, coatings that prevent ice to stick to the blades and different blade heating systems are available.

Wind turbines have been sited to cold climate sites for some years and today operational experiences exist. In Scandinavia down time for older turbines have been recorded due to low temperature, modern turbines instead are already adapted to the low temperatures and recorded down times have been relatively low. Low temperatures have also recorded to extend the duration of maintenance and reparation breaks during winter.

Severity of icing varies a lot depending on local parameters especially altitude compared to surrounding landscape has great effect on severity of icing. Icing has been recorded to retard energy production at elevated sites in Scandinavia, Alpine regions of Europe as well as elevated sites in North America in Canada and Alaska. But in Norway for example icing have not had that kind of effect to wind power production that it would have been recorded, even though turbines locate up to 200m level above sea level and even higher latitudes than for example in Finland. Previous underlines the fact that icing is very much local phenomenon. Similar to low temperature icing and snow has been recorded to extend the duration of maintenance and reparation breaks. Snow may even prevent accessing to site during winter. In severe icing climate of Canada and Finland systems that keep blades free of ice have been found compulsory.

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WIND POWER DEVELOPMENT IN SUB-ARCTIC CONDITIONS WITH SEVERE RIME ICING

by

John F. Maissan, P.Eng.,
Director, Technical Services
Yukon Energy Corporation

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by
John F. Maissan, P. Eng., Director, Technical Services
Yukon Energy Corporation
P. O. Box 5920
Whitehorse, Yukon
Y1A 5L6
Canada
Telephone (867) 393-5347
Fax (867) 393-5322

INTRODUCTION

Yukon is the North-Westerly most part of Canada and lies immediately East of Alaska. It has a population of about 33,000 people, two thirds of which live in the capital city, Whitehorse, situated in South central Yukon.

Electrical energy is supplied principally from two hydro-electric plants located on the main (Southern) power grid and a third on a small grid in central Yukon. However, peaking energy and capacity are normally supplied by diesel generators. As well, there are 8 communities that are supplied by entirely by diesel plants because they are not connected to either of these hydro based power grids.

With the mining industry in full operation, electrical loads can peak at up to 78 MW in the main grid in the coldest days of winter. Annual energy requirement with this mining load on is about 450 GWh. At present the mining load is shut down, resulting in peak loads of just over 50 MW and annual energy requirements of only 250 GWh (there is now a hydro-electric energy surplus). In the diesel served communities the annual energy requirement totals about 50 GWh.

The climate in Whitehorse is sub-arctic, mean daily January lows are -25°C with the lowest temperatures around -40°C, and occasionally to -45°C or lower. Weather data analyses have shown that at altitudes of 4,000 to 6,000 feet rime icing can occur from 800 to 1200 hours per year -- equivalent to a continuous duration of 4 to 7 weeks per year. Rime icing is the buildup of ice on anything solid from moist, supersaturated air at sub-zero temperatures. Essentially whenever and wherever there is a cloud on a mountain there is rime icing (cover photograph). Rime ice looks like the pretty frost that builds up on trees around open water in the winter. In our location rime icing is most severe in the early winter: mid October to the end of December. Severe rime ice on wind monitoring equipment is illustrated in Photograph 1.

BACKGROUND

The potential for commercial wind power generation in Yukon was investigated in the early and late 1980s on the basis of data from airports and two wind monitoring stations. In all cases the conclusion was that it was not economic.

In 1990 two local citizens investigated Environment Canada's upper air data and found that wind speeds increased substantially with altitude. This led to the establishment of a 65 foot (20 meter) wind monitoring station on a shoulder of Mt. Sumanik that is known locally as Haeckel Hill, located west of the city. This site has an altitude of about 4,700 feet (1430 meters), about 2500 feet above the valley floor, and consists of a ridge perpendicular to the prevailing wind. Road access and a single phase power line to a forest fire look out tower located on top were positive factors in the selection of this site. Monitoring results confirmed the higher wind speeds at higher altitudes, but also found severe rime icing conditions at the site. Another interesting feature, since confirmed by long term monitoring, is that inversions keep the temperatures from reaching the low extremes, it seldom drops below -30°C (-22°F) even with valley temperatures down to -45°C (-50°F) or lower.

A subsequent analysis of upper air data (Table 1) showed that the annual average wind speed at 4,000 feet was 6.6 m/s (meters per second), at 5,000 feet was 6.9 m/s, and at 6,000 feet was 7.3 m/s. Since the kinetic energy in wind increases with the cube of the wind speed, these are significantly better than the 3.9 m/s long term average at the airport. It is also very significant that the wind speeds are much higher in winter than in summer, almost perfectly following the seasonal electrical load profile. It was felt that with these wind speeds commercial wind power could be cheaper than diesel generation if the low temperatures and the effects of the rime icing could be overcome. Producing electrical power at costs below the cost of diesel generation was and remains our primary goal. Environmental benefits are the icing on the cake.

THE FIRST WIND TURBINE

Since the monitoring generally confirmed the upper air wind regime, and found that severe rime icing was present there, it was decided, in 1992, that a program of adaptation of commercial wind generating equipment to this climate was needed. With our limited resources we decided that we could not do anything other than take existing, proven commercial equipment and try to adapt this to our conditions. Several large, reputable manufacturers were considered and Bonus Energy A/S of Denmark was selected for their 150 kW MARK III unit. This 150 kW machine, a conventional three bladed, horizontal axis, up wind and stall regulated design, represented the small end of the commercial range available and therefore the lowest capital cost. Bonus was a large proven commercial equipment supplier with a good reputation, had some northern experience, was willing to work with Yukon Energy on modifications, and had a hinged tower design for a winch up raising that did not require a large crane to be brought in from southern Canada.

In consultation with Bonus a number of modifications were made to their standard design. A hinged, winch up 30 meter tower was an important feature. To overcome the effects of the cold, low temperature tolerant steels were selected for the tower plus other key components, and synthetic lubricants (including hydraulic fluid) were used throughout. Electric heaters, controlled by thermostats, were installed on the gearbox, in the generator, in the computer control cabinet, and in the radio communications cabinet.

To overcome rime icing effects the anemometer and wind vane used to control the turbine were equipped with heated bearings. The blades were equipped with heating strips about 6 inches wide and running along the entire length of the leading edge. The heat output was about 1/4 watt per square inch, or 1,700 watts for all three blades. An ice detector to turn the blade heating on and off was also supplied. The power production target was set at 300,000 kWh per year representing a capacity factor of 22.8% (Table 1).

A firm order for this unit, plus a two year service agreement from the manufacturer, was placed in December 1992. The turbine was erected in July of 1993 (Photograph 2) and was commissioned on August 13. The project cost about $CDN 800,000, of which $CDN 200,000 was for upgrading the road and power line. Yukon Energy received a grant of $300,000 from government sources toward the project.

PROJECT RESULTS

Rime icing causes were briefly described in the introduction. The practical effects can be substantial. Any solid object accumulates ice which "grows" into the wind (Photograph 3). Trees become ice domes, towers become ice posts, power lines grow to six or eight inches in diameter, and chain link fences become solid walls. As you can see it is no wonder that exposed equipment has difficulty working under these conditions. Low temperatures and severe rime icing are the challenges we need to overcome.

The following features have worked well and have not needed further attention:

1. The winch up tower worked well even though it is not as easy to winch up or down as expected.

2. The low temperature steels have not been a problem so far.

3. Lubrication with synthetic products has worked well.

4. The heating systems in the gearbox, generator, and electronic cabinets have been very reliable.

Aspects of the project that did not work initially but have since been overcome are:

1. The heated bearing anemometer and wind vane were still immobilized by ice and were replaced with fully heated Hydro-Tech instruments which have not iced up (Photograph 1).

2. The overhead power line was causing about five outages per month due to the heavy accumulation of ice in combination with wind, and was replaced with a buried cable which is not affected by the ice.

3. The Ice detector supplied with the turbine was not effective and was removed from the control circuit. The heating circuits are now simply switched on for the winter. A Rosemount ice detector was purchased in 1996 and has been running reliably on site since then, but has not been installed into the turbine control circuit. This ice detector has indicated that we average over 800 hours of rime icing per year on the site.

One aspect of the project that did not work and has not been overcome is the inability of the electrical contacts between the main portion of the blades and the tips to work reliably under icing conditions. Several redesigns have also failed to operate reliably.

The leading edge blade heaters (1/4 watt per square inch) have worked reasonably well even though one burnt out in 1996. We replaced them all in 1998 with heaters 12 inches wide, rather than 6 inches, to improve performance in very severe rime icing and in very cold temperature conditions. Perhaps because of other problems and advances we have not been able to attribute specific production improvements to the larger heaters.

The effect of rime icing on the blades of the wind turbine is such an important issue that it is worth examining in detail. Without blade heaters rime ice builds up especially heavily on the leading edges, and the build up increases with distance from the blade root (Photograph 4). It seems to be directly related to the velocity at any point and therefor perhaps the amount of moisture or moist ice contacted. When shut down the ice builds up on the edges of the blade surface facing the wind, the pressure side. When running through an icing event the ice build up on the "back", or suction side, of the blade is much less than on the "front" (Photograph 5). Ice can also build up on the trailing edge. Power production drops off dramatically when the blades are coated with rime ice and without leading edge blade heaters can stop altogether (Graph 1).

The 6 inch wide heaters did, under lighter icing conditions, keep portions of the blade downwind of the heater clear (Photograph 6). Under heavier icing conditions ice would build up on the blade right up to the heater (Photograph 7). Build up of ice on the leading edges did not occur except under the most severe conditions, and it cleared off quite quickly afterwards. It was from this that we concluded that more heat on the front of the blade in the form of wider leading edge heaters would be of benefit if the increased area was applied to the front (pressure side) of the blade. It was also obvious that the leading edges of the blade tip would need to be heated to minimize the air drag and associated production losses.

One aspect of the project that was very positive was the bird monitoring work. Concern over the possibility of bird kills in collision with the turbine blades, especially during spring and fall migrations, led to a five year monitoring program. It was found that the migrating waterfowl, at least, stayed lower down in the valley well below the altitude of the turbine. The only bird mortality documented in the program was a grouse that flew into the chain link fence.

POWER PRODUCTION

From a production perspective the project has not yet met the target but, all considered, we are satisfied with our accomplishments. In the first year we solved the power line and control instrument problems. Once those were resolved performance improved substantially.

In the third year of operation we had a failure of one of the blade heaters early in winter and we had to operate without any leading edge heat for the rest of the winter. With the heaters working on only two of the blades there was a significant blade weight imbalance. At this time annual "losses" due to rime icing were estimated to be in the range of 60,000 to 70,000 kWh per year, about 20% of the production target.

Repairs to the power line (a local feeder) were made in 1996 and since that time there have been very few of the electronic problems that bothered us early on, and turbine availability has been very high. Also in 1996 we "painted" the blades with a black coloured coating called StaClean. We believed that the solar heating from the black colour would assist in clearing the blades of accumulated rime ice, and we felt that the special low adhesion formula for ice could be beneficial too. We saw an immediate noticeable improvement in performance, 1998 and 1999 have been the best production years yet. Photograph 8 shows accumulated ice shedding from the blades.

On the whole we are pleased with the performance, especially considering where the turbine is physically located, the unfamiliarity of maintenance personnel with this type of equipment, and our dependence on a few key people. Due to the ladder being outside for the top portion of the tower and the weather exposed servicing, maintenance is not done during severe weather conditions. Detailed monthly performance statistics from project commissioning are presented in Table 2. Annual figures based on revenue metering which commenced in July 1994 is presented in Table 3.

THE SECOND WIND TURBINE

With funding from the Yukon government, the Yukon Energy installed a new larger wind turbine this past September, a Vestas 660 kW V47 LT II, low temperature version (photograph 9). This turbine incorporates most of the features that we believe will move wind energy from the development phase into commercial viability. This machine is a pitch regulated machine designed for unrestricted operation down to -30° C (-22° F). It was fitted with fully heated wind instruments, StaClean coated (black) blades and leading edge blade heaters. Our experience with the stall regulated 150 kW machine have convinced us that a pitch regulated machine will lose less power when affected by rime ice as the lowering of the stall wind speed is not as critical with the pitch regulation design. In the higher wind speeds the blades will remain pitched to a more aggressive angle until full output is achieved. Since the blades do not have tip brakes maintaining electrical continuity and effective heating to the very tip should not be a problem.

Two features that we would have liked to have had but were not able to get in a turbine in the 500 to 1,000 kW size range this time, were a full surface blade heating system, and an operating temperature range down to -40°.

The new turbine was installation was completed in mid September (photograph 10). Detailed performance comparisons between the two turbines has not been possible so far. We are still in the process of fine tuning the various operating and control systems. These analyses will be part of our work in the coming years.

SUGGESTIONS FOR SIMILAR APPLICATIONS

For anyone contemplating a wind turbine in a cold, severe rime icing environment such as Haeckel Hill, which is on the warmer side of typical of the interior of Yukon and Alaska, we would recommend the following:

1. Low temperature steels
2. Low temperature synthetic lubricants and fluids
3. Equipment heaters (gearbox, generator, control cabinets)
4. Fully heated wind instruments
5. Black coloured fluorourethane (StaClean) coated blades
6. Full surface blade heating if available, or otherwise leading edge heaters at least 12 inches wide
7. For simplicity and reliability in leading edge heating one piece blades would be better than the two piece such as we have on our Bonus machine
8. Tubular tower for “indoor” climbing and maintenance work for shelter from the weather
9. Pitch or active stall regulation as we believe this will result in higher power production

CONCLUSION

In conclusion, substantial progress has been made in understanding the effects of rime icing on wind turbines and in learning how to overcome them. It is our goal to establish a track record of performance under these conditions that puts wind power into the list of realistic and practical power supply options available to us in Yukon. Like the trees that survive in these conditions we northerners need to stand together, we need to be tough, we need to be innovative, we need to be persistent, and, most importantly, we need a strong positive attitude.

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TABLE 1 WHITEHORSE UPPER AIR WIND SPEEDS AND BONUS PRODUCTION TARGETS						
Whitehorse, Yukon Mean Wind Speeds 1980 - 1995					**Bonus 150 Production Targets**	
Month	**(Airport) 2305' ASL**	**4000' ASL**	**5000' ASL**	**6000' ASL**	**Target kWh**	**Target Capacity Factor**
January	3.6	8.5	8.7	9.2	30.000	26.9%
February	4.1	7.9	8.3	9.0	28.000	27.8%
March	4.0	6.9	7.3	7.7	28.000	25.1%
April	4.0	6.2	6.5	6.8	25.000	23.1%
May	4.0	5.6	5.8	6.1	24.000	21.5%
June	3.6	5.0	5.0	5.3	15.000	13.9%
July	3.4	4.3	4.6	4.8	15.000	13.4%
August	3.3	5.5	5.5	5.8	18.000	16.1%
September	3.4	6.6	6.9	7.6	27.000	25.0%
October	4.6	7.7	8.1	8.5	30.000	26.9%
November	4.4	7.9	8.3	8.4	30.000	27.8%
December	4.0	8.2	8.5	9.0	30.000	26.9%
Annual	**3.9**	**6.6**	**6.9**	**7.3**	**300.000**	**22.8%**

Graph 1 Rime Icing Effects on Power Production Curves

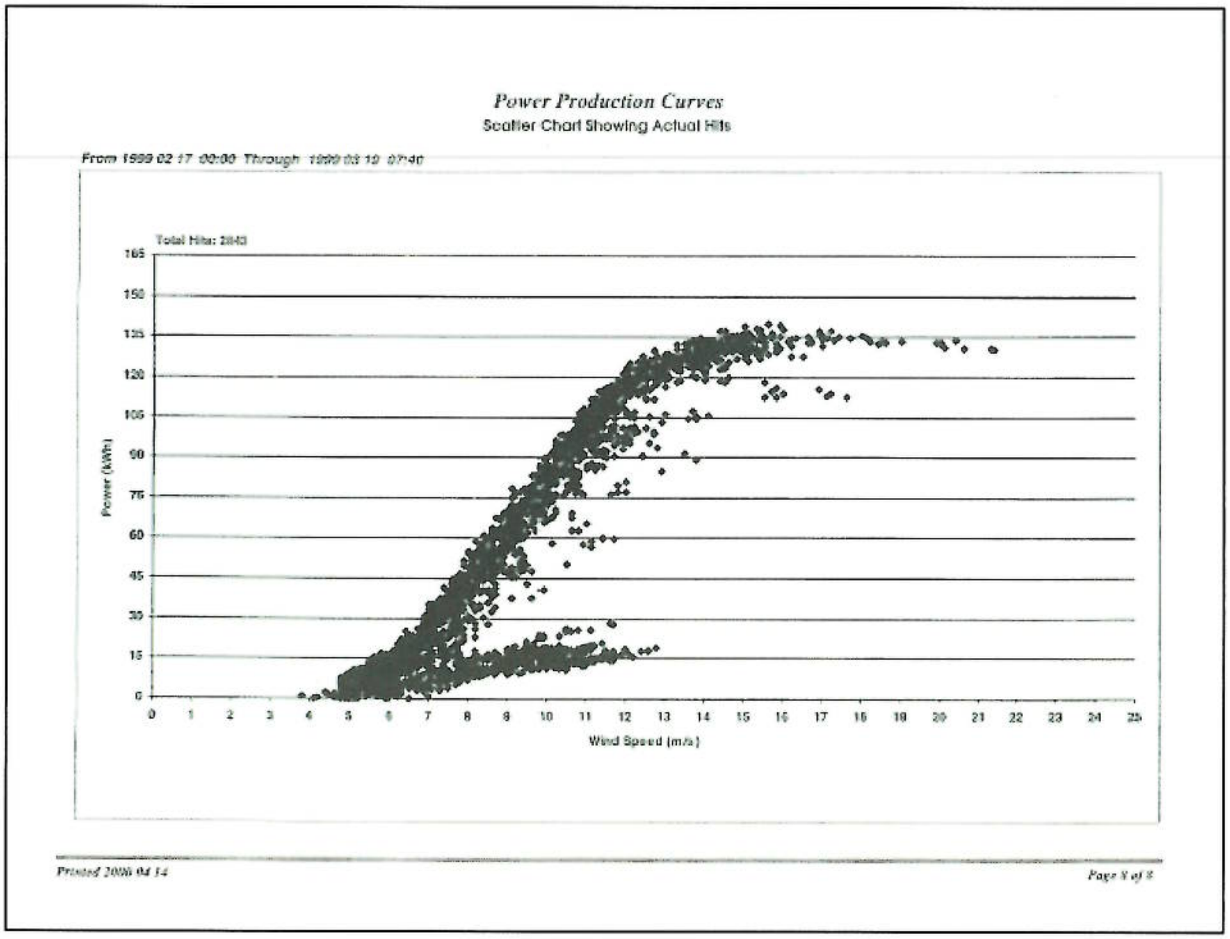


Table 2 Detailed Production Record

WIND TURBINE PRODUCTION DATA

Month	Prod. (kWh)	Total Hours	Hours in Prod.	Maint. Hours	Break Down Hours	Grid Outage Hours	Cap. Factor	Turbine Avail.	Overall Avail.	Revenue Meter Gross	Cap. Factor
Aug-93	10,949	408	222	0	0	0	17.9%	100.0%	100.0%		
Sep-93	19,290	720	379	7	19	58	17.9%	96.4%	88.3%		
Oct-93	15,890	744	309	12	48	24	14.2%	91.9%	88.7%		
Nov-93	21,331	720	331	14	1	163	19.8%	97.9%	75.3%		
Dec-93	18,728	744	317	36	3	186	16.8%	94.8%	69.8%		
Tot-93	**86,188**	**3,336**	**1,558**	**69**	**71**	**431**	**17.2%**	**95.8%**	**82.9%**		
Jan-94	4,896	744	152	40	96	300	4.4%	81.7%	41.4%		
Feb-94	11,335	672	320	37	0	0	11.2%	94.5%	94.5%		
Mar-94	38,262	744	652	4	9	0	34.3%	98.3%	98.3%		
Apr-94	26,666	720	570	12	0	0	24.7%	98.3%	98.3%		
May-94	24,227	744	505	0	26	0	21.7%	96.6%	96.6%		
Jun-94	14,849	720	225	0	0	6	13.7%	100.0%	99.2%		
Jul-94	15,307	744	400	0	0	3	13.7%	100.0%	99.6%	17320	15.5%
Aug-94	10,980	744	385	5	61	26	9.8%	91.2%	87.7%	12090	10.8%
Sep-94	28,636	720	542	0	17	0	26.5%	97.6%	97.6%	29230	27.1%
Oct-94	28,326	744	549	37	0	0	25.4%	95.0%	95.0%	30980	27.8%
Nov-94	19,415	720	422	0	67	0	18.0%	90.7%	90.7%	22430	20.8%
Dec-94	20,541	744	442	0	0	0	18.4%	100.0%	100.0%	22144	19.8%
Tot-94	**243,440**	**8,760**	**5,164**	**135**	**276**	**335**	**18.5%**	**95.3%**	**91.5%**		
Jan-95	21,363	744	511	0	0	12	19.1%	100.0%	98.4%	23760	21.3%
Feb-95	27,379	672	423	0	0	0	27.2%	100.0%	100.0%	29620	29.4%
Mar-95	18,060	744	344	0	288	0	16.2%	61.3%	61.3%	18790	16.8%
Apr-95	24,299	720	559	0	0	0	22.5%	100.0%	100.0%	27190	25.2%
May-95	20,395	744	478	12	0	7	18.3%	98.4%	97.4%	22210	19.9%
Jun-95	12,751	720	339	0	99	2	11.8%	86.3%	86.1%	14380	13.3%
Jul-95	8,298	744	306	0	49	3	7.4%	93.4%	93.1%	9230	8.3%
Aug-95	14,785	744	306	0	0	0	13.2%	100.0%	100.0%	16080	14.4%
Sep-95	31,919	720	571	8	0	0	29.6%	98.9%	98.9%	34030	31.5%
Oct-95	13,911	744	368	6	0	1	12.5%	99.2%	99.0%	15742	14.1%
Nov-95	11,265	720	313	9	0	2	10.4%	98.8%	98.6%	11991	11.1%
Dec-95	22,736	744	477	3	11	9	20.4%	98.2%	97.0%	25226	22.6%
Tot-95	**227,161**	**8,760**	**4,995**	**37**	**447**	**35**	**17.3%**	**94.5%**	**94.1%**	**248249**	**18.9%**
Jan-96	971	744	42	0	702	0	0.9%	5.6%	5.6%	1020	0.9%
Feb-96	26,597	696	470	16	0	2	25.5%	97.7%	97.5%	29257	28.0%
Mar-96	38,309	744	559	0	0	0	34.3%	100.0%	100.0%	41599	37.3%
Apr-96	12,060	720	226	3	114	273	11.2%	83.8%	45.8%	14408	13.3%
May-96	16,275	744	412	6	81	0	14.6%	88.4%	88.4%	18009	16.1%
Jun-96	17,488	720	496	0	0	2	16.2%	100.0%	99.7%	19130	17.7%
Jul-96	6,216	744	259	192	7	0	5.6%	73.3%	73.3%	7317	6.6%
Aug-96	11,037	744	391	205	0	0	9.9%	72.4%	72.4%	11803	10.6%
Sep-96	24,850	720	494	6	0	10	23.0%	99.2%	97.8%	27490	25.5%
Oct-96	14,376	744	377	43	0	0	12.9%	94.2%	94.2%	13502	12.1%
Nov-96	24,890	720	475	0	0	0	23.0%	100.0%	100.0%	27716	25.7%
Dec-96	27,601	744	441	6	0	0	24.7%	99.2%	99.2%	31604	28.3%
Tot-96	**220,670**	**8,784**	**4,642**	**476**	**904**	**287**	**16.7%**	**84.3%**	**81.0%**	**242,855**	**18.4%**

Month	Prod. (kWh)	Total Hours	Hours in Prod.	Maint. Hours	Break Down Hours	Grid Outage Hours	Cap. Factor	Turbine Avail.	Overall Avail.	Revenue Meter Gross	Cap. Factor
Jan-98	14,600	744	n/a	0	0	n/a	13.1%	100.0%	n/a	15698	14.1%
Feb-98	31080	672	n/a	0	0	n/a	30.8%	100.0%	n/a	32048	31.8%
Mar-98	26080	744	n/a	0	0	n/a	23.4%	100.0%	n/a	26980	24.2%
Apr-98	31570	720	n/a	0	0	n/a	29.2%	100.0%	n/a	32454	30.1%
May-98	32370	744	n/a	0	0	n/a	29.0%	100.0%	n/a	33227	29.8%
Jun-98	13280	720	n/a	25	0	n/a	12.3%	96.5%	n/a	13932	12.9%
Jul-98	17600	744	n/a	111	0	n/a	15.8%	85.1%	n/a	17781	15.9%
Aug-98	22260	744	n/a	54	0	n/a	19.9%	92.7%	n/a	22465	20.1%
Sep-98	21790	720	n/a	0	0	n/a	20.2%	100.0%	n/a	22001	20.4%
Oct-98	23130	744	n/a	2.5	0	n/a	20.7%	99.7%	n/a	24984	22.4%
Nov-98	10310	720	n/a	0	0	n/a	9.5%	100.0%	n/a	10937	10.1%
Dec-98	14520	744	n/a	0	2	n/a	13.0%	99.7%	n/a	17623	15.8%
Tot-98	**258,590**	**8,760**	**n/a**	**193**	**2**	**n/a**	**19.7%**	**97.8%**	**n/a**	**270,130**	**20.6%**
Jan-99	n/a	744	n/a	0	0	1	n/a	100.0%	99.9%	21,410	19.2%
Feb-99	n/a	672	n/a	0	0	0	n/a	100.0%	100.0%	23,310	23.1%
Mar-99	28,014	744	566	1	0	1	25.1%	99.8%	99.8%	29,590	26.5%
Apr-99	25,788	720	532	0	0	0	23.9%	100.0%	100.0%	26,920	24.9%
May-99	18,545	744	489	0	0	0	16.6%	100.0%	100.0%	19,980	17.9%
Jun-99	12,726	720	412	0	0	1	11.8%	100.0%	99.9%	14,940	13.8%
Jul-99	18,716	744	437	0	0	1	16.8%	100.0%	99.9%	20,680	18.5%
Aug-99	11,465	744	416	0	3	1	10.3%	99.6%	99.5%	12,730	11.4%
Sep-99	27,451	720	496	0	21	2	25.4%	97.0%	96.8%	29,620	27.4%
Oct-99	25,998	744	518	9	4	5	23.3%	98.3%	97.7%	27,530	24.7%
Nov-99	12,374	720	303	0	50	2	11.5%	93.1%	92.8%	12,290	11.4%
Dec-99	34,448	744	593	0	8	0	30.9%	99.0%	99.0%	34,780	31.2%
Tot-99	**215,525**	**8,760**	**4,762**	**10**	**86**	**11**	**16.4%**	**98.9%**	**98.8%**	**273,780**	**20.8%**
Jan-00	22,524	744	438	0	0	0	20.2%	100.0%	100.0%	21,080	18.9%
Feb-00	13,961	696	426	0	0	0	13.4%	100.0%	100.0%	14,940	14.3%
Mar-00	31,152	744	570	0	13	0	27.9%	98.3%	98.3%	31,070	27.8%
Apr-00	24,539	720	502	1	0	1	22.7%	99.8%	99.7%	25,830	23.9%
May-00	12,867	744	411	0	80	0	11.5%	89.2%	89.2%	13,070	11.7%
Jun-00	10,135	720	386	14	0	0	9.4%	98.1%	98.1%	9,950	9.2%
Jul-00	14,257	744	456	0	0	1	12.8%	100.0%	99.9%	16,400	14.7%
Aug-00	18,802	744	496	0	0	0	16.8%	100.0%	100.0%	19,410	17.4%
Sep-00	20,404	720	544	2	0	0	18.9%	99.7%	99.7%	20,602	19.1%
Oct-00	30,905	744	602	0	3	0	27.7%	99.6%	99.6%	30,768	27.6%
Nov-00	19,963	720	402	0	1	0	18.5%	99.9%	99.9%	19,420	18.0%
Dec-00	23,296	744	472	0	0	0	20.9%	100.0%	100.0%	22,660	20.3%
Tot-00	**242,805**	**8,784**	**5,705**	**17**	**97**	**1**	**18.4%**	**98.7%**	**98.7%**	**245,200**	**18.6%**
TOTAL	**1,720,618**	**64,704**	**30,953**	**950**	**1,882**	**1,155**	**17.7%**	**95.6%**	**93.8%**		

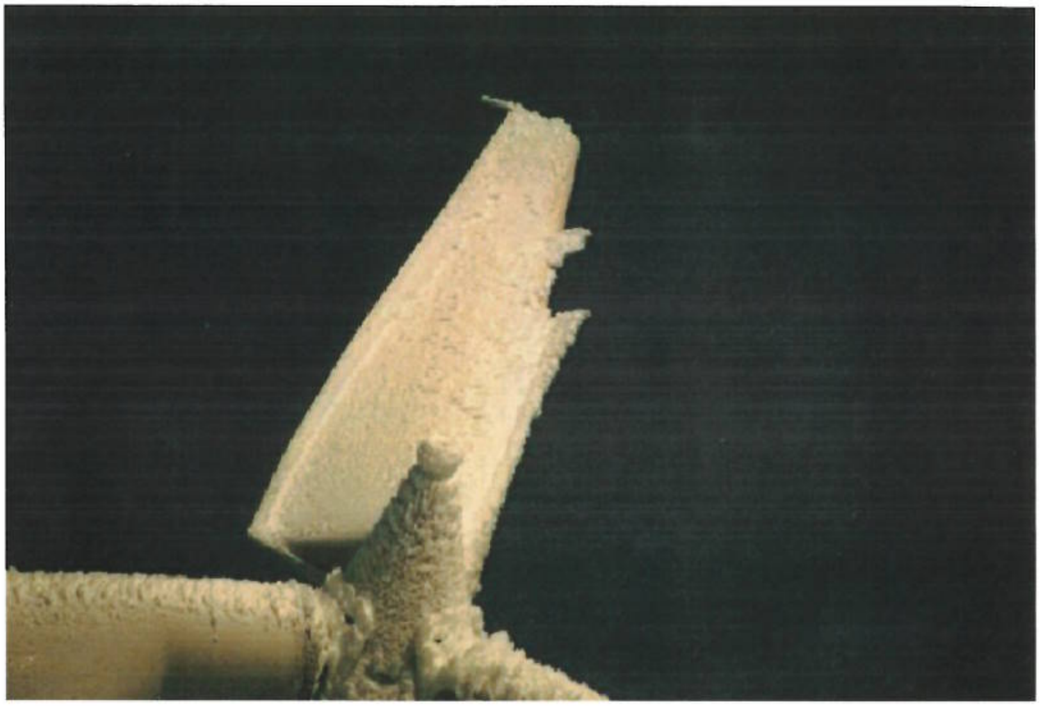
TABLE 3
ANNUAL PRODUCTION BASED ON REVENUE METERING
(REVENUE METERING COMMENCED IN JULY 1994)

Yukon Energy 150 kW Bonus Wind Turbine - Annual Production

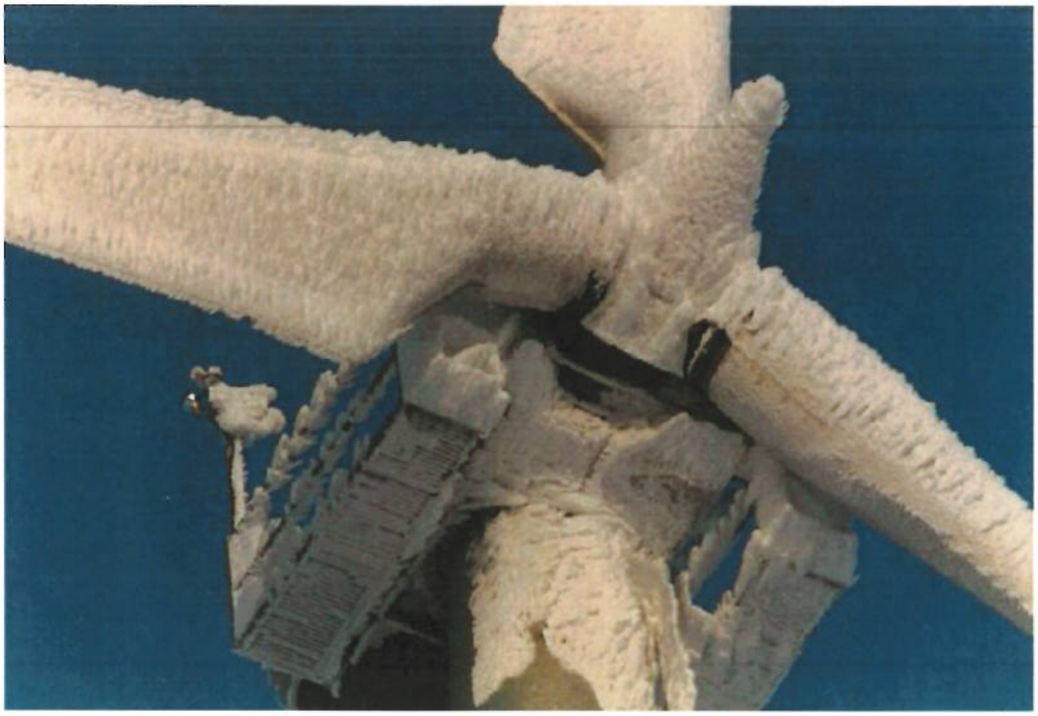
Year	Hours	Actual gross kWh	Actual gross C.F.%
1994	8,760	254,429	19.4%
1995	8,760	248,249	18.9%
1996	8,784	242,855	18.4%
1997	8,760	242,307	18.4%
1998	8,760	270,130	20.6%
1999	8,760	273,780	20.8%
2000	8,784	245,200	18.6%

Photograph 1: Rime ice on monitoring equipment, only heated instruments stay clear

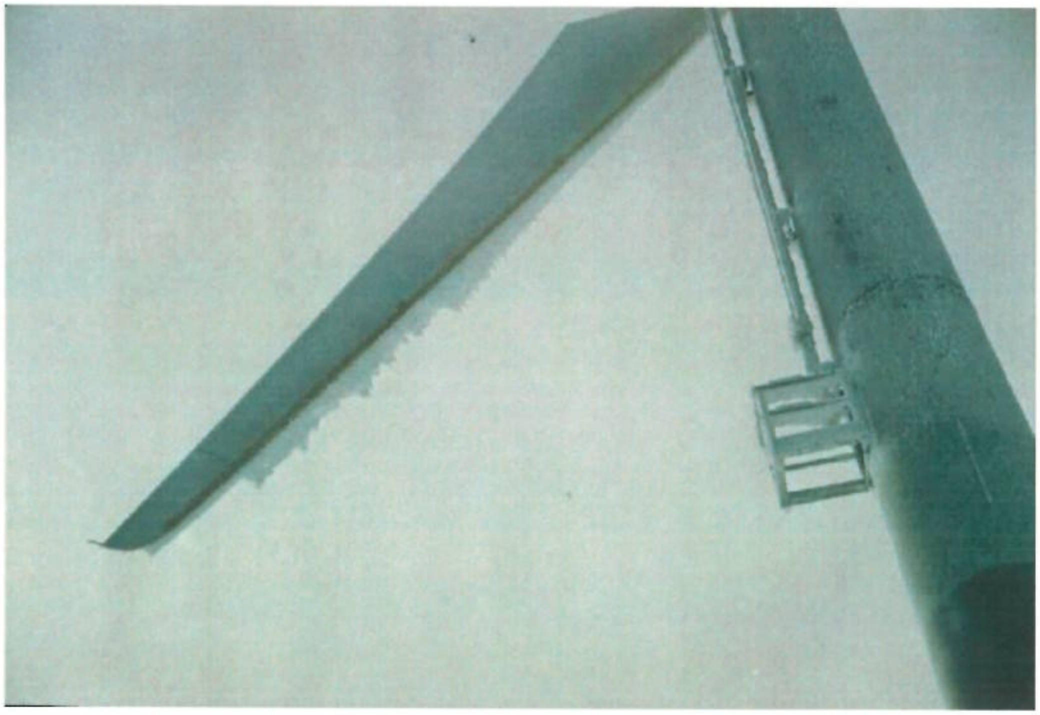
Photograph 2: the first wind turbine being winched up on hinged tip up tower



Photograph 3: turbine heavily iced, did not run through icing period

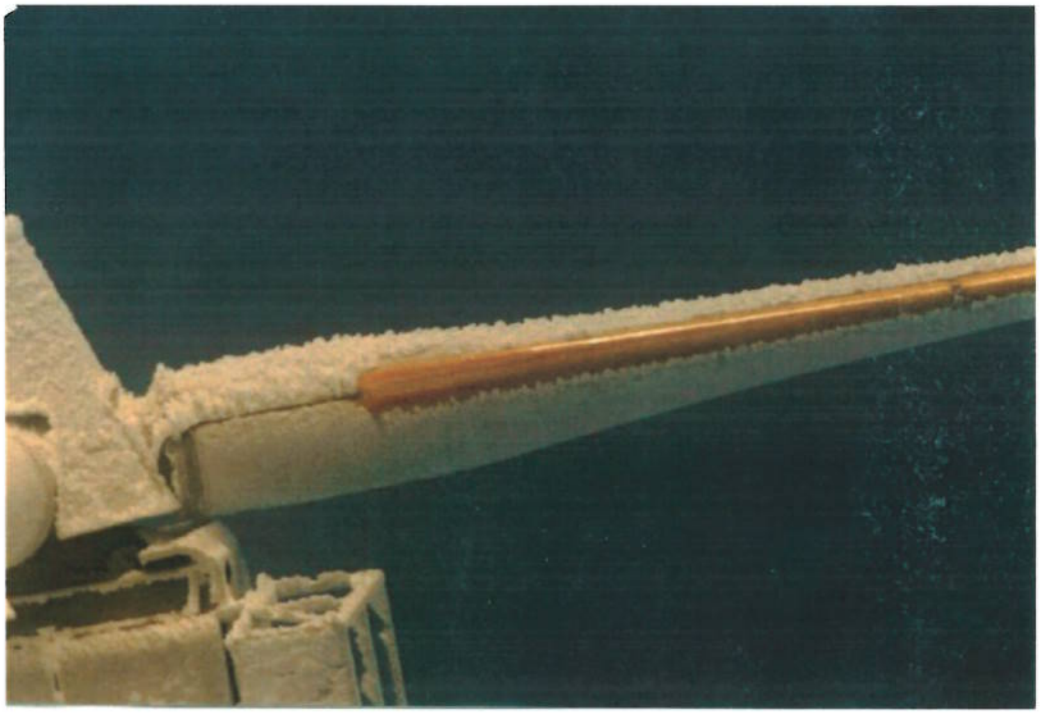


Photograph 4: wedge shaped ice builds up on the blades when running through icing events – leading edge heaters not working



Photograph 5: wedge shape build up from back, note clear back of blade – leading edge heaters not working

Photograph 6: in less severe rime icing the effect of the leading edge heaters extends past the leading edge



Photograph 7: in severe icing conditions the effect of the leading edge heaters does not extend as far

Photograph 8: accumulated ice shedding from black blades

Photograph 9: the second wind turbine being installed

Photograph 10: both wind turbines in place

GLOBAL ENERGY CONCEPTS, LLC
ENGINEERING & TECHNOLOGY CONSULTING

March 16, 2004

The following summarizes the readily available information on cold weather options for the various wind turbine manufacturers.

Typical Design Environment

The temperature environment for which turbines are designed varies among manufacturers. Table 1 summarizes the available temperature information. Virtually all the manufacturers design their standard turbines to a -20°C minimum operating temperature. Most of the manufacturers have available low-temperature packages which enable operation to lower temperatures, typically -30°C.

Table 1 - Turbine Design Temperature Characteristics

Turbine	Std. Min. Operating Temp.	Min. Operating Temp. with Options	Power Rating of Added Heaters
GE 1.5S	-20	-30	20 KW
GE 1.5 SL	-20	-30	20 KW
MHI 1000	-20	-40	5 KW
MHI 1000A	-20	-40	5 KW
Vestas V-80	-20	-30	18 kW
Vestas V-90	-20	-30	N/A
Enercon	-20	N/A	N/A
NEG Micon NM 72	-20	-30	43 kW
NEG Micon NM 72C	-20	-30	43 kW
Gamesa G52	-20	-30	18 kW
Gamesa G80	-20	-30	40 kW
Bonus 1.3	-10	N/A	N/A

Note: Bonus and Enercon will evaluate need by project

Low Temperature Option Costs

GEC has limited visibility on the costs the manufacturers charge for the cold weather packages. The information available indicates that the price increase is between $5,000 and $25,000 per turbine. It is apparent that the costs of the package are negotiable as we have seen the same package priced at both $15,000 and $25,000 per turbine.

Low Temperature Package Contents

Varies by manufacturer – generally some or all of the following:

- Lubricant heaters
- Additional generator heaters
- Control cabinet heaters

5729 Lakeview Dr. NE, Suite 100, Kirkland, Washington 98033 USA
email: rpoore@globalenergyconcepts.com
Phone: (425) 822-9008 Ext. 25
Fax: (425) 822-9022

- Nacelle space heaters
- Ice detector
- Heated anemometry
- Special alloy ductile iron for hub and machine frame
- Special alloy tower steel

Operating Characteristics

The operating characteristics of the low temperature packages varies by manufacturer, however they are generally thermostat driven, with the individual heaters controlled by their own thermostats. Temperature sensors in critical locations provide inputs to the turbine control system. Some turbines have a "warming time" after a prolonged cold soak that prevents operation above specified power levels until the ambient temperature had been above a threshold for a specified time period. This prevents overloading the structural components while they are cold soaked. Some machines may require different grease be used for summer and winter operation, depending on the temperature extremes at the site. General Electric turbines have limits on the peak gusts that can be experienced at low temperatures and Mitsubishi de-rates the turbines at low temperatures. In GEC's experience, these limits have not been material in the turbine selection process because the limits represent unusual site conditions. However, these issues must be evaluated when selecting a turbine

Energy Production Issues

The cost effectiveness of the cold weather packages needs to be evaluated carefully. The amount of energy generally available at temperatures below -20 degrees C is generally small, even after considering the relatively high air density at these temperatures. The energy available at temperatures below -30 degrees C is generally very small, in GEC's experience less than one half of one percent. However, in GEC's experience, low-temperature packages can improve availability and reliability even at temperatures above -20°C by reducing icing related downtime and maintaining more benign temperatures for components. The most appropriate elements of a cold weather package for a particular site will depend on the actual site conditions and turbine design.

There is a significant variation among turbines in terms of power requirements for the heaters on the low-temperature packages. GEC recommends a detailed understanding of all the power requirements for each manufacturer's system and the control logic used to operate it, so that the power consumption of the turbines can be accurately evaluate and compared.

Please contact me if you have any further questions on this issue.

Sincerely:

Robert Z. Poore
President

Appendix:

Low Temperature Option

Vestas MW Wind Turbine

Item no.: 943517.R3

(11c)

Contents .... Page

1. LT-Wind Turbine Description

The VESTAS MW Wind Turbines – Low Temperature (LT) are standard VESTAS pitch regulated upwind wind turbines with active yawing and a rotor with three blades. The VESTAS MW LT wind turbines are specially equipped to operate in areas, where temperatures below –20°C occur. The wind turbine is designed to operate at ambient temperatures ranging from –30°C to 40°C (–30°C to 30°C for 1.8/2.0 MW turbines).

For non-operational conditions a temperature range down to –40°C is permissible.

1.1 Description of the "LT (Low Temperature) Option"

The nacelle is equipped with extra effective sealing. Necessary ventilation openings are equipped with dampers, which during heating periods ensure that the nacelle is completely sealed.

At ambient temperatures below –30°C the wind turbine controller will stop the wind turbine by means of the outdoor temperature sensor. The temperature inside the nacelle will be kept above –20°C by three electric fan heaters. The fan heaters are switched off at nacelle temperatures in accordance with Table 1- Temperature settings.

During operation at low temperatures, flaps and curtain closes air inlet openings to the nacelle. Cooling air for the generator system will be re-circulated controlled by a motor driven flap valve. When the nacelle temperature reaches a setting value in accordance with Table 1- Temperature settings, the flap valve in the cooling air outlet from the generator is closed, and a the same time the motor driven air inlet opening in the rear end of the nacelle is opened.

In order to keep the nacelle as tight as possible, sealing between spinner and nacelle front end is mounted. Sealing between spinner and blades are fitted as standard.

Outlet openings from oil coolers are supplied with flap valves, which automatically open when the oil cooler fan starts. Otherwise the openings are closed to prevent cold air from outside from getting into the nacelle due to wind or draught.

Both the ground controller and the nacelle controller are supplied with a heating panel to warm up the computers and other parts in the controller panels.

Special lubricants are selected for the power transmitting components of the transmission system such as blade bearings, main bearings, gearbox, yawing system and generator.

1.2 Climatic Conditions

The wind turbine is designed to operate at ambient temperatures ranging from –30°C to +40°C (–30°C to 30°C for 2.0 MW turbines). At temperatures below –30°C the control system stops the turbine. (Please see section 1.3 - General Specifications for the wind turbine for further information).

At an ambient temperature below –30°C the stopped wind turbine will be kept tempered by the electrical fan heaters, but even without heating all parts are able to withstand temperatures down to –40°C.
During operation at ambient temperatures below –20°C separate heaters - if necessary - raise the inside temperature of the nacelle while flaps close openings to the outside.

2. Technical Description

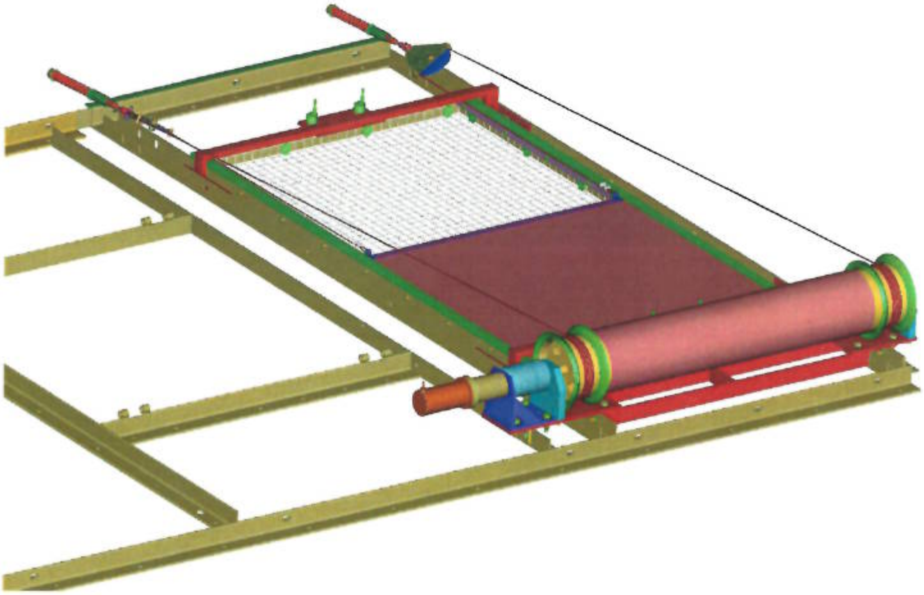
2.1 Electric Heaters in the Nacelle

Three fan heaters are placed in the nacelle. They keep the temperature above –20°C during operation at very low ambient temperatures down to –30°C. One fan is placed underneath the main shaft blowing warm air under the rear main bearing and under the gearbox. The second heating unit blows warm air upwards against the bottom of the gearbox. The warm air is directed against the rear end of the nacelle. The third fan heater is placed in the front end of the nacelle sending warm air through an opening at the lower position into the spinner. The air re-circulates back to the nacelle through an upper opening.

Specifications for each of the electric heaters:

Power:	6.0 kW
Voltage:	690 V ~
Fan:	650 m^3/hour

2.2 Rolling Damper with Armoured Curtain Design

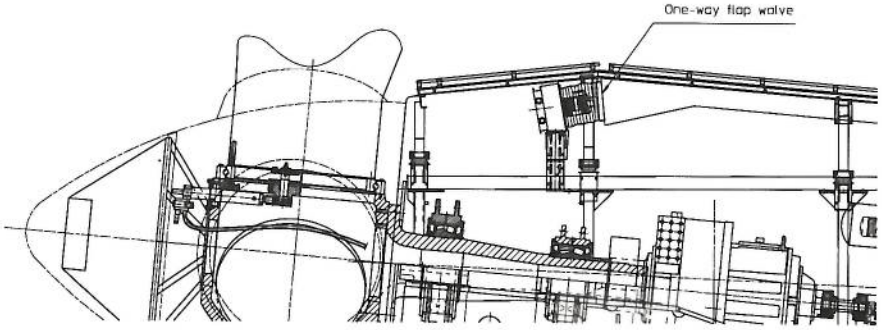


Picture 1. Rolling damper with armoured curtain.

The rolling damper with armoured curtain is placed in the normal air inlet opening at the rear end of the nacelle bottom. Above the rolling damper is shown in half open position. An electric motor controls the position of the rolling damper. Air is let in through the air inlet of the nacelle for cooling transformer, generator, oil coolers and other components in the nacelle. The electric motor is placed in the end of the rolling damper system.

2.3 Flap Valves at Oil Cooler Air Outlet Opening

One-way flap valves close the oil cooler outlet when operating at very low temperatures, preventing cold air from being drawn backwards into the nacelle.



2.4 Controller Heating Panels

Heating of ground controller and nacelle controller.

A 400W heating element is mounted in the control sections of the ground and nacelle controllers in order to warm up the computer and the panel.

3. Temperature Settings for LT and Offshore Options

The default temperature settings on the Controller for the MW LT and Offshore wind turbines are set according to the figures below. At all sites the specific temperature and wind conditions can necessitate alternative settings.

Fan Heaters for heating of nacelle and hub (standard temp. control)				
	Start temp.	Stop temp.	Backup	**Action fans**
1.65/1.75/1.8/2.0 MW-LT	–5	2	-	*Start/Stop*
Fan Heaters for heating of nacelle and hub (difference temp. control)				
2.0 MW Offshore	6	2	-	*Start/Stop*
Curtain below medium voltage transformer				
	Start temp.	Stop temp.	Backup battery	**Action curtain**
1.65/1.75/1.8/2.0 MW-LT 2.0 MW Offshore	10		24 VDC	*Opening*
		4		*Closing*
Flap in RCC air outlet				
	Start temp.	Stop temp.	Backup	**Action flaps**
1.65 MW-LT	10		-	*Opening*
		4	Spring return (in case of power failure)	*Closing*

Table 1- Temperature settings

3.1 1.75/1.8/2.0 MW Nacelles - Curtain

Mode of operation of curtain below medium voltage transformer:

Inside the controller cabinet a temperature unit records the nacelle temperature. This unit works independently from the main computer. The temperature is measured at the side of the control section (approximately in the centre of the nacelle). The relay is placed on the rear side of the control board.

Conditions that will close the curtain:

- The nacelle temperature is below setting value.
- Grid failure to the wind turbine.

3.2 1.75/1.8/2.0 MW Nacelles - Heating (Offshore)

Heating control (temperature difference relay) - offshore wind turbines

3 fan heaters heat the nacelle and hub. The control box is mounted on the main beam below the main shaft. The nacelle temperature sensor is located at the **A18** box. The outside temperature sensor is mounted through a hole in the fibreglass of the machine cover.

Mode of operation

The heating is controlled by a temperature difference relay to ensure that the nacelle temperature will always remain higher than the outside temperature.

3.3 1.65/1.75/1.8/2.0 MW Nacelles - Low Temperature (LT)

Heating control (standard temperature control) - LT - wind turbines

The nacelle and hub are heated by 3 fan heaters. The control box is mounted on the main beam, below the main shaft. The temperature sensor is located at the **A18** box.

Mode of operation

The heating is controlled by a temperature relay and operates as follows:

If the temperature is lower than the setting value the control unit will start the fan heaters.

HÉLIMAX

MEMORANDUM

Date : 17 March 2004

To : Manitoba Hydro

From : Michael Cookson

CC : Bouaziz Aitdriss, Richard Legault

Subject : Cold Weather Operation

Manitoba Hydro's questions on cold weather operation of wind turbines:

Q1. Which wind turbine manufacturers provide cold weather operation packages (arctic packages)?

Most turbine manufacturers offering products to the Canadian market (including main suppliers Vestas, GE, NEG Micon, Gamesa) offer cold weather packages for their lines of turbines.

Q2. How low in ambient temperature does this permit the wind turbine to operate and at what ambient temperature will the turbines resume operation after they have been shut down due to cold temperatures?

The specifications for cold weather packages generally state an ambient temperature of -30°C as the limit for operation. This limit can be interpreted as the result of a cost-benefit analysis done by the manufacturers.

The cold weather packages generally allows for resumption of operation at an ambient temperature of -30°C. The exact temperature depends on the strategy adopted by the manufacturer with respect to nacelle heating.

It should be noted that these turbines are designed to withstand wind conditions at standstill at temperatures as low as -40°C.

Q3. Provide a description of what parts of the wind turbine are affected by the cold and what would happen (such as lubricants too stiff or hub material becoming too brittle, etc).

All major components of the wind turbine (nacelle, rotor blades, hub, shafts, electronic controller, hydraulic system, cooling unit, tower, and instrumentation) are either directly or indirectly affected by the temperature. The effects are intuitive and based on fundamental engineering principles. The properties of materials change (become more brittle), the properties of lubricants and heat transfer fluids change, and electronics need to be adequately adapted.

Q4. How much does the cold weather package add to the cost of the wind turbine and if such a package was not utilized, then what are the temperature limits for operation?

A typical cold weather package for turbines can cost from 2.5 to 5% of the cost of the turbine. These packages can include a heating scheme for the nacelle, choice of lubricants, and material selection for the tower (grade of steel) and blades (type of epoxy). It should be noted that manufacturers are not always transparent with respect to costs.

The specifications for turbines without cold weather packages generally state an ambient temperature of -20°C as the limit for operation. These types of turbines are not designed to withstand extreme temperatures.

Q5. Comment on the expectation or likelihood that at ambient temperatures below -30 C that wind speeds are usually low or not? (ie would the wind turbine likely not be producing much power anyway). Do we have enough information from the Manitoba Hydro monitoring to comment on this?

Because the meso and micro meteorological effects are always site-specific, it is difficult to state a correlation between extreme low temperatures and wind speeds. However, an analysis of the data at the MH Lizard Lake site (St. Leon) provides an indication of how marginal this case is. Some results are stated below.

- For the winter season of 2003-2004, 2 days had an average ambient temperature of less than -30°C (January 28 and 29th, 2004)
- Average wind speeds at 40m (the instruments at 60m were frozen due to rime icing) for these two days were 5.8 and 4.7 m/s respectively. This compares to average monthly wind speeds at 40m for January of 4.8 m/s
- For the winter season of 2003-2004, an ambient temperature of -30°C was experienced on 10 separate days.

Q6. The heaters that are used in the gearbox and the nacelle will add to the station service load. Can Helimax provide an estimate on the amount of this station service load in MW for a 100MW wind farm?

Although statistics for the percentage of auxiliary load due to heating systems is not readily available, it can be stated that the total auxiliary parasitic load during winter operation represents 0.5% of nameplate capacity.

1.5sl/1.5s wind turbine

English

imagination at work

The 1.5sl/s wind turbines – proven results...

Fenner, USA
20 x 1.5s
total capacity: 30 MW

Arneburg, Germany
20 x 1.5sl
total capacity: 30 MW

Bassum, Germany
13 x 1.5s
total capacity: 19.5 MW

Gatun, Spain
33 x 1.5sl
total capacity: 14.5 MW

When it comes to "megawatt-plus" technology, our proven 1.5 MW wind turbine continues to raise the bar. Without resting on its past successes, our efforts to build on this proven performer include everything from technology investments in reliability and dependability, to more cost effective and versatile configurations. With over 1,300 units in operation worldwide, the 1.5 MW continues to be one of the world's most widely used wind turbines in its class.

The 1.5 MW machine is active yaw and pitch regulated with power/torque control capability and an asynchronous generator. It utilizes a bedplate drive train design where all nacelle components are joined on a common structure, providing exceptional durability. The generator and gearbox are supported by elastomeric elements to minimise noise emissions.

Slufter, the Netherlands
8 x 1.5s
total capacity: 12 MW

Fenner, USA
20 x 1.5s
total capacity: 30 MW

Calvengo, Spain
33 x 1.5sl
total capacity: 49.5 MW

Slufter, the Netherlands
8 x 1.5s
total capacity: 12 MW

...adaptable solutions.

With variable hub heights and rotor diameters, the 1.5 MW wind turbine is both versatile and adaptable, and has proven itself in a wide variety of wind energy sites around the world, both on-land and off-shore. The 1.5 MW wind turbine features variable-speed control and independent blade pitch to assure aerodynamic efficiency and reduce loads on the drive train, yielding reduced maintenance cost overall and longer turbine life. The turbines' independent blade pitch system also mitigates the need for large emergency braking systems and enables the use of larger rotors to allow increased energy yield. At the same time, GE's unique Wind Volt-Amp-Reactive ("WindVAR") electronics provide transmission efficiencies and enable the turbine to function harmoniously within the local grid. Reliable, cost-effective operation...it was designed in from day one.

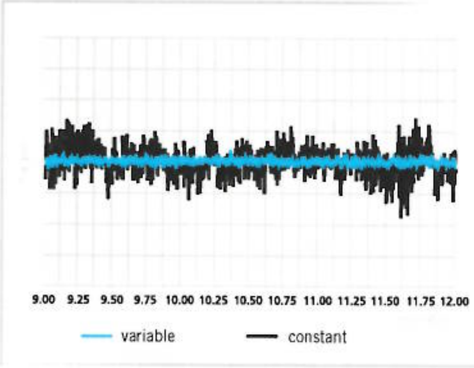
Variable Speed – for higher energy capture and reduced loads.

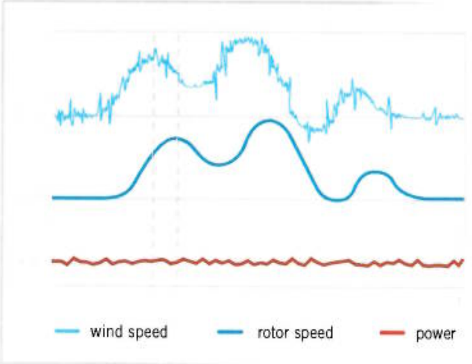
Through the use of advanced electronics, the 1.5 MW turbine features efficient and reliable variable speed control. This feature enables the turbines' control system to continually adjust the rotor rpm level for optimum thrust at each wind speed – allowing the wind turbine to continually operate at its highest level of aerodynamic efficiency. Fixed-speed wind turbines, by contrast, only attain peak efficiency at one speed.

Also, unlike conventional variable-speed machines where all power generated is forced through the converter, the 1.5 MW design is outstandingly efficient. Through the turbines' high-efficiency converter, it is only necessary to convert a quarter of the power generated – substantially minimizing conversion losses. Tower oscillation is kept to a minimum as well, through active damping of the entire turbine system. Active damping also limits peak torque, providing greater drive train reliability, reduced maintenance and longer turbine life.

Fenner, USA
20 × 1.5s
total capacity: 30 MW

Below – The energy in a wind gust is stored by accelerating the rotor. This leads to reduced loads, improved transmission efficiencies and performance.





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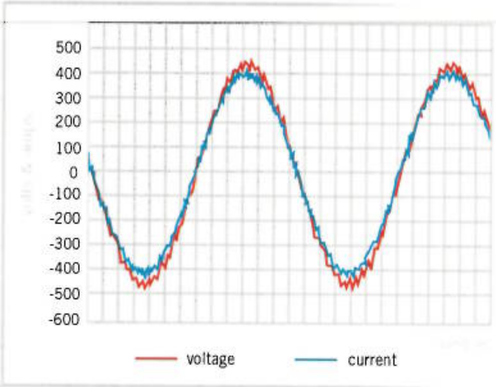
Escurillo, Spain
33 x 1.5sl
total capacity: 49.5 MW

Dynamic reactive power for transmission efficiency and local-grid compatibility.



WindVAR Technology:
Leading, lagging or unity power factor

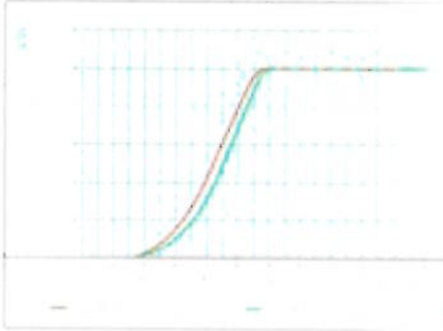
GE Energy's WindVAR power conversion system with VAR control enables the wind turbines to operate at unity, leading or lagging power factor (unity power factor shown left), providing the highest transmission efficiencies and enhanced voltage stability. This is particularly beneficial in weak grid applications.

At the heart of the GE Energy technology, our unique WindVAR power electronics system converts the wind turbine's variable-speed operation into constant-frequency power required by the utility. Through WindVAR, voltage is controlled and regulated in real-time. Similar to conventional utility generators, WindVAR enables the turbine to supply reactive power to the grid at the time it's needed, in a fraction of a second, providing transmission efficiencies and enhanced voltage stability. This feature is especially beneficial when the local grid is weak, or in larger turbine installations.

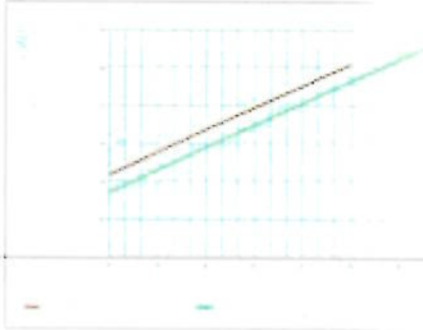
Bassum, Germany
12 x 1.5s
total capacity: 18 MW

Hinte, Germany
11 x 1.5s
total capacity: 16.5 MW

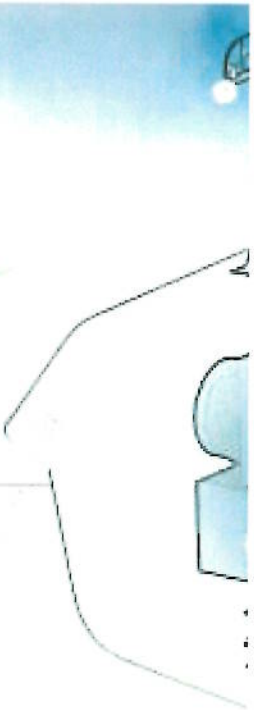
[illegible], USA
[illegible]
[illegible]



Power curve



Annual energy yield



Support services that keep your goals and expectations at the forefront.

Trent Mesa, USA
100 x 1.5s
total capacity 150 MW

With a wide range of capabilities and proven wind project success, we can provide you with your desired level of assistance. From operation and maintenance to project development assistance – we can put our experienced, worldwide resources to work for you.

Once online, your unique project needs are our priority. We will work with you to determine your individual needs and preferred level of assistance – then, we'll be there for you whenever you need us. Our customers are our highest priority and our goal is to deliver the absolute highest customer value – when you're pleased, we are successful.

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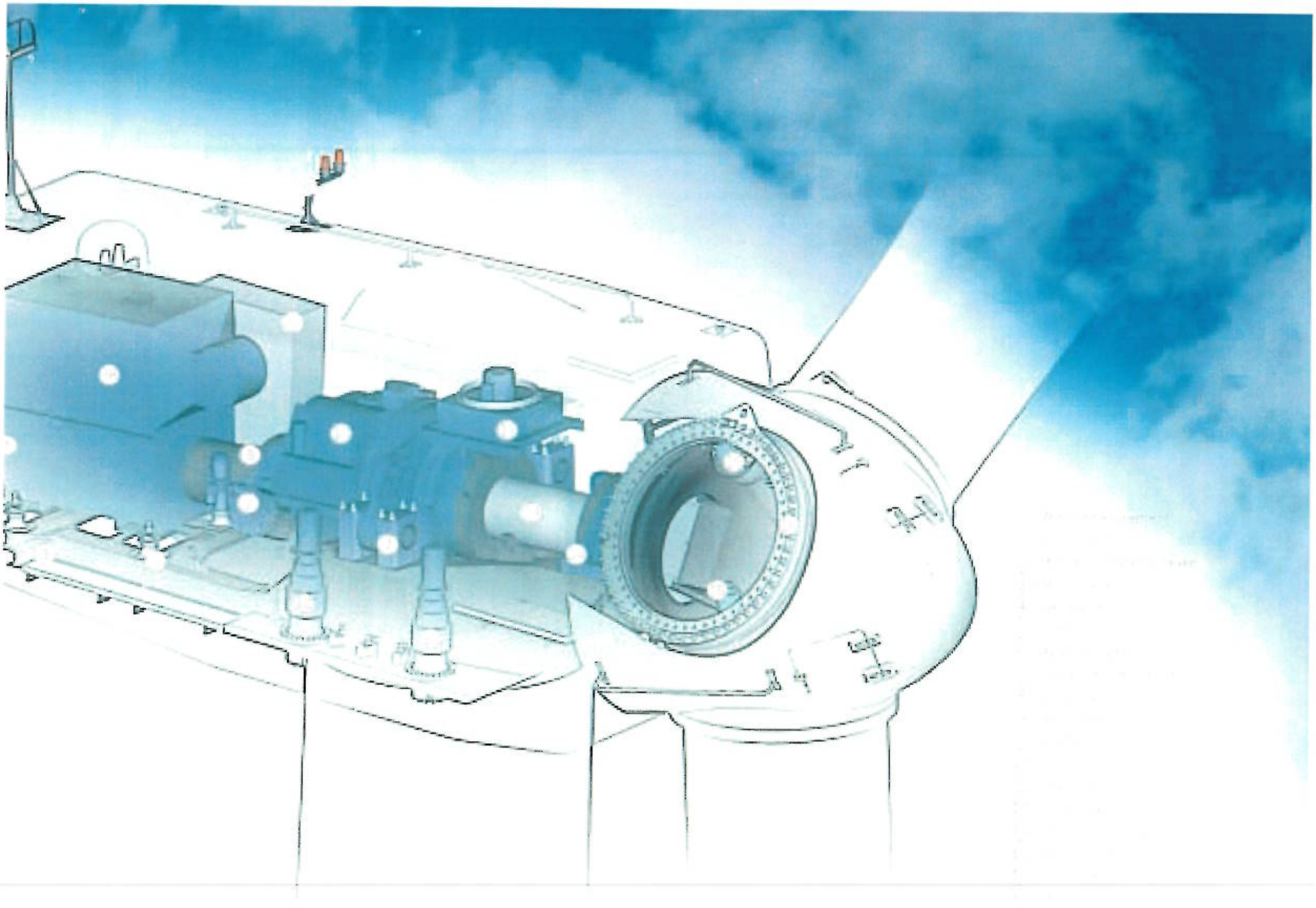

Technical specifications

	1.5sl	1.5s
Operating data		
• Rated capacity:	1,500 kW	1,500 kW
• Cut-in wind speed:	3 m/s	4 m/s
• Cut-out wind speed		
300 s average:	25 m/s	25 m/s
30 s average:	WZ II: 23 m/s, IEC s: 28 m/s	WZ II: 25 m/s, WZ III, IEC II: 28 m/s
3 s average:	WZ II: 25 m/s, IEC s: 30 m/s	WZ II: 27 m/s, WZ III, IEC II: 30 m/s
• Cut-back-in wind speed		
300 s average:	WZ II: 17 m/s IEC s: 22 m/s	WZ II: 19 m/s, WZ III, IEC II: 22 m/s
• Rated wind speed:	11.8 m/s	12 m/s
Rotor		
• Number of rotor blades:	3	3
• Rotor diameter:	77 m	70.5 m
• Swept area:	4,657 m^2	3,904 m^2
• Rotor speed (variable):	10.1 – 20.4 rpm	11.1 – 22.2 rpm
Tower		
• Hub heights for WZ II:	61.4 / 80 / 85 / 100 m	64.7 / 80 / 85 / 100 m
• Hub heights for WZ III/IEC s:	64.7 / 80 / 85 m	64.7 / 80 / 85 m
Power control:	Active blade pitch control	Active blade pitch control

Operating limits (outside temperature)
- cold weather light: -20° C to +45° C
- cold weather extreme: -30° C to +45° C / -40° C survival without operation

Control system
- PLC (Programmable logic controller) Remote control and monitoring system

Gearbox
- Three step planetary spur gear system

Generator
- Doubly fed three-phase asynchronous generator

Braking system (fail-safe)
- Electromechanical pitch control for each blade (3 self-contained systems)
- Hydraulic parking brake

Yaw system
- Electromechanical driven with wind direction sensor and automatic cable unwind

Converter
- Pulse-width modulated IGBT frequency converter

Tower design
- Multi-coated, conical tubular steel tower with safety ladder to the nacelle
- Load lifting system, load-bearing capacity over 200 kg
- Service platform for 100 m hub height (service lift optional)

Noise reduction
- Impact noise insulation of the gearbox and generator
- Sound reduced gearbox
- Noise reduced nacelle
- Rotor blades with minimised noise level

Lightning protection system
- Lightning receptors installed on blade tips
- Surge protection in electrical components

GE Energy

GE Energy is one of the world's leading wind energy companies and wind turbine suppliers. With over 6,100 worldwide wind turbine installations, comprising more than 4,000 MW of capacity, our knowledge and expertise spans more than two decades. We currently design and produce wind turbines ranging from 900 kilowatts to 3.6 megawatts in Germany, Spain and the U.S. In Florida, USA, and the Netherlands, we also manufacture advanced wind turbine blades to assure the highest quality, advanced designs and quick on-time delivery. We know that wind power will be an integral part of the world energy mix in this century and we are committed to helping our customers design and implement energy solutions for their unique energy needs.

Our facilities conform to the international ISO 9001 Quality Systems Standard. This standard, together with our adherence to the rigorous Six-Sigma-control discipline, provide you with quality assurance backed by the strength of GE. As a part of GE Power Systems, we also share the diverse resources of one of the world's leading suppliers of power generation technology and management systems. GE is a company widely known for its commitment to excellence in products and services. Every relationship we pursue bears our uncompromising commitment to quality and innovation.

Germany

GE Energy Headquarters,
Wind Turbine Manufacturing
Holsterfeld 16
48499 Salzbergen
[illegible]
[illegible]

Australia

Sales Australia, New Zealand
Level 5, 473 Collins Street
Melbourne, Victoria 3000
[illegible]
[illegible]

Greece

Sales Greece, Cyprus, Balkans
[illegible]
[illegible]
[illegible]
[illegible]

Japan

Sales Japan
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

USA

American Sales Headquarters,
Wind Turbine Manufacturing
13000 Jameson Road
Tehachapi, CA 93561
[illegible]
[illegible]

China

Sales China
52nd Floor, Plaza 66
1266 Nanjing (W) Road
Shanghai 200040
[illegible]
[illegible]

India

Wind Turbine Assembly
Sales India & Surroundings
Golden Enclave Corporate Towers
[illegible]
Airport Road, Bangalore [illegible]
[illegible]
[illegible]

Korea

Sales Korea
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Spain

Wind Turbine Manufacturing
Sales Iberian Peninsula
[illegible]
28006 Madrid
[illegible]
[illegible]

Denmark

Sales Scandinavia
[illegible]
9220 Aalborg
[illegible]
[illegible]

Ireland

Sales Ireland
Clonshaugh Industrial Estate
Clonshaugh, Dublin 17
[illegible]
[illegible]

United Kingdom

Sales United Kingdom
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

France

Sales France
Immeuble Le Bayard Part Dieu
[illegible]
[illegible]
[illegible]
[illegible]

Italy

Sales Italy
[illegible]
50127 Firenze
[illegible]
[illegible]

Asia - new markets

Sales Asia - new markets
240 Tanjong Pagar Road
GE Tower
[illegible]
[illegible]
[illegible]

Canada

Sales Canada
[illegible]
[illegible]
[illegible]
[illegible]

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NM72/82 Arctic Specification

This document describes the solutions chosen for operating the NM72/82 in extreme cold weather conditions.

	Name:	Date:	Signature:
Written by:	Ellen Hyldgaard Thomsen	07.05.2003	EOL
Checked by:	Steen Kirkegaard Jensen		SKJ
Filename:			
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Document revisions

Revision:	Date:	Changed by:	Changed page:	Description of change:
1	02.03.04	SKJ	All	Doc. Name changed, details added, wording changed

Contents

1 Arctic specification turbines

For use in areas with extremely low temperatures, the Arctic specification for NM72/82 has been developed.
The limitations are to operate at temperatures down to ÷30° C AT (Ambient Temperature) and structural endurance down to ÷40° C at stand still.

In general, all steel, welds, casts and cables are specified to meet above requirements. Further, all components, lubrication and hydraulic oil are selected to meet the cold conditions keeping required properties.

Some components are specifically selected to replace normal equipment, and special heating systems are added. The following is a description of the items where the arctic version of the NM72/82 Arctic differs from the standard version.

2 Strategy for operating in cold weather conditions

During normal operations the gearbox and generator will generate heat within the closed nacelle compartment, and secure suitable temperature conditions for all components.

Sensors monitor the ambient temperature, as well as all relevant component and system temperatures, and shut the turbine down if operational limits are exceeded.

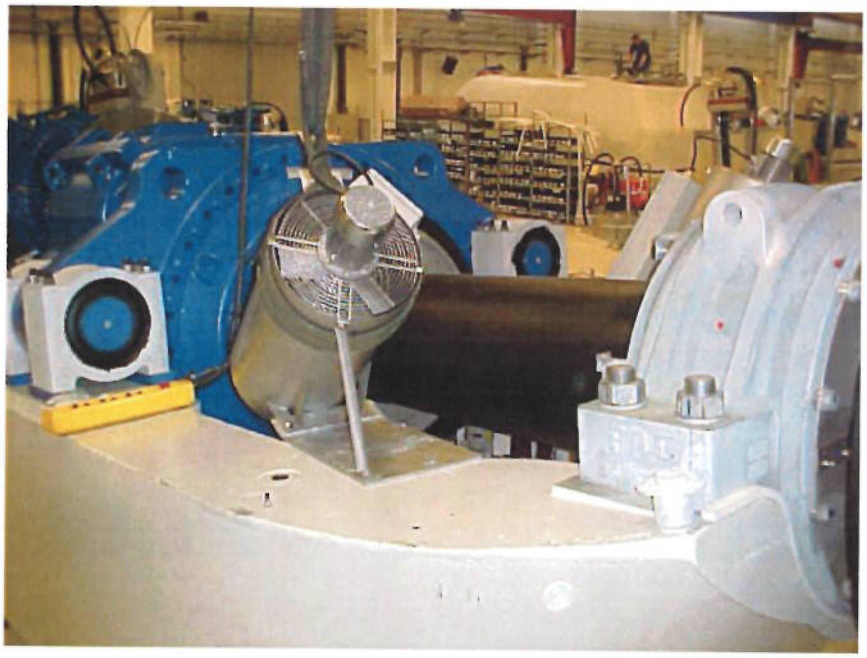
After a stand still, where components have become very cold, nacelle-heating equipment will ensure heating up before resuming normal operation.
There are two purposes for this: first to ensure that the lubricants have optimal properties and secondly to heat up the nacelle including gearbox, generator, main bearing and yaw mechanism.
Operation will not commence until specified components have obtained their minimum temperature acceptance level. The wind turbine computer continuously checks the temperature level.

During operation the nacelle heating equipment will automatically be turned on and off, to secure acceptable operation temperature inside the compartment.

3 Arctic equipment and component specific details

3.1 Nacelle heating

In order to heat the nacelle, 2 fan heaters are installed in the nacelle. They have a capacity of 20 kW each. The fan heaters are mounted primarily to warm up the yaw mechanism and the main gear. Secondarily, they heat all other components in the nacelle.



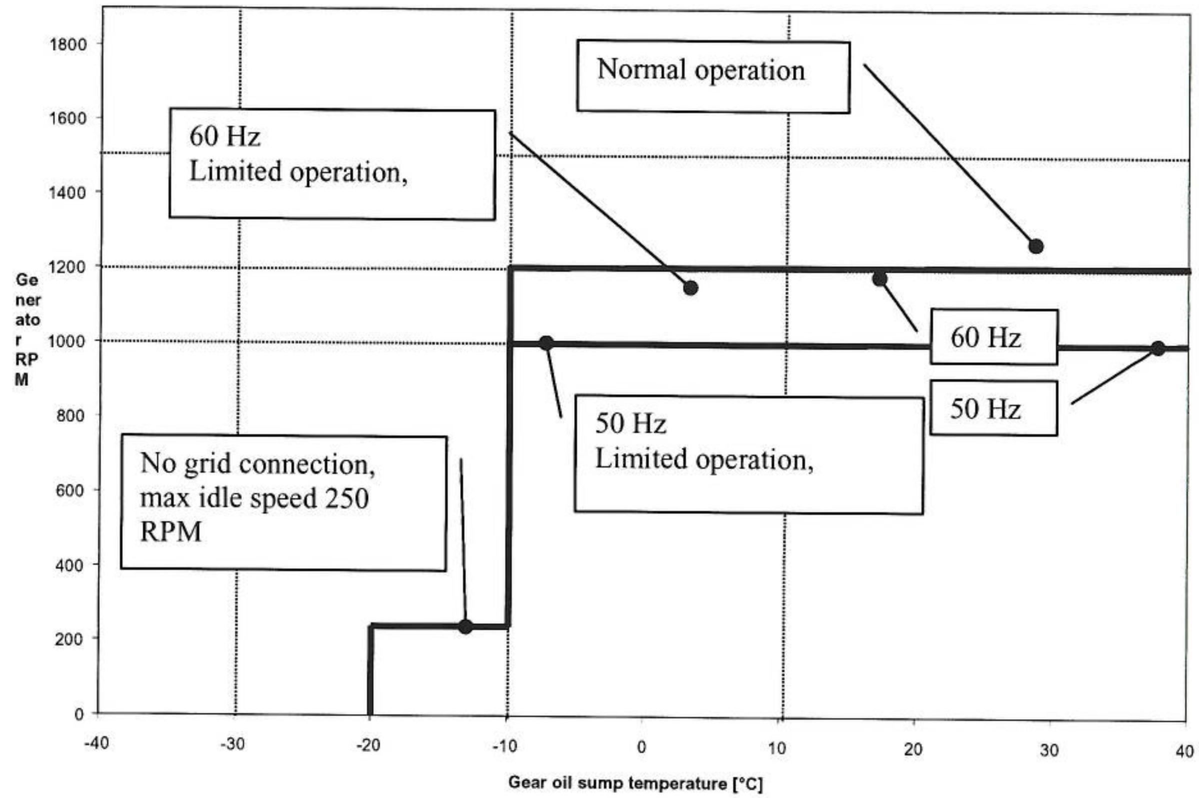
The heating units are controlled by the wind turbine computer on basis of temperature sensors, which are placed in the nacelle compartment, gear oil and bearings, cooling liquid, and the bearings of generator, rotor shaft and yaw system.

3.2 Gearbox

Cartridge heaters are installed in the gearbox, in order to heat the oil, when starting up at low temperatures. The gearbox is equipped with 3 heaters at a capacity of 0.8 kW each.
The sequence of heating up the oil in the gearbox is:

1. Cartridge heaters and the nacelle heaters will heat up the oil from –30 °C to –20 °C
2. When the oil reaches -20°C the turbine will be allowed to idle with at max speed of 250 RPM. The idling operation is an effective way of heating up the gear box oil.
3. When the oil temperature reaches –10 °C the turbine is allowed to generate max. 400 kW of power.
4. When the oil temperature reaches +10 °C the turbine is released for normal operation.

The procedure is shown in the graph below.



3.3 Cooling system

The NM72/82 cooling system is designed to operate in temperature ranges from –30°C to +40°C This system is standard for all NM72/82s.

3.4 Meteorological equipment

The arctic specification turbine will, as a standard, have:
One Ultra sonic FT702LT combined wind vane and anemometer
One NRG IceFreeII Wind Direction Vane
One NRG IceFreeII Heated anemometer

The ultra sonic instrument has three heating elements and an "intelligent" deicing control.
Parameters for the control of the heating element can be set by the user.
The heaters draw up to 6A in extreme conditions.
The picture below shows the ultra sonic instrument, mounted next to standard wind vanes and anemometers in an icing situation.

The NGR instruments have a simple internal heater that maintains the instrument at 140°C by means of a PTC resistance element.

3.5 Rotor

The pitch hydraulic system uses oil with low index of viscosity suitable for operation at -30°C. The accumulators mounted in the hub are equipped with heating mats to ensure proper viscosity of the oil. There are 9 heating mats at a capacity of 0.2 kW each. Furthermore, the grease on the bearings is different from standard due to the viscosity.

As a standard, blades are suitable for operation at –30°C.

3.6 Controller

The controller is, as a standard, mounted with heaters as follows: 2 x 0.35 kW in the power panel, 2 x 0.35 kW in the control panel, 2 x 0.35 kW in the power factor correction panel and 1 x 0.35 kW in the top box. There are no additional heaters mounted in the controller at the arctic version.

Thermal sensors in the cabinets control the heating elements, which are turned on if the temperature falls below the preset minimum limit. The heaters will secure adequate temperatures for running the wind turbine computer.

3.7 Structural parts

All structural parts, e. g. tower, mainframe, hub, bolts and blades are, as a standard, suitable for operation at –30°C and survival to at least –40°C.