Wind Energy: Cold Weather Issues

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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^{o} 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^{o}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)

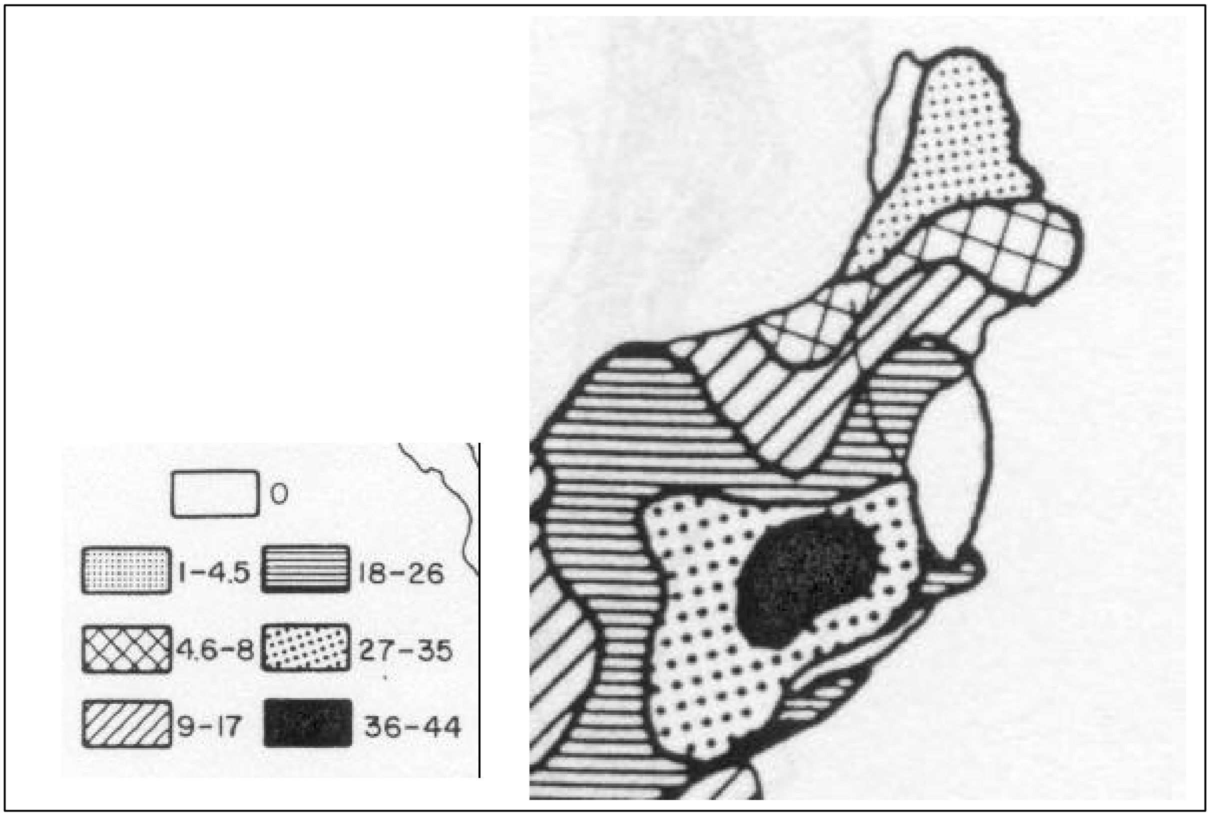

Figure 3. Total number of glaze storms, without regard to ice thickness, observed during the 9-year period of the Association of American Railroads study (undated) (Adapted from Bennett, 1959)

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.

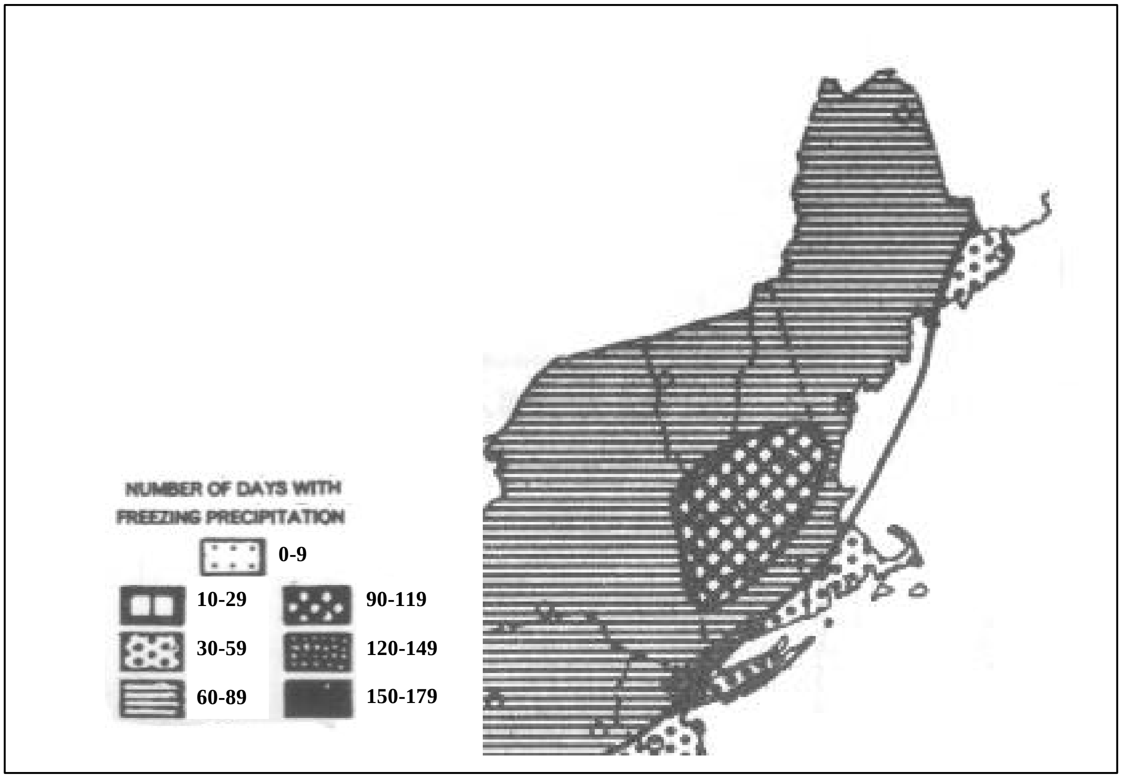

Figure 4. Total number of days with freezing rain or drizzle in the 10-year period from 1939 to 1948. Based on data from 95 Weather Bureau stations (Adapted from Bennett, 1959)

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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