Wind Energy in Cold Climates IEA Task 19 – Outlook 2010

Timo Laakso, Lars Talhaug , Göran Ronsten, René Cattin, Ian Baring-Gould, Antoine Lacroix, Esa Peltola, Tomas Wallenius, Michael Durstewitz

Pöyry Energy Oy
Tekniikantie 4A, P.O. Box 93
Tel.: +358 10 33 24931
E-mail: timo.laakso@poyry.com

Abstract — **An increasing number of wind turbines are being installed at sites where atmospheric icing and low operating temperatures have a significant effect on the operation of standard equipment. International Energy Agency; IEA R&D Wind, started a Task 19; "Wind Energy in Cold Climates" in 2002. This international collaboration has gathered information about wind turbine operation in cold climates ever since. The second term of the Task 19 ended in the spring 2009. Further extension for another 3 years is under planning. This paper introduces the present status and gives an outlook of cold climate wind energy development. The outlook focuses on cold climate related R&D trends and near future development in the task 19 participant countries.**

I. Introduction

International Energy Agency; IEA R&D Wind, started a task 19; "Wind Energy in Cold Climates" in 2002. This international collaboration has gathered information about wind turbine operation in icy and low temperature environments in participant countries ever since. The present participants include Finland, Norway, Switzerland, USA, Canada, Sweden and Germany.

Due to the positive market development in recent years and still existing unsolved cold climate specific technical, economical and policy related challenges, various R&D projects which aim at lowering the costs of cold climate wind energy deployments are under way in participant countries. The common aim of those projects is to reduce the risk and thereby the cost of wind electricity produced in cold climates. More reliable production estimates to lower the investor risk, new technology solutions for anti- and de-icing, statistical information on operation of cold climate wind turbines and market information for the cold climate technology are among other things under development. Thus, this paper provides an outlook of cold climate wind energy development in participant countries and introduces the ongoing cold climate R&D trends.

II. State of the Art of Technology Development

Technology that would meet the additional requirements set by the cold climate conditions has been developed in the Task 19 participant countries since late nineties.

Thus, several wind energy related technical solutions covering adapted turbine technology and cold climate engineered meteorological sensors are available commercially or are under development and in prototype stage around the world. Meteorological community alone has done considerable amount of work in order to solve the problem of anemometer and wind vane icing, which in cold climate wind turbine installations is perhaps the first and likely the largest source of error. The importance of correct wind measurements cannot be overemphasized. Appropriate anemometers for cold climate applications are commercially available. However, expertise will be needed when selecting the instruments as well as when interpreting the results as anemometer 100% ice free does not seem to exist up to now. As an 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. Cables, connectors and cable ties specified for low temperature usage should be employed in order to maximize the reliability of a measurement setup. Also heating for the boom of wind sensors in severe icing climates should be provided to avoid distorted results.

Several methods to detect ice and icing are available. Ice detectors for meteorological, aviation, road safety, power line monitoring etc. purposes are on offer. It is possible to measure icing indirectly with dew point detector or with pair of anemometers, one heated and one unheated. However, a standardized method for the calibration of ice sensors does not exist.

Icing maps describing annual icing time have been developed on the basis of the results of existing ice measurement and computer based climate simulations, but a verified method to map icing and ice loads still lacks. In general the cover of ice measurement network is scarce and it can be difficult to obtain accurate icing estimate for a certain site, since typically ice parameters are not routinely measured in any country by the national meteorological services. Also a verified method for the calculation of icing time from routine meteorological measurements does not exist. Considerable progress is expected to happen in this field during the next few years as an international collaboration has been formed to tackle the above mentioned topics.

Wind turbine icing appears to the owner of a wind project as a reduced energy production. The origin of the reduced performance is the adverse effect of ice to the rotor aerodynamics. It was found that wind energy, meteorological and aviation communities have all developed models for the estimation accumulated ice shapes on a windward side of objects, meteorologists for optimization of power line support structures and aviation industry to improve the safety of air passengers. However, due to the complexity and randomness of the physics of icing and aerodynamics, the development of accurate models for the estimation of the ice induced changes in aerodynamic forces of a wind turbine blade, has been moderate. Wind tunnel tests on the topic have been carried out up to now mainly by the aviation industry. Therefore the effect of ice on the performance of a wind turbine is not completely clear yet and partly because of that a verified method for the estimation of ice induced production losses does not exist at the present moment. Technical solutions for wind turbines operating at low temperature are available. Low temperature specified materials and oils should be used if temperatures outside the standard limits are probable. Many turbine manufacturers have already so called low temperature versions of their standard turbines available. In addition to cold specified materials used, those turbines often are equipped with gearbox or nacelle heaters. Some manufacturers have also adapted technology for icing climate on offer. In addition to low temperature versions, those turbines usually include some measures against icing of the rotor. This could mean ice detectors, coatings that prevent ice to stick to the blades or a blade heating system. The experience from the anti- and de-icing systems is still, however, relatively small.

III. Cold climate wind power projects

Operating in arctic and arctic-like climates adds costs and performance variability that must be assessed when any wind turbine site or project is considered. A framework for assessing this risk must be developed as part of the project development process.

Examples of these risks are:

- Increased initial costs of the turbine project because of limited installation schedules and higher equipment and installation costs.
- Increased downtime or power reduction caused by icing events over seasons or even in relation to forecasted spot markets if a storm results in an un-expected icing event.
- Turbine downtime and liability because of concerns for public safety from turbine blades and tower ice throw.
- Long exposure of rime ice, which may increase fatigue loading and cause premature failures.
- Increased downtime caused by extreme low temperatures in combination with any potential increase in power from higher air density in passive stall controlled wind turbines.
- Increased maintenance costs because of low temperatures and the likely higher average downtime between repairs because of turbine inaccessibility.
- Assessment of the economic impact of potential de- or anti-icing and low temperature operation equipment.

Risk mitigation strategies such as blade de-/anti-icing equipment, increased preventive maintenance, and pre-stocking replacement parts are available, but these increase the operational costs of the turbine and of the overall project. Any economic risk assessment should assess and weigh such strategies. Detailed site and meteorological information will be crucial to any risk mitigation calculation.

IV. Public safety

Ice on turbine blades and towers can pose a safety risk for the general public depending on the site being considered. The fact that no serious accidents caused by ice throw have been reported is no reason to think otherwise. Special technical solutions may have to be implemented to prevent accidents associated with the use of turbines in CCs that is accessible to the public. Additionally, an assessment should be made of legal protection to limit the risks associated with wind applications at specific sites.

Turbine operation with iced blades may not be permitted in certain countries or permitted only in the case of rime ice, as glaze ice is considered more dangerous. However, rime ice can be almost as dense as glaze ice, so there is no obvious reason to make such an exception. As visibility can be very poor under active icing conditions, warning signs should be closely spaced unless the area is accessible only via specific posted entry points.

The areas of potential ice throw should be calculated and the proximity of developed areas, roads, and tourist infrastructure such as ski slopes and lifts must be taken into account in placing the turbines. The turbines are likely to attract visitors if permissible. Visitor numbers to surrounding areas and to the site in question should be analysed and a risk assessment made. Local authorities may already have issued ordinances that restrict placement and/or operation of wind turbines due to the risk of ice throw.

V. Recommended practices

IEA Task 19 has elaborated and published recommendations and guidelines how to handle and assess potential installations at sites considered to be as cold climate sites. The basic messages and recommendations can be summarized as follows:

- Be aware of the extra risks involved in cold climate wind energy production at early stages of the project.
- Employ available best practises as far as possible, even though they generally do not consider cold climate issues.
- Instrument and turbine manufacturers have cold climate solutions available. Conduct a survey to find solutions for each project, because cold climate circumstances vary greatly.
- Perform a thorough site assessment measurement of at least one year with measurement devices, including ice measurements. This phase provides valuable information on site a cold climate and working conditions.
- There is no standard method for estimating ice induced

production losses. Make the best estimate based on the results of site measurements.

- Notice the cold climate related safety aspects, low temperature working conditions, and risk of ice throw in the project planning phase.
- Carry out a risk assessment that includes assessment of the quality of the selected turbine and experience and references of the installation company, contractors, and operator.
- Include the results of the risk assessment as part of the specifications for turbine, equipment, manufacture, installation, and operation.

VI. Market outlook

Limited efforts have been made to assess the potential of wind development in arctic and arctic-like microclimates, but papers by Tammelin et al. [1,2] report potential markets of 20% of the installed capacity by 2010. This outdated estimate would correspond to some 40 GW in CC if combined with the forecast for 2010 wind production presented in BTM's 2008 World Market Update [3].One thing is sure, wind turbines are and will be installed to areas where icing and low temperatures are outside the operational limits of standard turbines also in future.

The IEA Task 19 estimated that the share of cold climate installations annually has been 4 - 6% of total installations in US, Canada, Europe and China. Thus, the volume being about the same as offshore installations globally. If the cold climate market continues to grow at the same speed as markets on average the annual installations in cold climate around 3000MWin Task 19 member countries in 2014.

There is however an inherent lack of market studies for the potential of wind energy in cold climates on which manufacturers can base strategic production plans. The main reason for this has been a natural choice to focus initially on sites where no adaptation is required.

VII. Recent Technology development

Wind power related cold climate market is likely to segregate in the coming years. The basic reason is that the climate conditions in different cold climate markets are different. Thus in some areas the main issue is low temperature whereas in some other regions the most prominent challenge is atmospheric icing. In the following there is brief overview from the present R&D activities in Task 19 countries that also underlines the different R&D needs in different geographical locations.

A. *Finland*

The ongoing R&D activities include development of methods that could be used in evaluation of ice induced production losses during the project development phase. Also next generation anti-icing systems are under development. Third area of development is mapping of icing climate i.e. icing map for Finland is in preparation in connection to the development of national wind atlas.

B. *Switzerland*

The wind energy research program in Switzerland focuses on "Development of specific concepts and components for installations in difficult area and under rough climatic conditions". The main projects are:

- Alpine Wind Test Site in Gütsch: Important experience on the use of wind energy under climatically extreme conditions has been gained, with the 800 kW plant on the Guetsch near Andermatt (2300 m above sea-level). The main tasks are:

- Testing of blade heating
- Testing of ice sensors
- Ice throw safety study
- Monitoring of ice build up

- Alpine Windharvest was a project within the frame work of EU INTERREG III B Alpine Space Programme. Goals of this project were: Development of Information Base Regarding Potentials and the Necessary Technical, Legal and Socio-Economic Conditions for Expanding Wind Energy in the Alpine Space. Participating partners from Austria, Slovenia, Italy, France and Switzerland, www.alpinespace.org/alpinewindharvest.html

- Alpine Test Site Gütsch links the activities of Task 19 with the research activities of COST 727 "Meteorological measurements and wind turbine performance analysis ". Issues treated were monitoring ice detectors and wind measuring equipment in relation to the performance of a 600 kW wind turbine and establishing tools and guidance for operating wind turbine under harsh climatic conditions. www.meteotest.ch/cost727/index.html

- Nano Technology on rotor blades of wind turbines: Main objective of this project is to investigate the possibilities to implement Nano materials in coatings of wind turbine blades to reduce the freezing point of the surface. The responsible researcher presented promising results at a task 19 meeting in Kassel 2007. A major wind turbine manufacturer and a Swiss chemical company are pursuing this development.

C. *Sweden*

Mastering wind energy in cold climates is now considered important for Sweden. There are currently some 54 TWh of large scale projects in various stages in the planning process of which 30 TWh is planned for at potential cold climate sites.

Enercon's de-icing system has been shown to improve the energy production during light icing conditions. Another two or three de-/anti-icing systems are currently planned for to be tested in 2009-2011 in wind pilot projects organized by The Swedish Energy Agency.

Mapping of icing and low temperatures are needed to enable the assessment of energy production losses due to icing and low temperature. Such mapping requires icing to be measured. In Sweden, development of ice detectors and ice load sensors as well as icing measurements, frequency mapping of icing and the development of icing forecasting methods are planned for within the next three year period.

D. Norway

In 2001 Institute for Energy Technology, The National Met Office and Kjeller Vindteknikk initiated a project for the development of icing prediction tools. A test station was installed at the coastal mountain Gamlemsvæten 830m a.s.l. At the site the icing can reach more than 25kg/m. Two web cameras were installed. One of them took pictures of the ice thickness on a guy wire; the other web camera took images of 8 signs on increasing distance from the camera. The images of the signs were used to calculate the visibility. A method based on climatic parameters from a Met station or an airport to calculate ice on a standard object has been developed. For cases with accumulation, good match was found with the observations. Larger discrepancies were found for cases where the ice melts or falls off.

In 2007, the method for calculating ice thickness on a standard object was implemented as a post processor for the meso-scale model WRF. Since WRF operates in the time domain, time series for specific points can be compared with observations. The comparisons so far show the same pattern as the airport data, the model works well for accumulation but discrepancies appears for situations where the amount of ice decreases. There are also other situations where the model does not reproduce the observations. For strong inversions, the model can overestimate the ground temperature leading to too small amounts of ice. Since the model calculates the ice in a geographic grid, it is well suited for making icing maps.

A method for calculating production losses using a two parameter power curve has also been developed. The two parameters are wind speed and ice thickness.

In 2008 two web cameras has been installed on a wind turbine at Nygaardsfjellet 430m asl and 68° north. One of the web cameras takes pictures of one of the blades of the turbine, the other one takes pictures of the instruments on the nacelle. The WRF model is also run in parallel. One of the goals with the project is to develop the production loss method further.

E. Canada

Early in the fall of 2002, Yukon Energy Corporation (YEC) installed a Goodrich 0871LH1 ice detector on a mountain near Old Crow, Yukon. The ice detector was part of an autonomous wind resource assessment station that included anemometers and data loggers. The icing severity at Old Crow proved too much for the limited built-in deicing function of the ice detector. Only the 2.5-cm sensing probe got deiced once every detection cycle. This was insufficient and the whole detector assembly soon became engulfed in rime ice. This caused the detector to become inoperative and confirmed the importance of having an ice detector with full deicing capability.

Another project was done in collaboration with the University of Manitoba where experiments were performed in a state-of–the-art academic wind tunnel with icing capabilities. One of the objectives of this project was to simulate the icing conditions found in Southern Manitoba near St. Leon where there is a large wind farm. Experiments in the tunnel helped to understand the fundamentals of ice formation and to estimate how the turbines production is affected by the presence of ice. The work also focused on optimising ice mitigation techniques and allowed for progress towards developing new innovative design solutions for wind turbine applications in cold climates.

A third project consisted in the acquisition of scientific material to study and document the climatic conditions of a cold climate area favourable for the operation of wind turbines. This area is located at an elevation of approximately 610 meters in a mountainous domain of Eastern Canada. Two towers were instrumented to characterize the local environment in terms of wind speeds, wind direction, atmospheric pressure, humidity, duration of icing events and precipitation. The scientific information collected will help explain the failures of turbines that were designed for the European climates. It will also help to design turbines that are more adapted to severe North American climatic conditions.

F. USA

The U.S. has not conducted cold climate specific research projects during the course of the second period of Task 19. NREL has continued to conduct deployment related activities in cold climates, specifically in Alaska, Greenland, and Antarctica. These activities have helped to support U.S. state and federal activities regarding turbine implementation and operation in cold and extreme climates. A key focus of multiple projects has included wind turbine foundation design in cold climates with a specific emphasis on foundations designed to address the impacts of changing permafrost depth due to annual freeze thaw cycles. A second prime focus of the U.S. participation in Task 19 have been outreach based on fundamental knowledge and basic information on cold climate related issues with wind turbines. These activities have been carried out primarily through lectures, conference papers, posters and the redrafting of the Experts Group Study on Wind Energy Projects in Cold Climates. Efforts have also been undertaken to better document the implementation of wind projects in U.S. cold climate regions and supporting the assessment of resources in cold climate environments, specifically Alaska.

G. Germany

In the frame of national funding programmes “Scientific Measurement and Evaluation Programme” and the “German Windmonitor” ISET is contributing to the Task 19 work programme with support of the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). The main activities of ISET during its participation to Task 19 have been to spread fundamental knowledge and basic information on cold climate related issues to administration, industry and education. Several lectures, conference contributions, posters etc. have been given in national seminars and abroad.

ISET’s wind energy database, first established under the “250MW Wind”-programme, including hundreds of reported icing observations in Germany, has provided valuable information for the task by means of a broad statistical basis of sites affected by atmospheric icing, observed downtimes, repaired components and related cost figures.

ISET is presently analysing the influence of specific weather situations and meteorological parameter with possible incidence of atmospheric icing in order to improve the quality of wind power forecasts.

VIII. Conlusions

First wind turbines with real cold climate modifications were built some decade ago and recently the first steps from demonstrations into fully commercial implementations have been taken. The development of ice free wind sensors and ice sensors has advanced alongside. However, it can be said that from project developer point of view there is neither reliable commercial ice sensors nor commercial wind turbine technology that would enable development of high wind areas where icing conditions at winter time are challenging.

Technical development continues and turbine and sensor manufacturers are demonstrating new solutions. As the applications are entering a commercial phase, there is a need to gather experiences in a form that can be utilized by developers, manufacturers, consultants and other financiers. This is especially the case in present situation where more challenging inland sites, including cold climate sites, are becoming more and more competitive with offshore wind due to the increased offshore deployment costs.

It is likely that increasing numbers of wind turbines will be installed to the sites within next five to ten years that can be described as cold climate sites. The areas where cold climate sites will be developed at increasing pace are Scandinavia and Northern parts of America and mountainous areas of Europe. There are also several R&D projects taking place and starting in the member countries of present task 19. Thus, it seems clear that cold climate wind energy development will continue during the next years. Moreover, the size of the cold climate market may be similar to offshore i.e. around 2000MW to 4000MW annually. Some of the sites can be described as cold climate sites due to low temperatures and some due to atmospheric icing and at some sites both.

There still is a need to develop methods for project developers for the estimation of cold climate related risks that originate from cold climatic conditions. There are still not available methods for the estimation of production losses due to ice and low temperature and thus it is still typical that the uncertainties regarding production estimates of cold climate sites are higher compared to standard low land undertakings. Icing atlases are not easily available. Methods to produce such maps exist but are still not often used. Operational experiences exist but are also not easily available as the owners of the turbines are often not willing to share the experiences gained often the hard way. Thus the collection and dissemination of the cold climate specific information is still very much topical.

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[1] Tammelin, B. and H. Seifert (2000), The EU WECO-project Wind Energy Production in Cold Climate, Proceedings of an International conference BOREAS V, Levi, Finland. CD-ROM. Finnish Meteorological Institute.

[2] Tammelin, B., M. Cavaliere, H. Holttinen, C. Morgan, H. Seifert, and K. Säntti (2000), Wind Energy Production in Cold Climate, Meteorological Publications No. 41, Finnish Meteorological Institute, Helsinki. 41 pp..

[3] International Wind Energy Development – World Market Update 2008, BTM Consult ApS, ISBN 978-87-991869-5-2, March 2009