IEA CO-OPERATION ON WIND TURBINES IN ICING AND COLD CLIMATES

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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 the paper, 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

The paper will present the objectives of the international collaboration as well as the state-of-the-art of arctic wind energy

1 INTRODUCTION

IEA R&D Wind is an agreement between 19 countries and the European Commission to follow international development on wind energy deployment and to stimulate co-operative research and development of wind technology. The co-operation takes places in form of Annexes to the main agreement. At present the following Annexes and their operating agents are

- Task XI Wind technology information exchange (FOI, Sweden)
- (Task XVI Round robin test program (NREL, U.S.), work completed)
- Task XVII Database on wind characteristics (Riso, Denmark)
- Task XIX Wind Energy in Cold Climates (VTT, Finland)
- Task XX HAWT Aerodynamics and Models from Wind Tunnel Measurements (NREL, USA)
- Task XXI Dynamic Models of Wind Farms for Power System Studies (Sintef, Norway)

The r&d-projects are usually task shared, only the coordination costs of the operating agent cost shared.

2 ANNEX XIX WIND ENERGY PRODUCTION IN COLD CLIMATES

In 2001, International Energy Agency, IEA R&D Wind started Annex XIX Wind Energy in Cold Climates. In the annex we are looking at sites that have icing events or low temperatures outside the standard operational limits for wind turbines. International collaboration between the participating countries has as objectives to gather operational experience of wind turbines and measurement campaigns in icing or cold climates.

The goal is to formulate site categories based on climatological conditions and site infrastructure, and link the wind turbine technologies and operational strategies to these categories. This will give guidelines to operators and manufacturers for 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, NREL from the USA, ENCO from Switzerland and NRCan from Canada [1].

The total budget for three years is $ 650 000 divided into

- Cost of Operating Agent $ 50 000
- Total estimated costs of participants $ 600 000

The project is first transatlantic co-operation in the field.

Expected results of the project are summarized as follows

- The experiences of as well building, installing and operating wind turbines in a new market segment with specific requirements as availability, accessibility and reliability will be collected.
- A site-classification procedure for feasibility studies and market assessments will be established.
- A methodology for monitoring icing conditions during site assessment and operation will be presented.
- Estimated losses of production due to icing will be quantified. Tools for estimating the feasibility of different adapted technical solutions will be developed.
- Guidelines for developing wind energy in cold climate conditions, including all aspects of cold climate engineering, not only limited to icing will be presented. These are necessary when entering new markets, e.g. in non-OECD countries.

As the first step the project has gathered a state-of-the-art-report on wind energy production in cold climate. Some points of the report are shortly summarized below. The entire report can be downloaded from the Annex web-site http:\\arcticwind.vtt.fi.

3 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). In the Annex a database has been established to collect the information on the turbines operating in cold climate. The turbines are shown in Figure 1. The toal capacity of these turbines is approximately 500 MW. The climatic conditions these turbines are facing differ from each other though the conditons are outside the standard operational limits set for wind turbines.

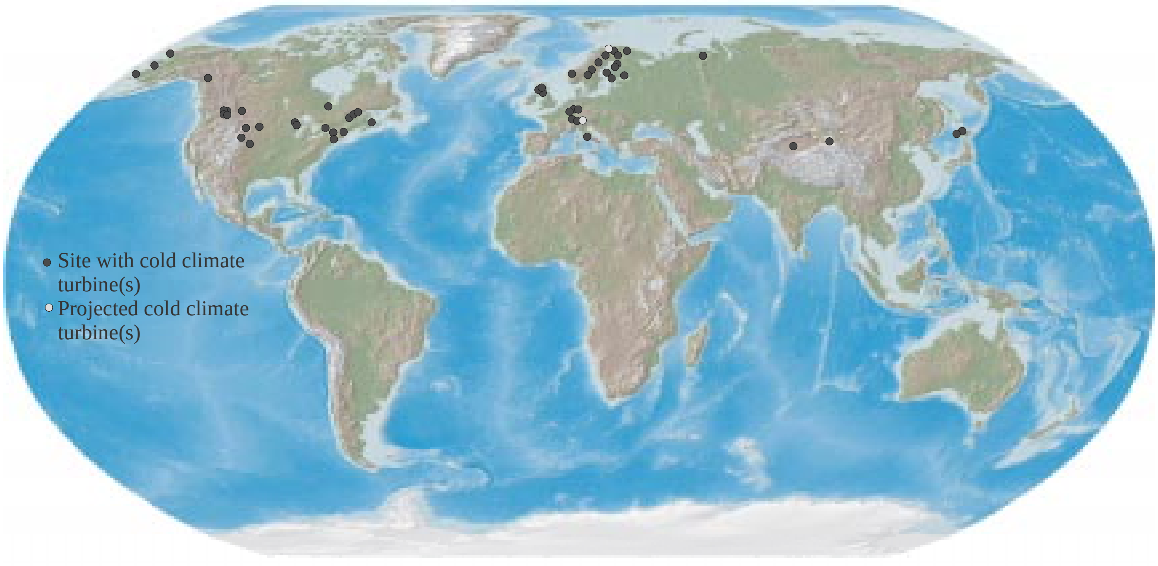

Figure 1 Locations of operating wind turbines in cold climate sites [2,3,4,5,6,7].

4 KNOWLEDGE IN 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.

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 is 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 away may also not give enough information about a specific site in question.

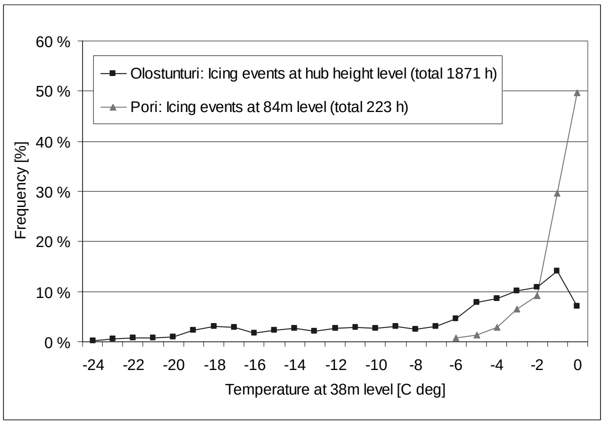

Figure 2. Temperatures during icing events. Two different sites in Finland with annual mean temperatures of 0.3 °C (Olos) and 7.1 °C (Pori).

Measurements

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.

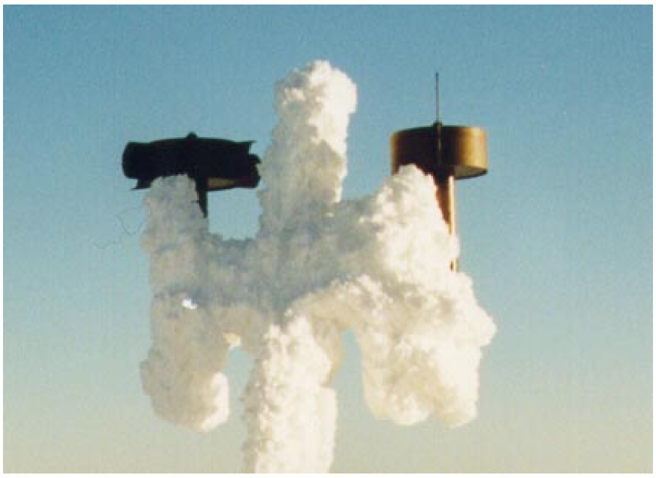

Figure 3. Ice free anemometer in severe icing conditions.(Photo, VTT)

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..

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.

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 EU project Wind Energy in Cold Climates. More detailed maps are available in some countries, suh as the map developed in Switzerland.

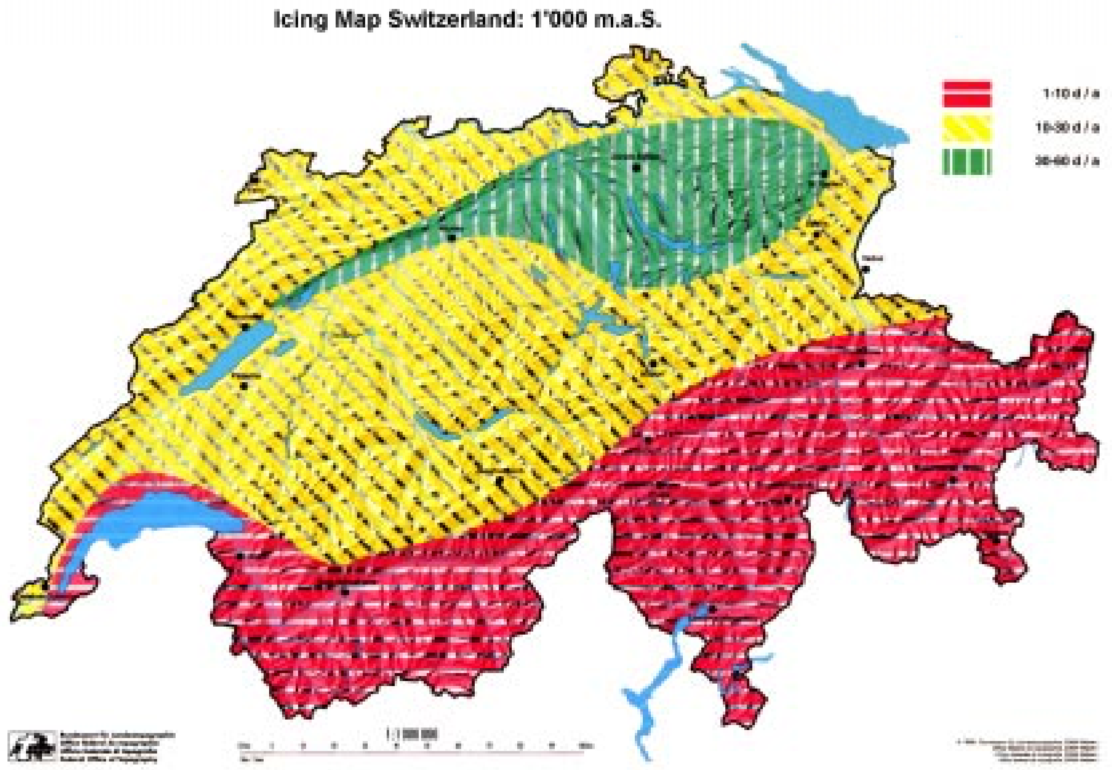

Figure 4 Icing map of Switzerland

5 EFFECTS OF ICING AND COLD CLIMATE ON WIND TURBINES

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). For example there can be freezing rain or in-cloud icing, when small water droplets in the cloud impinging on the surfaces of rigid structures and rotating blades form ice.

5.1 Icing

- affect the aerodynamics of the blade resulting in production losses
- affect the anemometers, both in resource estimation and in turbine control
- may increase the structural loads of a turbine significantly
- ice thrown off the blade may pose a safety risk even in areas where icing is infrequent.

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, tower etc. is needed.

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 site are needed. Especially on mountainous areas the local effects can be difficult to assess in modeling. Measurements of the conditions further than 1 km away may not give enough information about the site.

Sites with icing events require turbines with heated wind sensors. A variety of heated wind sensors are available, tested and used at sites with frequent icing conditions [11]. This is discussed in greater depth later in this paper.

5.2 Low temperatures

Low temperature alone has several effects on the wind turbine and it's operation and maintenance, suh as:

- brittle fracture of materials
- insufficient lubrication of bearings and gearbox
- malfunctioning hydraulics
- malfunctioning electronics
- service and monitoring under difficult conditions

6 TECHNICAL SOLUTIONS IN USE AND OPERATIONAL EXPERIENCE

6.1 Icing conditons

Icing of the blades causes production losses from 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. 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.

Current practice indicates that in heavy icing conditions the outer surfaces of the blades need to be heated in order to achieve satisfactory results. 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. The Finnish blade heating system, where carbon fiber elements are mounted to the blades near there surface, has the widest operating experience, from 18 turbines at various sites, with a total of nearly 100 operating winters [12].

In sites where icing is slight, infrequent and the icing periods are most likely followed by temperature rising above 0 °C, blades coated with black paint may be sufficient, making use of the eventual solar radiation. Stopping the turbine and circulating heated air inside the blades may be adequate in slight icing conditions. Stopping the wind turbine when icing starts may also be a sufficient solution in such environments, although ice detectors are then required.

Blade heating may be necessary or profitable on sites having frequent icing or on sites with high safety requirements. The break-even cost of such a system depends on many turbine and location parameters

- Site specific parameters: the probability or the time of icing, the wind resources, safety precautions required in the planning or permission granting process
- Turbine specific: the effect of the icing on the turbine power curve and production
- Economic: value of the produced energy

A simple approach to estimate the break-even conditions has been developed by Peltola et. at. [12]. A number of different approaches for the blade heating have been presented, developed and tested.

The structural loads of a turbine may be significantly increased due to icing of the blades. Icing usually sheds from the blades unevenly and this results in increased loading on the turbine [10].

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 a public road, or by skiing resorts, for example.

Ice shedding off the tower or the nacelle can also pose a similar though a more limited risk especially for the service personnel and the public. There are also cases when icing of the yaw gear has resulted in the damage of yawing motor.

Icing also affects the 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. A wind vane stuck by icing means operation in misaligned yaw or a production stop due to the misalignment.

6.2 Low temperature conditions

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 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). 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. [16].

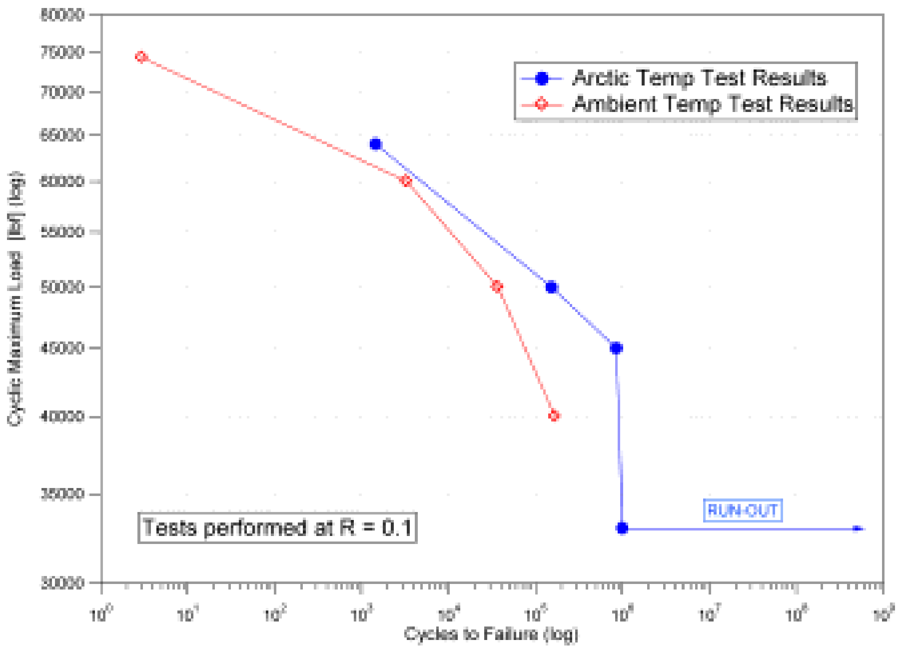

Figure 5 Stud testing, NREL

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.

Low temperatures effect materials, in the case of wind turbines primarily the plastics, steel and lubricants, as low temperatures cause brittle fracture of materials. Insufficient lubrication of bearings and the gearbox is the result of oils getting too stiff. Malfunctioning of hydraulics and electronics have been reported. When changing the hydraulic oil to a stronger arctic version, the tubes, valves and equipment associated may also have to be changed or modified. However, even when cold rated lubricants are used, adverse impacts on unit performance have been identified. One clear case is low speed startup of turbines in cold environments, specifically for turbines that freewheel up to synchronous speed. In such cases, freewheel start-up may be retarded due to the high viscosity of the gearbox oil.

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 who's insulation becomes brittle and fractures, 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.

7 SUMMARY

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

With the increased use of wind turbines in cold environments, more specific scientific research will be required for components specifically related to wind turbines. Variable gearbox loading at low temperatures and more experimental testing of bonding of wind turbine blade elements should be conducted.

Internationally accepted standards for resource assessment as well as turbine specification in arctic and extreme conditions needs to be determined, specifically in conjunction with existing standards that may actually restrict implementation of this technology in these environments.

Also operational experience should be further gathered and shared to benefit investors, manufacturers and operators. Annex XIX is one step to this direction.

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