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THE STATE-OF-THE-ART OF 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

1 INTRODUCTION

In 2001, International Energy Agency, IEA R&D Wind started a new annex number XIX called 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].

There are at the moment few projects in the cold climate market segment of wind power. There seems 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. The global market is estimated to be substantial, but real assessment of the market has yet to be performed.

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.1).

Europe: There are occasional icing events on the coastline, and severe icing conditions in high altitudes. Low temperatures below –20 °C occur only in Scandinavia and some parts of Rumania. There are existing sites in Finland, the mountains of Sweden and Norway, Germany, Austria and Switzerland. Low temperature modifications are used in Scandinavia, and there are some projects with anti- or de-icing of blades in use.

North 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. In northeastern parts of the US and Canada, 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. The last clarification of sites are along the arctic coast, such as the 0.5 MW plant located in Kotzebue, Alaska and specific units in northern Canada. These sites experience icing, cold temperatures and high density air flows.

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

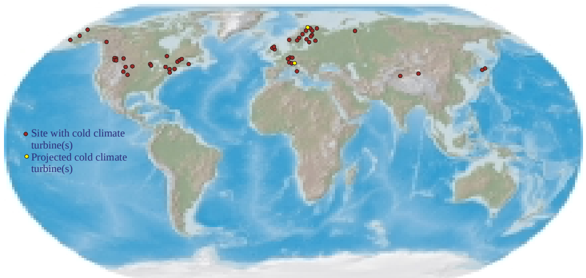

Figure 1. Locations of operating wind turbines in cold climate sites [2,3,4,5,6,7].

3 ICING IN 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.

There are different icing climates: icing can be frequent only in temperatures close to 0 °C or it can also happen in lower temperatures. This is demonstrated in fig.2, 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].

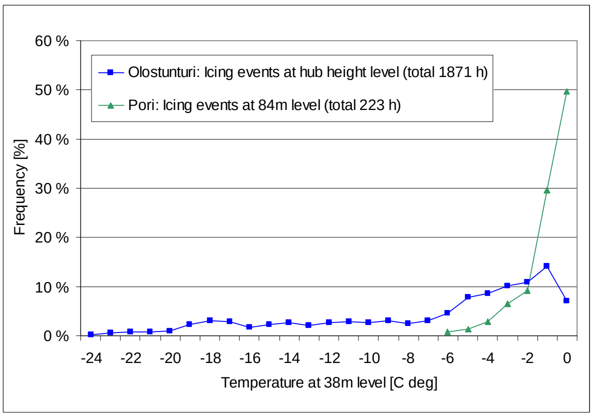

Figure 2. Temperatures during icing events. Two different sites in Finland with annual mean temperatures of 0.3 °C (Olos) and 7.1 °C (Pori).

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.

3.1 Operational experience

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.

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.

3.2 Technical solutions in use

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.

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.

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.

At the present moment there are some commercially available solutions. 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.

4 LOW TEMPERATURES

4.1 Operational experience

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.

4.2 Technical solutions in use

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. 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.

Recent testing at the National Wind Technology Center 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 fiberglass. 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.

In the area of lubrication, 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. At the present moment surface heated gearboxes are used to avoid the cold starts after a standstill of turbines. A thermostatic controller heater is also needed at some sites [15].

5 KNOWLEDGE ON CLIMATIC CONDITIONS AND RESOURCES

5.1 Instruments suited for wind turbine applications

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 our case, these need not only to be weather- and UV-resistant but also 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 shown in ref [17]. The gel will also protect a cable against breaking if exposed to a) unforeseen external loads by a maintenance crew (or reindeers) and b) movements when cable attachments are deteriorating. Cable attachments occasionally will break and weather resistant cable ties are not sufficient in cold climates. Weather Resistant Nylon 6.6 [18] has greater resistance to UV light, which damages natural nylon, but one should use Weather Resistant Nylon 12 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. Icing conditions most probably require, depending on the required accuracy, neighbouring objects such as attachment and connecting booms/tubes to be heated as well. In practice, the latter is often overlooked, thus diminishing the value of such cold climate instrument testing.

Figure 3. Ice free anemometer in severe icing conditions.

In the field of wind energy a properly acquired wind speed is of outmost importance. We have two basic categories of needed accuracy when measuring wind speed in flat terrain:

a) resource estimation, required accuracy: ±3-4%

b) verification of wind turbine performance, required accuracy: approximately ±2%

In addition, accurate wind speed measurements in complex terrain is difficult on its own and does not need the uncertainty introduced by improperly heated or mounted wind speed sensors.

Detection of ice is similarly complex. Traditional ice-detectors used to be extremely unreliable. Ice detection technology has improved considerably, as has our knowledge about the occurrence of ice. Organisations are also developing and sharing extensive research on ice accretion versus temperature, humidity, radiation, wind direction, wind speed and precipitation.

5.2 Maps and Models

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]. Updated versions are currently under development in the framework of the EU project ICETOOLS although a tool for estimating the number of icing days on a given site is still missing. Also models for predicting local weather events (wind, icing) more accurately are being developed. Model development needs to be done in connection with accurate measurements for verification and validation before they can be used freely.

DISCUSSION

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. 4). 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 gathered and shared to benefit investors, manufacturers and operators. Annex XIX is one step to this direction.

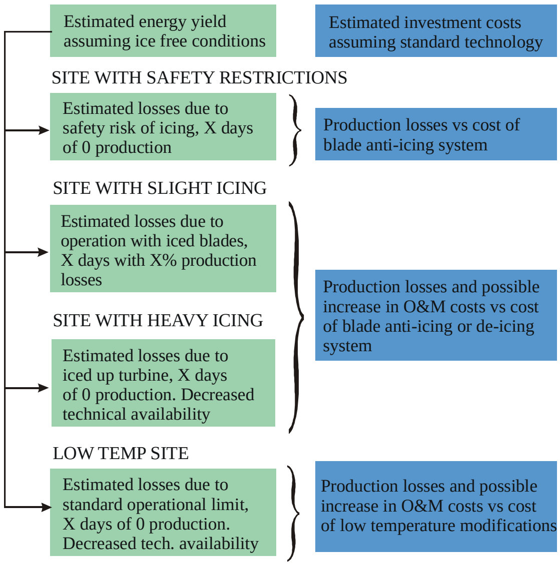

Figure 4. Assessment of sites in cold climates: there are sites in very low temperatures but dry climate with no icing events. Icing is most frequent just below 0°C. Some sites have to consider all the cases above.

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