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Performance Warranty Guidelines for Wind Turbines in Icing Climates

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Performance Warranty Guidelines for Wind Turbines in Icing Climates

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Executive Summary

The aim of this document is to set out a number of possible options for Wind Turbine Generator (WTG) Ice Protection System (IPS) warranties. In the future, further standardization on the topic on performance warranties for wind turbines in icing climates could be developed based on actual testing experiences derived from the industry.

This document also describes how different warranties can be tested via full-scale wind turbine or component level performance tests that have been identified so far. IEA Wind Task 19 considers wind turbine performance tests in icing climates as a key element for accelerated improvement of WTGs in Cold Climate conditions.

It is recommended that an IPS product warranty, availability, as well as a performance warranty is negotiated with the wind turbine original equipment manufacturer (OEM) whenever an IPS is included in the turbine contract. The warranty should aim at setting an availability and performance of the system throughout the lifetime of the turbine. The IPS should be viewed as an integral sub-component of the turbine, subject to similar level of expectations and service as for any other sub-component in the wind turbine. It is recommended that all warranties in the Turbine Supply Agreement are seen in conjunction and that down-time of the turbine caused by any maintenance or malfunction of the IPS is covered by the warranties, be that the IPS performance warranty or availability warranty, or the turbine contract itself.

The warranty should aim at setting minimal performance of the IPS by setting out clear requirements/criteria including any exclusions, a method to test if the requirements/criteria are met and contractual consequences based on the results of the tests. This document will focus on the performance warranties and the product warranty will therefore not be discussed further within this document.

There are two main approaches that could be utilized for performance warranty coverage for wind turbines equipped with an IPS.

- **Availability Warranty –** Based on IEC 61400-26, this type of warranty is commercially used today but the IPS system functionality, being connected to icing climate, may often be excluded from the warranty[*]. The efficacy of this will depend on the type and setup of the availability warranty included in the contract.
- **Turbine Performance Warranty with IPS (A)** or **IPS Performance Warranty (B) –** This type of warranty would be a separate document in a Contract, similar to a Power Curve warranty or a Sound Emission warranty. This warranty would set out the performance criteria/requirement, test method and consequences for the performance of the IPS, either as part of the whole WTG (Turbine Performance Warranty A) or purely taking into account the IPS performance (IPS Performance Warranty B). Depending on the test method chosen the performance criteria/requirement may be different. Three

[*] Some manufacturer(s) may offer this.

different test methods for testing the system as part of the WTG have been identified and one for testing the IPS system on a "stand alone" basis. The three tests for Turbine Performance Warranty A are:

- **Power performance test** – similar to IEC 61400-12, based on standard power curve testing standard (Figure 1, A1)
- **Side-by-side comparison test** – comparison of two turbines positioned in similar locations, with similar wind and icing climate, where one WTG is run with an active IPS system and the other has a deactivated IPS system (Figure 1, A2)
- **Turbine self-comparison test** – self-comparison of the summer and winter power curves of a test turbine (Figure 1, A3)

For IPS Performance Warranty (B) – measurement of ice removal efficacy on blade is described in (Figure 1, B).

Figure 1 illustrates the different warranty test options, A1) Power performance, A2) Side-by-Side, 3) Turbine self-comparison and B) IPS System Performance.

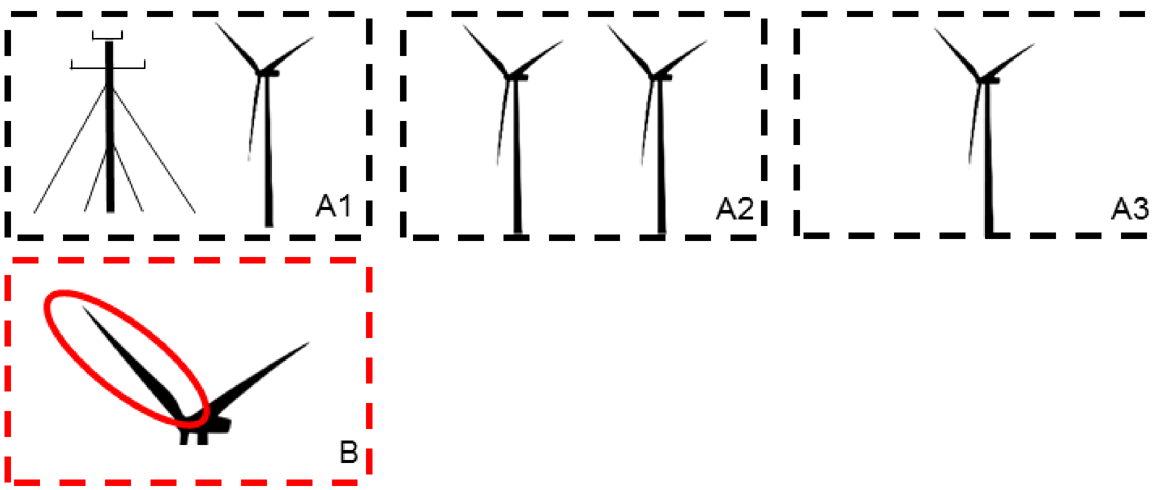

Figure 1. Overview of different full-scale turbine performance tests options (top row) and sub-component test option (bottom row)

1. Background

This document sets out guidelines for wind farm Developers and Wind Turbine Generator (WTG) Original Equipment Manufacturers (OEMs) operating in cold climate areas, where there is a risk for icing. There are a number of different Ice Protection Systems available on the market for mitigating icing effects on wind turbines. These recommendations should be seen only as a guide as different systems may be suitable for different types of IPS warranty methods.

In the latest IEA Wind Task 19 Recommended Practices – report (IEA Wind Task 19, 2017), the IEA Wind Task 19 have provided a guide for developing wind farms in cold climates which also provides more information on the complexity of the icing. Although a considerable amount of experience and knowledge already exists about operation of wind turbines in cold climates, there is a great deal that is still unknown. However, wind farm development in cold climates is becoming more mature, partly by ensuring that icing risks can be quantified during the project development phase.

One of the largest production risks developing wind farms in cold climate is due to ice build-up on the blades leading to aerodynamically changed blade profiles or stand still of the turbines and consequently loss of production (see Figure 2). A number of turbine manufacturers have developed Ice Protection Systems (IPS) that should mitigate ice build-up on the blades and therefore minimize the majority of the icing losses. The losses due to cold climate will never be zero, however with time; wind turbines developed for icing condition sites should become increasingly more efficient.

Figure 2. Icing on wind turbine blades in different parts of the world (source: Task 19)

The goal of these guidelines is to describe a number of options how wind turbines equipped with IPS can be warranted and tested. The expected impacts of these guidelines include substantially accelerating the R&D efforts related to wind turbines in icing climates and to enable the wind industry to develop wind projects in Cold Climates at a reduced risk. The principle objective of an IPS warranty should be to ensure that there is a contractual coverage to mitigate negative impacts on production and revenue in the case the IPS system does not meet the stated performance criteria. Warranties are important in general to ensure that the development of the systems are followed up and the risk of unexpected losses are significantly mitigated by having a mutual contractual understanding of what IPS system performance can be expected.

To summarize, the main reasons for why it is important to ensure that the performance of any Ice Protection System is warranted:

- Decrease uncertainties in investments in cold climate sites
- Enable increased understanding of the performance and limitations of the IPS
- Increase incentive to ”optimize” system/operations

There are also indirect benefits for the industry, as icing climate operation becomes more predictable and means of comparison are created. Being able to have certainty about the performance of the IPS to keep the turbines running at an acceptable level, and this risk being partly shared with the OEM through a contractual warranty brings a lot of security to the owners and investors during the development, pre-and post- construction phase.

However, for a warranty to be useful, it is important to have sufficient knowledge of the functionality of the IPS from ice detection to ice removal, through to the performance that can be expected in different types of weather conditions. In addition, it can be even more important to understand the limitations of the system to enable realistic, pre development calculations of potential production losses, allowing for proper quantification of the risks.

It is also recommended to have agreements with the IPS supplier to optimize the functionality of the system for each particular site as much as possible since different cold climate sites may require different operational settings, which can be reflected in different warranted performance levels. In addition, a warranty will also increase the incentive to optimize IPS/icing climate operations, as it may become a competitive advantage.

This guideline focuses on the operational performance of turbines in icing climates and does not address ice throw risk, with or without IPS. For more information on ice throw please see IEA Wind Task 19 Recommended Practices (IEA Wind Task 19, 2017).

No standard to evaluate the performance of IPS has been proposed and widely adopted by the wind industry. In general, very few IPS technologies have gone through rigorous validation by third parties. It is important to request such validation reports, should they exist and to assess the following:

- understand the icing conditions in which such validation was performed and try to understand how the same system will perform in different conditions;
- Understand the limitations and design envelop and the start/end triggers of the IPS and compare them to the specific site under development;

- Finally, understand in detail the testing methodology and how the actual measurement conditions might differ from normal operations.

IPS technologies are, in most cases, quite recent, and several OEMs are marketing IPS that have been deployed only at a few sites, and only on certain turbine platforms. It is crucial to discuss with the OEM about their specific experience of deploying this technology and how the system is adapted or scaled to the specific WTG design and size.

When planning to execute performance validation of an IPS, it is recommended to engage early with the OEM to discuss where the additional sensors will be installed, how they will be mounted, powered and connected for communication.

2. Definitions

2.1. Cold Climate

Following general cold climate definitions from IEA Wind Task 19 Recommended Practices – report are used (IEA Wind Task 19, 2017):

- **Cold Climate** area is defined as an area or region that experiences frequent atmospheric icing or periods with temperatures below the operational limits of standard IEC 61400-1 ed3 wind turbines (IEC, 2005)
- A Cold Climate area can be either **Low Temperature Climate** and/or **Icing Climate**. Areas that have periods with temperatures below the operational limits of standard wind turbines are defined as Low Temperature Climate (LTC) regions, whereas areas with atmospheric icing are defined as **Icing Climate** (IC) regions.
- Within **Icing Climate** areas, the following icing definitions apply
    - **Meteorological Icing** is defined as the period [% of time] during which the meteorological conditions (temperature, wind speed, liquid water content, droplet distribution) allow ice accretion
    - **Instrumental Icing**: The period [% of time] during which ice is present/visible on a structure and/or a meteorological instrument.
- For an area to be defined as **Icing Climate**, **Instrumental Icing** is present more than 1 % of the year and/or **Meteorological Icing** is present more that 0.5 % of the year.
- Within **Low Temperature Climate**, the following definitions apply:
    - If minimum temperatures of below -20°C have been observed during long term measurements (preferably ten years or more) on an average of more than nine days a year, the site is defined as a LTC site. The nine-day criteria is fulfilled if the temperature at the site remains below -20°C for one hour or more on the respective days or;
    - The long-term average annual air temperature of the site is below 0°C.

Figure 3 illustrates the definitions for Cold Climate, Low Temperature Climate and Icing Climate (IEA Wind Task 19, 2016).

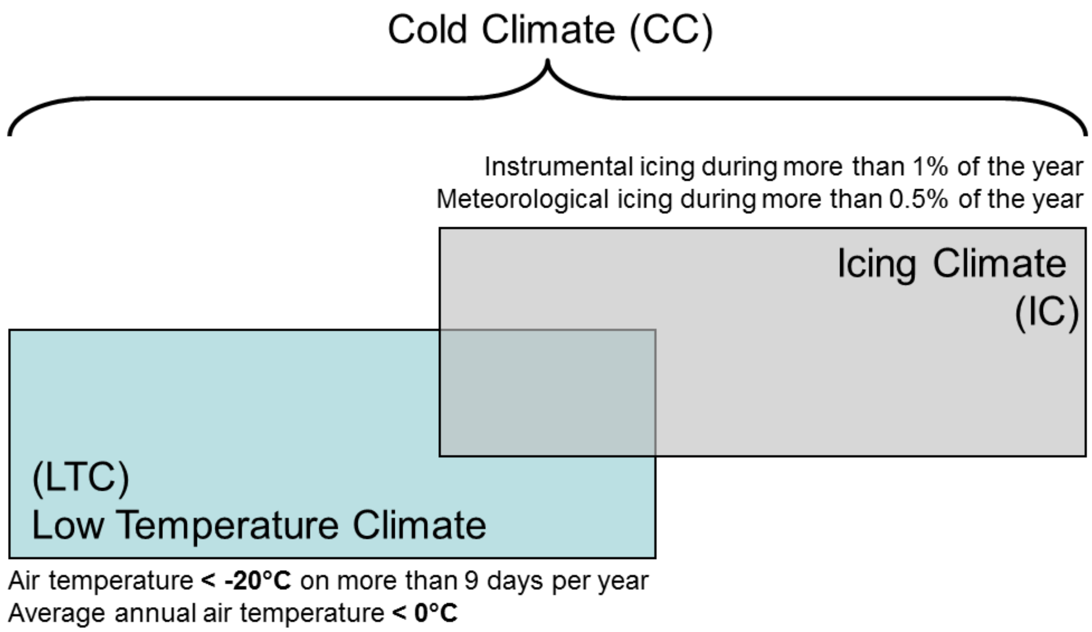

Figure 3. Definition of Cold Climate, Low Temperature Climate and Icing Climate (IEA Wind Task 19, 2016)

Icing Climate is not only prevalent in cold climate sites with low temperatures, but can also be found in sites where the temperature is around 0°C during the winter. The amount of icing experienced by the wind farm may also depend on the terrain e.g., exposed hilltops may experience more icing than surrounding terrain at blade tip height.

2.2. Ice Protection Technology

Turbine OEMs have developed different Ice Protection Technologies (IPT) to ensure that the turbines can continue to operate throughout the winter[†]. IPTs are not only used in cold climate areas for icing loss mitigation, but can be required for health and safety reasons by local regulations in areas not generally considered as Cold Climate areas.
There are two main categories of active IPT currently commercially developed for wind turbine blades and these are:

- forced hot air heating systems and
- electro-thermal convectional heating mats.

Other active IPT solutions currently being explored in R&D projects are for example, advanced loads control software, microwave technologies and other mechanical removal methods. There is also research into passive technologies for example icephobic coatings.

These guidelines will focus on the commercially available active technologies, e.g. the forced hot air system and the convectional electro-thermal heating mat system. IPT solutions that are not commercially readily available from the majority of the OEMs are excluded from the

[†] Operation should be within the icing limits of the WTG and IPS system in order to prevent turbines from damage.

focus of these guidelines. However, more technologies might become commercially available in the future and it is recommended that these guidelines be updated accordingly.

It is important that the whole system (if possible) is taken into account when considering the IPS technology used. The operational methodology and the location also play an important part in the effectiveness of energy production.

The forced hot air system consist of a heater though which air is forced by a fan inside the blade, the heater-fan unit are usually located in the blade root. Hot air is forced in the blade towards the leading edge to heat the blade surface by conduction through the blade material.

The heating mat system consists of electro-thermal mats placed on the leading edge of the blade. The mats can be embedded under the resin/ gel layer of the blade, or be added on the outer blade surface using adhesives. In all cases, the mats are powered by cables and connectors coming from the nacelle and through the hub.

2.3. Ice Protection System

In addition to the IPT, there are two main operational strategies that can be used: **de-icing operation** or **anti-icing operation**. Some hybrid system and control strategies are also being used in cases of intense ice-build up where the anti-icing operation, can turn into a de-icing operation to remove the ice. Other operational strategies (even for turbines without any specific IPT) can also include advanced loads control software for optimizing the balance between ice induced turbine loads and power production

2.4. Operational Strategy

2.4.1. De-icing

The de-icing operation is a reactive strategy that initiates ice removal once the likelihood of ice build-up has been identified by the ice detection system. The turbine will be in standstill or idling mode during the ice removal cycle and the ice removal time and performance will depend on the IPT, ice build-up, climatic conditions and operational setup and can range from under an hour to six hours or more. Once a de-icing cycle has been completed, the turbine will then attempt to restart. If the ice detection system identifies that ice has not been sufficiently removed, the system will restart the de-icing cycle. This process will be repeated until the ice has been removed and the turbine can be restarted, or a set number of cycles has been reached. The system is only operational when ice has been detected and the automatic or manual activation of the de-icing system has been made.

2.4.2. Anti-icing

The anti-icing operation is a preventative strategy which is triggered with the objective to prevent or limit ice build-up on the blades. In a similar way to the de-icing operation, the anti-icing operation is triggered by ice detection or some other method when icing is assumed to accrete on the blades. The system will remain active as long as the climatic conditions are in line with pre-set ice detection criteria.

3. Warranty options

It is recommended that when developing wind energy projects in icing climates an IPS option should be procured within the turbine contract and this should also include an IPS warranty[‡].

It is natural that the IPS, being a part of the wind turbine, should carry the same warranty protection as the turbine (e.g. related to product and availability).

An IPS warranty could be covered either as part of a turbine availability warranty or have a separate IPS warranty:

- **Availability warranty –** This type of warranty is a commercial standard and typically warrants that the IPS will be technically available to be turned on in the case an icing event is detected by the WTG. The warranty can be solely linked to IPS components, or included in the more general availability warranty of the entire turbine. Such a warranty does not address the risk due to poorly performing systems that many investors are looking for, but only that the system is ready to work. The term of such warranty is typically the same as the service management agreement, or longer and generally in line with the availability criteria defined in an accompanying Full Services Agreement.
- **Performance Warranty.** Within the envelope of an IPS Performance warranty, there are two main directions that have been identified. The first is a **Turbine Performance warranty with IPS (A),** which takes into account the performance of the complete turbine during icing events. This type of warranty takes into account the capability of the IPS to get the turbine back into operation, but could also take into account its ability to keep the turbine operating above a certain threshold defined contractually, as close to its normal operating limit as possible. Typically, the performance is warranted within some predefined operational range, for example within a temperature range and/or wind speeds limits and will therefore also be dependent on site conditions. The second is the **IPS Performance warranty (B),** which focuses purely on the function of the IPS system and would take into account the performance of the IPS system of removing or ice from the blades, but does not consider the full turbine operation.

The focus of these guidelines is on the Performance warranty; however this does not exclude the possibility of warranting the turbine in Cold Climate site in some other way.

3.1. Turbine Performance warranty with IPS

Turbine Performance Warranty for a wind turbine equipped with IPS takes into account the performance of the whole WTG during icing events. The advantage of such a warranty is that

[‡] A **warranty** is not explicitly defined in this document as it has different legal interpretations depending on country and wind farm case nor is there a widely accepted definition available within the wind industry. However, in the context of this guideline, a warranty in the case of wind turbines in icing climates could be roughly described as a legally binding assurance, promise or guarantee that a wind turbine fulfils predefined specifications, functionalities or performance.

it considers the WTG performance and not only the IPS system, minimizing the risk of unexpected ice losses during the icing events. There is also potential for optimization increases based on site conditions and turbine operation. The disadvantages are that there are more factors to consider when developing the test method for such a warranty. In all tests, the uncertainty of the test method needs to be assessed prior to starting the tests in order to understand the reliability of the test results.

3.2. IPS Performance Warranty

Ice Protection System Performance Warranty is solely focused on the performance of the IPS itself and not on the turbine as a whole. It is to be considered simpler as it take fewer factors into consideration and would focus on measuring, for example, time to de-ice or the time it take the IPS to remove ice from the heated parts of the blade or validation of the IPS design envelope criteria and specifications. The requirements/criteria and method of evaluation set out in such a warranty would purely be related to the physical performance of the IPS to mitigate or remove ice.

3.3. Warranty testing

A warranty that only sets out criteria without a test method is inadequate as there can be no follow up and therefore the value of such warranty is most probably insignificant. The test method needs to be

(i) practicable for the turbine, IPS system and site in question
(ii) cost effective
(iii) based on criteria and parameters that are measurable and as unambiguous as possible, and with clear data sources

The test method will determine how the criteria for pass or fail are formulated.
It should also be considered how many turbines would need to be tested within the frame of the warranty. In most cases, a selection of turbines representative for the whole wind farm should suffice.

The consequences of the test results should also be clearly outlined and agreed to ensure that should the test fail, there is an opportunity for corrective action and re-test, which would be followed by compensation for lack of performance in case of failure.

3.4. Documentation

In principle, a basic warranty document should include the following:

- Clear methodology to baseline the existing or expected icing losses for turbines not equipped with IPS (including uncertainty for icing loss estimate) on a site
- Parameters defining the operational start and end for the IPS
- Operational envelope (including weather and/or icing climate) of the IPS
- Clear definition of the performance parameters that will be warranted
- Methodology for measuring the parameters defined above, including specific additional sensors and modifications to the normal operational algorithm above

- Consequences based on the results of the tests, usually in the form of Liquidated Damages (LDs)

4. Test Methods

There are currently a number of different possible test options identified, both for testing the IPS system as part of the turbine performance (Turbine Performance Warranty with IPS[A]) and for testing the IPS system only (IPS Performance Warranty [B]). These are presented below. For testing the Turbine Performance Warranty with IPS (A) the “power performance” test method, the “side-by-side” test method and the “turbine self-comparison” method could be used. For testing IPS System Performance warranty (B), only one method has been identified and that is the “IPS Ice Removal or Surface Temperature Test” method.

The method chosen will determine the criteria that needs to be set in the warranty and choosing a test method will depend on a number of different factors. The type of site will matter, for example, a complex terrain site may make a side-by-side comparison difficult, as suitable turbines for comparison will not be available. If the site’s wind direction varies significantly between winter and summer, then the Turbine self-comparison may not be the ideal test method, as this will then have a bias due to wind direction seasonality. The OEM will probably also have a preferred methodology or methodologies that they have used and can recommend for the site. In the end, the aim is to choose the most cost effective test method, which provides the lowest uncertainty for the site conditions.

4.1. Turbine Performance Test Methods with IPS

4.1.1. Power Performance Test

This methodology is based on the same IEC 61400-12 methodology as used in power performance. The main advantage of this methodology is that it’s an established method for power curve testing in wind industry. The disadvantages are that it is costly, and should a site calibration be required, this takes time and should be planned well in advance.

This test could potentially also be carried out using remote sensing technology having a mix of masts and remote sensing device.

4.1.2. Side-by-Side Comparison Test

This methodology is based on the comparison of two turbines positioned in similar locations, with similar wind and icing climate, where one WTG is run with an active IPS system and the other has a deactivated IPS system. Simplified, the production output is compared between the turbines. The main advantages of such a test is providing a simple estimate of the performance of the IPS given that the majority of the factors could be considered equal for both turbines. The disadvantage is the lack of production from the WTG with the deactivated IPS system through the duration of the test. It may also be difficult on a complex site to find two suitable positions for side-by-side comparison.

4.1.3. Turbine Self-Comparison Test

This methodology is based on the comparison of the summer and winter power curves of the selected test turbines. Both power curves are based on the curves plotted on the turbines own SCADA. When a set of defined icing conditions are met, the wind and power output data in the SCADA are used to plot a winter power curve and the rest of the time the data is used to plot a summer power curve. The ratio of the two is compared and the result is warranted to be above a defined guaranteed limit. The advantages of such a test is providing a simple estimate of the performance of the ice removal system as a majority of the factors should be the same or can be corrected. The disadvantage is that seasonal variations, especially concerning wind direction and roughness, that may affect the performance in the test year.

4.2. IPS Performance Test Methods

4.2.1. IPS Ice Removal or Surface Temperature Test

This methodology is based testing the IPS as a sub-component of the wind turbine and is solely focused on the performance of the IPS itself and not on the turbine as a whole. Method of testing could for example include the use of temperature sensors on the blade, cameras or ice detection systems. The main advantage of this type of warranty is the simplicity of the approach. The main disadvantage is that it only considers the performance of the IPS and not its impact on WTG performance. For example, an IPS that is not mitigating icing effects on a sufficient blade area might have a minimal impact on the energy recovery during and after an icing event. Although the system would be triggered automatically and functioning according to the design envelope, none or limited energy gain could be achieved.

An example for IPS component level performance test (illustrated in Figure 1, B) could be focusing on IPS design envelope validation so that within certain wind speed and temperature combinations, the blade leading edge surface temperature would reach +5°C within 2 hours at standstill.

5. Risks

In general, it is important to consider the risks when developing a cold climate site. The developer has the primary control over the site and any possible pre construction measurements or modelling carried out, and should therefore be responsible for the “weather risk” site baseline icing data. Once these are set and agreed, the developer should seek to cooperate with the OEMs to ensure that the most suitable turbine including IPS, is chosen for the site. Thus the OEM should be responsible for the technology solution and carry the “technology risk”. The risk is therefore justly shared between parties, and overall the aim should distribute the commercial risk in a just and fair way between OEM and developer/investor.

When it comes to track record, there are a number of OEMs with IPS systems in the market that have more than a couple of years of track record and depending on the site this could be a consideration to minimize risk. A good warranty should also weigh heavily in any decision.

The cold climate challenge is a challenge for the all parties developing, supplying, or operating turbines for cold climate sites and there is still a lot of unknown factors and there is a considerable advantage for the industry in working together to increase knowledge.

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