Wind energy icing research and activities in Sweden

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Abstract — A summary is provided of the international conference Winterwind 2017 as well as an overview of Swedish market conditions and research programs dealing with wind energy in cold climates.

Keywords— wind energy; cold climates; icing; noise; low temperature; ice throw; curtailment; de-icing; anti-icing; market study; research.

I. INTRODUCTION

Cold climate sites are herein defined as locations exposed to significant icing on wind turbines or sites where the air temperature falls significantly below the operating range of standard wind turbines.

The goal of any wind farm owner is to keep the wind turbines (WT) operating when there’s wind, i.e. maintain a high availability. Iced up WT blades poses a significant challenge to WT manufacturers as well as to wind farm developers and owners in cold climate regions around the world. The main reasons for the concerns are: personal safety, loss of production, increased noise and an expected reduction of the technical life length of components.

Electricity produced by Swedish wind farms is sold either through long-term contracts at fixed prices or on the Nordic spot market to the marginal price from the most expensive, currently needed, production unit. Not producing due to iced up wind turbine blades when production has been forecasted, based on wind only, isn’t a major problem to the system if the installed wind energy production capacity is small (low penetration).

However, a large increase in wind energy capacity in N. Sweden requires commercially available de- and anti-icing systems. De-icing systems were, likely due to a lack of market studies, only available from one single manufacturer in 2008. Although this situation has changed dramatically since de-icing systems are now being offered by multiple wind turbine manufacturers, there’s a lack of performance warranties, a need for classification of sites and equipment as well as an ongoing effort to include cold climate issues in the IEC standards under review.

Most issues related to icing would be of little concern if anti-/de-icing systems were capable of handling all local icing conditions. IEA RD&D Wind’s Task 19 has recently published two reports on the subject, [1] and [2].

II. WINTERWIND

A. Background

BOREAS I-VII was a series of wind energy conferences, dealing with the technical aspects of wind energy in cold climates, arranged in N. Finland by the Finnish Meteorological Institute (FMI) between 1992 and 2005. Over the years, the number of participants at the BOREAS conferences increased from approximately 30 to 60.

By 2005 the global wind energy industry started to experience a growing backlog of orders that lasted until the financial crises in August 2008. The Swedish green certificate system, which had been in effect since May 2003, enabled profitable investments in wind energy while Finland didn’t yet have a remuneration system to promote wind energy. Hence, cold climate wind energy activities moved from Finland to Sweden. However, technical adaptions of wind turbines to cold climate requirements were largely unavailable at the time.

Starting in 2005 and due to the industry backlog, a large number of MW-size wind turbines lacking de-icing systems were installed at ice infested sites in N. Sweden. From 2003 until 2008 and at a cost of M€ 35 [1 € = 10 SEK], the Swedish Energy Agency had been funding large scale wind energy pilot projects with a focus on offshore. In 2007, one of the recipients of such funding withdrew, announcing that offshore wind farms were currently unprofitable. When wind pilot projects carried out between 2008 and 2012 were funded by another M€ 35 from the Swedish Energy Agency, the focus was consequently shifted from offshore to onshore and cold climate wind farms.

B. Winterwind 2008-2016

A private initiative, Vintervind 2008, was a second special topic conference in Sweden, that in March 2008 attracted some 150 Swedish speaking participants. By then, a European cooperation, COST 727 - Measuring and forecasting atmospheric icing on structures, [3], had been ongoing since 2004. As the interest in icing of wind turbines was growing, the Swedish Wind Power Association decided to co-arrange Winterwind 2008 with COST 727. Since then the number of participants at the annual, international Winterwind conference has increased from 150 to roughly 500. Proceedings from the previous Winterwind conferences are available here [4]. A summary of Winterwind 2016 is available in [5]. A list of priorities based on IEA Wind Task 19 workshops and panels at international conferences and from Winterwind conferences 2015-2016 was also presented in [5].

1 The first cold climate wind energy conference in Sweden was arranged in Östersund 1999 by Mr. Tore Wizelius.
Winterwind isn’t the only icing conference having been arranged in Sweden lately. Winterwind has benefitted from cooperating with the experts involved in IWAIS.

C. IWAIS – International Workshop on Atmospheric Icing of Structures

The primary mission of IWAIS, the International Workshop on Atmospheric Icing of Structures, is to bring together leading researchers and industry representatives to facilitate exchange and interaction in view of finding practical and economical solutions to the disruptive effects of atmospheric icing. The first IWAIS conference was held in 1982 in Hanover, USA. The diversity of the locations of the past IWAIS workshops illustrates the extent of impacts of atmospheric icing.

The sixteenth conference, IWAIS 2015, was held in Uppsala, for the first time in Sweden. Researchers, students and industry delegates from many countries around the world, mainly from North America, Europe and Asia, attended. The workshop covered a wide range of topics, including icing measurement and modeling, icing of power network equipment such as conductors and insulators, wind turbines, techniques to reduce ice adhesion and accretion, health and safety issues, icing standards, and other topics related to atmospheric icing of structures. A list, information and proceedings of some previous conferences, can be found here, [6]. The seventeenth IWAIS conference, IWAIS 2017, will be arranged in Chongqing, China in September 2017, [7].

III. THE CURRENT MARKET SITUATION

A. Cost of energy from renewables in 2017

1) International outlook

In 2017, the cost for offshore wind in Europe and solar in countries with 2000 full load hours or more started to come down to levels where they could be competitive with conventional energy production. For offshore wind, the cost reduction for bids have been quite dramatic, Figure 1.

Soon, it is therefore likely that the price for onshore wind will be limited upwards by alternative investments in solar and offshore wind farms. Cold climate sites are often located in sparsely populated regions where large wind farms can be built. However, if onshore wind is going to be competitive, it is, according to IEA RD&D Wind’s Task 19 – Wind Energy in Cold Climates, important for the industry to pay attention to the priorities in Table 1.

B. The situation for wind energy in Sweden 2017

By early 2017, the turn-key investment price for onshore wind energy had come down from approximately €700/MWh in 2010 to €350/MWh. 2015, a year with record high wind energy production (16.6 TWh) and record low spot market prices, was in 2016 followed by a year that offered significantly less wind energy production at slightly higher prices.

C. Green certificates

During 2016, a large surplus of green certificates forced the price of certificates to dive towards a record low in February 2017. By now, the economic crisis for early investors in wind energy was apparent even for members of parliament. But instead of relieving troubled investors by, for example, indexing the green certificates with respect to the lowest annual investment cost at the time of the investment, an agreement was made to increase the quota to slowly reduce the surplus of certificates.

It was once again proven that the risk in a politically controlled green certificate system is the investor’s burden. This is contrary to the conditions for investors in a feed-in tariff system where consumers are paying, admittedly a higher price, for defending national markets for wind turbine manufacturers.

D. Large write offs required

Dolff has listed the assets of owners of Swedish wind farms as of by the end of 2015, Figure 2, [8]. Here, a line indicating the present cost for turn-key installations has been added to Dolff’s original plot. In general, assets above this line, expressed in SEK/annual kWh (Kr/årsKWh) ought to be written off, particularly so considering the age of the assets.

### Table 1: Priorities presented at Winterwind 2016.

<table>
<thead>
<tr>
<th>#</th>
<th>Priorities</th>
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<tbody>
<tr>
<td>1</td>
<td>Standards, certifications and recommended practices</td>
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<tr>
<td>2</td>
<td>Assessment of production losses prior to deployment</td>
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<tr>
<td>3</td>
<td>De/anti icing, equipment and procedures</td>
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<td>4</td>
<td>Testing: test sites, field testing &amp; lab testing including subcomponents and ice detection</td>
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<td>5</td>
<td>Health, safety and environment (HSE) including ice throw</td>
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<td>6</td>
<td>Financing including risk, uncertainty and ice assessment</td>
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<tr>
<td>7</td>
<td>Construction, installation, operation, maintenance and repairs</td>
</tr>
<tr>
<td>8</td>
<td>Market potential and limitations</td>
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<tr>
<td>9</td>
<td>Grid issues</td>
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<tr>
<td>10</td>
<td>Small wind turbines</td>
</tr>
</tbody>
</table>

### Figure 1: Cost development of producers’ bids for electricity from European offshore wind farms.

![Auctions - Offshore Windpower €/MWh](chart.png)

Data gathered by Per Ribbing

<table>
<thead>
<tr>
<th>Wind Farm</th>
<th>Capacity (MW)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horns Rev 3</td>
<td>100</td>
<td>2017</td>
</tr>
<tr>
<td>Industry I &amp; II</td>
<td>208</td>
<td>2018</td>
</tr>
<tr>
<td>E Cortrack 2 &amp; 3</td>
<td>146-158</td>
<td>2014-17</td>
</tr>
<tr>
<td>Vattenfall Nord &amp; Systad</td>
<td>200</td>
<td>2014-16</td>
</tr>
<tr>
<td>Vattenfall Silleram</td>
<td>100</td>
<td>2015-16</td>
</tr>
<tr>
<td>Krigges Torn 1</td>
<td>100</td>
<td>2015-16</td>
</tr>
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![Figure 1](chart.png)
The current need for large write-offs reflects not only a steep decrease in the cost for new wind farms but also, which is hard on early investors, a low price for electricity and, most importantly, a drastic drop in the price of green certificates.

As a comparison, the EU Commission has issued “Guidelines on State aid for environmental protection and energy 2014-2020”, [9]:

“3.3.2.4. Aid granted by way of certificates

Member States may grant support for renewable energy sources by using market mechanisms such as green certificates. These market mechanisms (69) allow all renewable energy producers to benefit indirectly from guaranteed demand for their energy, at a price above the market price for conventional power. The price of these green certificates is not fixed in advance, but depends on market supply and demand.

The Commission will consider the aid referred to in paragraph (135) to be compatible with the internal market if Member States can provide sufficient evidence that such support (i) is essential to ensure the viability of the renewable energy sources concerned; (ii) "...

In Sweden, an increasing number of bankruptcies has become the inevitable consequence of a redistribution system, i.e. green certificates, that does not provide sufficient security for early investors.

Only two wind turbines were ordered in Sweden during Q1 2017, [28]. History has proven wind energy to be quickly deployable and competitive with conventional energy sources.

IV. WINTERWIND 2017

More than 50 titles were presented at the latest Winterwind conference. [13]. The presentations were, in broad terms, divided evenly between a) forecasting, cloud physics and aerodynamics, b) de-/anti-icing including ice detection, control and standards and c) pre-construction site assessments, measurements, models and standards. Only a crude overview is made here as it is impossible to present all titles in this paper.

Summaries of Winterwind 2017 was provided at the end of the conference by Holttinen, [19], and Thompson, [20].

Holttinen ended with the following statements: “More efforts, larger projects/collaboration – getting cold climate/icing in the research agenda.

Towards standardisation

- Continue with offering and track record for anti/de-icing – towards guarantees?
- Continue with health and safety /ice throw statistics to confirm safety distances”

Thompson focused on the basics: “Icing data collection and validation. Many problems with instruments in severe conditions.

- Scientific projects help collect specialized data. Examples: WISLINE, FRoNTLINES, SNOWIE (Idaho, USA; now) and ICICLE (Great Lakes USA region; FAA funded; 2018-2019)
- Validation of NWP and icing models requires specialized observations
- Liquid water content (LWC) and droplet sizes
- Ice accretion (modeling)
- How to apply to turbine blades
- How to apply to POWER production

Personal plea: Providing more data helps developers improve the models

A. Wind turbine manufacturers’ session

At Winterwind, it is customary not to allow manufacturers to present their products outside of the exhibition hall. One notable exception from the rule of not allowing commercial presentations is the wind turbine manufacturers’ session, which in 2017 gave room for in-depth technical presentations of de-icing systems and their functionalities.

One particularly interesting presentation was made by DongFang in which a dual de-/anti-icing system, based on both hot air and a leading edge foil, was described in surprising detail, [14]. It should be noted that most wind turbine manufacturers will provide less information in the proceedings compared to what is presented at the conference.

B. IEA RD&D Wind Task 19 – Wind Energy in Cold Climates

IEA RD&D Wind’s Task 19 was during Winterwind 2017 given the opportunity to arrange workshops on ice throw as well as on ice protection systems, the latter for customers only. The coordinator of IEA Wind Task 19, Ville Lehtomäki from VTT, presented “Long-term visions for standards & R&I” (Research & Innovation), [10]. The current priorities are to provide recommendations concerning the risk of ice throw, develop standards for pre-construction site assessments and updating the reports, [1] and [2].

C. Market studies

According to Lehtomäki, a market study carried out in 2012 played a significant role in improving the acceptance of wind energy in cold climates as a significant market, comparable with offshore in the short and medium time frames, [11]. The results from a more recent market study, [12], is shown in Figure 3.

Figure 2: Book value, investment cost per annual energy produced (blue), of combinations of Swedish wind farms listed by owners. The present turn-key investment cost for new onshore wind farms in Sweden is indicated by the line.

The current priorities are to provide recommendations concerning the risk of ice throw, develop standards for pre-construction site assessments and updating the reports, [1] and [2].
Market studies might be of little interest to researchers in the technical fields but they are indeed essential to motivate wind turbine manufacturers to develop adapted solutions and they are, in most cases, required to motivate funding of research. One exception to the latter was when the Swedish Energy Agency in 2008, without the support of a cold climate oriented market study, decided to focus significant resources to wind pilot projects in which de- and anti-icing solutions were to be developed. It was obvious that icing would become a significant obstacle for large scale deployment in N. Sweden unless icing could be mastered.

D. Icing

Experience from IEA RD&D Wind’s Task 19, see Table 1 in [1], shows that icing can reduce the annual energy production from a wind farm by more than 20%. As a coincidence, in February 2017 when Winterwind 2017 was about to start, many wind turbines in N. Sweden were iced up. A small number of wind turbines equipped with de-icing systems fought the ice more or less unsuccessfully, see Figure 4 for an example.

Icing will also cause increased noise that may prevent a wind farm from legally operating as environmental conditions required by the authorities are not met.

E. Cloud physics – modeling and measurements

The real cause of atmospheric icing is the presence of liquid water droplets at sub-zero temperatures in the air. Humidity is by definition a gas and it cannot as such cause icing. As there are currently no commercial sensors available to measure liquid water content and droplet size distribution, humidity, or the presence of clouds, is often used as a crude substitute.

Thompson from NCAR presented the latest development of cloud microphysics schemes in WRF and comparisons with measurements and competing models, [15]. The models have become quite capable of forecasting the risk of icing and Thompson was asking for more measurements that can be used to develop the models further.

The forthcoming ICEMET-sensor, presented as capable of measuring liquid water content and droplet size distribution was introduced by Arstila from The University of Oulu in Finland, [16]. If the ICEMET sensor can deliver accurate measurements it would create an interesting opportunity to verify the models.

F. The risk of ice throw

At Winterwind 2017, a workshop arranged by IEA RD&D Wind’s Task 19 was devoted to issue of ice throw with the intention to develop recommendations during the next few years. Pieces of ice thrown from wind turbines have been found to damage cars not parked on the safe(r) upwind side of the turbine. For an example, see Figure 5.

While ice throw poses an obvious risk for staff and visitors, travelling to and from the wind farm can be significantly more dangerous.

A visually attractive way of presenting the risk of ice throw was shown by Bredesen, [17] during a comprehensive introduction to the workshop on ice throw. The emphasis was on the importance of the wind power community to be proactive themselves and take safety measures for passers-by and service personnel. Establishing good practices and communication routines is key to avoid accidents. Burgeois presented the results from measurements carried out and work on forthcoming recommendations concerning ice throw, [18].

G. Standardisation in wind energy – not a priority for Swedish authorities

Standards are on the top of the list of priorities in Table 1 as their sound development is important for a future large-scale deployment of wind energy in cold climates. As a comparison, standardization work in, for example, telecommunication, construction and pharmaceuticals is normally carried out by industry partners interested in defending their patents.

In Sweden, however, there’s no wind turbine manufacturer and the Swedish Energy Administration is, by regulation from the government, unfortunately prevented from financing...
standardization work. This situation seems awkward considering plans to produce up to 60 TWh annually from wind. One example of ongoing standardization work where it’s obvious that Sweden ought to participate with insights from a cold climate perspective is IEC 61400-15, “Assessment of site specific wind conditions for wind power stations”.

V. SWEDISH WIND ENERGY RESEARCH PROGRAMS, PRIORITIES AND PROJECTS

A. Background

The Swedish Energy Agency (EM) has co-financed government agency administered wind energy research through “Vindval”, [21], as well as industry collaboration through the “Vindforsk”, a more technically oriented wind energy research program, [22]. EM administered the M€ 70 million funding of wind pilot projects between 2003 and 2012 in which significant resource were dedicated to cold climate issues including icing. Two wind energy research clusters are being supported by EM, the Swedish Wind Power Technology Centre, [24], and StandUpForWind, [25]. Between 2013 and 2016 EM administered the M€ 3.2 cold climate wind energy research program.

B. The cold climate wind energy research program 2013-2016

The, strictly national, call for proposals contained a vision of cross-industry development and innovations. As in all Swedish research programs, maximizing the number of PhD students involved was a priority. International collaboration is encouraged but due to a government regulation, no project funding can be spent on foreign entities. The following projects were accepted [k€]:

| 1. | Vibrations and loads of wind turbines exposed to ice load | 750 |
| 2. | Ice detection for smart de-icing of wind turbines | 570 |
| 3. | Imaging method for determining the liquid water content and MVD of air | 450 |
| 4. | Modeling of ice accretion and production losses | 440 |
| 5. | Active de-icing of wind turbine blades with advanced coatings | 390 |
| 6. | Wind turbines in cold climates: Fluid Mechanics, ice and terrain effects | 310 |
| 7. | Sound Effects by icing of wind turbines – Long-term measurements of sound for verification | 91 |
| 8. | Repair and development of anti-icing system for wind turbine blades | 67 |
| 9. | ICETHROWER - mapping and risk analysis tools | 64 |
| 10. | Evaluation of ice detector for wind energy applications | 13 |

Total allocated 3 145

Table 2: Projects accepted in the 2013-2016 cold climate wind energy research program.

The final reports from these projects can be found through the search string in [26]. Some of the projects are strictly academic and must as such be viewed as an important part of a long-term industry supply chain. Other projects have a more direct influence on standards, environmental requirements, health and safety and the capability to detect and de-ice wind turbine blades.

In icing research, it has long been a goal to measure the liquid water content of air and the droplet size distribution. The project “Imaging method for determining the liquid water content and MVD of air” aimed for this capability and the intention is for prototypes to be tested during the 2017/2018 winter season. Please note that a similar instrument was presented in [16].

Several presentations at previous Winterwind conferences, based on measurements and modeling, indicate an increase in sound power level from an iced up wind turbine in the order of 10 dB(A) and 15 dB(A) from an iced up wind farm. If local restrictions permit for example maximum 40 dB(A) at nearby houses, icing can, due to increased noise, prevent wind turbines from being permitted to operate.

Modeling of ice accretion and production losses requires a standardized method for evaluation of actual production losses. Such a method has been developed by the IEA RD&D Wind’s Task 19 and is readily available, [27].

VI. CONCLUSIONS

Mastering wind energy in cold climates will be increasingly important for Sweden in the future. The technologies required are under constant development and there is a great potential for a) technical improvements and b) innovations as well as for c) testing in laboratories and test centers, d) the development of recommendations through IEA and e) standards through IEC. A large number of cold climate wind energy related activities in Sweden have served as a sound base for future deployment of large wind farms in cold climates.

ACKNOWLEDGMENTS

The Swedish Wind Power Association (Svensk Vindkraftförening) organizes Winterwind conferences. It has been my privilege to act as program coordinator for Winterwind on behalf of the organizer. Between 2008 and 2017, EM has also co-financed many of the Winterwind conferences. The experts in IEA RD&D Wind’s Task 19 provide valuable information and feed-back on wind energy in cold climates.

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