Lessons learned from "Large scale, cost-effective deployment of wind energy in icing climates"

Göran Ronsten
OX2 & WindREN
goranronsten@windren.se

***Abstract*: The two primary goals of this project have been to a) support the development and installation of 40 de-icing systems and b) for 4 competing meteorological entities to develop and improve methods to assess production losses caused by icing. Funding, some 7,25 MEuro (72,5 MSEK), was provided by Swedish Energy Agency between 2008 and 2015. The activities carried out include synoptic icing measurements, mapping of icing, daily production forecasts with a focus on losses caused by icing, seasonal reports, de-icing of wind turbine blades and the evaluation of performance and loads with respect to icing. In a European perspective, the support for development of wind energy technologies adapted to icing climates has improved since 2008. Initially to be blamed for the lack of interest was a Catch-22-like situation where a lack of mapping of icing had prevented market studies to be carried out. A milestone market study, [1] is available since early 2013.**

Keywords: wind energy, icing, measurements, mapping of icing, de-icing, production losses

LEGEND AND ABBREVIATIONS

CC	*Cold Climate, both LT and icing*
IEA	*International Energy Agency*
EM	*Swedish Energy Agency*
LT	*Low Temperature (not icing)*
LWC	*Liquid Water Content*
MVD	*Median Volume Diameter*
RD&D	*Research, Development & Demonstration*
Task 19	*IEA WG dealing with CC challenges*
WG	*Working Group*
WT	*Wind Turbine*
10 SEK	*1 Euro (exchange rate used in this paper)*

INTRODUCTION

A. *Wind energy in Sweden – present and future*

By the end of 2014, Sweden had a growing, installed wind power capacity of 5 425 MW, [2], that produced 11.5 TWh, equaling 8% of the electricity consumed in the country, [3]. A scenario with 100% renewable energy has been studied by Söder, [4], where 60 TWh of electricity come from wind and photo voltage.

How much is 60 TWh compared to electricity produced by nuclear power in Sweden? Until 1999, Sweden had 12 nuclear reactors in operation. One of two units in Barsebäck ceased production in 1999 and the other was shut down in 2005. The majority owners of the reactors in Oskarshamn (E.ON) and Ringhals (Vattenfall) recently (June 2015) announced their intentions to, with reference to current and forecasted low electricity prices, close down another four units before 2020. The average annual production from nuclear power in Sweden between 2005-2014 was 59.6 TWh. Statistics for 2001-2013 can be found in [5].

B. *Wind energy in icing climates*

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

I. MOTIVATION

A. *Not producing when expected is expensive*

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 if the installed wind energy production capacity is small (low penetration). However, a large increase in wind 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 when this project was initiated in 2008.

B. *Icing reduces the reimbursement for electricity in long-term contracts*

Before a standard wind farm has been built, the developer focuses on four issues; wind, wind, wind (power is proportional to the third power of the wind speed) and infrastructure.

Once the wind farm has been built and the normalized annual energy production is known, the income will be dependent on wind speed, electricity price and, in the case of Sweden and Norway, the price of the green certificates. On a liberalized electricity market the most stable parameter of wind, electricity price and reimbursement for green certificates is… the wind resource and thereby the energy production.

Icing will in the near future, unless a large-scale deployment of de-icing systems is carried out, reduce the payment for electricity in long-term contracts, as the cost for balance of power will be indirectly charged through a lower reimbursement. Luckily, icing doesn't influence the price of the green certificates, which can be saved over the years and sold anytime.

II. Why didn't we start mapping of icing earlier?

Before the start of COST Action 727 (Atmospheric icing of structures) in April 2004 Sweden had carried out a number of cold climate wind energy evaluation projects, participated in IEA RD&D Task 19 and been involved in the EU-project NEW ICETOOLS. No new cold climate projects could be foreseen by the Swedish Energy Agency (EM) as the plans for large scale offshore wind energy were ambitious.

The wind turbine manufacturers were only seemingly interested in adapting the turbines to cold climates until early 2005 when long backlogs at the wind turbine manufacturers made niche segments like wind energy in icing climates uninteresting for all but Enercon. Only one cold climate wind pilot project was ordered by EM as offshore was at focus until March 2007. At this time, the utility E.ON announced that the compensation for offshore wind farms in Sweden was insufficient and surprisingly handed 70 MSEK (7 MEuro) in wind pilot project support back to the EM.

One challenge encountered in European wind energy research development, from an icing point of view, has been the one-sided focus on offshore. A Catch-22 situation appears when European funding for the development of de-/anti-icing systems requires market studies, which require mapping of icing, which requires the development and verification of icing forecasts. All of a sudden we're, no surprise, once again back at the core of IWAIS, i.e. measuring and modeling atmospheric icing on structures.

III. National funding was made available based on intuition rather than on a market study

In March 2007, the message from E.ON to the EM was clear, "offshore is too expensive". EM ordered another 4 cold climate related wind pilot projects with a total budget exceeding 200 MSEK (20 MEuro). The wind turbine manufacturers' backlogs shrank when the financial crises hit also the wind turbine manufacturers in August 2008. Additionally, an increased international competition has since made many more wind turbine manufacturers that are active in areas prone to significant icing interested in finding cost-effective de-/anti-icing solutions.

Living in a cold climate makes people, at least in the wintertime, aware of the challenges associated with iced up objects. During the winters, the hit, near-hit or even the risk of falling ice from tall buildings, are in the news multiple times per week. It is therefore no wonder if the EM in 2009 decided to promote the development of wind energy in icing conditions, in four separate projects through its wind pilot project program, without having access to either a market study or a national icing map. EM's best option was to encourage the WT manufacturers to provide WT equipped with de-icing systems.

IV. The wind pilot project

OX2 Wind (7.25 MEuro) – The main objective for OX2's wind pilot project has been to promote the development and installation of de-icing systems.

For all reports provided to EM, OX2 has requested confidentiality with reference to commercial interests. By Sep 15, 2015, some of the reports produced within this project will be made publicly available. Results from the project has been continuously presented at conferences in general and at Winterwind, [6] and [7], in particular.

A. De-icing systems

In this project alone, more than 40 de-icing systems were to be installed. As commercial de-icing systems were largely unavailable, 3rd party development was initially encouraged with an aim to catch the interest of the WT manufacturers.

Starting in the fall of 2008, **Kelly Aerospace Thermal Systems (US)** installed three de-icing systems on Vestas V90-2MW. Three de-icing systems from **EcoTEMP (CA)** were deployed on Vestas V90-2MW and one system was installed on a Siemens SWT 2.3 with a rotor diameter of 101 m. Later, **Siemens** developed a first and a second generation de-icing systems for OX2. The former was installed on a wind turbine on Brahehus. The latter system was installed in 9 turbines on Korpfjäll in 2011. In 2014, **Vestas** erected 30 of its V90-2MW wind turbines, all equipped with a newly developed de-icing system. Described above are 47 de-icing systems. Additionally, funding from the project, for the development of de-icing systems, has been made available to a wind turbine manufacturer for testing the performance of a de-icing system. De-icing systems from all four providers mentioned above have been presented at the Winterwind conferences, [6] and [7].

Figure 1 shows a significant amount; several hundred kg, of ice collected on a non-de-iced wind turbine blade.

Figure 1: Ice collected on a wind turbine blade, which was taken down for the removal of a de-icing system.

B. Synoptic icing measurements

Measurements have been carried out in four tall masts from N to S and at neighboring wind farms or planned sites.

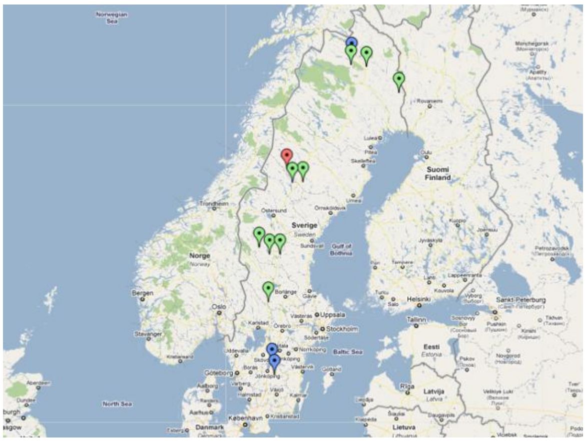

Figure 2: Distribution of ice measurement stations in OX2's wind pilot project.

At most of the measurement stations there's been a camera installed to enable verification of the icing measurements. The cameras have provided valuable empirical data not only for ice build-up, but also for ice ablation (melting, sublimation and breaking off). Inherently difficult to calculate, the cameras have captured when brittle ice has braked into pieces at low temperatures.

Figure 3: A view of the instruments at the Sjisjka icing measurement station. This particular mast is 60 m tall.

Monthly evaluations of icing measurements and production have been carried out by **a)** Weathertech (SE), **b)** Kjeller Vindteknikk (NO, **c)** Leading Edge Atmospherics (US)/Finnish Meteorological Institute FMI (FI) and **d)** The Swedish Meteorological and Hydrological Institute SMHI (SE). These executors have also provided daily forecasts as well as seasonal reports. Results have been presented at five Winterwind conferences, i.e. Winterwind 2011 to 2015, [6] and [7].

V. Results and Discussion

A. De-icing systems

Since 2008, the Swedish Energy Agency has been using significant resources to actively promote a rapid development of wind energy in cold climates. A major hurdle for the developers has been overcome as WT manufacturers have developed and made de-icing systems available. It still remains, however, to include icing in the guaranteed availability.

Knowledge regarding the surprisingly large energy production losses caused by icing comprises sensitive information for the WT owners and is therefore generally kept confidential. The initial, major drawback of this secrecy made developers in general unable to put sufficient pressure on the WT manufacturers to offer de-icing systems. Another drawback of the secrecy has been that authorities, for better and worse, have been largely unaware of the challenges associated with wind farming in icing conditions. Authorities might want to interfere if ice is causing an unacceptable increase of noise and risk of ice throw.

At Winterwind 2014, Madsen presented examples of the performance of Siemens de-icing systems, [8]. No results were presented by Siemens at Winterwind 2015, [9]. Siemens has announced large orders, several hundred units, for wind turbines equipped with de-icing systems.

The 30 Vestas de-icing systems funded by the project were deployed in late 2014 and no information regarding the performance of these de-icing systems is yet publicly available. The performance has, however, been evaluated by the meteorologists involved in the wind pilot project. The results will be made available, likely in confidential reports, to EM by Aug 15, 2015. Since 2012, a general description of Vestas de-icing system has been made annually at Winterwind, the latest by Nielsen at Winterwind 2015, [10]. Nielsen provided examples of the performance of the system and mentioned orders of 72 wind turbines equipped with de-icing systems.

B. Mapping of icing

If the anti-/de-icing systems would be capable of handling light, medium and severe icing conditions as required according to local site conditions, mapping of icing and an increased cost of balancing of power with respect to icing would be of little concern.

Evaluations of modeled and measured icing and power performance show a) icing periods to be captured relatively well in time, b) the magnitude of icing to be difficult to estimate correctly and c) the actual production losses due to iced up wind turbine blades to be surprisingly large, although d) generally smaller than the initially modeled losses. Results from the evaluation of performance of wind farms exposed to icing using data from OX2's wind pilot project were presented at Winterwind 2015 by

Weathertech, [11] and [12]: *"Much can be learned by careful analysis of SCADA data from existing wind farms"* and *"The variability coefficient for icing hours is an order of magnitude larger than for wind speed"*,

Kjeller Vindteknikk, [13]: *"General improvement of the power forecasts when the icing is included."* and

The Swedish Meteorological and Hydrological Institute SMHI, [14]: *"Production loss forecast a bit too pessimistic, needs tuning"*.

Leading Edge Atmospherics & the Finnish Meteorological Institute FMI presented [15] at

Winterwind 2014: *"Each of the 4 [analysis] systems "wins" some of the time"*.

At IWAIS 2015, there will be ten presentations from the wind pilot project, [16]-[25].

VI. Conclusions

Significant progress has since 2008 been made both with respect to the development and commercial availability of de-icing systems as well as the ability to map and forecast icing.

The wind turbine manufacturers were, mainly due to a large order backlog, initially hesitant to develop de-icing systems. A developer ordering third party de-icing systems was a drastic call for help. This project has, according to at least one manufacturer, played an important role in making the importance of de-icing capability catch the manufacturer's attention.

Mapping of icing, forecasting of icing and verification of production losses has been carried out by the four executors in an atmosphere of close cooperation, in spite of being competitors. This has been in line with OX2's goal to raise the standards to a level from which all stakeholders of wind energy in icing climates can benefit.

Acknowledgment

The author would like to thank all those involved in various cold climate related projects in Sweden for contributing, actively or passively, to the content of this paper. It's also worth mentioning that the Swedish Energy Agency luckily didn't need a market study to realize that icing of WT blades can be a showstopper.

References

[1] "World Market Update 2012", Navigant Research, March 26, 2013

[2] "New Record in Worldwide Wind Installations", World Wind Energy Association, February 5, 2015, http://www.wwindea.org/new-record-in-worldwide-wind-installations/ (2015-06-27)

[3] "Global Wind Report – Annual Market Update 2014", Global Wind Energy Council, March, 2015, p.70, http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf (2015-06-27)

[4] Söder L., "På väg mot en elförsörjning baserad på enbart förnybar el i Sverige - En studie om behov av reglerkraft och överföringskapacitet", Version 4.0 (in Swedish), 2014-06-22, http://kth.diva-portal.org/smash/get/diva2:727697/FULLTEXT01.pdf (2015-06-27)

[5] "Electricity supply and use 2001–2013", http://www.scb.se/en_/Finding-statistics/Statistics-by-subject-area/Energy/Energy-supply-and-use/Annual-energy-statistics-electricity-gas-and-district-heating/Aktuell-Pong/6321/24270/ (2015-06-27)

[6] Winterwind presentations, previous conferences, 2008-2014 http://winterwind.se/about-the-conference/previous-conferences/ (2015-06-27)

[7] Winterwind 2015, presentations, http://winterwind.se/about-the-conference/presentations/ (2015-06-27)

[8] Madsen F.D., "Siemens Wind Power Blade De-Icing - 25 years of experience with turbines in cold climate", presented at Winterwind 2014, Sundsvall, Feb, 2014, http://www.winterwind.se/sundsvall-2014/presentations-2014/?edmc=2860 (2015-06-27)

[9] Birkemose B., "Siemens Wind Power Blade De-icing", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_57_711_Birkemose_Siemens_Deicing.pdf (2015-06-27)

[10] Nielsen,B.D., "Vestas De-icing System", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_61_715_Nielsen_Vestas_Deicing.pdf (2015-06-27)

[11] Baltscheffsky M., Söderberg S., "Towards an increased understanding of icing conditions within a wind farm through visualisation of SCADA data in a topographic context", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_34_433_Baltscheffsky_Weathertech_Ice_intrafarm.pdf (2015-06-27)

[12] Söderberg S., Baltscheffsky M., "Analysis of spatial and temporal variability in icing conditions and production losses due to icing using a new long-term icing climate database", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_36_512_Soderberg_Weathertech_Icewind_Production_losses.pdf (2015-06-28)

[13] Byrkjedal Ø. Et al, "Validation of icing and wind power forecasts at cold climate sites", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_37_513_Byrkjedal_Kjeller_Icewind_Forecast_validation.pdf (2015-06-28)

[14] Olsson E., "High resolution forecast maps of production loss due to icing", presented at Winterwind 2015, Piteå, Feb, 2015, http://windren.se/WW2015/WW2015_42_531_Olsson_SMHI_Icing_forecast_maps.pdf (2015-06-28)

[15] Bernstein B. C., "Validation of Icing and Power Predictions for the O2 Wind Pilot Program", presented at Winterwind 2014, Sundsvall, Feb, 2014, http://windren.se/WW2014/02_03_053_Validation%20of%20icing%20and%20power%20predictions%20for%20the%20O2%20wind%20pilot%20program.pdf (2015-06-28)

[16] Ronsten G., "Lessons learned from "Large scale, cost-effective deployment of wind energy in icing climates"", (This paper), IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[17] Bernstein B. C. et al, " Innovations in F-LOWICE real-time forecasts of wind power and icing effects, IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[18] Byrkjedal Ø., "Development of operational forecasting for icing and wind power at cold climate sites", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[19] "Vestas de-icing system", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[20] Levati D., "Siemens de-icing system", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[21] Norén B., "What we learned – Adaption and development of measurement technique and camera supervision for icing conditions", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[22] Söderberg S., "Experiences from studies of icing and production losses due to icing in OX2's Vindpilot project", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[23] Olsson E., "Modelling icing conditions for a selection of Swedish wind farms during winter 2014–2015", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[24] Westerlund R., "Controller for Surface heating", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28)

[25] Kolar S., " Comparison of three different anti and de-icing techniques based on SCADA-data", IWAIS 2015, Uppsala, July, 2015, http://iwais.org/. (To be published, 2015-06-28