Energy production losses due to iced blades and instruments at Nygårdsfjell, Sveg and Aapua

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***Abstract*—Estimates of energy production losses caused by iced blades and meteorological instruments were performed for three wind power sites in Norway and Sweden. The turbine types are Vestas V90-2MW, Vestas V82-1.5MW and Siemens SWT-2.3-93. Analysis was performed with the same data processing for all of the three sites. One main conclusion is that an anemometer which can operate during icing conditions is absolutely necessary for analysis of power losses. According to the calculations performed, the energy losses were least severe at the Nygårdsfjell site and most severe at the Aapua site.**

I. Introduction

One, in some cases insurmountable, challenge for the developers and owners of wind farms in icing climates is the current lack of de- or anti-icing equipment available on the market. This state of things is likely, apart from a previously booming market, caused by an historic lack of icing climate related market studies available to the wind turbine manufacturers. Important basis for such market studies are not only frequency and severity of local icing conditions but also the effect on power performance and other wind turbine related properties caused by iced-up blades and meteorological instruments.

Iced-up blades will not only reduce the energy output, but will increase noise and the risk of ice throw and may also cause vibrations in the drive train nacelle and tower, outside the permitted envelope specified in the certification process of the affected wind turbine. The latter may be particularly true if operation with iced-up blades is permitted during extended periods of time. In this paper, both 10-minute and 1-hour data is used to estimate the losses due to iced-up wind turbine blades and sensors for three wind power sites in Norway and Sweden.

II. Site Descriptions and Analysis

The data analysis generally followed the form of first removing periods when the turbine was stopped, then generating expected power production curves based on the median of all operating data (including periods when the turbines were affected by ice) in 0.5 m/s bins. The median is used so as to give less weight to outliers. Thereafter a threshold of 85% of the expected power production was used to determine if the turbine was producing too little power for each time period, Ronsten [1]. During periods when the actual power production was less than the threshold, the difference between the expected power (from the power curve) and the actual power was counted as a power loss.

This method is expected to underestimate the actual power losses because of two reasons. The first being that using all data to generate the power curve may result in the curve being lower than it really should. The second is that power losses that are less than 15% are within the threshold and are not counted as power losses.

The method can also underestimate power losses in certain conditions, if the anemometer is more affected by the icing than the power production, then the anemometer will record an incorrect low wind speed, thereby making it appear that the turbine is producing better than expected, even though the turbine may be producing less than it should due to the icing.

A. *Nygårdsfjell windpark*

Nygårdsfjell windpark is an alpine arctic wind park which consists of three 2.3 MW pitch controlled Siemens wind turbines, in northern Norway. The wind park is in mountainous terrain above tree line and power losses due to icing in earlier years were analyzed by Homola, et al. [2] and found to be less than previously reported for a mountainous arctic site. Instrumentation consisted of standard wind turbine instrumentation, an optics based icing sensor on the nacelle, and two web cameras monitoring the blades and the other instruments. Data analysis was performed for the two one year periods, May 1, 2007 – May 1, 2008 and May 1, 2008 – May 1, 2009.

During data analysis some slight modifications to the general procedure were made. Firstly, energy losses were only calculated for periods when the wind speed was greater than 5 m/s to avoid the nonlinearities associated with starting and stopping.

Secondly, analysis of the data for the winter periods showed that the anemometers had many periods when they were clearly reporting a wind speed that was too low. So, only data from the summer period of May 1 – Oct. 1 with ambient temperature above +2 C was used to generate the expected power curves. And, due to the problems with the anemometers, an area of “overproduction” was identified. This corresponds to periods when the anemometers are falsely giving too low of a value and thereby appear to be unrealistically good production. The threshold for this was set to 115% of expected power plus 50 kW for wind speeds above 3 m/s and above 0 kW below 3 m/s. The percentage of time that the turbine was operating in this overproduction region is shown in table 1.

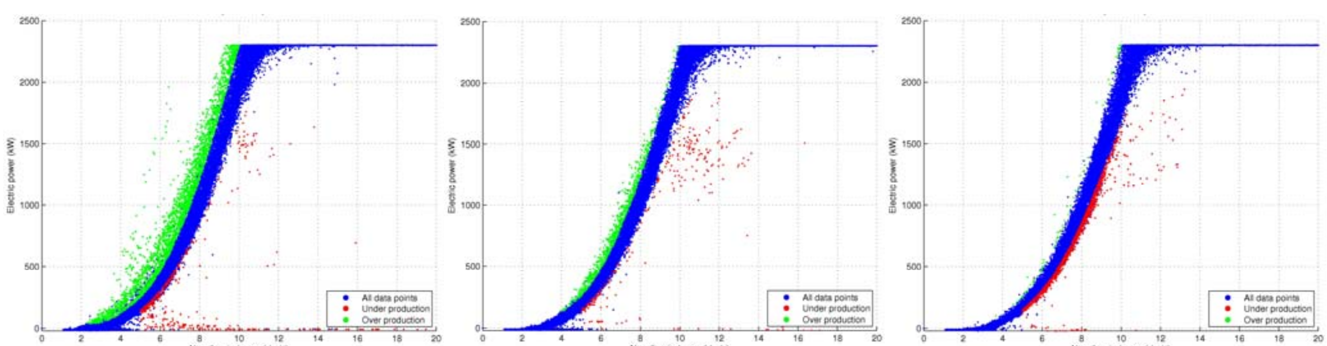
It can be seen from table 1 that the energy losses during the 2008-09 winter were somewhat less than during the 2007-08 winter, and that in all but one case the energy losses are dominated by the winter component, indicating that low temperature related events are causing the losses. In all cases it can also be seen that there is a significant percentage of the winter period with overproduction indicated. Therefore the estimate of energy lost must be considered a conservative estimate.

Finally, plots of the power production data from the turbines, with all data points plotted in blue, and the areas of over and under production plotted in green and red respectively are shown in figure 1.

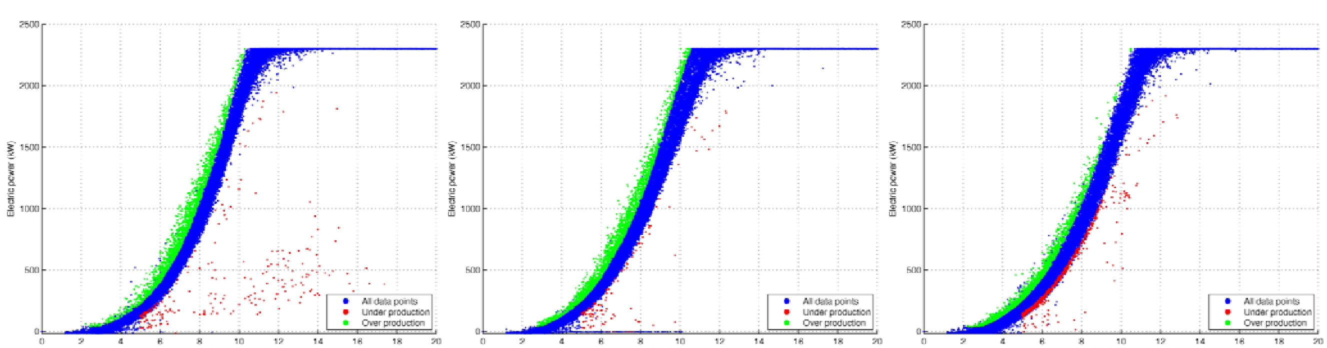
These figures also illustrate that there were problems with the wind measurements during both winters.

Table 1: Production analysis results from Nygårdsfjell.

	2007-2008			**2008-2009**		
Production [MWh]	**573**	**574**	**575**	**573**	**574**	**575**
Summer	2170	2040	2209	2277	2083	2234
Winter	4827	5054	4553	6085	5747	6025
Total	6934	7092	6762	8362	7830	8259
Losses, Summer	7	2	9	1	17	4
Losses, Winter	44	25	40	34	5	14
Losses, Total	51	28	48	35	21	19
Losses, Summer	0.3%	0.1%	0.4%	0.1%	0.8%	0.2%
Losses, Winter	0.9%	0.5%	0.9%	0.6%	0.1%	0.2%
Losses, Total	0.7%	0.4%	0.7%	0.4%	0.3%	0.2%
Time with Overproduction, Summer	0.7%	0.1%	0.0%	0.3%	0.3%	0.6%
Time with Overproduction, Winter	7.2%	2.1%	0.2%	4.2%	5.4%	4.1%



a. Turbine 573 b. Turbine 574 c. Turbine 575



d. Turbine 573 e. Turbine 574 f. Turbine 575

Figure 1: 10 minute production data from Nygårdsfjell showing all data in blue, overproduction in green and underproduction in red. Subfigures a, b and c are from 2007-2008, while d, e and f are from 2008-2009.

Some of the difference in the power data figures between the two winters is most likely due to the NRG Icefree 3 anemometers, which were present during the 2007-08 winter, being replaced with sonic anemometers. It appears that the combination including the sonic anemometer gives results that appear consistent between the turbines.

The losses calculated here for Nygårdsfjell do not seem to be too large, with the average for all three turbines for both years being only 0.5%. Unfortunately the losses are probably somewhat higher than calculated due to the anemometer problems. Also, for Nygårdsfjell all stopped periods were also removed such that any unexpected stops caused by icing are not included in the above statistics.

B. Sveg

One-hour data from a Vestas V90-2MW at Svegström (Brickan) in the municipality of Härjedalen have been analyzed, [3]. The available data include nacelle wind speed and power from the turbine, as well as meteorological data from the Swedish Meteorological and Hydrological Institute (SMHI). The influence of icing on power performance and energy production was of primary interest. The time period covered is 2007-12-11 to 2008-04-30.

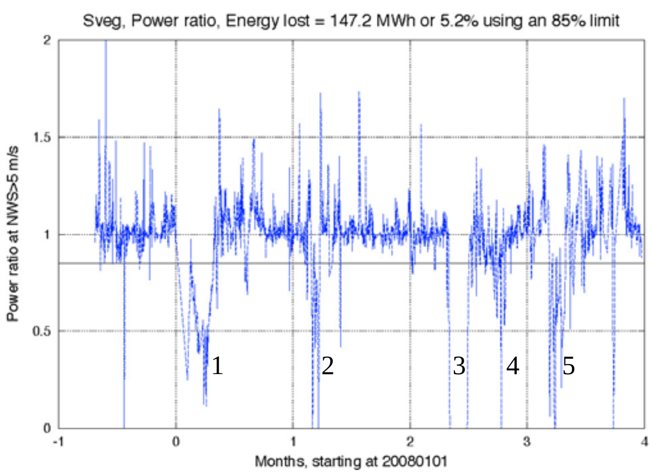


Figure 2: Five periods of icing. The energy production loss due to icing is estimated to be 5% during the period shown. The threshold shown is at 85%.

It is not obvious that operation with iced-up wind turbine blades lies within the specifications of presently used wind turbines. In general, the aerodynamic consequences of icing are present long before a significant mass imbalance occurs as all three blades are not iced-up identically. Consequently, one of the results from the EU-project NEW ICETOOLS was that icing was proposed to be identified via spectral analysis of, for example, the power signal. Long-time operation with iced-up blades is currently not covered as a design load case. For this purpose, NEW ICETOOLS, [4], proposed that individual pitch angle offsets in the order of 5-7 degrees could be used to simulate icing. Such settings are far larger than those included in current design load cases.

The analysis of power performance data shows that icing of the Sveg wind turbine caused an energy production loss in the order of 5%, or 150 MWh out of totally 2.8 GWh, between 2007-12-11 and 2008-04-30.

C. Aapua

The Aapua wind farm consists of 7 V82-1.5 MW on Etu-Aapua, a hilltop in the Municipality of Övertorneå and was put into regular operation in Sep 2005.

Figure 3: Aapua wind farm on Etu-Aapua.

It is well known by the owners that icing has significantly influenced the power performance of the Aapua wind farm. The magnitude of this effect has, however, not been investigated previously.

The wintertime energy production losses, based on the measured nacelle wind speed, are significantly higher compared to those during the summers. More alarming, however, is the increase in downtime during the winters over the years due to a lower availability resulting in reduced energy production.

The average energy production loss, not including manual stops during 205 turbine days, is more than four times higher in the wintertime compared to those in the summertime. The average energy production loss, based on actual production, was 27.9% in the wintertime (t<+2C) and 6.6% in the summertime (t>+2C).

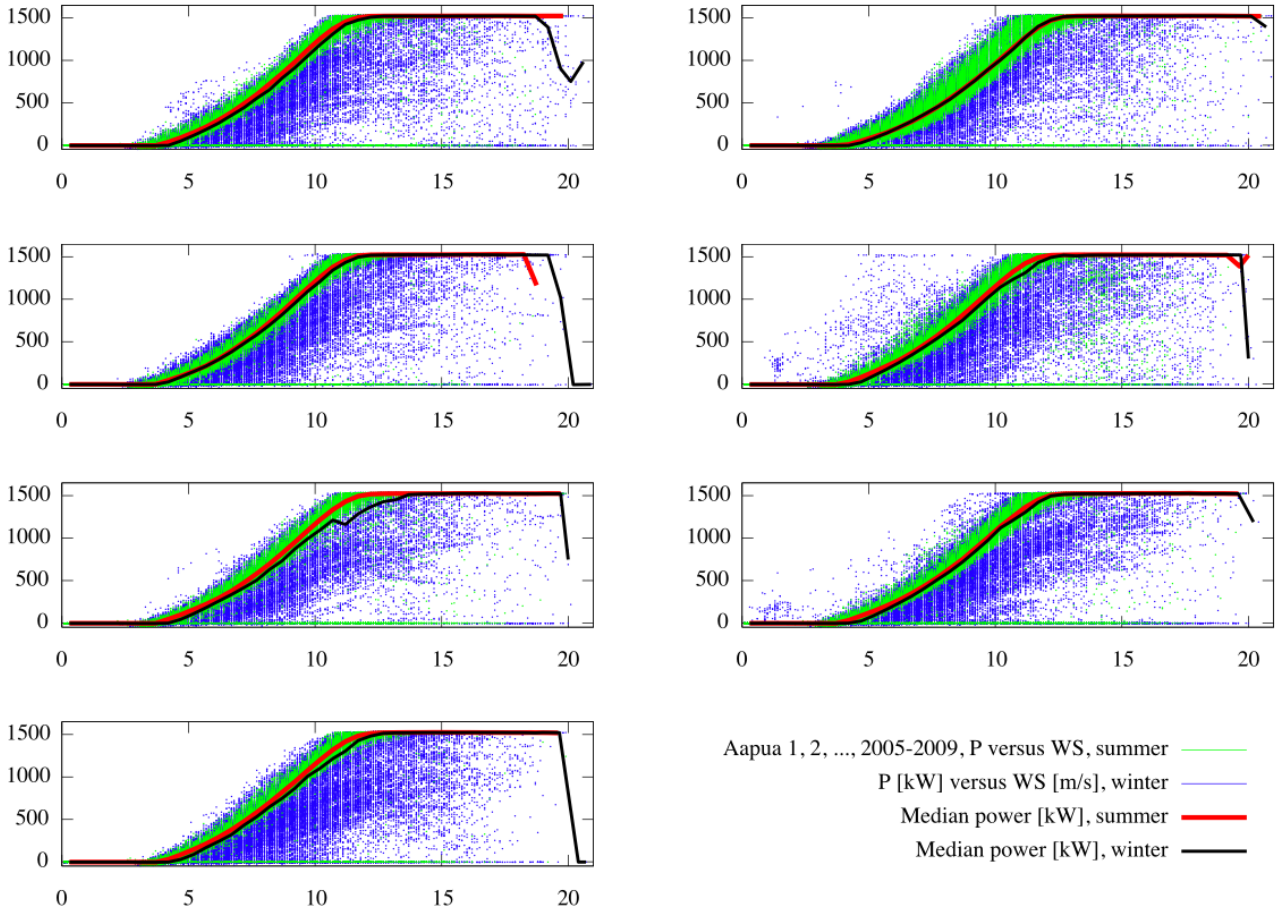


Figure 4: 10-min data plotted for three summers and four winters from October 1st 2005 to March 31st 2009. As data for the winters were plotted first, data for the summers (green dots) are placed on top of the winter data (blue dots). Aapua 1 is top left, Aapua 2 is top right etc.

Table 2: Energy production losses in Aapua during summer- and wintertime from October 1st 2005 to March 31st 2009. Winter is defined as t<+2°C. All manual stops, a total of 205 days, are excluded, as are periods with missing data.

Production [MWh]	Aapua 1	Aapua 2	Aapua 3	Aapua 4	Aapua 5	Aapua 6	Aapua 7	Total
Summer	8272	7390	5690	7620	5765	6933	7262	48932
Winter	6844	6799	7131	6641	4027	7170	7866	46478
Total	15116	14189	12821	14261	9793	14103	15128	95409
Losses, Summer	507	448	393	523	479	518	362	3230
Losses, Winter	1850	1308	1600	2157	1314	2286	2454	12968
Total losses	2356	1756	1993	2680	1793	2804	2816	16199
Losses, Summer	6,1%	6,1%	6,9%	6,9%	8,3%	7,5%	5,0%	6,6%
Losses, Winter	27,0%	19,2%	22,4%	32,5%	32,6%	31,9%	31,2%	27,9%
Total losses	15,6%	12,4%	15,5%	18,8%	18,3%	19,9%	18,6%	17,0%

The method chosen, i.e. comparing the actual power for both summers and winters with the nominal power in each wind speed bin, enables the determination of when the power output is affected by low temperature related conditions. It is, based on a comparison of data from the summer time, assumed that icing, and not wakes, is causing this significant increase in losses.

In [1], data for all turbines are missing during the start of the icing seasons in 2006 and 2007. Data from missing periods are not included in the evaluation. The most recent and frequent error codes are presented, as are the power performance for each turbine during winters and summers. The increased spread in power performance data during the winters is obvious and significant.

The losses caused by iced-up wind turbine blades can be decreased by the use of de- or anti-icing systems.

III. Comments and Discussion

Though the 85% filtering is a simple way to get an idea of potential icing losses, several points may be considered.

First, examination of the power production data from the summer periods shows a normal power spread that is not dependent on a percentage. Therefore a future study could attempt to quantify how using a variable percentage or another method to identify low production periods. For example, during periods of high wind, a more correct limit could be 99.5%, since the power control scheme of the turbine normally maintains rated power within a very narrow band. On the other hand, at low wind speeds the spread is normally much larger than 15%, particularly near the nonlinear start and stop wind speeds.

Second, the spread of data may vary for different sites, depending on the complexity of terrain and other site parameters.

While the energy losses due to icing were examined here, with regards to fatigue and turbine lifetime the duration and amount of ice on the wind turbine are more important parameters and methods of measuring them should be documented.

IV. Conclusions

Estimation of energy losses due to iced-up blades and instruments was performed for three sites. It can be clearly seen that instruments which function properly during icing are absolutely critical for evaluating the performance of a wind turbine.

An error condition caused by icing called overproduction is defined and the analysis showed that in the event of problems with anemometers this will affect energy loss estimates and should also be calculated.

The generation of a normal power curve based on the median power production during each wind speed bin gives a simple method to relatively easily analyze energy losses due to icing.

Nygårdsfjell wind park appears to have significantly less energy losses due to icing than the other two sites and Aapua has significantly more energy losses.

V. Acknowledgment

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