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139

Icing production loss module for wind power forecasting system

Timo Karlsson | Ville Turkia | Tomas Wallenius

VTT

VTT TECHNOLOGY 139

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ISBN 978-951-38-8073-6 (URL: http://www.vtt.fi/publications/index.jsp)

VTT Technology 139

ISSN-L 2242-1211
ISSN 2242-122X (Online)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

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PB 1000 (Teknikvägen 4 A, Esbo)
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Icing production loss module for wind power forecasting system

Jäätämisen aiheuttamia tuotantotappioita arvioiva moduuli osana tuulivoiman tuotantoennustejärjestelmää. **Timo Karlsson, Ville Turkia & Tomas Wallenius.** Espoo 2013. VTT Technology 139. 20 p.

Abstract

Icing conditions may cause significant wind power production losses, which increase short-term wind power forecasting errors if not taken into account. In this study real measurements and production data were used to evaluate a method to estimate production losses due to icing. The result of this study is called production loss module and it can be used as part of wind power forecasting system. Production loss module defines production losses based on icing time and wind speed inputs from weather prediction model. This publication describes only the production loss module and the procedure how it was created. Weather prediction models and forecasting of icing events are not considered here.

Production loss estimation method used by the module is based on icing induced power loss in reference data. Icing periods in real production data were classified based on wind speed and duration of power loss. Statistics of these power losses were then used to estimate the production losses during icing events.

Power loss gets increasingly more severe the longer the icing event lasts. The largest power loss occurs during the first icing hour. This would suggest that even short icing events can have significant effects on wind power plant performance and on short term wind power forecasting.

Keywords icing, wind turbine, production loss

Jäätämisen aiheuttamia tuotantotappioita arvioiva moduuli osana tuulivoiman tuotantoennustejärjestelmää

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Tiivistelmä

Jäätäminen voi aiheuttaa merkittäviä tuotantotappioita tuulivoimaloissa, mikä johtaa ennusvirheen kasvamiseen lyhyen aikavälin tuulivoiman tuotantoennusteissa, jos jäätämisen vaikutuksia ei ole otettu huomioon. Tässä työssä jäätämisen aiheuttamien tuotantotappioiden arvioimista varten kehitettiin menetelmä, joka perustuu todellisiin mittauksiin ja tuotantolukuihin. Menetelmää kutsutaan tuotantotappiomoduuliksi ja sitä voidaan käyttää osana tuulivoiman tuotantoennustejärjestelmää. Tuotantotappiomoduuli arvioi tuotantotappioita perustuen jäätämisaikaan ja tuulennopeuteen, jotka saadaan sääennustemallista. Tässä julkaisussa kuvataan ainoastaan tuotantotappiomoduuli eikä oteta kantaa sääennustemalleihin eikä siihen, kuinka jäätäminen ennustetaan.

Moduulin käyttämä tuotantotappioiden arviointimenetelmä perustuu jäätämisen aiheuttamiin tehon alenemiin vertailutuotantolukemissa. Jäätämisjaksot tuotantodatassa jaoteltiin tuulennopeuden ja tehon aleneman keston perusteella. Tämän perusteella voidaan arvioida tulevien jäätämistapausten aiheuttamia tehon alenemia.

Tuotantotappio kasvaa jäätämistapahtuman keston suurentuessa. Suurin pudotus tuotannossa tapahtuu ensimmäisen tunnin aikana. Tämän perusteella lyhyilläkin jäätämistapahtumilla näyttäisi olevan merkittävä vaikutus tuulivoimaloiden suorituskykyyn ja sitä kautta tuulivoiman lyhytaikaisen ennustamisen ennusvirheisiin.

Avainsanat icing, wind turbine, production loss

Preface

This publication describes a method based on real production data to estimate wind turbine production losses due to icing and serves as a deliverable D1.7 for project Icewind "Improved forecast of wind, waves and icing" work package 1.3 "Icing – Production Losses". The aim was to develop an engineering tool for production loss assessment of wind turbines due to icing.

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1. Introduction and background

Atmospheric icing causes ice accretion on wind turbine blades and may cause significant production losses. Unexpected losses due to icing increase forecasting errors of wind power forecasting systems leading to increased balancing costs. Other challenges caused by icing are presented more thoroughly in Expert group study about Wind Energy projects in Cold Climates (IEA Wind, 2012).

The topic of ice induced production losses and how the losses correlate with weather is complex and depends on number of parameters, such as weather, geography and turbine technology, and there is no easy way to define exact numbers for production losses using all parameters. The approach for quantifying the losses can be for example through simulations, experimental research based on measurement data or combination of these. The simulation approach was used in an earlier study (Turkia et al., 2013) where power performance of iced up wind turbine were simulated for use in the Finnish Icing atlas. In that study different ice accretions were modelled on wind turbine blade, aerodynamic coefficients of the blade with the ice formations were calculated numerically and power curves were simulated using these iced aerodynamic coefficients as input.

Modelling and simulations may differ from real world phenomena due to assumptions and simplifications done in modelling. Therefore, experimental analysis provides often more realistic approach but may require more effort by getting access to reliable and appropriate data. In this study, real production data of two different sites in Finland with different wind turbine types were used to evaluate production losses due to icing.

This method, which is called production loss module, produces an estimate of foreseeable icing impact on wind power production in short term. The module was constructed by collecting real icing events from production data. Descriptive statistics of these icing events were then calculated across the entire dataset. Finally, a set of power loss curves were built based on these icing event statistics.

The production loss module can be used as a part of the wind power forecasting system, explained in more detail in Section 1.1, in order to reduce forecasting errors.

1.1 Wind power forecasting system

To be able to estimate wind energy production and manage wind energy as a part of the whole electricity network a wind power forecasting system is needed. Weather forecasting, typically done with numerical weather prediction, gives forecasts of wind speed and other relevant weather parameters to a module which calculates the wind power forecast. The wind power forecast can then be used to balancing the grid or to define the electricity price in the markets.

An additional module, calculating ice induced production losses, can be seen as a new value adding component in wind power forecasting system. As a simplest form, this production loss module shall take inputs from the weather prediction module and transfer that into a useful number to be used by the production forecasting module. It has to be highlighted that the out-coming production losses from the production loss module and production forecasts of the whole system are highly dependable on the quality of the weather and icing forecasts.

The above description is a rough simplification for sake of clarity and is further illustrated in **Figure 1**.

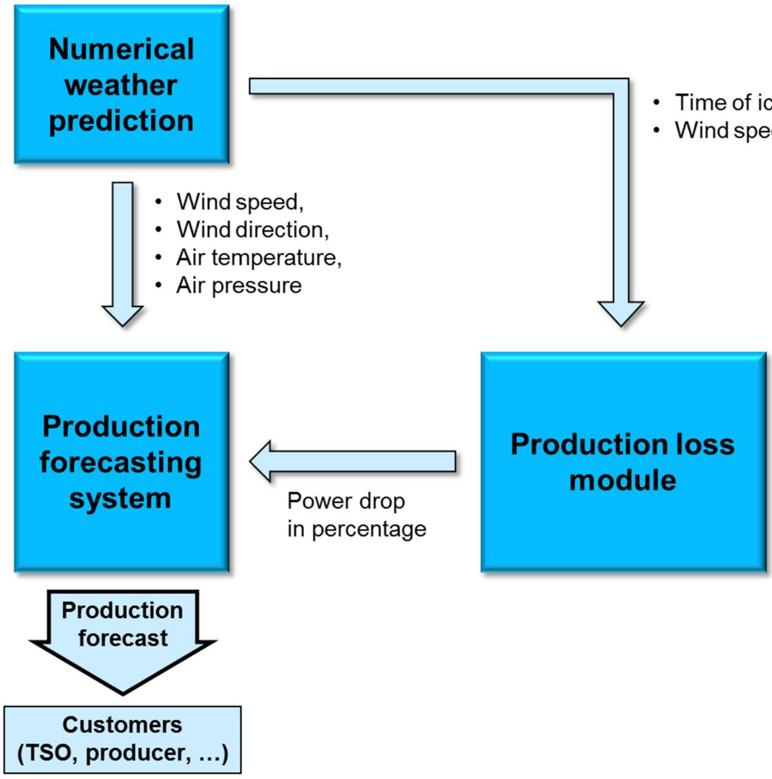

Figure 1. Example of wind power forecasting system including production loss module for forecasting ice induced production losses.

2. Method for production loss estimation

The aim of this study was to produce a simple method, an engineering tool, to estimate production losses caused by icing of the wind turbine rotor blades. In order to give wider possibilities to use this method across different forecasting models, detailed parameters affecting to the production losses, such as wind turbine aerodynamics, wind turbine control parameters, and parameters related to actual icing phenomena were not considered as inputs or parameters, but instead treated as a variation in the statistics of larger dataset. The number of required inputs was minimized. Also, the weather parameters can change during an individual icing event. Over time these differences will even out, if there is enough data from different kinds of events. The resulting production loss levels can be redefined easily later by applying the method described in this study to a different set of icing data.

The production loss module was built as an add-on to any existing production forecasting model. The module will produce an estimate of the impact a possible icing event has on the wind power plant production in the short term, for example over the next hour. The icing impact was represented as a power loss, a simple multiplier, for the turbine describing the relation of power including the icing impact and the theoretical power of the turbine at a certain wind speed. This power loss can then be applied to the output of the production forecasting model to produce a forecast for the production output of an iced wind power plant.

The design described here was meant to be as simple as possible without sacrificing accuracy too much. This was done in order to minimise the number of required inputs and make the resulting module portable across different prediction models. The internals of the production loss module were kept as simple as possible. The module was built statistically using real production data.

Resulting model only uses the length of the icing event and wind speed as inputs. This way the model is usable regardless of the method used to predict the icing events. Icing length was chosen because it is directly related to the impact of icing. Wind speed was chosen, because it has big impact on the ice accretion rate based on the icing rate formula according to the standard of atmospheric icing (ISO 12494, 2001) and because wind speed has naturally a big impact on wind turbine production.

Wind speed division is also useful (see Chapter 3): the relative effect of icing seems to be larger at smaller wind speeds. This is mostly due to icing forcing the wind turbine to be able to start producing later (at a larger wind speed) than a clean turbine would.

The module was constructed by collecting real icing events from operational data. Statistics of these icing events were calculated across the entire dataset. Finally a set of power loss curves as a function of the length of the icing event was created based on the icing event statistics.

The dataset constructed in this way could be incomplete; the data set might lack for example high wind speeds. Thus the effects of some icing events need to be extrapolated from the data. From the reference dataset used in this study it seemed that the difference between the different wind speed groups was a constant offset more than anything. As a result the missing data points were estimated with help of extrapolation.

The process of building the module is illustrated in Figure 2. The process of constructing the module from raw production data can be broken down into three steps. First the output power of the turbine was compared to the expected output power.

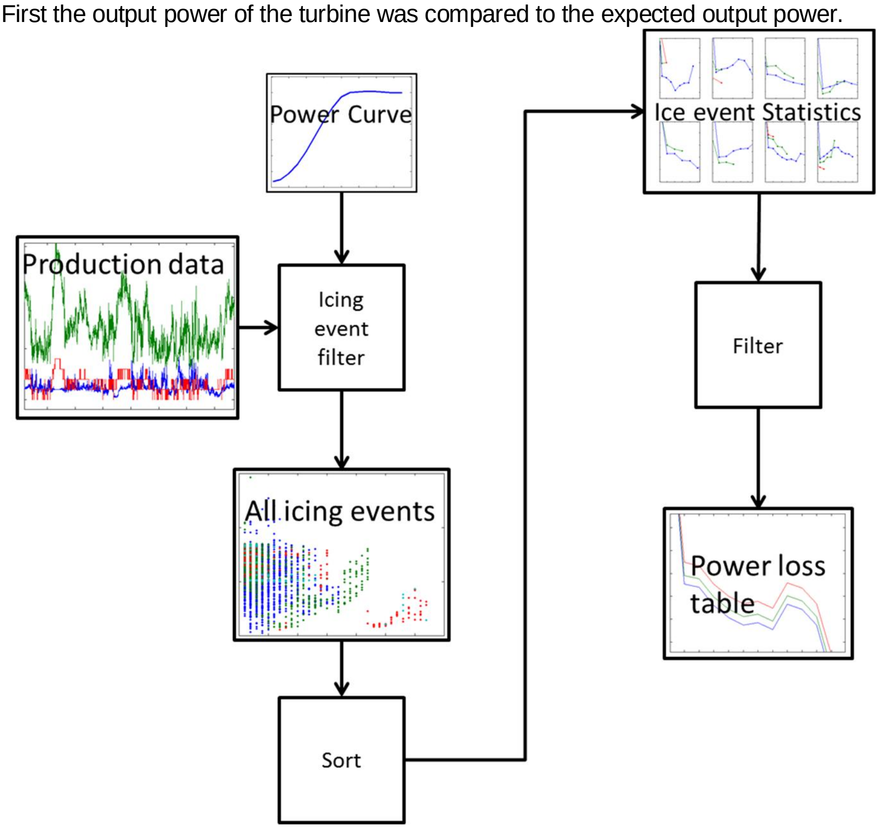

Figure 2. Flow chart of the construction of the production loss module.

Ice cases were constructed from production data by observing any sustained production losses in the turbine output power. This was based on the assumption that a reduction in the output power of otherwise normally operating turbine in cold temperatures was evidence of icing. The power loss needed to be below nominal values for a predefined time period before it was judged as icing event. The time criterion was used to filter out naturally occurring noise in the production data: individual measurements can differ quite a lot from expected values.

In this study the criteria used are presented **Table 1**. As a result the shortest time that could be detected was one hour. The resulting curves for production losses were built using one hour resolution, meaning that the icing events were classified based on the number of full hours the event lasts.

Table 1. Criteria for icing events.

Parameter	Value
Power loss [%]	15
Minimum duration [h]	1

Output power losses were observed by comparing the output power to the turbine power curve. Power curve can be pre-defined or calculated from the production data as well.

Calculating the power curve from the data required defining a “clean” subset of available operational data. Clean subset refers to a subset of production data that does not have any icing events or any other instances of abnormal behaviour included. This was done by taking a dataset from warmer temperatures and filtering out all cases where the turbine was not operating normally.

After icing incidents were found those were sorted according to length of the icing event and wind speed. Finally the power loss curves were constructed for the module by augmenting the data in the collected statistics. Data augmentation for the final power loss curves was done by either interpolating between existing data points or by extrapolating based on existing data. The augmentation of power loss curves were done by calculating the distances between the curves based on the data, see **Figure 6** in Section 3 Results and discussion. Then the curves were extended with an extrapolation routine, always making sure that the distance between two different curves representing two separate wind speed bins would remain at least as large as it was for the portion of data where measurements did exist. Because the data had gaps at higher wind speeds, the gaps were filled by extrapolating from the existing data. In addition to the extrapolation, an additional condition was used so that the distance between the curves remained at least as big as it was at the wind speeds where there was data available.

The power loss curves in a tabulated format can be used to predict the effect of icing on wind turbine performance using simple look-up functions based on the icing event length and wind speed.

Using production losses to identify icing events means that the icing was already severe enough to have an impact on turbine behaviour. Thus, meteorological icing, the weather conditions favourable for icing, has been started a little bit earlier than when icing is visible for the method described in this study.

2.1 Description of the measurement data set

The data used in this study was collected from operating wind turbines in two different sites in Finland.

- Site A: located in the end of Bay of Bothnia near Oulu. Data available was from two 3 MW wind turbines, collected during years 2010–2012.
- Site B: located in southern Finland near coast line on a small island. Data available was from one 2MW wind turbine, collected during years 2007–2009).

Data used in the study consisted of turbine SCADA data and following measurements were used:

- Wind speed, measured from top of nacelle
- Wind direction, measured from top of nacelle
- Produced power
- Turbine status
- Ambient temperature, measured at the top of nacelle.

3. Results and discussion

Icing event distribution as a function of wind speed is shown in **Figure 3**. The analysis indicates that significant majority of the icing events occur at wind speeds lower than 10 m/s. It can be seen that there is a serious lack of data at the upper end of the dataset. The reason for this is unclear: it is possible that icing really occurred at lower wind speeds but it might have been so that wind sensors have been collecting ice which might have had an influence on wind speed measurements.

The distribution of the lengths of icing events is presented in **Figure 4**. From there it can be seen that majority of icing events were shorter than 4 hours long.

The variance of the power measurements in the test dataset was rather large. As a result the deviation of the power differences was also rather large. However, the large variance evened out due to relatively large number of measurements available.

Both the mean and standard deviation of the power losses were relatively similar at both measurement sites; the differences between the mean power losses at different sites were within one standard deviation of each other at all wind speeds and at all icing event lengths.

When comparing these results to the results of CFD simulations conducted in an earlier study (Turkia et al., 2013), the power losses based on the measurements are larger in all cases. Also the difference between wind speed cases seems to be bigger in the real data than it was in the simulations. This suggests that the simulations were not able to catch all phenomena existing in real world icing cases.

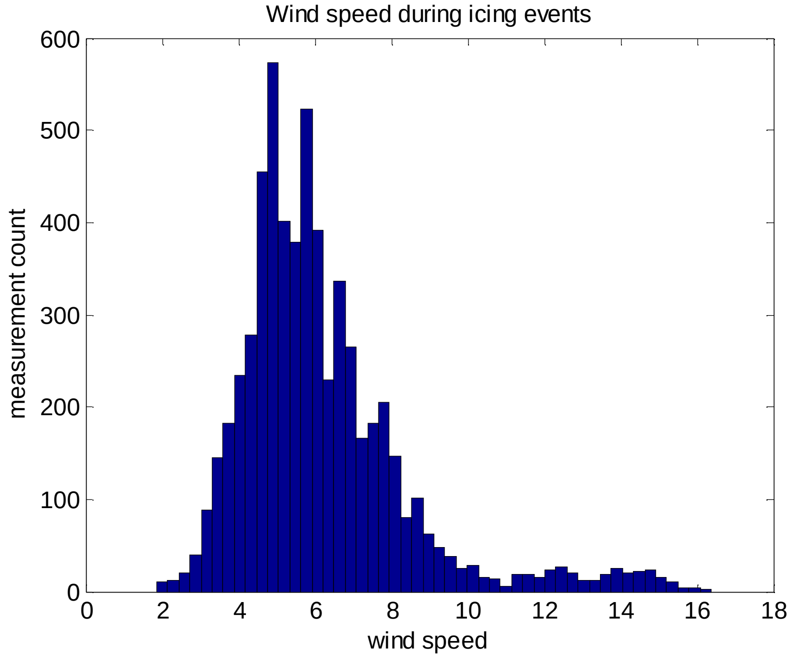

Figure 3. Icing event distribution as a function of wind speed.

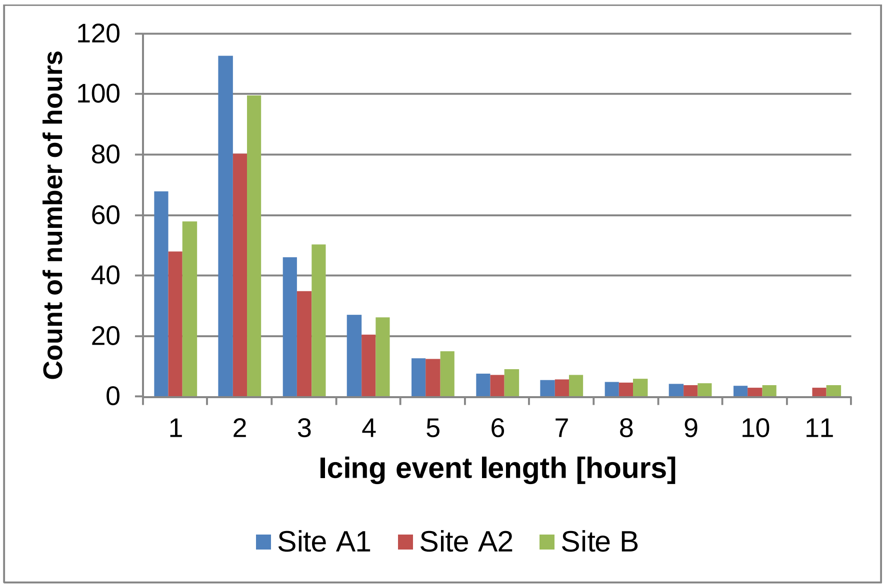

Figure 4. Distribution of icing event lengths in the data.

The power losses at different sites are presented in **Figure 5**. The results of the earlier study (Turkia et al., 2013) are plotted in the same figure for comparison. The average power loss seems to be similar at both sites, with the mean slowly decreasing as the icing event lasts longer. The effect was also more apparent at smaller wind speeds, but this was mainly due to the method used to calculate relative power loss. At smaller absolute values of output power the apparent losses were more dramatic.

The relation between the icing time and the magnitude of the power loss was interesting, because the loss after 1 hour of icing was relatively large. The average power loss found all icing incidents was 30% for wind speeds 7 m/s and higher and almost up to 40% for wind speeds less than 7 m/s. This indicates that the turbine output power decreases dramatically in the beginning of an icing event

Another point, worth wile to discuss, is that based on the data the wind turbines were not shut down due to icing, although the power loss for low wind speeds was nearly 50% and for wind speeds from 7 to 10 m/s loss was up to 40%. According to the knowledge of authors, this might not be always the case; some wind turbine types are shutting down themselves much earlier when the turbine is producing less than the current wind speed indicates. This should be considered when production losses are estimated, especially when forecasting short term wind power production.

Overall the results showed a nearly linear relationship between the icing time and the power loss after the first hour. The behaviour during the first hour could not be extracted using this method due to the chosen time resolution. If a shorter time horizon than one hour would be needed, easiest method would be to use linear interpolation for the first hour.

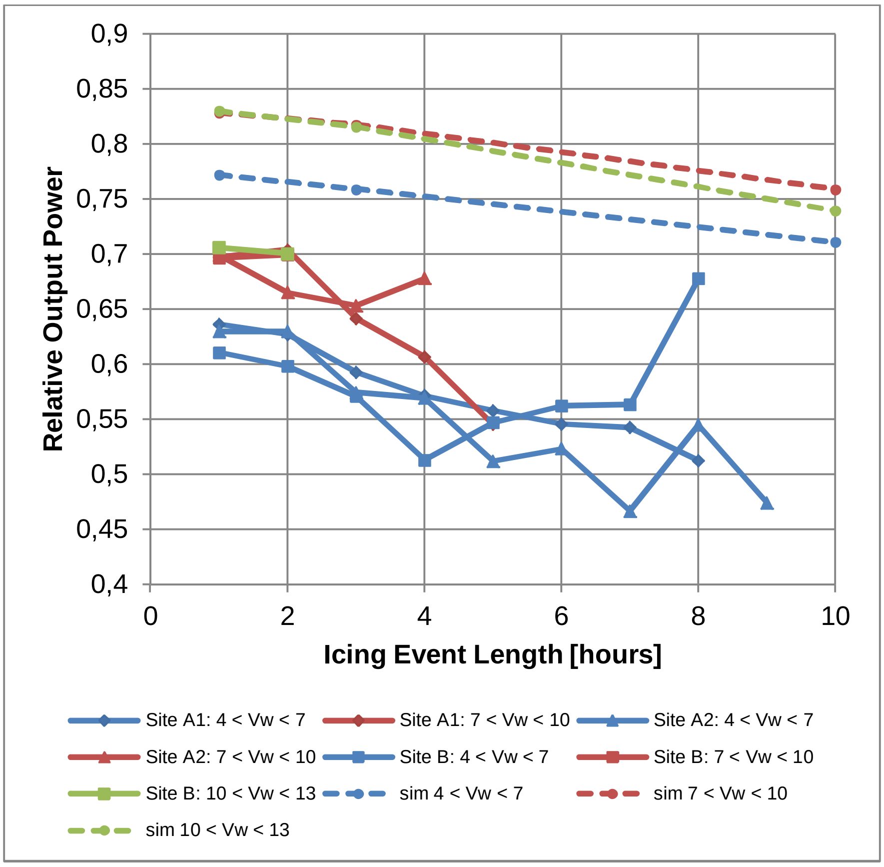

Figure 5. Production losses from two different measurement sites (solid line) and simulations (dotted line) from Turkia et al. (2013). Blue colour is for wind speed range 4…7 m/s, red for 7…10 m/s, and green for 10…13 m/s.

The cross site mean, average of both sites, power loss curves are presented in **Figure 6** and the augmented curves are presented in **Figure 7**.

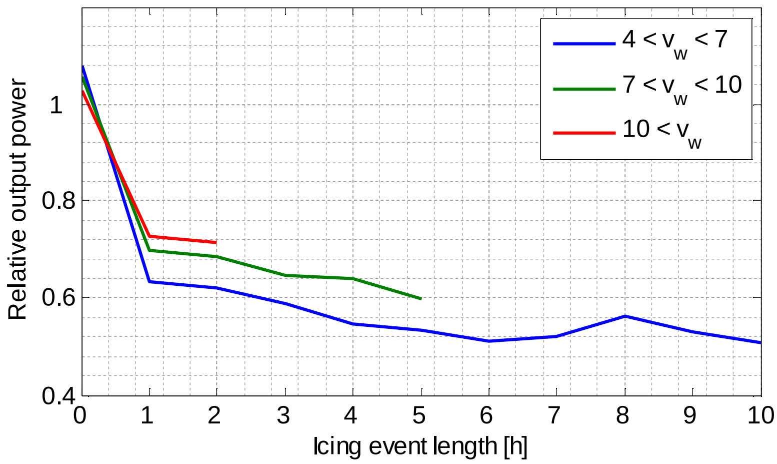

Figure 6. Mean power losses for the different wind speed categories.

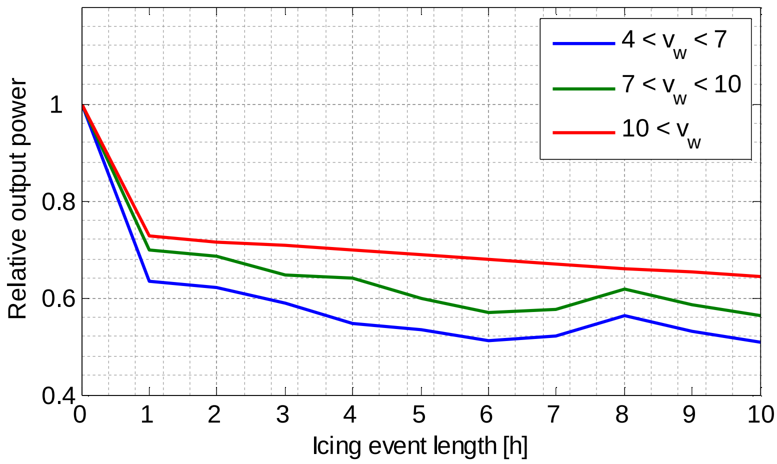

Figure 7. Augmented mean power losses.

4. Conclusions and recommendations

A production loss module due to icing of wind turbines for production forecasting system was developed. The method for the module was tested with a dataset from two sites.

The result is a very portable production loss module that can be used in many different kinds of wind power production forecasting systems. The behaviour of the production loss module is independent on the implementation of the icing modelling and forecast. The needed inputs are only icing time and wind speed. The output is power loss in percentage.

Interestingly the relationship between icing time and power loss was similar in both sites used to build this module despite the fact that the turbines are of different size and make.

The results drawn from the measurement dataset showed a more drastic drop in the power than the simulations conducted in an earlier study. This difference seems to remain constant regardless of icing time. The other difference was that the effect of wind speed into power loss was more significant in the real production data than it was in the simulations.

Power loss increases the longer the icing event lasts. The largest power loss occurs during the first icing hour. This would suggest that even short icing events can have significant effects on wind power plant performance and thus it would be important to take ice induced power losses into account in short term wind power forecasting, because otherwise the forecasting error is increased due to the unexpected power loss. It has to be noted that due to the limited number of different turbine types, the results in this study might underestimate the production losses, if wind turbines are shutting down earlier than the turbines in this study did due to the lower actual production compared to the wind speed.

The next step would be to evaluate the real-world performance of the production loss module by incorporating it into a production forecasting system in order to see if forecasting errors could be reduced.

Acknowledgements

This study was carried out under the project ICEWIND 2010–2014, which was funded by Nordic Energy Council through Nordic Top-level Research Initiative. The authors greatly acknowledge the use of data from Innopower.

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Series title and number

VTT Technology 139

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ISBN, ISSN	ISBN 978-951-38-8073-6 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242-1211 ISSN 2242-122X (Online)
Date	November 2013
Language	English, Finnish abstract
Pages	20 p.
Name of the project	ICEWIND 2010–2014
Commissioned by	Nordic Energy Council
Keywords	icing, wind turbine, production loss
Publisher	VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland, Tel. +358 20 722 111

Julkaisun sarja ja numero

VTT Technology 139

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ISBN, ISSN	ISBN 978-951-38-8073-6 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242-1211 ISSN 2242-122X (verkkojulkaisu)
Julkaisuaika	Marraskuu 2013
Kieli	Englanti, suomenkielinen tiivistelmä
Sivumäärä	20 s.
Projektin nimi	ICEWIND 2010–2014
Toimeksiantajat	Nordic Energy Council
Avainsanat	icing, wind turbine, production loss
Julkaisija	VTT PL 1000, 02044 VTT, puh. 020 722 111

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