BEFORE
THE OHIO POWER SITING BOARD

In the Matter of the Application of **SENECA WIND, LLC** for a Certificate to Site Wind-Powered Electric Generation Facilities in Seneca County, Ohio.	))))))	Case No. 18-488-EL-BGN

SENECA WIND, LLC'S RESPONSES TO STAFF'S SECOND SET OF DATA REQUESTS

1) Please provide the "Tabulated Acoustic Modeling Results by Residence" table in excel format for the GE 2.5-127 and SG 2.5-127 turbine models.

RESPONSE
The spreadsheet has been provided in excel format via e-mail to Jim O'Dell on October 23, 2018.

2) The GE 2.5-127 and SG 2.5-127 turbine models both have a hub height of 134 m. The GE 2.5-127 has a blade length of 62.2 m and SG 2.5-127 has a blade length of 63.5 m which would give you the total heights below.

	Hub Height	Hub	Blade length	Max total height
GE 2.5-127	134 m	1.8 m	62.2 m	198 m
SG 2.5-127	134 m	1.8 m	63.5 m	199.3 m

But the September 14, 2018 filing lists the maximum heights as

	Hub Height	Blade length	Max total height
GE 2.5-127	134 m	62.2 m	198 m
SG 2.5-127	134 m	63.5 m	198.9 m

Please explain the discrepancy in the total height of the SG 2.5-127.

RESPONSE

The rotor diameter for the SG 2.5-127 is 129.69 meters. Dividing the rotor diameter in half (as half will overlap with the hub height metric) for a length of 64.845 meters, and adding that to the hub height of 134 meters, the total height would be 198.845 meters, which we conservatively rounded up to 198.9 meters.

3) What are the wind and temperature conditions during which the SG 2.5-127 power boost to 2.9 MW is available?

RESPONSE

Power boost is available for the SG 2.5-127 turbine only (not the equivalent GE mode), and is subject to limitations. Power boost cut-in can occur at wind speeds of 10.5 m/s and would cut out at wind speeds of 21 m/s. Power boost will also only be active at ambient temperatures below 25°C (77°F) at 0 meters mean sea level and 16°C (61°F) at 2,000 meters mean sea level.

4) What is the maximum sound power levels for the GE 2.5-127 and SG 2.5-127 (with and without power boost) turbine models?

RESPONSE

The GE 2.5-127 turbine does not include a power boost. The requested information is provided for each turbine model in the tables below.

Broadband Sound Power Levels (dBA) Correlated with Wind Speed, GE 2.5-127

	WTG L_{max} Sound Power Level (L_W) at Reference Wind Speed (m/s)									
Wind Speed	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
GE 2.5-127	96.7	96.9	100.4	103.9	106.8	109.2	110.0	110.0	110.0	110.0

Broadband Sound Power Levels (dBA) Correlated with Wind Speed, SG 2.7-129

	WTG L_{max} Sound Power Level (L_W) at Reference Wind Speed (m/s)									
Wind Speed	4	5	6	7	8	9	10	11	12	13
SG 2.7-129	95.6	98.5	101.5	104.4	106.8	108.5	108.5	108.5	108.5	108.5
SG 2.7-129 with Power Boost	95.6	98.5	101.5	104.4	106.8	108.5	108.5	110.5	110.5	110.5

5) Sound power levels are given at 1 m/s intervals from 4 m/s to 13 m/s. What are the sound power levels at 1 m/s intervals from 13 m/s to the cut-out speeds for the GE 2.5-127 and SG 2.5-127 (with and without power boost) turbine models?

RESPONSE

Sound power levels remain the same above 13 m/s for both the SG 2.5-127 (without power boost) and GE 2.5-127; however, ambient sound levels would increase as wind speed increases. Of the two proposed turbine models, only the SG 2.5-127 has power boost; sound power levels with and without power boost are provided in Response 4.

6) Will any of the turbines have blades that have trailing edge serrations?

RESPONSE

Yes. The 'low noise trailing edge' (LNTE) mitigation proposed on select GE 2.5-127 turbines are serrations.

7) Please provide the shadow flicker tables in the September 14, 2018 filing in excel format.

RESPONSE

The spreadsheet has been provided in excel format via e-mail to Jim O'Dell on October 23, 2018.

8) Please provide these cited studies:
   a. Garrad Hassan 2010. Turbine Failure Literature Review and the Wind Turbine Certification Process. Prepared for Green Mountain Power Corp. November 2010.
   b. Gipe 2013. A Summary of Fatal Accidents in Wind Energy. Available at: http://www.windworks.org/cms/index.php?id=43&tx_ttnews[tt_news]=414&cHash=5a7a0eb3236dd3283 a3b6d8cf4cc508b. Last updated May 1, 2013.
   c. Global Wind Energy Council. 2014. Wind Power FAQs. Available at: http://www.gwec.net/faqs/how-many-windturbines-World
   d. Cattin et al. 2008. Two Years of Monitoring of a Wind Turbine Under Icing Conditions. Proceedings of DEWEK, Bremen, Germany. November 26-27, 2008.
   e. Cattin et al. 2009. Four Years of Monitoring a Wind Turbine Under Icing Conditions. IWAIS XIII, Andermatt, September 8 to 11, 2009.
   f. Global Wind Energy Council. 2014. Wind Power FAQs. Available at: http://www.gwec.net/faqs/how-many-windturbines-World

RESPONSE

The cited studies are attached. Note that references c) and f) are the same document and that the cited version is no longer available, as it has been updated. The updated version is provided, with a corrected citation as "Global Wind Energy Council. 2016. Wind in Numbers. Available at http://gwec.net/global-fires/wind-in-numbers/." Use of this updated reference would change the narrative on page 96 of the Application from "…more than 268,000 turbines were spinning around the world at the end of 2014…" to "…341,320 turbines were spinning around the world at the end of 2016…" No material change results from this update.

9) Will the proposed turbines have nacelle-mounted ice sensors?

RESPONSE

The wind turbines have vibration sensors that continuously monitor the health of the wind turbine. If the wind turbine vibration exceeds a predetermined value, the turbine control will shut the turbine down. The turbine control system constantly monitors blade pitch angle, and if blade pitch exceeds a predetermined value, the turbine control will shut the turbine down. The formation of ice on the blades is assumed to increase vibration and loss of lift, which in turn would cause the turbine control to increase blade pitch angle to maintain power output at a given wind speed.

Although ice on the blade would not be the only reason for vibration or excessive blade pitch, it is one potential cause, and would shut the turbine down regardless of the cause.

10) If ice is detected on the turbine blades how are blades to be de-iced?

RESPONSE

There is no deicing feature on the turbines. Ice buildup on turbine blades would be detected by the SCADA system as vibration and loss of lift and turbines would be either slowed or stopped until the buildup has melted.

11) Do the turbine blades have deicing features?

RESPONSE
No (see previous response).

12) If the turbines are shut down due to ice being detected on the turbine blades, describe the restart procedures.

RESPONSE
The turbine does not restart until the rotor blades are detected to be free of ice or the operator confirms the ice-free condition of the rotor blades, has acknowledged the ice alarm message and restarts the plant.

13) Do the turbines require grid power for the lightning protection system to operate?

RESPONSE
No.

14) On page 62 of the application it is stated, “The SCADA system will document all critical lightning events and, if a problem is detected, the turbine will shut down automatically and be inspected to assure that damage has not occurred.” What is the definition of “critical lightning events”?

RESPONSE
A critical lightning event is defined as an event that results in vibration exceeding a predetermined level or other performance issues. The SCADA system will monitor and document suboptimal turbine performance and shutdown turbines that deviate from predetermined ranges of normal operation, as described in Response #9.

15) How powerful of a lightning strike would need to occur to prompt turbine shutdown and inspection?

RESPONSE
A lightning strike or other environmental conditions that might affect optimal turbine performance (e.g., vibration or blade pitch) would be detected by the SCADA system, which automatically shuts down turbines that deviate from normal operations.

ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/242131278

TWO YEARS OF MONITORING OF A WIND TURBINE UNDER ICING CONDITIONS

Article · January 2008

CITATIONS
6

READS
112

5 authors, including:

René Cattin
Meteotest
29 PUBLICATIONS **91** CITATIONS

SEE PROFILE

Alain Heimo
Meteotest
31 PUBLICATIONS **919** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project IEA Wind Task 19 View project

Project SWISSMETNET CHARM View project

All content following this page was uploaded by René Cattin on 07 April 2014.

The user has requested enhancement of the downloaded file.

TWO YEARS OF MONITORING OF A WIND TURBINE UNDER ICING CONDITIONS

René Cattin[1], Stefan Kunz[1], Alain Heimo[1], Markus Russi[2], Gabriela Russi[1]
[1]Meteotest, Bern, Switzerland, +41 31 307 2626, rene.cattin@meteotest.ch
[2]Elektrizitätswerk Ursern, 6490 Andermatt, Switzerland

Summary

Icing is an important issue when operating wind turbines in high altitude or arctic areas as it can cause significant production losses and represent a safety risk. The Swiss research project "Alpine Test Site Gütsch" which is embedded in the European "COST Action 727: measuring and forecasting atmospheric icing on structures", aims to extend the knowledge on icing on structures in the Swiss Alps.
The ratio between meteorological and instrumental icing becomes important when the implementation of a blade heating is considered. Therefore, several additional measurement parameters were evaluated for their suitability to deliver this information. The study revealed, that in-cloud icing conditions can be detected fairly well by use of air temperature, relative humidity and the sky temperature, which is derived from incoming long wave radiation. It further showed that there is currently no ice detector on the market which is able to reliably measure icing. The monitoring of the Enercon E-40 wind turbine showed, that the ice detection via power curve seems to work considerably well except for light icing and during periods with low wind speed. However, this method gives no information if blades are still iced after heating cycle. This makes the automatic restart a safety risk. In many cases, not all the ice could be melted during one heating cycle, especially at the leading edge of the blades. The heat transfer to the leading edge therefore should be optimized. An extensive field study on ice throw revealed that ice throw is a safety risk especially during or right after a blade heating cycle and in the area under the blades

1. Introduction

Icing is an important issue when operating wind turbines in elevated or arctic areas as it can cause significant production losses and represent a safety risk [1]. In 2004, a 600 kW Enercon E-40 wind turbine with integrated blade heating was installed on Guetsch mountain, central Switzerland, at 2'300 m asl. Coincidentally, a fully equipped test station of the Swiss meteorological network SwissMetNet was installed about 200 m away from the wind turbine in 2003 (Fig. 1). The immediate proximity of the two facilities operating under icing conditions led to the launch of the research project "Alpine Test Site Gütsch: meteorological measurements and wind turbine performance analysis" [2, 3, 4] which is embedded in the European "COST Action 727: measuring and forecasting atmospheric icing on structures" [5, 6].

Fig. 1: Alpine Test Site Guetsch.

2. Site Description

The test site is located on a ridge in highly complex terrain in the midst of the Swiss Alps at 2'300 m asl. The prevailing wind directions are north and south (Foehn). Winds are very variable and during strong Foehn events, wind speeds can easily reach 120 km/h or more. The long term average monthly air temperature varies from -6.9°C in February to 7.3°C in July and drops below 0°C from November to April. The main icing periods are late autumn and early spring when the temperature often lies around 0°C. Icing can occur throughout the year. In mid winter the temperature can fall below -20°C.

3. Site Assessment under icing conditions

3.1. Meteorological and instrumental icing
In phase 1 of COST Action 727, a state of the art report about icing measurements was compiled by the members of the action [7]. In this report the following definitions were introduced:

- Meteorological icing M_{icing}: duration of a meteorological event or perturbation which causes icing
- Instrumental icing I_{icing}: duration of the technical perturbation of the instrument due to icing
- Incubation time: delay between the beginning of the meteorological icing and the start of the instrumental icing
- Recovery time: delay between the end of the meteorological icing and the full recovery of the instrument

Figure 2 illustrates how wind measurements are affected by icing according to the definitions described above. From the point when icing conditions are given to the start of the meteorological icing,

there is a certain delay until ice accretion at the anemometer begins, the incubation time. When ice accretion has started, the measured values cannot be used anymore for further analysis. Ice is accreted continuously to the sensor until the meteorological conditions for icing are not present anymore. But after the end of the meteorological icing, the ice will remain at the instrument for a certain time until it melts or falls off. This recovery time can be even longer than the period of meteorological icing. Although icing conditions are not given anymore, the readings of the instrument have to be discarded until the end of instrumental icing.

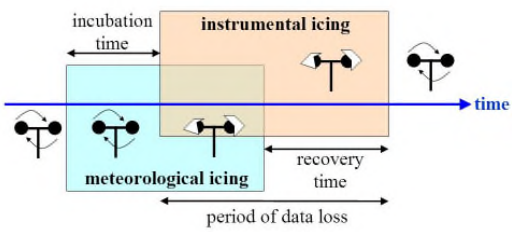


Fig. 2: Meteorological and Instrumental Icing.

3.2. Importance for wind energy

For wind energy purposes, the ratio between meteorological and instrumental icing becomes important when the implementation of a blade heating is considered. If the periods of meteorological icing are short compared to the following instrumental icing, the use of a de-icing system will lead to a significant increase of power production compared to a wind turbine without such a system. On the other hand, if the periods of meteorological and instrumental icing are about of equal duration, there will be losses in production even with a de-icing system. In such cases only an anti-icing system might be the solution to optimize power production. Unfortunately, such systems are not available so far.

3.3 Additional measurement parameters

A wind resource assessment is often based on wind measurements of an unheated anemometer. Within this data, only instrumental icing is visible when the sensor gets stuck. It is impossible to distinguish between meteorological and instrumental icing. Therefore it cannot be estimated if a blade de-icing or anti-icing system would lead to an economic benefit for the operator or not. Several possible additional measurement parameters were evaluated for their suitability to deliver this additional information:

Heated vs. unheated anemometer

The comparison between a heated and an unheated anemometer cannot give additional information concerning the durations of meteorological and instrumental icing as the heated anemometer is (or should be) completely unaffected by icing. But the use of a heated anemometer certainly increases the accuracy of the evaluation of the wind potential itself as wind data is available throughout the whole time.

Temperature

Additional measurements of temperature give essential information about the occurrence of extremely low temperatures at the site. However, they cannot say anything about meteorological or instrumental icing as icing must not necessarily occur when temperature falls below 0°C (dry air).

Temperature and relative humidity

Measurements of temperature and relative humidity allow an indication about meteorological or instrumental icing. A widely used approach is the simple definition that icing occurs at air temperatures below 0°C and a relative humidity higher that 95%. However, several studies showed that this approach is not able to reliably detect icing conditions [8].

In addition, measurements of relative humidity are mostly performed according to WMO/CIMO standards where saturation water vapour pressure is always calculated with respect to water [9]. Below 0°C, saturation cannot be reached anymore using this procedure. In order to be able to use relative humidity as a parameter for the determination of icing conditions, the readings for relative humidity have to be re-calculated with respect to saturation water vapour pressure over ice for temperatures below 0°C.

Temperature, relative humidity and incoming long wave radiation

When icing mostly occurs as in-cloud icing, the approach described above can be improved by use of the incoming long wave radiation $L\downarrow$ with a pyrgeometer. This allows the calculation of the sky temperature T_{sky} according to Stefan-Boltzmann's law:

$$T_{sky} = \sqrt[4]{\frac{L\downarrow}{\sigma}} - 273.15 \qquad [°C]$$

$$\sigma = 5.67 \cdot 10^{-8} Wm^{-2}K^{-4}$$

If the cloud base is higher than the wind turbine (or if there are no clouds at all), the sky temperature is lower than the ambient air temperature. If the sky temperature gets close to or is equal to the air temperature at hub height, there is a high probability that the sensors, e.g. the nacelle of the wind turbine or the tip of the blades are in-cloud (fig. 3).

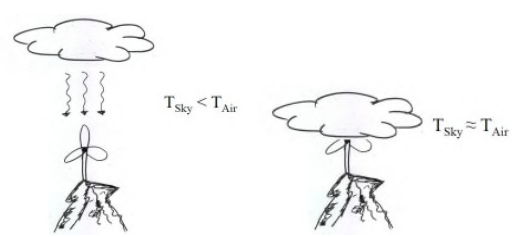


Fig. 3: Left: when the cloud base is higher than the wind turbine's nacelle, the sky temperature is significantly lower than the air temperature at the nacelle. Right: when the sky temperature is approximately equal to the air temperature, there is a high probability that the wind turbine's nacelle is in-cloud.

In a first approach, icing conditions were defined as situations with air temperatures below 0°C, relative

humidity above 95% and a difference between air temperature and sky temperature of less than 2°C. First analysis of the data is promising and seems to lead to an improvement of the detection of icing conditions. A comparison between the met station and the wind turbine data clearly shows that the wind turbine's nacelle is more often in-cloud than the met station. A comparison of images from the met station and the wind turbine confirmed that icing happens more often and stronger at the nacelle of the wind turbine than at the met station [8]. This underlines the importance of carrying out icing measurements at the specific height of interest (e.g. at hub height for wind turbines).

Temperature, relative humidity, incoming long wave radiation and wind speed (heated anemometer)
Icing is dependent on wind speed as wind is transporting the water droplets in the air and forces them to collide with a structure. Currently, first studies are carried to verify if the inclusion of wind speed leads to an improvement of the detection of icing conditions.

Ice Detectors
The most reliable instrument to detect icing conditions is the ice detector. Unfortunately, a comprehensive inter-comparison of commercially available ice detectors on the Guetsch site clearly showed that there is currently no instrument available which reliably and automatically measures ice accretion [10, 11]. However, two promising instruments could be identified (Fig. 4):

- The Combitech Mk I IceMonitor is manufactured according to ISO 12494. It uses a freely rotating vertical cylinder and measures the weight of ice accreted on the probe.
- The Goodrich ice detector 0872J1 has a probe that oscillates at 40 kHz and monitors the frequency change due to ice accretion. A heater melts the ice at regular intervals depending on the accretion rate.

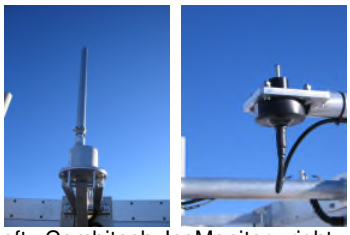


Fig. 4: Left: Combitech IceMonitor, right: Goodrich Ice Detector.

4. Performance of wind turbine under icing conditions

The performance of the wind turbine on Guetsch with respect to power production, ice detection and efficiency of the blade heating was monitored by use of the operational data as well as the installation of web cams monitoring the nacelle anemometer and the rotor blades [12].

4.1. Monitoring of the wind turbine's blade heating
The wind turbine's blade heating is basically controlled by comparison of the turbine's effective power production and the theoretic power production, which is computed from measured wind speed and the turbine's power curve. If icing is detected, the power production is stopped and each blade is heated with a 4 kW hot air fan for 90 minutes. Afterwards, power production is resumed.
In general, the performance analysis of the ice detection showed good results. However, after comparison with the webcam images, it turned out that icing on blades cannot be detected with this method when wind speed is low. Furthermore, this procedure is not suitable for detecting light icing. Therefore, icing might occur at low wind speeds but is only detected when wind speed increases and the turbine resumes power production. Thus, the heating process takes place during a period with high wind speed which makes the loss in power production is higher than if the blade would have been de-iced before. Finally, this approach is not capable to determine if, after a blade heating cycle, the blade is ice-free or not. This makes the automatic restart of the turbine a safety risk.

4.3 Monitoring of the blade heating
In many cases the accreted ice could not be fully removed from the blades, especially from the leading edge, during one heating cycle but only after several additional heating cycles. This resulted in a higher loss in power production and allows the possibility that the wind turbine resumes operation while there is still some ice on the blades: this significantly increases the risk of ice throw. It seems that the heat transfer to the leading edge of the blades should be optimized.

5. Ice throw

As the wind turbine is located close to ski slopes, ice throw is an important safety issue [13]. In order to achieve more information about the ice throw of the wind turbine, the area around the wind turbine was, if accessible, inspected after every icing event by a local person for ice fragments that had fallen off the blades. Distance from and direction relative to the turbine as well as size and weight of the recovered fragments were mapped and, together with photos, collected in a data base.
Until now, more than 200 fragments could be recorded, some of them even during summer time. The maximum distance was 92 m, the maximum weight 1.8 kg. The theoretical maximum distance according to [13] of 135 m was not reached so far. Figure 5 shows the distribution of the ice fragments around the wind turbine.
Approximately 40% of the fragments were found within a distance of 20 m from the wind turbine (rotor diameter 40 m). This makes the area under the blades the most dangerous area concerning ice throw. The studies revealed that Ice throw is a significant safety risk at the Gütsch site. Therefore warning signs have been installed and a nearby

winter walking trail was placed further away from the wind turbine [14].

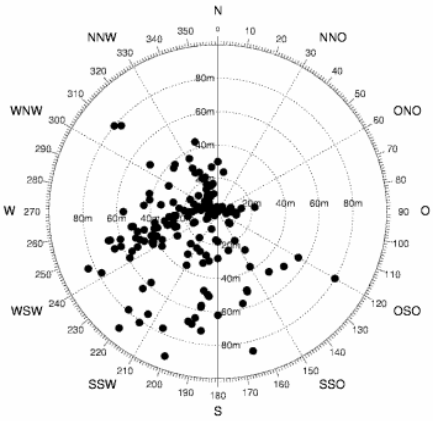


Fig. 5: Distribution of ice throw around the turbine.

6. Conclusions

Concerning the topics discussed in this paper, the following conclusions can be drawn:

- Additional parameters need to be measured for a reliable distinction between meteorological and instrumental icing for a reliable site assessment under icing conditions
- In cloud icing conditions can be detected fairly well by use of air temperature, relative humidity and the sky temperature which is derived from incoming long wave radiation
- Currently, there is no instrument available on the market which is capable of measuring icing reliably. However, the Combitech IceMonitor and the Goodrich Ice detector seem to be promising instruments
- The ice detection of the Enercon E-40 via power curve seems to work considerably well except for light icing and during periods with low wind speed
- This ice detection method gives no information if blades are still iced after heating cycle. This makes the automatic restart a safety risk.
- Often, not all the ice can be melted during one heating cycle, especially at the leading edge of the blades. The heat transfer to the leading edge therefore should be optimized
- Ice throw is a safety risk especially during or right after a blade heating cycle and in the area under the blades

7. Acknowledgments

The authors wish to thank their project partners for the financial and technical support: Swiss State Secretariat for Education and Research, Swiss Federal Offices of Energy and of Transport, Elektrizitätswerk Ursern, Enercon, Kelag and Swisscom.

8. References

[1] Laakso T., Holttinen H., Ronsten G., Tallhaug L., Horbaty R., Baring-Gould I., Lacroix A., Peltola E., Tammelin B., 2003, State-of-the-art of wind energy in cold climates

[2] www.meteotest.ch/cost727/index.html

[3] Cattin R., Kunz S., Heimo A., 2006, Alpine Test Site Gütsch: Monitoring of a wind turbine under icing conditions, Proceedings of DEWEK 2006

[4] Cattin R., Heimo A., Kunz S., Russi G., Russi M., Tiefgraber M., Schaffner S., Nygaard B.E., 2007, Alpine Test Site Guetsch: Meteorological measurements and wind turbine performance analysis, Proceedings of IWAIS 2007

[5] COST Action 727: Memorandum of understanding

[6] Heimo A., Tammelin B, Fikke S, Makkonen L, Kunz S., Cattin R., 2006, COST 727: Measuring and forecasting atmospheric icing on structures, TECO 2006

[7] Fikke S., Ronsten G., Heimo A., Kunz S., Ostrozlik M., Persson P.E., Sabata J., Wareing B., Wichura B., Chum J., Laakso T., Säntti K., Makkonen L., COST-727, Atmospheric Icing on Structures: 2006, Measurements and data collection on icing: State of the Art, Publication of MeteoSwiss, 75, 110 pp.

[8] K. Säntti, B. Tammelin, T. Laakso, E. Peltola, "Experience from measurements of atmospheric icing", BOREAS VI, April 2003

[9] WMO/CIMO: Guide to Meteorological Instruments and Methods of Observation, Chapter 4, Annex 4.A, Item 17

[10] Cattin R., Heimo A., Kunz S., Russi G., Russi M., Tiefgraber M., Schaffner S., Nygaard B.E., 2007, Alpine Test Site Guetsch: Meteorological measurements and wind turbine performance analysis, Proceedings of IWAIS 2007

[11] H. Winkelmeier, Ch. Tiefgraber, A. Wölfler, "Vereisungsmessung Sternwald: Erfassung und Prognose von Vereisungszeiträumen als Grundlage zur Planung von Windkraftanlagen an vereisungsgefährdeten Standorten", Projektbericht zum Förderungsvertrag GZ A2.10354 vom 04.04.2003 im Rahmen der Umweltförderung der Österreichischen Kommunalkredit AG, Sept. 2006

[12] R. Cattin, S. Kunz, A. Heimo, G. Russi, M. Russi, M. Tiefgraber, "Alpine Test Site Guetsch: Monitoring of a wind turbine under icing conditions", DEWEK 2006, Nov. 2006

[13] H. Seifert, A, Westerhellweg, J. Kröning, "Risk analysis of ice throw from wind turbines", BOREAS VI, April 2003

[14] R. Cattin, S. Kunz, A. Heimo, G. Russi, M. Russi, M. Tiefgraber, "Wind turbine ice throw studies in the Swiss Alps", European Wind Energy Conference Milan, May 2007

View publication stats

Four years of monitoring a wind turbine under icing conditions

Cattin René[1], Russi Markus, Russi Gabriela
METEOTEST
Fabrikstrasse 14, 3012 Bern, Switzerland
+41 31 307 26 26, *rene.cattin@meteotest.ch*

***Abstract*— Icing is an important issue when operating wind turbines in high altitude or arctic areas as it can cause significant production losses and represent a safety risk. The Swiss research project "Alpine Test Site Gütsch" which is embedded in the European "COST Action 727: measuring and forecasting atmospheric icing on structures", aims to extend the knowledge on icing on structures in the Swiss Alps.**

The ratio between meteorological and instrumental icing becomes important when the implementation of a blade heating is considered. Therefore, several additional measurement parameters were evaluated for their suitability to deliver this information. The study revealed, that in-cloud icing conditions can be detected fairly well by use of air temperature, relative humidity and the sky temperature, which is derived from incoming long wave radiation. It further showed that there is currently no ice detector on the market which is able to reliably measure icing. The monitoring of the Enercon E-40 wind turbine showed, that the ice detection via power curve seems to work considerably well except for light icing and during periods with low wind speed. However, this method gives no information if blades are still iced after heating cycle. This makes the automatic restart a safety risk. In many cases, not all the ice could be melted during one heating cycle, especially at the leading edge of the blades. The heat transfer to the leading edge therefore should be optimized. An extensive field study on ice throw revealed that ice throw is a safety risk especially during or right after a blade heating cycle and in the area under the blades

I. Introduction

Icing is an important issue when operating wind turbines in elevated or arctic areas as it can cause significant production losses and represent a safety risk [1]. In 2004, a 600 kW Enercon E-40 wind turbine with integrated blade heating was installed on Guetsch mountain, central Switzerland, at 2'300 m asl. Coincidentally, a fully equipped test station of the Swiss meteorological network SwissMetNet was installed about 200 m away from the wind turbine in 2003 (Fig. 1). The immediate proximity of the two facilities operating under icing conditions led to the launch of the research project "Alpine Test Site Gütsch: meteorological measurements and wind turbine performance analysis" [2, 3, 4] which is embedded in the European "COST Action 727: measuring and forecasting atmospheric icing on structures" [5, 6].

Fig. 1: Alpine Test Site Guetsch.

II. Site Description

The test site is located on a ridge in highly complex terrain in the midst of the Swiss Alps at 2'300 m asl. The prevailing wind directions are north and south (Foehn). Winds are very variable and during strong Foehn events, wind speeds can easily reach 120 km/h or more. The long term average monthly air temperature varies from -6.9°C in February to 7.3°C in July and drops below 0°C from November to April. The main icing periods are late autumn and early spring when the temperature often lies around 0°C. Icing can occur throughout the year. In mid winter the temperature can fall below -20°C.

Icing on Guetsch occurs mainly as in-cloud rime icing, mostly when winds from the North lift the humid air of passing fronts over the Guetsch ridge. Icing occurs regularly during winter time, but the ice loads are usually not very high (up to 6 kg/m). The duration of the ice accretion is in the range of hours, the persistence of the ice on unheated structures in the range of hours to single days.

III. Site Assessment under icing conditions

A. Meteorological and instrumental icing

In phase 1 of COST Action 727, a state of the art report about icing measurements was compiled by the members of the action [7]. In this report the following definitions were intro-

duced:

- Meteorological icing M_{icing}: duration of a meteorological event or perturbation which causes icing
- Instrumental icing I_{icing}: duration of the technical perturbation of the instrument due to icing
- Incubation time: delay between the beginning of the meteorological icing and the start of the instrumental icing
- Recovery time: delay between the end of the meteorological icing and the full recovery of the instrument

Figure 2 illustrates how wind measurements are affected by icing according to the definitions described above. From the point when icing conditions are given to the start of the meteorological icing, there is a certain delay until ice accretion at the anemometer begins, the incubation time. When ice accretion has started, the measured values cannot be used anymore for further analysis. Ice is accreted continuously to the sensor until the meteorological conditions for icing are not present anymore. But after the end of the meteorological icing, the ice will remain at the instrument for a certain time until it melts or falls off. This recovery time can be even longer than the period of meteorological icing. Although icing conditions are not given anymore, the readings of the instrument have to be discarded until the end of instrumental icing.

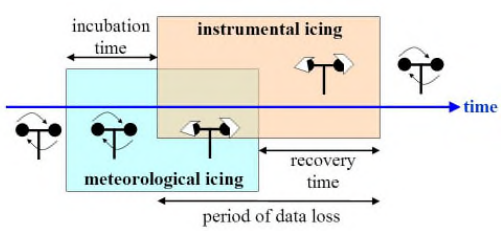


Fig. 2: Meteorological and Instrumental Icing.

B. Importance for wind energy

For wind energy purposes, the ratio between meteorological and instrumental icing becomes important when the implementation of a blade heating is considered. If the periods of meteorological icing are short compared to the following instrumental icing, the use of a de-icing system such as a hot air blade heating or a will lead to a significant increase of power production compared to a wind turbine without such a system. On the other hand, if the periods of meteorological and instrumental icing are about of equal duration, there will be losses in production even with a de-icing system. In such cases only anti-icing systems such as coatings might be the solution to optimize power production. Unfortunately, such systems are not available so far.

IV. Additional Measurement Parameters

A wind resource assessment is often based on wind measurements of an unheated anemometer. Within this data, only instrumental icing is visible when the sensor gets stuck. It is impossible to distinguish between meteorological and instrumental icing. Therefore it cannot be estimated if a blade de-icing or anti-icing system would lead to an economic bene-fit for the operator or not. Several possible additional measurement parameters were evaluated for their suitability to deliver this additional information:

A. Heated vs. unheated anemometer

The comparison between a heated and an unheated anemometer can only give information concerning the duration of instrumental icing as the heated anemometer is (or should be) completely unaffected by icing. But the use of a heated anemometer certainly increases the accuracy of the evaluation of the wind potential itself as wind data is available throughout the whole time.

B. Temperature

Additional measurements of temperature give essential information about the occurrence of extremely low temperatures at the site. However, they cannot say anything about meteorological or instrumental icing as icing must not necessarily occur when temperature falls below 0°C (dry air).

C. Temperature and relative humidity

Measurements of temperature and relative humidity allow an indication about meteorological or instrumental icing. A widely used approach is the simple definition that icing occurs at air temperatures below 0°C and a relative humidity higher that 95%. However, several studies showed that this approach is not able to reliably detect icing conditions [8].

In addition, measurements of relative humidity are mostly performed according to WMO/CIMO standards where saturation water vapor pressure is always calculated with respect to water [9]. Below 0°C, saturation cannot be reached anymore using this procedure (fig. 3). In order to be able to use relative humidity as a parameter for the determination of icing conditions, the readings for relative humidity have to be recalculated with respect to saturation water vapor pressure over ice for temperatures below 0°C.

D. Temperature, relative humidity and incoming long wave radiation

When icing mostly occurs as incloud icing, the approach described above can be improved by use of the incoming long wave radiation L ↓ with a pyrgeometer. This allows the calculation of the sky temperature T_{sky} according to Stefan-Boltzmann's law:

$$T_{sky} = \sqrt[4]{\frac{L\downarrow}{\sigma}} - 273.15 \qquad [°C]$$

$$\sigma = 5.67 \cdot 10^{-8} Wm^{-2} K^{-4}$$

If the cloud base is higher than the wind turbine (or if there are no clouds at all), the sky temperature is lower than the ambient air temperature. If the sky temperature gets close to or is equal to the air temperature at hub height, there is a high prob-

ability that the sensors, e.g. the nacelle of the wind turbine or the tip of the blades are in-cloud (fig. 3).

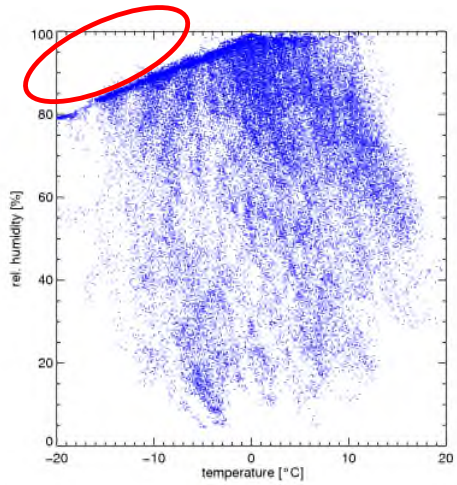


Fig. 3: Relative humidity measured according WMO/CIMO standards does not reach saturation anymore at temperatures below 0°C (red area).

In a first approach, icing conditions were defined as situations with air temperatures below 0°C, relative humidity above 95% and a difference between air temperature and sky temperature of less than 2°C. Data analysis showed promising results. A comparison between the met station and the wind turbine data clearly shows that the wind turbine's nacelle is more often in-cloud than the met station. A comparison of images from the met station and the wind turbine confirmed that icing happens more often and stronger at the nacelle of the wind turbine than at the met station [8]. This underlines the importance of carrying out icing measurements at the specific height of interest (e.g. at hub height for wind turbines).

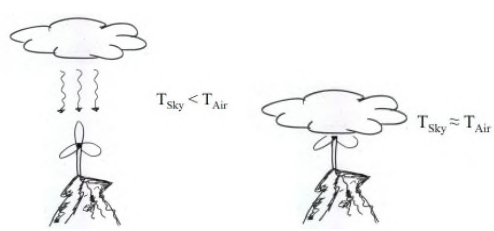


Fig. 3: Left: when the cloud base is higher than the wind turbine's nacelle, the sky temperature is significantly lower than the air temperature at the nacelle. Right: when the sky temperature is approximately equal to the air temperature, there is a high probability that the wind turbine's nacelle is in-cloud.

E. Temperature, relative humidity, incoming long wave radiation and wind speed (heated anemometer)

Icing is dependent on wind speed as wind is transporting the water droplets in the air and forces them to collide with a structure. Currently, first studies are carried to verify if the inclusion of wind speed leads to an improvement of the detection of icing conditions.

F. Ice Detectors

The most reliable instrument to detect icing conditions is the ice detector. Unfortunately, a comprehensive intercomparison of commercially available ice detectors on the Guetsch site clearly showed that there is currently no instrument available which reliably and automatically measures ice accretion [10, 11]. However, two promising instruments could be identified (Fig. 4):

- The Combitech Mk I IceMonitor is manufactured according to ISO 12494. It uses a freely rotating vertical cylinder and measures the weight of ice accreted on the probe.
- The Goodrich ice detector 0872J1 has a probe that oscillates at 40 kHz and monitors the frequency change due to ice accretion. A heater melts the ice at regular intervals depending on the accretion rate.

Fig. 4: Left: Combitech IceMonitor, right: Goodrich Ice Detector.

V. Performance of Wind Turbine under Icing Conditions

The performance of the wind turbine on Guetsch with respect to power production, ice detection and efficiency of the blade heating was monitored by use of the operational data as well as the installation of web cams monitoring the nacelle anemometer and the rotor blades [12].

A. Monitoring of the wind turbine's blade heating

The wind turbine's blade heating is basically controlled by comparison of the turbine's effective power production and the theoretic power production, which is computed from measured wind speed and the turbine's power curve. If icing is detected, the power production is stopped and each blade is heated with a 4 kW hot air fan for 90 minutes. Afterwards, power production is resumed.

In general, the performance analysis of the ice detection showed good results. However, after comparison with the webcam images, it turned out that icing on blades cannot be detected with this method when wind speed is low. Furthermore, this procedure is not suitable for detecting light icing. Therefore, icing might occur at low wind speeds but is only detected when wind speed increases and the turbine resumes power production. Thus, the heating process takes place during a period with high wind speed which makes the loss in power production is higher than if the blade would have been de-iced before. Finally, this approach is not capable to determine if, after a blade heating cycle, the blade is icefree or not. This

makes the automatic restart of the turbine a safety risk.

B. Monitoring of the blade heating

In many cases the accreted ice could not be fully removed from the blades, especially from the leading edge, during one heating cycle but only after several additional heating cycles. This resulted in a higher loss in power production and allows the possibility that the wind turbine resumes operation while there is still some ice on the blades: this significantly increases the risk of ice throw. It seems that the heat transfer to the leading edge of the blades should be optimized.

VI. Ice throw

As the wind turbine is located close to ski slopes, ice throw is an important safety issue [13]. In order to achieve more information about the ice throw of the wind turbine, the area around the wind turbine was, if accessible, inspected after every icing event by a local person for ice fragments that had fallen off the blades. Distance from and direction relative to the turbine as well as size and weight of the recovered fragments were mapped and, together with photos, collected in a data base.

Until now, more than 250 fragments could be recorded, some of them even during summer time. The maximum distance was 92 m, the maximum weight 1.8 kg. The theoretical maximum distance according to [13] of 135 m was not reached so far. Figure 5 shows the distribution of the ice fragments around the wind turbine, figure 6 an example of ice throw which occurred in the middle of the summer.

Approximately 40% of the fragments were found within a distance of 20 m from the wind turbine (rotor diameter 40 m). This makes the area under the blades the most dangerous area concerning ice throw. The studies revealed that Ice throw is a significant safety risk at the Gütsch site. Therefore warning signs have been installed and a nearby winter walking trail was placed further away from the wind turbine [14].

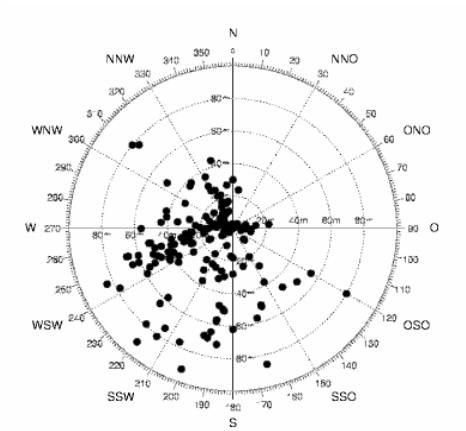


Fig. 5: Distribution of ice throw around the turbine.

Figure 3: Photo of ice fragments

VII. Conclusions

Concerning the topics discussed in this paper, the following conclusions can be drawn:

- Additional parameters need to be measured for a reliable distinction between meteorological and instrumental icing for a reliable site assessment under icing conditions
- In cloud icing conditions can be detected fairly well by use of air temperature, relative humidity and the sky temperature which is derived from incoming long wave radiation
- Currently, there is no instrument available on the market which is capable of measuring icing reliably. However, the Combitech IceMonitor and the Goodrich Ice detector seem to be promising instruments
- The ice detection of the Enercon E-40 via power curve seems to work considerably well except for light icing and during periods with low wind speed
- This ice detection method gives no information if blades are still iced after heating cycle. This makes the automatic restart a safety risk.
- Often, not all the ice can be melted during one heating cycle, especially at the leading edge of the blades. The heat transfer to the leading edge therefore should be optimized
- Ice throw is a safety risk especially during or right after a blade heating cycle and in the area under the blades

VIII. Acknowledgments

The authors wish to thank their project partners for the financial and technical support: Swiss State Secretariat for Education and Research, Swiss Federal Offices of Energy and of Transport, Elektrizitätswerk Ursern, Enercon, Kelag and Swisscom.

IX. References

[1] Laakso T., Holttinen H., Ronsten G., Tallhaug L., Horbaty R., Baring-Gould I., Lacroix A., Peltola E., Tammelin B., 2003, State-of-the-art of wind energy in cold climates

[2] www.meteotest.ch/cost727/index.html

[3] Cattin R., Kunz S., Heimo A., 2006, Alpine Test Site Gütsch: Monitoring of a wind turbine under icing conditions, Proceedings of DEWEK 2006

[4] Cattin R., Heimo A., Kunz S., Russi G., Russi M., Tiefgraber M., Schaffner S., Nygaard B.E., 2007, Alpine Test Site Guetsch: Meteorological measurements and wind turbine performance analysis, Proceedings of IWAIS 2007

[5] COST Action 727: Memorandum of understanding

[6] Heimo A., Tammelin B, Fikke S, Makkonen L, Kunz S., Cattin R., 2006, COST 727: Measuring and forecasting atmospheric icing on structures, TECO 2006

[7] Fikke S., Ronsten G., Heimo A., Kunz S., Ostrozlik M., Persson P.E., Sabata J., Wareing B., Wichura B., Chum J., Laakso T., Säntti K., Makkonen L., COST-727, Atmospheric Icing on Structures: 2006, Measurements and data collection on icing: State of the Art, Publication of MeteoSwiss, 75, 110 pp.

[8] K. Säntti, B. Tammelin, T. Laakso, E. Peltola, "Experience from measurements of atmospheric icing", BOREAS VI, April 2003

[9] WMO/CIMO: Guide to Meteorological Instruments and Methods of Observation, Chapter 4, Annex 4.A, Item 17

[10] Cattin R., Heimo A., Kunz S., Russi G., Russi M., Tiefgraber M., Schaffner S., Nygaard B.E., 2007, Alpine Test Site Guetsch: Meteorological measurements and wind turbine performance analysis, Proceedings of IWAIS 2007

[11] H. Winkelmeier, Ch. Tiefgraber, A. Wölfler, "Vereisungsmessung Sternwald: Erfassung und Prognose von Vereisungszeiträumen als Grundlage zur Planung von Windkraftanlagen an vereisungsgefährdeten Standorten", Projektbericht zum Förderungsvertrag GZ A2.10354 vom 04.04.2003 im Rahmen der Umweltförderung der Österreichischen Kommunalkredit AG, Sept. 2006

[12] R. Cattin, S. Kunz, A. Heimo, G. Russi, M. Russi, M. Tiefgraber, "Alpine Test Site Guetsch: Monitoring of a wind turbine under icing conditions", DEWEK 2006, Nov. 2006

[13] H. Seifert, A, Westerhellweg, J. Kröning, "Risk analysis of ice throw from wind turbines", BOREAS VI, April 2003

[14] R. Cattin, S. Kunz, A. Heimo, G. Russi, M. Russi, M. Tiefgraber, "Wind turbine ice throw studies in the Swiss Alps", European Wind Energy Conference Milan, May 2007

GL Garrad Hassan

TURBINE FAILURE LITERATURE REVIEW AND THE WIND TURBINE CERTIFICATION PROCESS

Client	**Green Mountain Power Corp.**
Contact	Charles Pughe
Document No	41404/AR/03A
Classification	Client's Discretion
Status	Final
Date	18 November 2010

Authors:

M P LeBlanc

Checked by:

P Heraud

Approved by:

B Ait-Driss

IMPORTANT NOTICE AND DISCLAIMER

This report is intended for the use of the Client on whose instructions it has been prepared, and who has entered into a written agreement directly with Garrad Hassan America, Inc. ("GH"). GH's liability to the Client is set out in that agreement. GH shall have no liability to third parties for any use whatsoever without the express written authority of GH. The report may only be reproduced and circulated in accordance with the Document Classification and associated conditions stipulated in this report, and may not be disclosed in any public offering memorandum without the express written consent of GH.

This report has been produced from information relating to dates and periods referred to in this report. The report does not imply that any information is not subject to change.

Key To Document Classification

Strictly Confidential	:	Recipients only
Private and Confidential	:	For disclosure to individuals directly concerned within the recipient's organisation
Commercial in Confidence	:	Not to be disclosed outside the recipient's organisation
GH only	:	Not to be disclosed to non GH staff
Client's Discretion	:	Distribution at the discretion of the client subject to contractual agreement
Published	:	Available to the general public

© 2009 Garrad Hassan America, Inc.

CONTENTS

		Page
1	**INTRODUCTION**	**1**
2	**LITERATURE REVIEW OF TURBINE FAILURES**	**2**
	2.1 Turbine rotor	2
	2.2 Turbine tower	3
3	**THE CERTIFICATION PROCESS**	**4**
	3.1 Safety system	4
4	**CONCLUSIONS**	**5**
REFERENCES		**7**

1 INTRODUCTION

Garrad Hassan America, Inc. ("**GH**") has been contracted by Green Mountain Power Corp. (the "**Client**") to provide a literature review of work relating to wind turbine failure and general information on the certification process of modern wind turbines.

The results of this work are presented in this report.

2 LITERATURE REVIEW OF TURBINE FAILURES

GH has undertaken a literature review of publicly-available sources of turbine failures, in particular turbine rotor and tower failures resulting in full or partial blade throws and tower collapse. GH has concluded that there are very few accounts in the literature of turbine failure and the associated reporting is very limited.

2.1 Turbine rotor

The most up-to-date comprehensive study of this topic can be found in a recent report ("California Report") prepared by the California Wind Energy Collaborative in November 2006 [1]. This report contains an exhaustive literature review of turbine failure rate studies and provides recommendations for assessing the risk of full or partial blade throws. The main types of blade failures are listed as:

- Full blade failure at root connection,
- Partial blade failure from lightning damage, defect or extreme load buckling,
- Failure at outboard aerodynamic device, and
- Failure from tower strike.

Factors attributed to these failures are:

- Unforeseen environmental events outside the design envelope,
- Incorrect design for ultimate or fatigue loads,
- Poor manufacturing quality,
- Failure of turbine control/safety system, and
- Human error.

Most failures are actually reported to be a combination of the above factors and it is reported that the probabilities of some failure events are highly correlated with each other [1].

A Dutch Handbook [2] which compiles the information of two large databases of wind turbines in Denmark and Germany covering turbine operation from the 1980s until 2001 has also been listed in the California Report. The authors of the Handbook analyzed the data and recommended the following risk values for blade failure rates:

- Full blade failure at nominal rotor speed – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~1.25 times nominal rotor speed) – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~2.0 time nominal rotor speed) – 1 in 20,000 turbines per year
- Failure of tip or piece of blade – 1 in 4,000 turbines per year

Documented blade failures and distances were also reported in the Handbook with the maximum distance reported for an entire blade 150 m and for a blade fragment 500 m.

The Handbook authors have compared these recommended blade failure rates to earlier ones developed by European agencies in the earlier 1990s, with the overall blade failure rate declining by a factor of three. The authors of the California Report have commented that "with the maturity of the industry blade failures will continue to decrease."

2.2 Turbine tower

While the California Wind Energy Collaborative [1] Report does not have any conclusions or recommendations specific to turbine tower failures, several sources reviewed suggests the failure rate of tower collapse is somewhat lower than blade failures with the actual area affected being significant less. Factors attributed to tower failures are also quite similar to blade failures and are considered to be:

- Design error in tower or foundation,
- Poor manufacturing quality in tower or foundation,
- Failure of turbine control/safety system (particularly pitch system), and
- Extreme weather/seismic event.

The authors of the Dutch Handbook [2] have also recommended a risk value of 1 in 7,700 turbines per year for tower failure rates. A maximum distance of tower height plus blade length was also reported in the Handbook.

3 THE CERTIFICATION PROCESS

The wind industry de facto standard calls for a turbine to be certified by a recognized certification agency. The two certifications that are commonly used for commercial turbines are:

- Statement of Compliance for Design Assessment according to IEC 61400-1
- Type Certificate according to IEC WT01:2001

The Design Assessment is a thorough review of the design documentation from the turbine manufacturer carried out by the selected certification agency. The design documentation must cover the whole turbine.

A Type Certification is far more comprehensive than a Design Assessment and includes prototype testing and an assessment of the manufacturing process. Therefore, Type Certification is to be preferred.

The Statement of Compliance is issued after review of the machine design using specified components. In order to maintain a valid certificate the machines delivered to site must consist of an assembly of these components. The turbine supplier cannot vary these components and maintain certification. It is therefore important to check that the machines delivered are, indeed, consistent with the certificate and hence with the specification. It is also important to establish, and to check during the manufacturing process, that the turbines delivered are consistent with the certified specification.

This procedure must be followed throughout the life of the machine. The providers of operation and maintenance service must either ensure that all components used for repair or enhancement are in accordance with the original certification or have the certification modified to reflect any alternative components.

The certification process also requires the inspection of the wind turbine on a periodic basis. This would be generally every two years but this may be extended in certain circumstances. Such inspections should include a detailed inspection of blades.

3.1 Safety system

A review and test of the safety system is standard procedure for certification. The design evaluation is performed in accordance with IEC 61400 Part 1. Additional areas including testing, manufacture and foundation design are included in the evaluation for the type certificate.

Compliance with the requirements for turbine safety systems defined in the design standard IEC 61400-1 is verified via certification. Particularly critical to turbine safety is the redundancy of the braking systems.

The control system of the modern wind turbine typically incorporates a number of safety features some of which are listed below:

- Vibration sensor to monitor blade vibrations,
- Vibration sensor to monitor tower vibrations, and
- Vibration sensor to monitor nacelle vibrations.

The controller also typically monitors the relationship between power and wind speed and, in the event of a significant difference from the expected value, the turbine is stopped.

4 CONCLUSIONS

It is the view of GH that the figures proposed in the Dutch Handbook [2] are significantly conservative in the context of current-day commercial wind turbines, because the various root-causes of blade and tower failures have been continuously addressed through developments in best practice in design, testing, manufacture and operation – much of which has been captured in the IEC standards series with which all current large wind turbines comply.

The reduction in failures referred to in the above reports coincides with the widespread introduction of turbine design certification and type approval. This process requires full scale strength testing of every certified design of turbine blades. It also often requires a dynamic test that simulates the complete life loading on the blade. The certification body will also perform a quality audit of the blade manufacturing facilities and perform strength testing of construction materials. This approach has effectively eliminated blade design as a root cause of failures. Unfortunately, this does not mean that blade failures do not occur, but when they do, the root cause is some other factors.

Wind turbine towers are generally simple fabricated structures. The methods used for analysis of the tower structures are well defined in national and international standards. Further guidance on tower design is provided in the IEC 61400 Part 1 standard. The loads applied to towers are dominated by the rotor loads. The design load assumptions are confirmed through load verification that is performed as part of the full Type Approval. The subject turbine has been subject to load verification.

The main causes of blade and tower failures are now a control system failure leading to an over speed situation, a lightning strike or a manufacturing defect in the blade. The latter cause does not often lead to detachment of blade fragments.

Turbine control systems are the subject of rigorous specification in the design standards for wind turbines (IEC 61400-1) and exhaustive analysis in the certification process; hence most systems operate in a safe and reliable manner. Turbines with industry certification must have a safety system completely independent of the control system. The safety system must also have two mutually independent braking systems capable of bringing the rotor speed under control in the event of loss of reaction torque – common in the event of failure of the utility grid connection. Usually the blades pitch to release the aerodynamic torque while a brake is applied to the shaft. In the event of a failure in one system, the other system must be able to control the rotor speed.

Anecdotal information now suggests that the most common cause of a control system failure is human error; where an operator makes an unauthorized adjustment. Many manufacturers recognize this and are now limiting the adjustments that can be made in the field.

Lightning protection systems for wind turbines have developed significantly over the past decade and best practice has been captured in industry standards to which all modern turbines comply. This has led to a dramatic drop in events where lightning causes structural damage.

The occurrence of structural manufacturing defects in rotor blades has also diminished dramatically due to improved experience and quality control in the industry, centered on a small number of companies who make blade manufacture their main or sole business. Design practice has also evolved to improve structural margins against any manufacturing deficiencies. Even in the rare event of blade failure in modern machines, detachment of whole blades is highly unusual.

Wind turbine towers are manufactured in specialty facilities with full Quality Assurance procedures in place. All such procedures will have been subject to verification in accordance with the ISO9001 quality standard.

It is considered that the above developments have substantially reduced the probabilities relating to blade and tower failures from those represented in the Dutch Handbook [2]. This has been necessitated by the increasing trend of locating wind turbines in very close proximity to population – notably in Northern Europe. For less populous sites, this has the effect of making the risk of injury resulting from a blade failure event diminishingly probable and almost certainly on a par with natural hazards. Even with applying the recommended values in the Dutch Handbook [2], it is noted that a previous risk assessment study for a proposed wind farm site in Washington State [3] concluded that the risk of an individual being struck by a modern turbine failure at a distance of 150 m is 1 in 1,000,000.

The literature review undertaken and certification process in place for modern wind turbines lead to the following conclusions:

- It is fully expected that if the site conditions are within the IEC Class design parameters and suitable operation and maintenance program is in place, the probability of turbine structural failure during the operational lifetime is considered to have a dramatically lower probability than represented by figures published in the Dutch Handbook [2] and, for sparsely-populated areas, almost certainly on a par with natural hazards.

- Should a blade failure occur, experience shows that, with modern design and manufacturing techniques, it is much more likely that most parts of the damaged blade will remain attached to the turbine rather than a whole blade detaches.

- The probability of tower failure during the operational lifetime of a certified turbine is considered to have lower probability than blade failures.

REFERENCES

1 "Permitting Setback Requirements for Wind Turbines in California", PIER Interim Project Report, November 2006.

2 H Braam et al., "Hanboek Risicozonering Windturbines", 2nd Edition, January 2005.

3 Daniel Kammen, "Analysis of Potential Safety Risks of the proposed Kittitas Valley Wind Power Project", Exhibit 39-2 before the State of Washington energy facility site evaluation council in the matter of application No. 2003-01.

WIND ENERGY
LARGE WIND
Debunking Myths
Grid Integration
Economic Calculations
Wind Training Courses
SMALL WIND TURBINES
WIND & THE ENVIRONMENT
HISTORY OF WIND POWER
ACCIDENTS & SAFETY

Accidents & Safety

A Summary of Fatal Accidents in Wind Energy

May 1, 2013
Paul Gipe

Note that the article below is out of date. See the most current database for the number of fatal accidents in the wind industry. Below is a summary table from the spreadsheet. Note that there are four other tabs not reproduced here.--Paul Gipe

Summary of Deaths in Wind Energy		
Copyright 2013 by Paul Gipe. All rights reserved. This data is provided as a public service. Please provide full citation.		
01-May-13		
Number of Deaths in Construction (Installation or Removal)	C	2
Number of Deaths in O&M	O&M	18
Number of Deaths of the Public	P	7
Number of Deaths in Manufacturing	Mfg	2
Number of Deaths in Training	T	7
Suicides	S	1
Total		37
Number of Deaths Offshore		6
Number of Deaths in Argentina		2
Number of Deaths in Brazil		1
Number of Deaths in Canada		5
Number of Deaths in China		12
Number of Deaths in Denmark		7
Number of Deaths in Germany		9
Number of Deaths in Great Britain		7
Number of Deaths in Ireland		1
Number of Deaths in the Netherlands		3
Number of Deaths in the New Zealand		1
Number of Deaths in the Portugal		1
Number of Deaths in Spain		2
Number of Deaths in Sweden		1
Number of Deaths in USA		27
Total		79
Age of Youngest Person Killed		3
Age of Oldest Person Killed		85
Median Age of Those Killed		35
Two females		
One member of the public, though not a passerby.		
One pilot.		
One child.		
One documented suicide.		
One prank death.		
Deaths per TWh of Cumulative Generation		0.031
Annual Deaths per TWh of Annual Generation		
Median		0.033
Minimum		0.000

- *Deaths Data Base (qpw)*
- *Deaths Data Base (xls)*

Adapted from the book *Wind Power: Renewable Energy for Home, Farm, and Business*. The information below is presented here so that everyone who works with wind energy, or who contemplates working with wind energy, will carefully weigh their actions. The consequences of error or of ignoring safe work practices can be grave. No portion of any of my books has been as controversial as the recounting of these accidents (And I began doing so in my 1995 book *Wind Energy*). However, no portion of my books has received more heartfelt appreciation than the brief mention made of those killed working with wind energy. Surviving family members have expressed the hope that if by describing the accident of their brother or their father, someone else would be shared the grief they suffered, then the pain would be somewhat diminished.

"We obey the law to stay in business, but we obey the laws of physics to stay alive." Anonymous windsmith.

The capture and concentration of energy--in any form--is inherently dangerous. Wind energy exposes those who work with it to hazards similar to those in other industries. Of course, there are the hazards which, taken together, are unique to wind energy: high winds, heights, rotating machinery and the large spinning mass of the wind turbine rotor. Wind energy's hazards, like its appearance on the landscape, are readily apparent. Wind energy hides no latent killers; no black lung, for example. When wind kills, it does so directly, and with gruesome effect.

In this chapter, we'll first examine the record and glean what we can from fatal accidents with wind energy. Then we'll turn to the tools and practices necessary for working safely with the technology. Unpleasant as the accounts described may be, they emphasize the need to work safely--because your life quite literally depends upon it.

Death in the maw of a wind machine is nothing new. H.C. Harrison recounts in The Story of Sprowston Mill how his great-grandfather, Robert Robertson, was killed in 1842 after becoming entangled in the sack hoist on his English windmill. There are historical accounts of similar deadly accidents in France, and no doubt like tales can be found in other countries where wind energy has been used.

Since its rebirth in the 1970s, wind energy has directly or indirectly killed 20 people worldwide. The first was Tim McCartney, who fell to his death near Depuyer, Montana in 1980 while trying to salvage a 1930s-era windcharger. There are few details on McCartney's death. He was with a co-worker and died two hours later at the hospital in Conrad, Montana. McCartney was followed a few years later by Terry Mehrkam, a pioneering Pennsylvania designer and manufacturer of wind turbines. Mehrkam was killed in late 1981 near Boulevard, California. Unfortunately, Mehrkam was not the last.

A short while later there was a spate of electrocutions. Pat Acker was killed while constructing the foundation for a wind turbine near Bushland, Texas and Jens Erik Madsen was electrocuted while servicing a wind turbine in Denmark. In 1983 Canadian Eric Wright rode an experimental Darrieus wind turbine to his death when it fell over during installation near Palm Springs, California.

1984 was a deadly year. Ugene Stallhut was driving a tractor as a tow vehicle when it flipped over and crushed him on a farm in Iowa. Then Art Gomez was killed while servicing a crane in California's San Gorgonio Pass. The same year J.A. Doucette was crushed to death while unloading a container of tubular towers in the Altamont Pass.

The simple medical description of John Donnelly's death found in the files of his company's insurer fails to describe the horror of his fate. Death by "multiple amputations" sanitizes a truly grisly accident in 1989, a nightmare witnessed by his coworker, who watched helplessly as Donnelley was drawn inexorably into the nacelle's slowly spinning machinery. What made Donnelley's accident even more terrifying for windsmiths everywhere was its cause: Donnelly's lanyard, a device designed to prevent falls, became entangled on the revolving main shaft and dragged him to his death.

Not long after Donnelly's accident near Palm Springs, Dutch homeowner Dirk Hozeman was killed in a like manner. Against professional advice, he climbed to the nacelle of his Polenko turbine in a vain attempt to stop the runaway rotor from destroying itself in a violent winter storm. Tragically, the turbine had been inoperative for two years and had just recently been returned to service. After squeezing into the small nacelle, Hozeman, like Donnelly, became snagged on a turning shaft. Rescue crews retrieved his body the next day, after the wind subsided.

Also in 1989 two men were killed in a single accident on the Danish island of Lolland. Three men were suspended from a crane in a basket when the rotor they were servicing unexpectedly began to move. Two, Leif Thomsen and Kai Vadstrup, were thrown to the ground. The third man dangled from his lanyard 30 meters (100 feet) above ground until rescued. Then in 1991, Thomas Swan, a crane operator, was electrocuted near Tehachapi when the boom on his crane snared a 66,000-volt power line.

Richard Zawlocki fell to his death in 1992 while descending a tower near Palm Springs.

Robert Skarski died in 1993 while installing a small wind turbine at his Illinois home. He was killed when the tower he was on buckled and fell to the ground.

Mark (Eddie) Ketterling was nearly cut in half by a chunk of ice knocked off the interior of a tubular tower in Minnesota in 1994.

Then the series of deadly accidents continued in 1997. Crane operator Randy Crumrine was crushed when his crane collapsed in Sibley, Iowa. Ivan Srrensen fell to his death near Lemvig on Denmark's Jutland peninsula while removing a wind turbine from its tower. And Bernhard Saxen was crushed inside the nacelle of a wind turbine when it flew off the top of its tower at the Kaiser-Wilhelm-Koog test center in Germany.

In a bizarre year 2000 accident, a young parachutist crashed into a wind turbine on the German island of Fehrmarn.

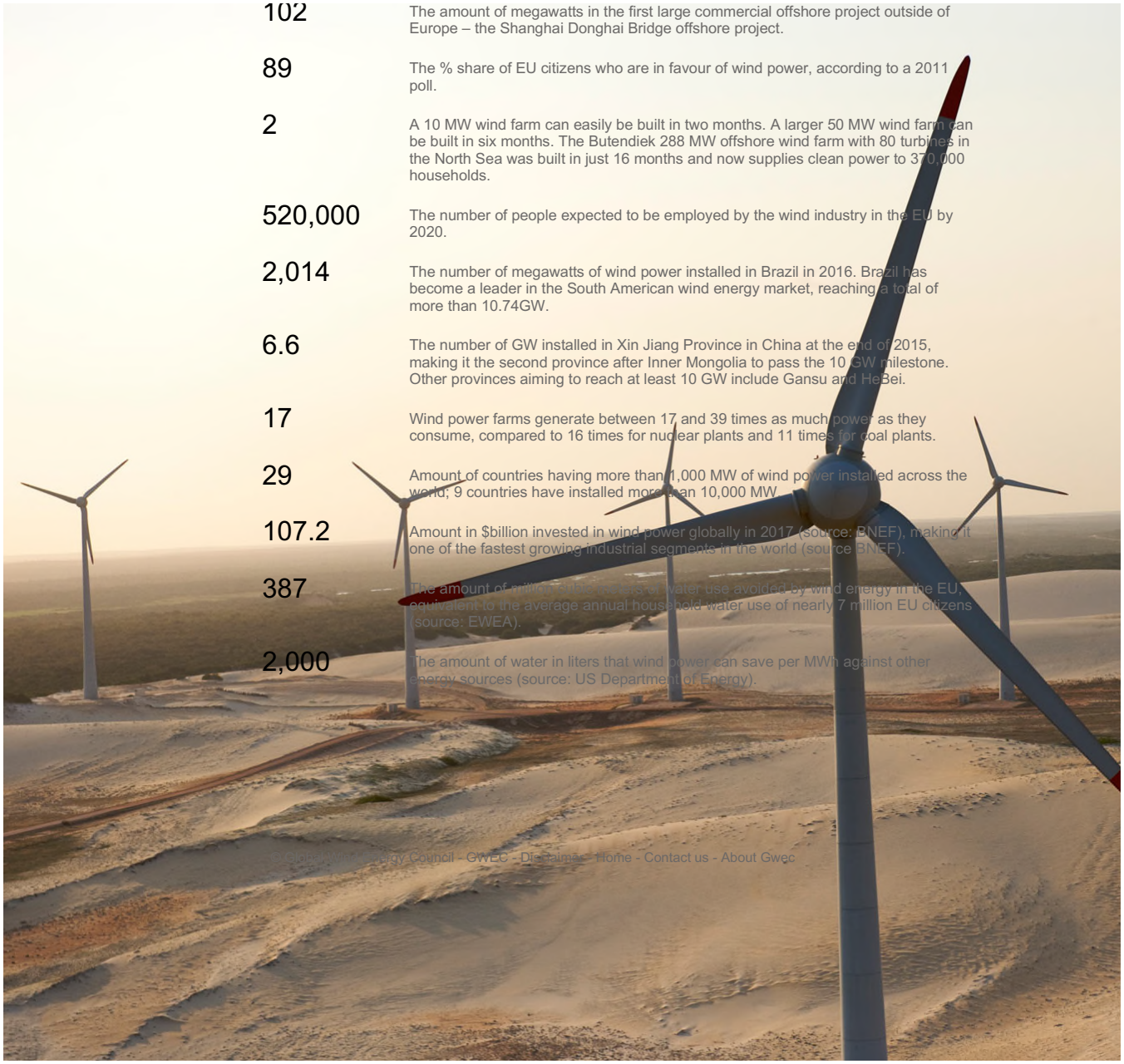
Falling from the tower is the single most apparent occupational hazard of working with wind energy. Industry practice and what some would argue to be common sense suggest that McCartney, Mehrkam, and Zawlocki all made the same fatal mistake: they did not use any form of fall protection. . . *(For more on this topic see Wind Power: Renewable Energy for Home, Farm, and Business.)*

<- Back to: Accidents & Safety

© 10/2011-10/2018 - ALL RIGHTS RESERVED BY WIND-WORKS.ORG - PAUL GIPE - WEBWORK BY *WWW.BEEBOX.COM*

Wind in numbers

1,155,000	Jobs created by the global wind industry at the end of 2016.
55.6	The record number of 55.6GW of wind power installed in 2016, bringing the total installed global capacity to 486.8GW at the end of 2016.
637	In 2016, wind power avoided over 637 million tonnes of CO2 emissions globally.
5,500	The number of average EU households that one 6 MW offshore turbine can power.
8,000	The number of parts a wind turbine has.
10,000,000	The amount of homes powered by wind energy in Spain.
49	The share % of all the electricity used by South Australia in June 2016 was generated by wind power, and on occasions during the month provided all the state's electricity needs.
5,497,522	The amount of avoided CO2 emissions by wind power each year in Brazil.
42.8	China's share of global wind installations in 2016.
37.6	The % of Denmark's electricity consumption was covered by wind energy in 2016. The Danish government aims to run 50% of its electricity from wind by 2020 and 100% from renewable energy by 2050.
341,320	The number of wind turbines spinning around the world at the end of 2016.
104,934	The amount of wind turbines up and running in China at the end of 2016.
52,343	The number of wind turbines in the US at the end of 2016.
3,589	The number of offshore wind turbines in Europe at the end of 2016.
10.4	In an average wind energy year, the EU's current wind power capacity covers 10.4% of the EU's electricity consumption.
14,384	The amount of installed wind power installed globally at the end of 2016 in megawatts.
3	It takes a wind turbine 3-6 months to recoup the energy that goes into producing, operating and recycling the wind turbine after its 20 to 25 year lifetime.
1	The amount of subsidies in USD given to all renewable energy technologies, versus the $USD 6-7 in subsidies given to fossil fuels (IEA World Energy Outlook).
3.7	The percentage of global electricity supplied by wind power in 2015.
51	Wind power installed more than any other form of power generation in Europe in 2016, accounting for 51% of total 2016 power capacity installations.
10,000	A farmer from Iowa who uses one tenth of a hectare for a wind turbine could earn about $USD 10,000 per year, compared to about $USD 300 using the same area to grow corn for ethanol.
17	The cost of integrating large, conventional power plants onto the power system in Texas is more than 17 times larger than the cost of reliably integrating wind energy.
8	The largest wind turbine in the world is the Vestas 8 MW turbine with a rotor diameter of 164 meters.
88.4	The world's longest wind turbine blade is LM Wind Power's 88.4 meters long blade.



102	The amount of megawatts in the first large commercial offshore project outside of Europe – the Shanghai Donghai Bridge offshore project.
89	The % share of EU citizens who are in favour of wind power, according to a 2011 poll.
2	A 10 MW wind farm can easily be built in two months. A larger 50 MW wind farm can be built in six months. The Butendiek 288 MW offshore wind farm with 80 turbines in the North Sea was built in just 16 months and now supplies clean power to 370,000 households.
520,000	The number of people expected to be employed by the wind industry in the EU by 2020.
2,014	The number of megawatts of wind power installed in Brazil in 2016. Brazil has become a leader in the South American wind energy market, reaching a total of more than 10.74GW.
6.6	The number of GW installed in Xin Jiang Province in China at the end of 2015, making it the second province after Inner Mongolia to pass the 10 GW milestone. Other provinces aiming to reach at least 10 GW include Gansu and HeBei.
17	Wind power farms generate between 17 and 39 times as much power as they consume, compared to 16 times for nuclear plants and 11 times for coal plants.
29	Amount of countries having more than 1,000 MW of wind power installed across the world; 9 countries have installed more than 10,000 MW
107.2	Amount in $billion invested in wind power globally in 2017 (source: BNEF), making it one of the fastest growing industrial segments in the world (source BNEF).
387	The amount of billion cubic meters of water use avoided by wind energy in the EU, equivalent to the average annual household water use of nearly 7 million EU citizens (source: EWEA).
2,000	The amount of water in liters that wind power can save per MWh against other energy sources (source: US Department of Energy).

© Global Wind Energy Council - GWEC - Disclaimer - Home - Contact us - About Gwec

This foregoing document was electronically filed with the Public Utilities

Commission of Ohio Docketing Information System on

10/25/2018 11:56:55 AM

in

Case No(s). 18-0488-EL-BGN

Summary: Response of Seneca Wind, LLC to Staff's Second Set of Data Requests electronically filed by Teresa Orahood on behalf of Devin D. Parram