Summary of a Technical Validation of ENERCON’s Rotor Blade De-Icing System

Project-No.: VC10019

Report-No.: PP11035, Version 2

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1 Introduction

In certain weather conditions, ice, white frost or snow can build up on the rotor blades of wind energy converters (WECs). This commonly occurs at times of low temperatures (< 0°C) and at the same time high air humidity, rain or snow. Water droplets freeze on the rotor blade surface and cause ice formation. White frost build-up on the rotor blade surface occurs when the rotor blades pick up airborne frozen particles such as water droplets that adhere to the rotor blade surface.

Ice formation adversely affects the aerodynamic properties and hence the energy yield. It causes imbalances of the rotor rotation and additional stress on the WEC due to higher loads on the blades.

WECs will therefore shut down when ice build-up is detected. The wind turbine manufacturer ENERCON GmbH (ENERCON) equips its WECs with a reliable internal ice detection system.

ENERCON has for years optionally offered a rotor blade de-icing system which can reduce the downtimes due to icing significantly. Heating the rotor blades by re-circulating heated air melts the ice at an early stage and the WEC is operational much sooner.

ENERCON offers the rotor blade de-icing for its E-44, E-48, E-53, E-70, E-82 and E-101 series of wind energy converters.

Deutsche WindGuard Consulting GmbH (DWG) has been commissioned by ENERCON for an independent technical validation of the performance of the ENERCON rotor blade de-icing system based on two wind farms in northern and central Europe respectively (Figure 1). The main findings of the validation are summarised in this report. Details of the validation are presented in DWG's report PP11009 on 2011-02-08. Health and Safety aspects have not been evaluated in this study.

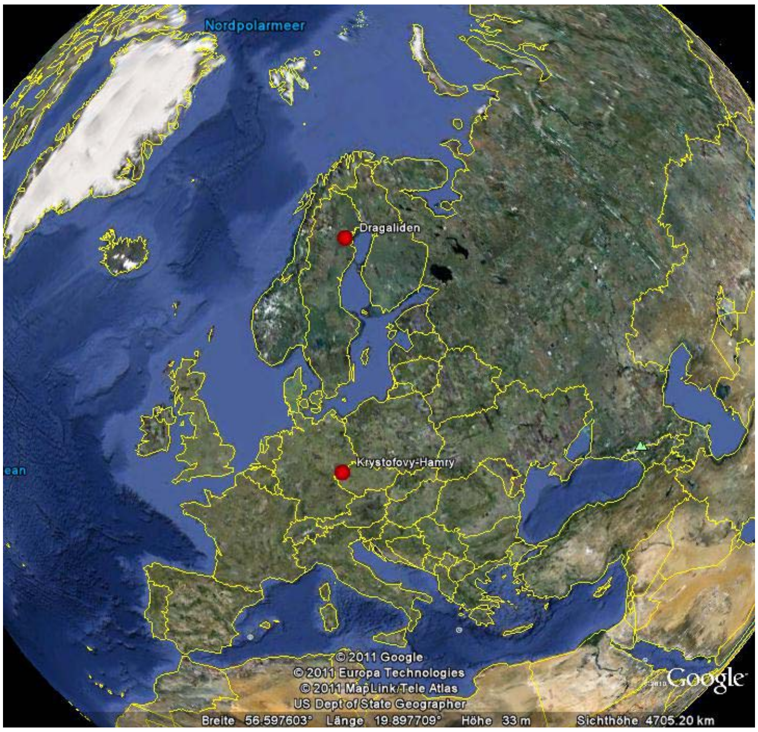

Figure 1: Wind farm sites Dragaliden, Sweden, and Krystofovy-Hamry, Czech Republic

This report covers 20 pages (including front cover).

2 Technology

2.1 Operating Principle of the ENERCON Ice Detection System

Rotor blades use high-grade aerodynamic profiles providing for optimal efficiency within a wide operating range. The aerodynamic properties of these profiles are very sensitive to contour and roughness changes caused by ice build-up. The resulting significant change in the WECs operating properties (interrelation of wind / rotational speed / power / blade angle) is used to detect ice build-up. For this purpose, interlinked WEC-specific values (wind / output / blade angle) are recorded on site as long-term mean values at temperatures above +2°C on the nacelle. When temperatures fall below +2°C (icy conditions), the current operating data is compared to WEC internal memory of site specific long-term mean values.

An empirically determined tolerance range is applied to the WEC specific wind/power and wind/blade angle curves. This is based on simulations, tests, and several years of experience with numerous WECs of different types. If the operating data of power or blade angle determined as an exponential average is outside the tolerance range, the WEC is stopped with main status 14 (ice detection).

The type of deviation from the tolerance range is also analysed and displayed as a sub status.

A measured power average below the power range indicates icing on the rotor. The WEC stops with Status 14:11 (ice detection: Rotor [power measurement]).

In the event of ice build-up on the anemometer, the measured power average may rise above the power range. In this case, the WEC stops with Status 14:12 (ice detection: Anemometer [power measurement]) because it must be assumed that ice has formed not only on the anemometer but also on the rotor blades. From 2011 onwards, all ENERCON WECs are equipped with heated ultrasonic anemometers, as these are hardly influenced by icing.

The pitch angle at rated power is smaller when there is ice build-up than when the blades are free of ice. A measured blade angle average below the blade angle range indicates icing of the rotor. The WEC stops with Status 14:13 (Ice detection: Rotor [blade angle]).

As with the power measurement, a measured blade angle average above the blade angle range indicates icing on the wind measuring unit. In this case, the WEC stops with Status 14:14 (Ice detection: Anemometer [blade angle]) since potential ice build-up on the rotor blades cannot be excluded. In this way, detection of ice formation across the entire wind speed range is ensured.

Because of the narrow tolerance range, the WEC is usually stopped within 30 minutes after icing is indicated.

2.2 Restarting the WEC Without the Rotor Blade De-Icing System

Automatic wind energy converter restart is not possible until the ice has melted and the outside temperature has risen above +2°C. The time required to de-ice the blades is calculated based on the outside temperature. During this period, the wind energy converter does not start-up automatically. An early manual restart is only possible directly at the WEC after an appropriate visual check. In this event, the operator/owner will be liable for any resulting hazard.

It is assumed that the ice will only melt at outside temperatures above +2°C. The time required for the ice to melt is determined depending on the outside temperature and based on empirical values so that when the WEC is restarted, the hazards due to icing on the rotor blades are minimised. Therefore, several hours may pass until restart of the WEC.

2.3 Technical Description Rotor Blade De-Icing

ENERCON offers two different operating principles for the rotor blade de-icing system, one for the de-icing of a WEC at standstill, one for the operating WEC. The following paragraphs describe the different operating modes of the rotor blade de-icing system.

In each rotor blade, a fan heater installed on additional webs near the blade flange (see Figure 2) heats up the air inside the rotor blades to a maximum of 72°C. The interior of ENERCON rotor blades is subdivided by webs. These webs are used to guide a re-circulating hot air stream passing through the rotor blade (Figure 3). From the fan heater, the heated air flows directly along the blade's leading edge profile to the blade tip and then back between the main webs to the blade flange. The returning air is then reheated and passed into the rotor blade. In this way, the blade's leading edge profile is heated up to a point above freezing, allowing ice build-up on the blade to melt.

Each rotor blade is equipped with an individual rotor blade de-icing system.

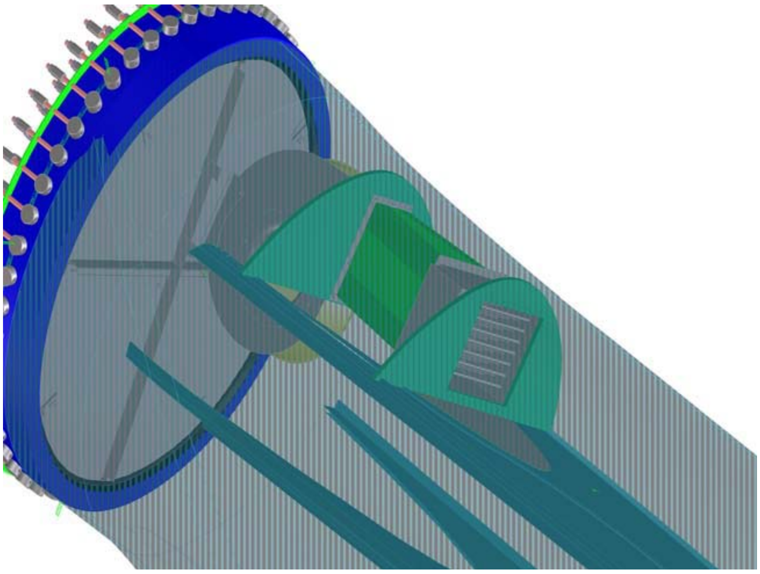

Figure 2: Fan heater integrated into the rotor blade

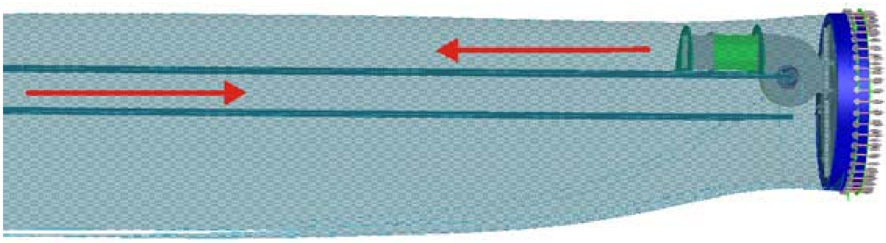

Figure 3: Representation of airflow

2.3.1 Power Input

The wind energy converter's own power consumption increases while the rotor blade de-icing system is active. Rated power (i.e., maximum power input) depends on the WEC type (Table 1).

Power input can be capped. This requires appropriate adjustment of the WEC control system settings. However, reducing the power input will also reduce the efficiency of the rotor blade de-icing system.

Table 1: Power consumption of rotor blade de-icing system

Wind Energy Converter	Rated Power Per Blade (kW)
E-44 / E-48 / E-53	12.2
E-70 E4	23.8
E-82 / E-82 E2 / E-82 E3	28.8
E-101	Under development

2.3.2 Operating Principle Rotor Blade De-Icing – WEC at Standstill

As a rule, the rotor blade de-icing system runs in automatic mode. However, it can also be activated manually. While in automatic mode, once the ENERCON ice detection system (power curve method) detects ice formation and the wind energy converter is shut down, the rotor blade de-icing system is automatically activated. The WEC starts up automatically after a heating period defined by means of the WECs control system. If ice is still detected on the rotor blades after the restart, the WEC will shut down again and initiate the de-icing process once more.

Since rotor blade de-icing is not intended for sites where potential ice throw causes a considerable safety hazard in the surrounding area, the de-icing system cannot be activated by means of the optionally available onboard ice sensor of type Labko.

Automatic mode cannot be activated if the automatic restart after icing function is disabled. This is typically the case in WECs at sensitive sites where automatic rotor blade de-icing is not permitted.

In manual mode, the rotor blade de-icing system must be manually activated once ice formation has been detected. The rotor blade de-icing system is then in operation for a defined period of time. This period can be extended or shortened as required.

After the heating period, the wind energy converter will start up automatically if the automatic restart after icing function is enabled.

2.3.3 Technical Description Rotor Blade De-Icing – Running WEC

The technical details like heaters, power consumption and the rotor blades are the same as the rotor blade de-icing system for a WEC at standstill as described before.

In automatic mode, the rotor blade de-icing system is activated with the WEC still running once ice formation is detected, provided that de-icing is permitted with the WEC still running. In this mode, the rotor blade de-icing system will be activated by a secondary ENERCON ice detection system, which is operated with a narrower tolerance range than for WECs without rotor blade de-icing system. This will detect and melt even thin ice build-up at an early stage. If, in extreme weather conditions (e.g. freezing rain), ice build-up continues to grow despite activation of the rotor blade de-icing system, the wind energy converter will be stopped by the regular ENERCON ice detection system responding.

The rotor blade de-icing system will continue operating for another 20 minutes (shut-off delay) after the ice detection system no longer detects any icing.

The de-icing process will be repeated as soon as new ice build-up is detected.

Manual operation in a running WEC is also possible. In this case, the rotor blade de-icing system must be activated manually. The rotor blade de-icing system will then operate for a pre-defined period of time and shut off automatically afterwards.

3 Description of Test Sites

An evaluation of the efficiency of the rotor blade de-icing system was performed during the winter 2009/2010 at a wind farm site in northern Sweden (Dragaliden) and in the Czech Republic (Krystofovy-Hamry). Both sites have a high potential for production losses due to icing in the winter period. On each site, two ENERCON E-82 2.0 MW wind energy converters with hub heights of 108 m (Dragaliden) and 78 m (Krystofovy-Hamry) were used for the evaluation. Each WEC was equipped with the ENERCON rotor blade de-icing system, while only one WEC on each site was operated with the system activated. The installed rotor blade de-icing systems had a power consumption of 23.8 kW per blade (slightly less than the standard system according to Table 1).

3.1 Site Description Dragaliden (Sweden)

Dragaliden is a heavily forested site in northern Sweden, approximately 47 km west of Piteå (Figure 1). The two WECs are located at a terrain altitude of 378 m and 355 m respectively, 363 m distant from each other. A summary of site parameters is given in Table 2.

Table 2: Site description Dragaliden, Sweden

Feature	Test WEC With Blade De-Icing System	Considered WEC Without Blade De-Icing System
Type of WEC	ENERCON E-82 2.0 MW	ENERCON E-82 2.0 MW
Tower height	108 m	108 m
Serial number	821160	821159
WEC number in wind farm	2	1
Coordinate East	20.518563°	20.513877°
Coordinate North	65.45017°	65.452784°
Altitude	378 m	355 m
Distance between WECs	363 m	
Evaluated Period (Energy metering data)	2009-10-20 – 2010-03-31	
Evaluated Period (SCADA data)	2009-11-26 – 2010-03-31	

3.2 Site Description Krystofovy-Hamry (Czech Republic)

The site is characterised as a plateau with open appearance, located at the German-Czech border in the Erz-mountains. The test WECs are situated in a terrain altitude of approximately 850 m, being 274 m distant from each other. A summary of site parameters is given in Table 3.

Table 3: Site description Krystofovy-Hamry, Czech Republic

Feature	Test WEC With Blade De-Icing System	Considered WEC Without Blade De-Icing System
Type of WEC	ENERCON E-82 2.0 MW	ENERCON E-82 2.0 MW
Tower height	78 m	78 m
Serial number	82268	82269
WEC number in wind farm	10	11
Coordinate East	13.144637°	13.147078°
Coordinate North	50.444906°	50.442993°
Altitude	848 m	851 m
Distance between WECs	274 m	
Evaluated Period (Energy metering data and SCADA-data)	2009-11-01 – 2010-04-06	

4 Description of Provided Data

4.1 Energy Metering Data

Energy metering data was provided by ENERCON for evaluation of the performance of the WECs on both sites. The period from 2009-10-20 to 2010-03-31 (Dragaliden) and 2009-11-01 to 2010-04-06 (Krystofovy-Hamry) was used for the evaluation.

The provided data showed the net energy production (the energy production minus the internal consumption including the rotor blade de-icing system). The consumption from the grid (under periods of no production) was not recorded in this setup. The same applies to periods when the WEC produced at low levels and still imported energy from the gird in order to operate the rotor blade de-icing system. Events in which energy was imported from the grid were excluded from the evaluation of the performance accordingly.

4.2 SCADA-Data

10-minute time series of the wind farm SCADA-system was provided by ENERCON for each of the two test WECs at the sites Dragaliden and Krystofovy-Hamry for the winter period 2009/2010. The data includes all measurement signals as needed for a detailed validation of the efficiency of the rotor blade-de-icing system, like power output data, wind speed as measured by the nacelle anemometer, status signals of the blade de-icing system, status signals of the ice detection system, air temperature data, relative air humidity data and in case of the site Krystofovy-Hamry data from an external ice sensor (not belonging to the blade de-icing system).

In case of the test site Krystofovy-Hamry, the SCADA-Data covers the same period than the energy metering data (Table 3). In case of the wind farm Dragaliden, the analysis of the SCADA-data had to be limited to the period after 2009-11-25 as the status signals of the blade de-icing system were not functioning before.

5 Results

5.1 General Functioning of the System

The ENERCON Ice Detection System operated well and reliable, indicating icing events on both WECs at the same time exemplified for the Krystofovy-Hamry site. This was also proven in comparison to an external LABKO ice sensor mounted on one of these WECs.

The combination of the ENERCON ice detection system with the ENERCON rotor blade de-icing system proved being reliable and effective.

The rotor blade de-icing system heated the blades sufficiently to increase the internal rotor blade temperature to levels above 0°C during the given test conditions. The infrared heat images pictures in Figure 4 show the rotor blade surface temperatures at ambient temperatures between -1°C and -3°C after different periods of heating (17 h, 3 h and less than 1 h). Build-up of ice was effectively prevented on the critical parts of the rotor blade and WEC.

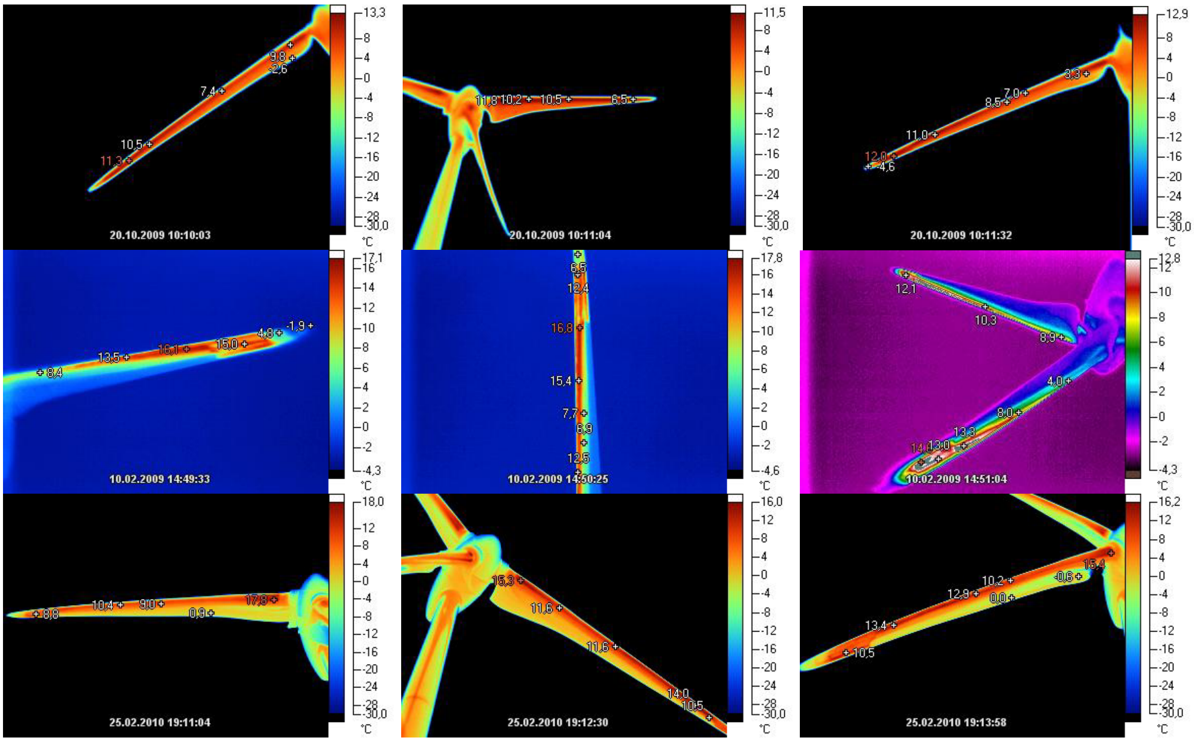

Figure 4: infrared heat images of heated rotor blades;
upper row: test site Dragaliden on 2009-10-20 at air temperatures of around -3°C after about 17 hours of heating during operation of the WEC
middle row: test site Krystofovy-Hamry on 2009-02-10 at air temperatures of around -3°C after about 3 hours of heating
lower row: test site Krystofovy-Hamry on 2010-02-25 at air temperatures of around -1°C after a short heating period (less than 1 hour)

A photographic analysis of the performance of the rotor blade de-icing system showing the outside of the rotor blade proved the absence of ice on the critical sections of the rotor blade, having only minor icing on the trailing edge of the rotor blade remaining (Figure 5). Only at very harsh icing conditions, the system is unable to de-ice the rotor (Figure 6).

Figure 5: test site Dragaliden on 2008-01-01; upper photos: with unheated blade at WEC 1 (left) and heated blade at WEC 2 (right), photo below: heated nacelle anemometer at WEC 2

Figure 6: example of extreme icing conditions at the wind farm Krystofovy-Hamry, left: nacelle anemometer and air temperature sensor of a test WEC on 2010-01-14 14:45, right: heated rotor blade of a test WEC at the wind farm Krystofovy-Hamry on 2010-01-15 12:26

The combination of the ENERCON ice detection system, the ENERCON rotor blade de-icing system and the heated ultrasonic anemometers kept the WECs mostly operational, whereas the unheated rotor blades caused a standstill and thus effective production losses.

5.2 Evaluation of Production Metering Data

The energy metering data of the WEC with blade de-icing system and the adjacent WEC without blade de-icing system is compared for the sites Dragaliden (Table 4, Figure 7) and Krystofovy-Hamry (Table 5, Figure 8).

On both sites, the WEC with the rotor blade de-icing system in operation produced significantly more energy than the corresponding WEC. The mean deviation in the production amounts to about 50 % and 46 % of the production of the WEC without blade de-icing system in case of the test sites Dragaliden and Krystofovy-Hamry, respectively. In single months, the deviation in production was even higher (Table 4 and 5). It is noted that the energy metering data includes the energy consumption of the blade de-icing system for the cases where the energy production of the WECs exceeds the self-consumption of the WEC.

The results clearly show the benefit of the rotor blade de-icing system on sites where the operator of a wind farm faces severe losses in production due to icing.

Table 4: Comparison of the energy metering data of the WECs with and without rotor blade de-icing system in Dragaliden, Sweden. In the period 2009-11-09 to 2009-11-22 the energy production of WEC 2 has been replaced by the energy production of WEC 1 as in this period the blade de-icing system of WEC 2 was switched off and the blade de-icing system of WEC 1 was switched on.

Starting Date	End Date	Energy Production [kWh]		Gain in Production by De-Icing System	Relative Gain in Production by De-Icing System
		WEC 2 (heated)	WEC 1 (no heating)	[kWh]	[%]
2009-10-20	2009-10-31	110251	77934	32317	41.5
2009-11-01	2009-11-30	397603	324661	72942	22.5
2009-12-01	2009-12-31	490840	211513	279327	132.1
2010-01-01	2010-01-31	675976	353515	322461	91.2
2010-01-31	2010-02-26	411511	253903	157608	62.1
2010-02-26	2010-03-31	645927	595132	50795	8.5
2009-10-20	**2010-03-31**	**2732108**	**1816658**	**915450**	**50.4**

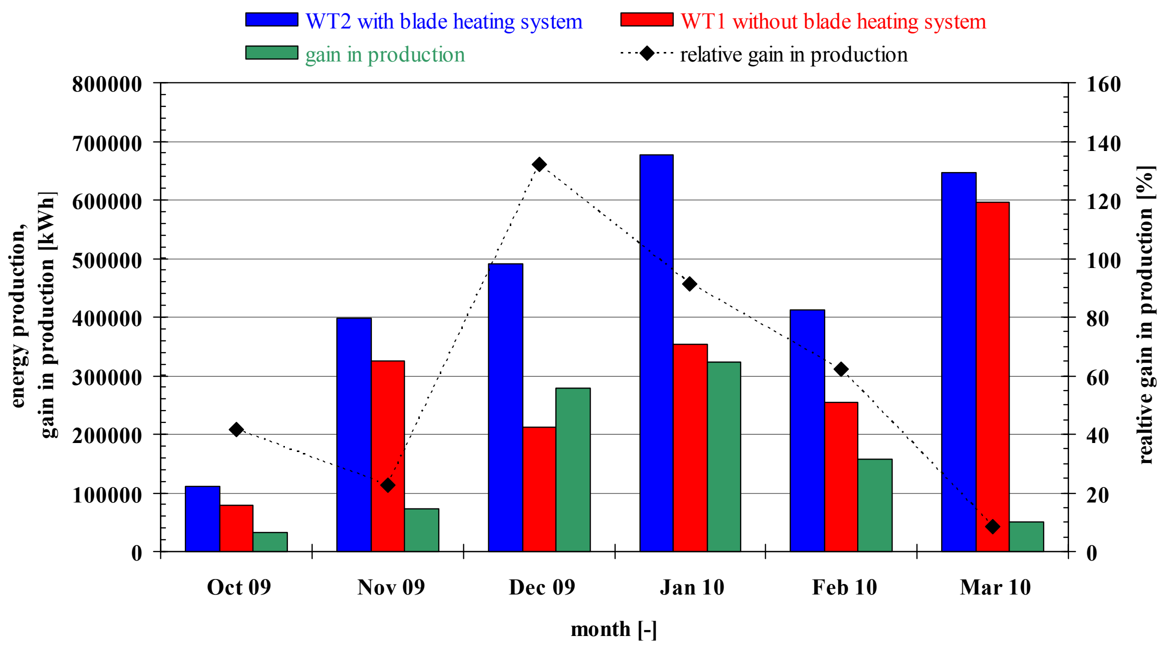

Figure 7: Comparison of the energy metering data of the WECs with and without the rotor blade de-icing system in Dragaliden, Sweden. In the period 2009-11-09 to 2009-11-22 the energy production of WEC 2 has been replaced by the energy production of WEC 1 as in this period the blade de-icing system of WEC 2 was switched off and the blade de-icing system of WEC 1 was switched on.

Table 5: Comparison of energy metering data of the WEC with and without rotor blade de-icing system at the site Krystofovy-Hamry, Czech Republic

Starting Date	End Date	Energy Production [kWh]		Gain in Production by De-Icing System	Relative Gain in Production by De-Icing System
		WEC 10 (heated)	WEC 11 (no heating)	[kWh]	[%]
2009-11-01	2009-11-30	500839	430993	69846	16.2
2009-12-01	2009-12-31	416693	284686	132007	46.4
2010-01-01	2010-01-31	280959	15045	265914	1767.5
2010-02-01	2010-02-28	335896	249403	86493	34.7
2010-03-01	2010-03-31	624609	485958	138651	28.5
2010-04-01	2010-04-06	68423	60638	7785	12.8
2009-11-01	**2010-04-06**	**2227419**	**1526723**	**700696**	**45.9**

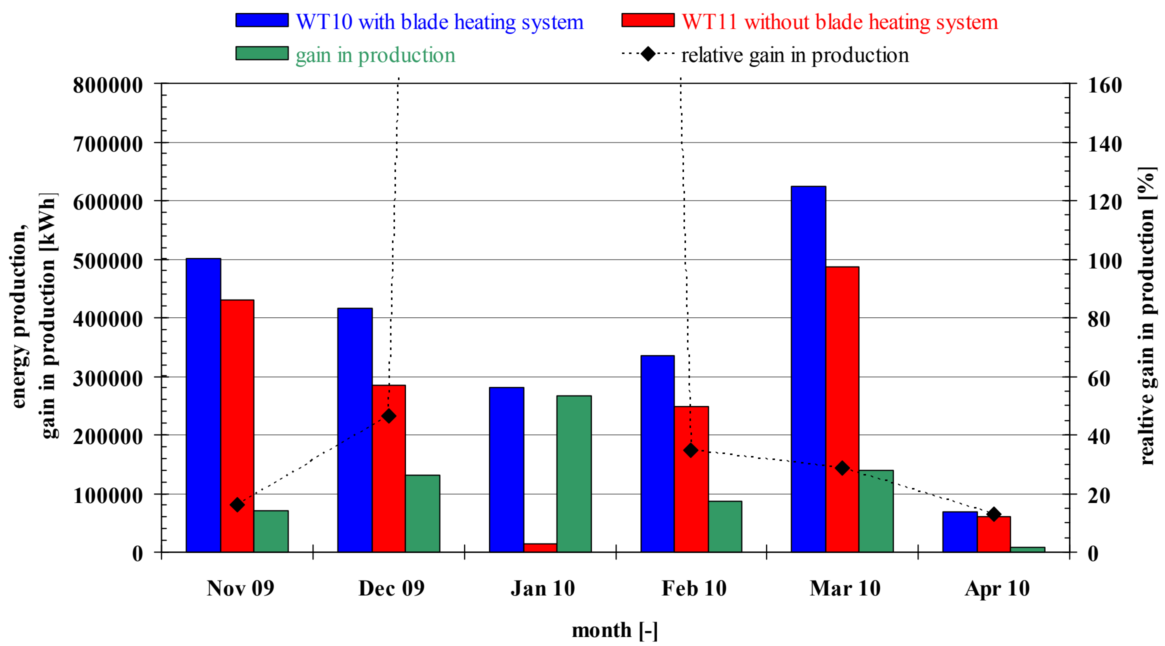

Figure 8: Comparison of energy metering data of the WEC with and without the rotor blade de-icing system at the site Krystofovy-Hamry, Czech Republic

5.3 Evaluation of SCADA Time Series Data

The SCADA-data allowed a more detailed analysis of the efficiency of the rotor blade de-icing system. Basically, the actual energy production of the WEC with blade de-icing system has been considered as gain in energy production due to the blade de-icing system for such periods where the WEC with blade de-icing system had no iced rotor blades according to status signals while at the same time the adjacent WEC without blade de-icing system had iced rotor blades according to the status signals. The results of this analysis are summarised in

Table 6 and Table 7 for the sites Dragaliden and Krystofovy-Hamry, respectively. Key outcome of this analysis is:

- Turbine standstill due to icing was reduced respectively by a factor of 14.0 and 5.6 at the WEC with rotor blade de-icing system in comparison to the WEC without this system at the sites Dragaliden and Krystofovy-Hamry.
- The WECs with rotor blade de-icing system had only rare events with blade icing of 2.4 % and 4.4 % of the analysed period respectively in case of the wind farm Dragaliden and Krystofovy-Hamry despite the very cold winter 2009/2010.
- The gain of energy production by the application of the rotor blade de-icing system exceeded the energy consumption of the rotor blade de-icing system by a factor of 12.1 and 7.2 at the sites Dragaliden and Krystofovy-Hamry, respectively.
- The rotor blade de-icing system has led to a gain in the energy production by 50.0 % in case of the wind farm Dragaliden and 25.7 % in case of the wind farm Krystofovy-Hamry. In this respect, the numbers deviate from the results gained based on the net energy metering shown in chapter 5.2 because of deviations in the analysed periods and because the ice detection system seems not to reflect all events of rotor blade icing completely.

Overall, the combination of the ENERCON ice detection system with the ENERCON rotor blade de-icing system proved to be reliable and effective.

Table 6: results of the analysis of the efficiency of the blade de-icing system at the wind farm Dragaliden on the basis of SCADA-data in the period 2009-11-26 to 2010-03-31

Feature	Unit	WEC 2	WEC 1
heating system implemented	[-]	yes	no
analysed period	[-]	2009-11-26 – 2010-03-31	
duration analysed period	[h]	2209.8	2209.8
standstill due to icing	[h]	52.5	734.8
percentage of standstill due to icing	[%]	2.4	33.3
duration of heating	[h]	666.4	
operating hours of WEC 2 while WEC 1 iced	[h]	687.3	-
gain in production by heating system (energy produced by WEC 2 while WEC 1 iced)	[MWh]	582.0	-
total produced energy	[MWh]	1747.2 (166.1%)	1051.7
relative gain in production by heating system	[%]	50.0	-
estimated heating energy	[MWh]	47.7	-
net gain in production	[MWh]	534.4	-
relative net gain in production	[%]	45.9	-
production when no icing of WEC 2 and WEC 1	[MWh]	1162.5 (111.1%)	1046.2

Table 7: results of the analysis of the efficiency of the blade de-icing system at the wind farm Krystofovy-Hamry on the basis of SCADA-data in the period 2009-11-01 to 2010-04-06

Feature	Unit	WEC 10	WEC 11
heating system implemented	[-]	yes	no
analysed period	[-]	2009-11-01 – 2010-04-06	
duration analysed period	[h]	3687.8	3687.8
standstill due to icing	[h]	161.3	910.0
percentage of standstill due to icing	[%]	4.4	24.7
duration of heating	[h]	888.7	
operating hours of WEC 10 while WEC 11 iced	[h]	797.5	-
gain in production by heating system (energy produced by WEC 10 while WEC 11 iced)	[MWh]	452.9	-
total produced energy	[MWh]	2215.5 (144.4%)	1534.7
relative gain in production by heating system	[%]	25.7	-
estimated heating energy	[MWh]	63.6	-
net gain in production	[MWh]	389.3	-
relative net gain in production	[%]	22.1	-
production when no icing of WEC 10 and WEC 11	[MWh]	1759.4 (114.8%)	1532.2

5.4 Evaluation of the Long-Term Value of the Rotor Blade De-Icing System in Case of the Test Wind Farms Dragaliden and Krystofovy-Hamry

The results of the analysis summarized in chapters 5.2 and 5.3 are valid only for the very cold winter 2009/2010. DWG has developed a procedure to evaluate the efficiency of the rotor blade de-icing system as to be expected in a long-term. This procedure has been applied to the sites Dragaliden and Krystofovy-Hamry, i.e. the efficiency of the system has been reconstructed for the 9-year period July 2001 to June 2010 at the site Dragaliden (Table 8) and for the 10-year period July 2000 to June 2010 at the site Krystofovy-Hamry (Table 9). According to this analysis, the rotor blade-dicing system leads to an improvement of the long-term annual energy production of about 12 % and 9 % at the sites Dragaliden and Krystofovy-Hamry, respectively.

Table 8: expected long-term efficiency of the rotor blade de-icing system at the wind farm Dragaliden

Feature	Unit	WEC 2	WEC 1
heating system implemented	[-]	yes	no
analysed long-term period	[-]	2001-07-01 – 2010-06-30	
standstill due to icing	[%]	1.4	13.7
gain in production by heating system	[%]	11.8	
net gain in production	[%]	10.8	
icing losses despite heating	[%]	1.2	
duration of heating	[h/a]	1268.7	
estimated heating energy	[MWh/a]	90.6	

Table 9: expected long-term efficiency of the rotor blade de-icing system at the wind farm Krystofovy-Hamry

Feature	Unit	WEC 10	WEC 11
heating system implemented	[-]	yes	no
analysed long-term period	[-]	2000-07-01 – 2010-06-30	
standstill due to icing	[%]	1.6	9.2
gain in production by heating system	[%]	9.1	
net gain in production	[%]	7.8	
icing losses despite heating	[%]	1.2	
duration of heating	[h/a]	832.2	
estimated heating energy	[MWh/a]	59.4	

6 Conclusions

ENERCON has since 2002 installed several hundred rotor blade de-icing systems worldwide. The ENERCON rotor blade de-icing system has been developed and continuously improved by ENERCON and works on the basis of the internal ENERCON ice detection system which is a standard for ENERCON WECs. The ENERCON ice detection system has been installed in more than 15,000 WECs worldwide since the 1990's. Deutsche WindGuard Consulting GmbH has been commissioned by ENERCON to undertake an independent technical validation of the de-icing system. This validation did not consider health and safety factors.

One wind farm in northern Sweden and one in the Czech Republic, both equipped with ENERCON E-82 2.0 MW wind energy converters, each equipped with the rotor blade de-icing system, were chosen for the evaluation of the system. On each site, one WEC was operated with the de-icing system in operation, whereas the other WEC was operated without. The performance of the WECs was monitored during the winter 2009/2010 for a minimum of 4 months.

The results clearly stated the high efficiency of the rotor blade de-icing system in combination with the ENERCON ice detection system. At the sites Dragaliden, Sweden and Krystofovy-Hamry, Czech Republic the system has proven to avoid more than 90 % and 80 % of all rotor blade icing events, respectively. The WEC with blade de-icing system produced about 50 % and 46 % more energy than an adjacent WEC without rotor blade de-icing system in the winter 2009/2010 at the sites Dragaliden and Krystofovy-Hamry, respectively. A detailed analysis of the SCADA-data and of the icing status signals has proven an increase of the energy production by avoidance of rotor blade icing of 50.0 % at the site Dragaliden and of 25.7 % at the site Krystofovy-Hamry. The energy consumption of the rotor blade de-icing system amounted to 8.2 % of the gain in the energy production in case of the site Dragaliden and to 14.0 % in case of the site Krystofovy-Hamry.

The long-term gain in the annual energy production by the rotor blade de-icing system is expected to be 11.8 % and 9.1 % at the sites Dragaliden and Krystofovy-Hamry, respectively. The expected energy consumption of the rotor blade de-icing system of a WEC of type ENERCON E-82 2.0 MW at the sites Dragaliden and Krystofovy-Hamry is expected to be 90.6 MWh/a and 59.4 MWh/a in the long-term, what is in any case by a multiple smaller than the gain in production.

The ENERCON ice detection system together with the ENERCON rotor blade de-icing system is characterised by its simplicity and high efficiency. Icing is detected reliably and the rotor blades are de-iced efficiently, resulting in a site dependent surplus yield in comparison to conventional WECs.