Performance evaluation of a commercial de-icing system in one year operation of a windfarm

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Summary

In this paper, a windfarm with seven 3MW windturbines equipped with rotor blade heating located in Central Greece at approximately 1100m asl, is monitored for one complete year in order to evaluate the performance under icing conditions. The windturbines are equipped with a commercial active de-icing system which could reduce the downtime due to icing, by heating the rotor blades by re-circulating heated air. This melts the ice at an early stage and the windturbine is operational sooner. The operational data of the windturbines and the reference onsite meteorological mast were examined.

Analyses are performed for the mild winter 2015-6, from 1 November to 31 March. The analyses are based on operational data of the windturbines (wind speed, wind direction, operation status, ambient, blades and nacelle temperatures, rotor speed, produced capacity, consumed energy) and the onsite meteorological mast (wind speed/direction and temperature).

Furthermore, for a month the de-icing system of one windturbine de-activated, so to be examined in detail the operational performance and to be extracted the energy production loss.

In the certain windfarm the theoretical increase of the energy production has estimated approximately 11,5% (in the limits of the 9-12% from relative literature) but in reality the percentage was approximately 6% due to time periods that the system was not be able to defrost satisfactorily the blades and after few minutes the windturbines stopped. Possible reason is the method of the ice detection and the high rate of icing due to existing humidity.

Based on the final gain in production, during the studied time period, the system is profitable and the payback period is less than a year. The energy consumption of the system is much lower than the gain in energy production.

1. Introduction

Atmospheric icing has a significant impact on the development and the operation of windfarms. It causes production losses and represents a safety risk for passers-by and the service personnel [1]. Also, there is an emerging market for wind energy projects in high altitudes with better wind potential but cold climate, frequent snowfalls and icing. Furthermore, reduced electricity tariffs increase the pressure on existing projects to maximise the production in order to stay sufficiently profitable [2]. In this context, the performance and the efficiency of a de-icing system is a main aspect for a successful operation of a windfarm.

In certain environmental conditions, ice, frost or snow can build on the rotor blades of windturbines. This commonly happens at low temperatures (below zero Celsius degrees) and with simultaneously high air temperature, rain or snow. Water droplets freeze on the rotor blade surface and cause ice formation which destroy the aerodynamic efficiency of the blades and weight is added. So, the ice formation affects the energy yield, cause imbalances of the rotor rotation, additional stress on the windturbines due to higher loads on the blades (thus reducing the lifetime) and noise emission. Also, ice deposits may become as thick as to represent a substantial hazard to persons and objects when dropping or being flung away [3].

Therefore the windturbines shut down when ice build-up is detected. Some windturbine manufacturers equip its products with ice detection systems (anti and de-icing systems) [4].

The under study system is rotor de-icing system with recirculation of heated air produced by electrical resistances. The target of this system is the reduction of downtimes due to icing.

2. The under study de-icing system

2.1 In general

Ice build-up most frequently occurs at temperatures between -1°C and -4°C. It does usually not occur at temperatures above +1°C and below -7°C. The available air humidity is too low at temperatures below -7°C. Using two independent temperature sensors on top of the nacelle and at the tower base, respectively, the wind energy converter control system measures the outside temperature to determine the presence of icy conditions.

2.2 Operating principle

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 height contours and roughness changes caused by ice build-up. The resulting significant change in a windturbine's operating mode (interrelation of wind /rotational speed / power / blade angle) is used to detect ice build up.

For this purpose, interlinked windturbine-specific values (wind-output-blade angle) are recorded 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 the long-term mean values.

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

The above mentioned power curve method is used as a standard in all windturbines with adjustable rotor blades.

Automatic windturbine 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 (higher temperature, smaller time period). During this period, the windturbine does not start up automatically. An early manual restart is only possible directly at the windturbine after an appropriate visual check, having the responsibility the operator/owner for any resulting hazard or damage.

It is assumed that the ice will only melt at outside temperature 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 windturbine is restarted, the hazards due to icing on the rotor blades are minimised. Therefore, several hours may pass until restart of the windturbine.

2.3 Short technical description of de-icing system

The used de-icing system with heated rotor blades with re-circulating warm air by electrical resistances melts the ice at an early stage and the windturbine is operational much sooner.

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

Each blade is equipped with an individual rotor blade de-icing system. The total rated capacity of the resistances in the under study windturbine is 85kW.

There are standard operational settings but there is a capability to change these.

3. Site description and the methodology

In this paper, a windfarm with seven 3,0 MW windturbines (with hub height of 78m) equipped with rotor blade heating located in Central Greece at appr. 1100m asl, is

monitored for one complete year in order to evaluate the performance under icing conditions.
The windturbines are equipped with a commercial active de-icing system which could reduce the downtime due to icing, by heating the rotor blades by re-circulating heated air. This melts the ice at an early stage and the windturbine is operational sooner. The operational data of the windturbines and the reference onsite meteorological mast were examined.
Analyses are performed for the mild winter 2015-6, from 1 November to 31 March. The analyses are based on operational data of the windturbines (wind speed, wind direction, operation status, ambient, blades and nacelle temperatures, rotor speed, produced capacity, consumed energy) and the onsite meteorological mast (wind speed/direction and temperature). Furthermore, it is used EMD ConWx data from a nearest grid point to assess the year-to-year variability for the 24 years period.
Energy production losses due to icing are calculated based on the real energy production derived from wind speed measured at the nacelle and site-specific power curves and the production numbers in the SCADA data.
Furthermore, for a month the de-icing system of one windturbine de-activated, so to be examined in detail the operational performance and to be extracted the energy production loss.

4. Results

4.1 Interannual variability

The winter of 2015-6 was mild with high temperatures and totally 27 days with temperatures under +2°C, (included 17 days with temperatures under +0°C) in the site. The lower temperature was -8°C and the icing events have started 29.11.2015 and finished 28.03.2016. Nevertheless, there was operation of de-icing system many days.
For the study of interannual variability it is used the monthly temperatures from the hourly data of mesoscale data EMD ConWx (nearest gridpoint to windfarm, about 900m) in 100m agl.
In figure 1 is presented the average temperature of periods November to March from 1993-2016. It is showed that the under study period present high temperature in this 24 years period (slight lower than 2000-1 period).

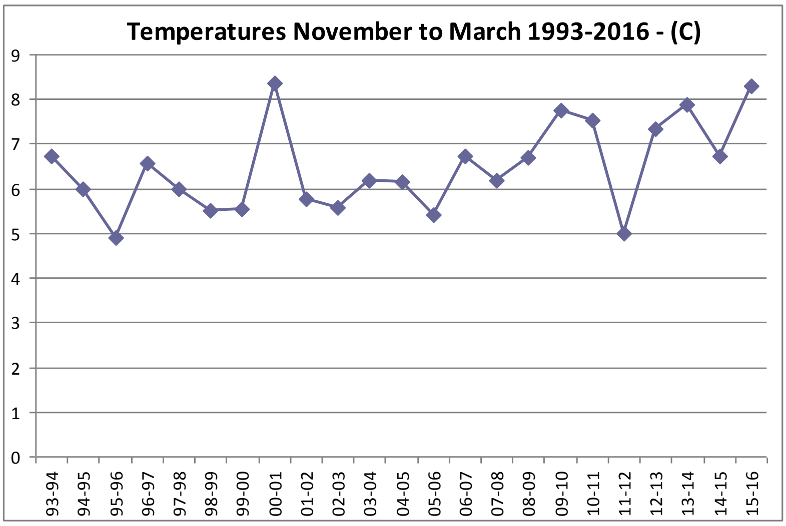

Figure 1 – Average temperatures in 100m agl of periods November – March, 1993-2016.

In figure 2, is presented the comparison of the average temperature of periods November to March from 1993-2016 with the same period of 2015-6. It is showed that the under study period presents high monthly temperatures than the period of 24 years.

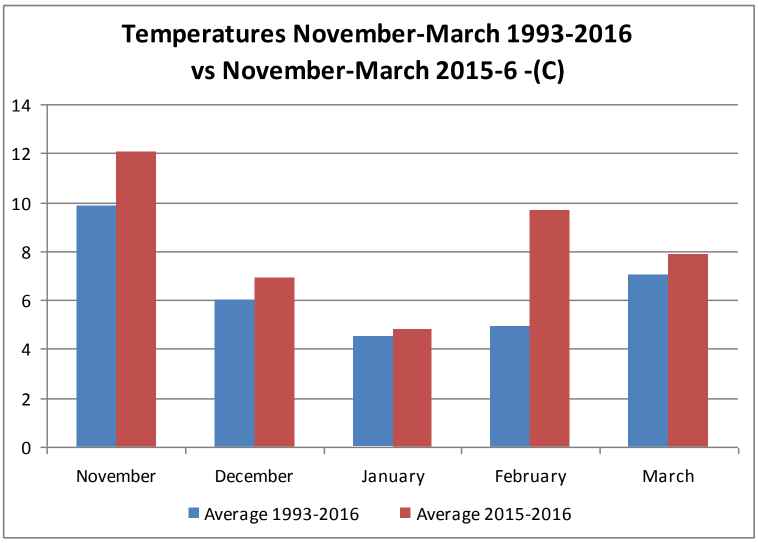

Figure 2 – Comparison of average temperatures in 100m agl of periods November – March of 1993-2016 versus the same period of 2015-2016.

So, this period was a really mild than the long-term situation in the site and any extracted results are representative only for this favorable and gentle situation (good scenario). There is strong interannual variability of environmental conditions (temperatures, icing) and underlines that general conclusion about icing conditions and power losses due to icing need to be derived based on long-term data.

4.2 De-icing system malfunction

In the period 1/11/2015 – 31/3/2016 main problems in the operation of the de-icing system were observed. As a result was the defective operation of the whole windfarm. Specifically, there were periods, where the temperature was about +0°C or less, the de-icing system had to operate. Unfortunately, during the de-icing operation the power output of the turbines wasn't according to the power curve and in some cases it was zero.

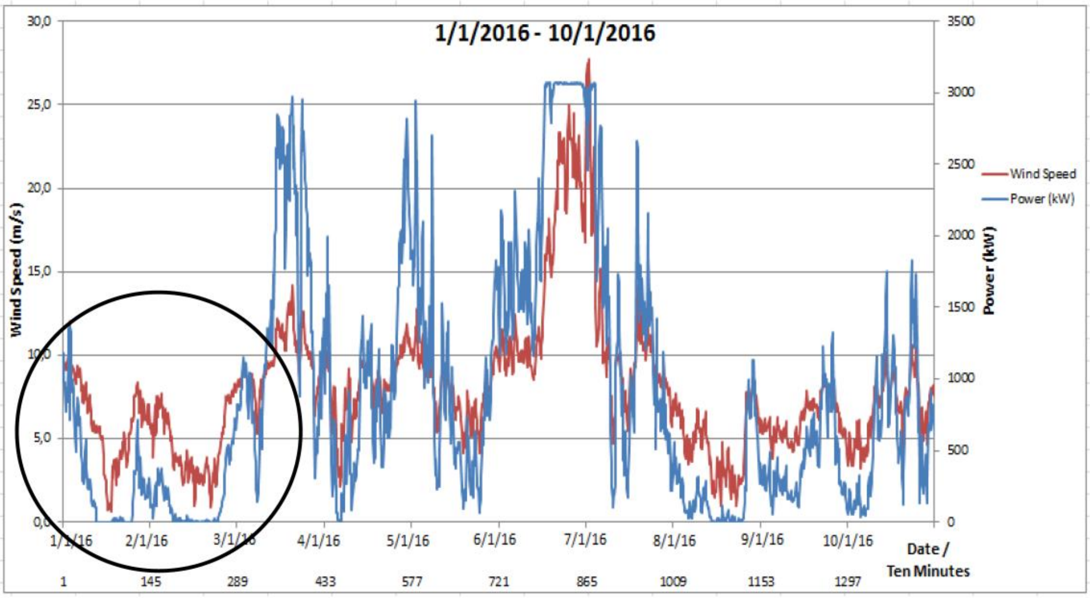

Figure 3 – Wind speed/power output (1-10/1/2016).

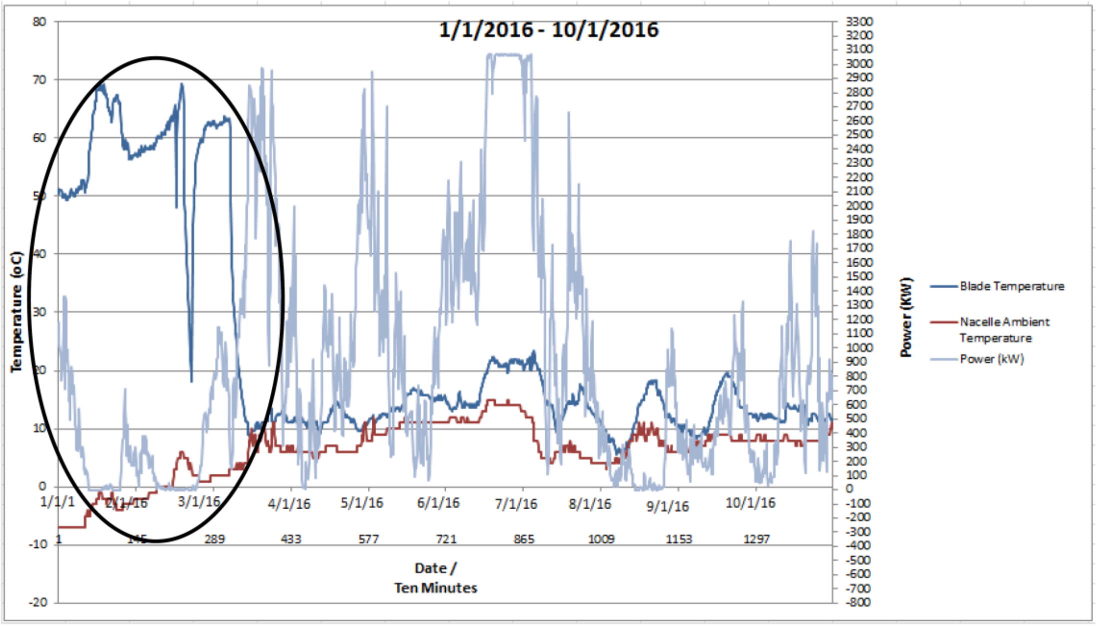

Figure 4 – Nacelle ambient temperature/blade temperature/power output (1-10/1/2016).

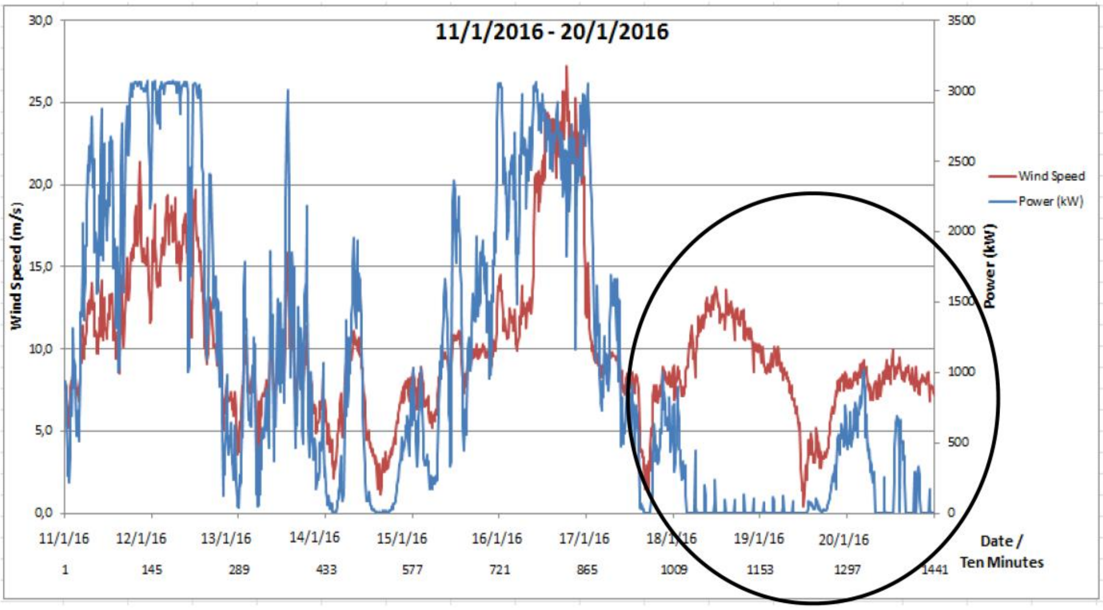

Figure 5 – Wind speed/power output (11-20/1/2016).

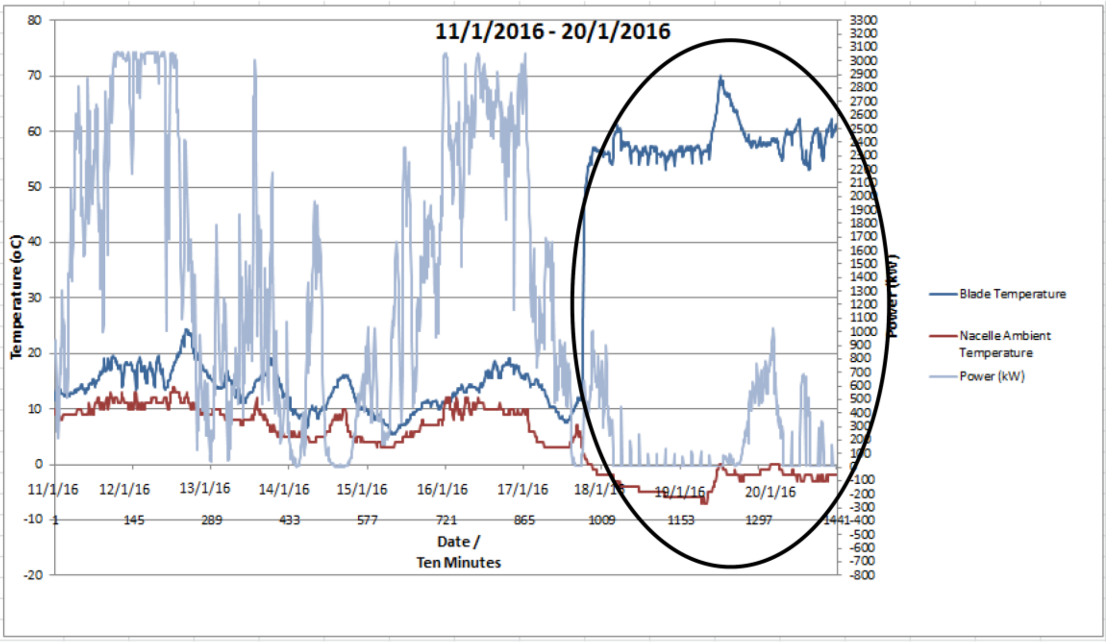

Figure 6 – Nacelle ambient temperature/blade temperature/power output (11-20/1/2016).

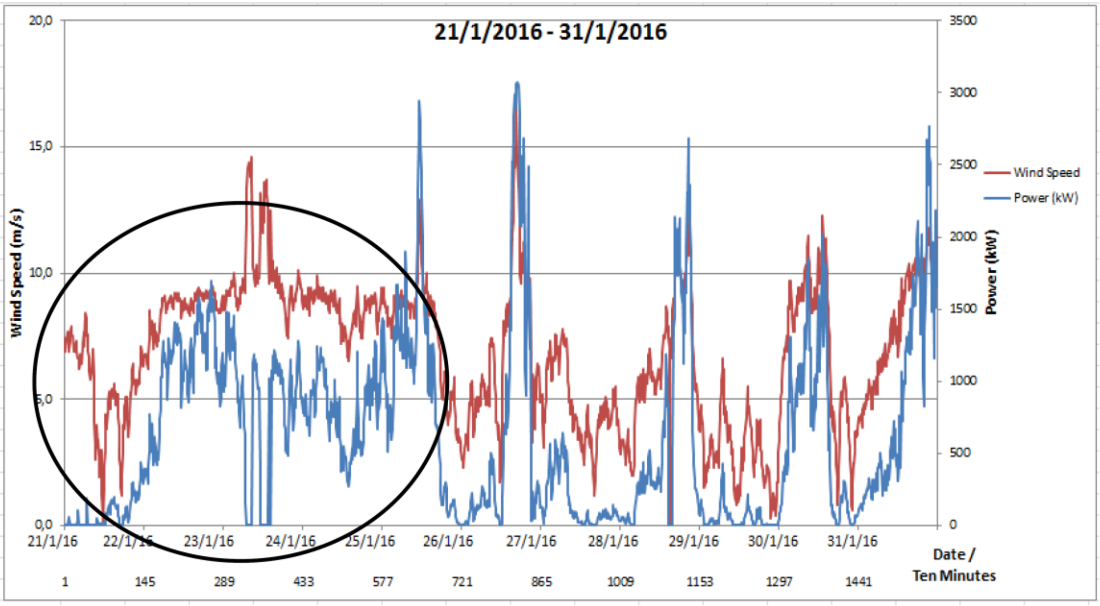

Figure 7 – Wind speed/power output (21-31/1/2016).

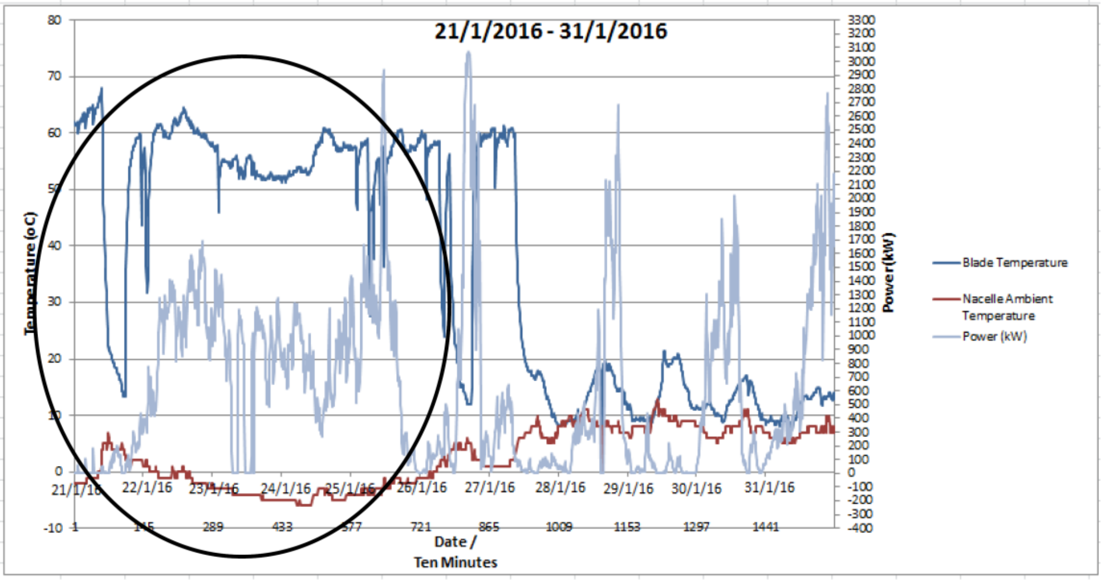

Figure 8 – Nacelle ambient temperature/blade temperature/power output (21-31/1/2016).

According to figures 3-8, indicative for one of the windturbines, while the de-icing system was activated, the turbines were stopped for a long period of time or they were operating for seconds to minutes and they stopped again. For these periods there is no reduction in availability.

This repeated many times showing that there is a problem in the de-icing system in the cases that were mentioned (mainly when the ambient temperature was below zero).

The installed de-icing system works normally without any error and fault message but it cannot be able to set in operation the windturbine and to continue the energy production. It is illustrated a lower than expected efficiency, despite the high operational availability of the de-icing system.

The behavior of the system is the following:

i. The control system recognizes that the weather conditions lead to ice formation. Preventive blade heating is activated.
ii. If the ice formation rate is high, then ice layers start to form. Again the control system recognizes that and the blade defrosting procedure initiates.
iii. Once the defrosting cycle is completed the control system checks again for ice formations. If the phenomenon persists the defrosting cycle starts again.
   In this site, this happens for many continuous hours (e.g. two days in figure 6), with increase of energy consumption and minimum energy production.

Even if the de-icing system is fully functional (desired temperatures are achieved in the inner part of the rotor blades), ice formation can take place if the weather conditions (temperature, humidity, wind etc.) on site favor the effect. So, the de-icing system is unable to melt the ice formation and its operation is failed.

The operation of the heating system includes the risk of ice throw and increases the energy consumption. Hence it is the owner of the windturbines who bares the responsibility of selecting the operational parameters of the blade heating system.

The icing conditions on site can vary significantly from time to time, so it is advisable to periodically change the settings of the system in order to optimize its performance.

4.3 The energy consumption of de-icing system

The average energy consumption of the windfarm for the period which the de-icing system does not operate is 1700 kWh. In winter months due to operation of de-icing system the energy consumption increases significantly.

In January 2016 the electrical consumption has increased 20 times as it is showed in figure 9.

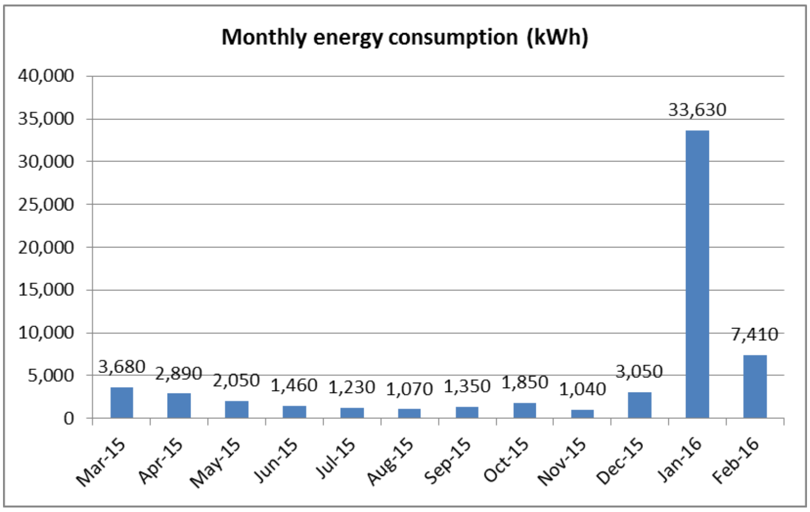

Figure 9 – Monthly energy consumption of the windfarm.

The estimated annual economic cost for the operation of the de-icing system was 4.500 euro.

4.4 The de-activation of de-icing system of one windturbine

There was weather forecast for ice and snow wave for 11 to 15 March 2016, in our site. It is decided to de-activate the de-icing system in a windturbine (no3) in the middle of the windfarm near to the reference mast. As reference has selected the neighboring windturbine (no 4) which has its de-icing system activated.

The windturbine no 3 was out of operation for 89,5 hours in comparison with the neighboring windturbine no 4. The rough estimation of energy losses was 75.102 kWh and the windturbine no3 has restarted on 18/3 when the environmental conditions were better and the temperature has been increased. There was not any intervention for manual operation of the windturbine with the de-activated de-icing system.

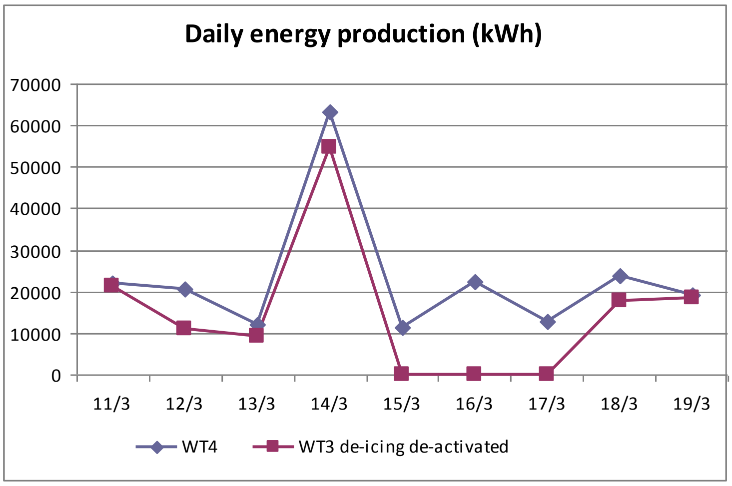

Figure 10 – Comparison of daily energy production of two windturbines from 11-19.03.2016.

The windturbine no3 has remained “frozen” from 14 to 18 March with low energy production (zero in the period of 15-17 March), with “ice detection” fault for 89,5 hours.

Setting corrective factor in energy productions due to slight difference in wind speed for the under study period (0,94) the final estimated energy loss is 70.384 kWh. The estimated economic cost was approximately 7400 euro.

For the same period, having the energy consumption of other six windturbines, it was approximately 1030 kWh, with estimated cost of 100 euro.

It is clear that the operation of the de-icing system for this period has positive impact in the energy production and economic result.

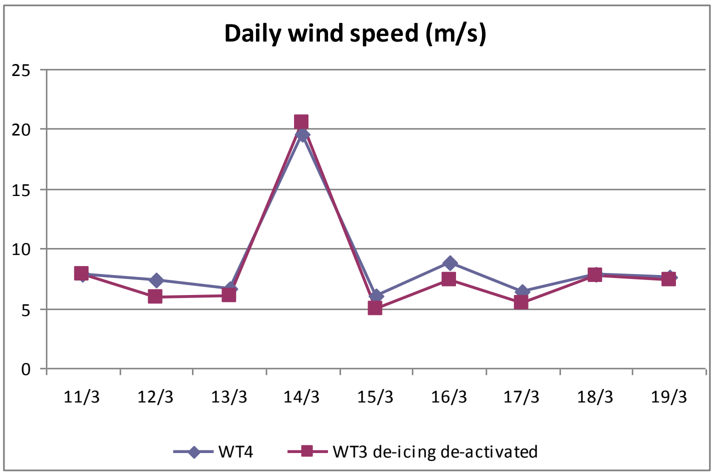

Figure 11 – Comparison of the daily wind speed between windturbine no3 and no4 for the period 11-19.03.2016.

		Wind [m/s]	Rotation speed [1/min]	Power [kW]					
WT	Time	Ø	Ø	Ø	max.	Energy prod. [kWh]	Op. hours	Nacelle pos. Ø [°]	Sample count
no4	19/3/2016	7,6	12,72	826	3075	19262	23:23:00	283	1438
no4	18/3/2016	7,8	12,79	1004	3146	23879	21:45:00	146	1438
no4	17/3/2016	6,4	10,81	581	2258	12737	20:16:00	31	1438
no4	16/3/2016	8,8	14,04	991	2940	22210	23:57:00	32	1438
no4	15/3/2016	6	9,94	528	2383	11491	18:43:00	193	1438
no4	14/3/2016	19,6	16,92	2637	3133	63201	22:54:00	11	1438
no4	13/3/2016	6,6	12,38	513	2822	12215	23:23:00	125	1438
no4	12/3/2016	7,4	12,71	853	3098	20530	23:02:00	123	1438
no4	11/3/2016	7,8	14,78	919	3098	22075	23:53:00	178	1438
		8,67				207600			

		Wind [m/s]	Rotation speed [1/min]	Power [kW]					
WT	Time	Ø	Ø	Ø	max.	Energy prod. [kWh]	Op. hours	Nacelle pos. Ø [°]	Sample count
no3	19/3/2016	7,4	12,72	774	3032	18577	23:29:00	278	1438
no3	18/3/2016	7,7	7,63	739	3153	17829	09:54:00	147	1438
no3	17/3/2016	5,4	1,66	0	0	0	00:00:00	33	1438
no3	16/3/2016	7,4	2,26	0	0	0	00:00:00	33	1438
no3	15/3/2016	5	1,38	0	0	0	00:00:00	236	1438
no3	14/3/2016	20,5	15,37	2274	3152	54622	20:24:00	6	1438
no3	13/3/2016	6	11,55	389	2354	9222	23:07:00	123	1438
no3	12/3/2016	5,9	11,39	459	2885	10941	22:46:00	123	1438
no3	11/3/2016	7,8	14,64	887	3094	21307	23:56:00	179	1438
		8,12				132498			

Table 1– Comparison of the operation data for windturbine no3 and no4 for the period 11-19.03.2016.

4.5 Analysis for the winter of 2015-6

Based on results of de-activation of de-icing system of windturbine no3 we estimated the energy loss and the economic result for one year period which include the period March 2015 – February 2016.

The annual energy production (SCADA) was equal to 60.493.725 kWh. For this period the de-icing system has operated for 1011 hours (42 days) or 11,5% of the year. This percentage (most favorable-optimistic) it would be the energy loss in annual energy production, which is consistent with the relative literature. The annual economic benefit would be 733.000 euro, if there wasn't de-icing system.

It is calculated from the existing temperature measurements from the meteorological mast and the operational data of the windturbines, that the de-icing system cannot ensure a continuous operation and after some minutes stopped again as described in paragraph 4.2. This percentage of de-icing malfunction was 5,5%, so the final percentage of efficient operation of the de-icing system was approximately 6,0% of the year.

The economic benefit is the difference between the operation of de-icing system and its energy consumption, which calculated for the under study year equal to 384.000 euro when the cost of the de-icing system for seven windturbines is 200.000 euro.

5. Conclusions

It was observed that the icing conditions varied significantly from year to year, so the assessment of icing conditions at a site should be based on a multiyear time period.
The produced energy is multiple of the consumed energy and in economic terms the operation of the de-icing system is satisfactory.
Especially examples during single ice events where the systems increased the power output was found, but the examples also showed possible improvements regarding the size of the system, the time response and the duration of the de-icing cycles. Additional benefits like for instance decreased loads, risk for standstill and ice throws could also be provided by the system.
Based on the final gain in production, during the studied time period, the system is profitable and the payback period is less than a year. The energy consumption of the system is much lower than the gain in energy production.
We consider that there is a problem with the accurate recognition of the ice from the power curve which controls the de-icing system, causing the interruption of the normal operation of the wind turbines during the heating of the blades.
Possible reasons are the settings of the method of the ice detection and the high rate of icing due to existing humidity.
Important characteristics of the system were found as the duration of the cycle, the trigger-point for activation of the system and the operation of the windturbine without it. The results, having a large percentage of unsuccessful operation with stopped windturbines which consumed energy, states the de-icing system is necessary for areas with snow and ice existence. It presents significant gain in energy production but system is not perfect, improvements are needed.
It is proposed changes in the settings of the de-icing system to be applied and to apply for a trial use an ice detector to one windturbine. Moreover, the installation of camera on the nacelle could give useful information about the ice formation on the rotor blades.

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