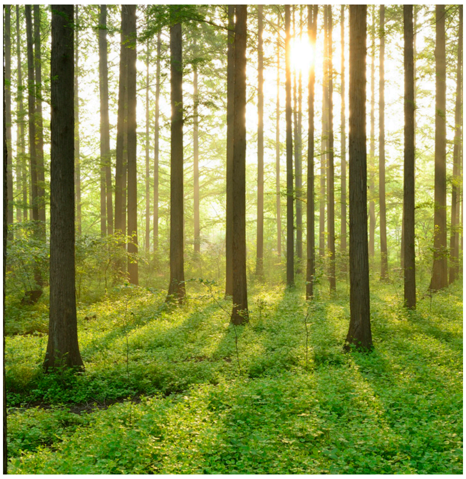
AIRBORNE DE-ICING SOLUTIONS FOR WIND TURBINES

REPORT 2016:300



VINDFORSK

Energiforsk

Airborne de-icing solutions for wind turbines

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ISBN 978-91-7673-300-4 | © 2016 ENERGIFORSK

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Foreword

With the increased demand for renewable energy, the wind power industry is expanding. The largest part of the expansion of wind power plants in Sweden takes place in the northern parts of the country. However, the cold climate poses a great challenge. As temperatures drop, icing forms on the turbine blades, causing considerable production losses in some wind farms. Several solutions for de-icing of the turbines exist, which are installed on the blades. Still, there is a need for an "emergency method" of de-icing, for example when the installed de-icing system is out of order or for turbines that lack such a system.

The aim of the project "Heli-deice – De-icing of turbine blade with helicopter" has been to design and test a cost effective method of de-icing with hot water, applied to the turbine by helicopter. This report presents the results from the study.

The project has been accomplished by Hans Gedda (project leader) and Mats Widgren, Alpine Helicopter AB. A reference group has been assigned to the project, consisting of Jan-Olov Aidanpää, LTU, Jonas Sundström, SKAB, Susann Persson, Jämtkraft, Niels Emsholm, Eon, and Finn Daugaard Madsen, Siemens. The project has been a part of Energiforsks research program for wind power, Vindforsk IV.

Stockholm, July 2016

Åsa Elmqvist
Progam manager, Vindforsk IV

Sammanfattning

Det är fullt möjligt att kostnadseffektivt avisa turbinbladen på ett vindkraftverk med hjälp av en helikopter och varmt vatten för att undvika stillestånd på grund av isbildning. Metoden går till på samma sätt som när man avisar ett flygplan, skillnaden är att man gör det i luften. Metoden är inte enbart kostnadseffektiv, den är även bättre ur ett miljöperspektiv då produktion från nedisade stillastående turbiner vanligtvis ersätt med kolkraftverk eller gasturbin vilket ger upphov till ett större utsläpp av CO_2 än vad metoden med avisning med helikopter medför.

Den här rapporten beskriver utvecklingsarbetet från ett prototypsystem till ett färdigt system för att utföra en kostnadseffektiv avisning med helikopter och varmt vatten. Projektet har genomförts som ett tillämpat projekt, där vunna erfarenheter hela tiden nyttjats och omsatts för det fortsatta arbetet.

Arbetet har resulterat i att det nu finns utvecklad utrustning framtagen för att kostnadseffektivt genomföra avisning med varmt vatten. Denna är testad under fältmässiga förhållanden i kallt klimat och är operativ ned till ca -20 °C.

Projektmål:

- Metod och utrustning för avisning med varmt vatten skall vara utvecklad och testad under fältmässiga förhållanden i kallt klimat.
- Projektet ska visa att metoden är tillämpbar och kostnadseffektiv.
- Tekniken ska presenteras vid konferenser och seminarium.
- Framtagande av manual om hur avisningen ska genomföras både säkert och effektivt. Manualen ska godkännas av Transportstyrelsen och Luftfartsverket.

Projektmålen har uppfyllts och projektet har presenterats i samband med Winterwind 2014 och 2015 samt på Vind 2014 och 2015. Medieintresset har varit stort och projektet har uppmärksammats i både tidningar och radio i Sverige, men även utomlands.

Summary

To avoid downtime due to icing, it is now possible to cost-effectively de-ice wind turbine blades using a helicopter and hot water. Hot water is sprayed onto the blade in the same way as when de-icing an aircraft, the difference is that you do it in the air. The solution is not only cost effective, but also better from an environmental perspective as production losses from a wind turbine means it must be replaced with alternative energy, such as coal or gas, which is more harmful to the environment compared to de-icing with a helicopter.

This report describes the development from a prototype to a complete system able to carry out a cost-efficient de-icing process by a helicopter and hot water in cold climates down to -20 °C. The project has been implemented as an applied project in which the experience gained is continuously utilized and applied in the on-going development work.

Project goals:

- Method and equipment for de-icing with warm water should be developed and tested during field conditions in cold climates.
- Demonstrate that the method is applicable and cost efficient.
- The technology should be presented at conferences and seminars.
- Develop a manual and routines of how to carry out a safe and effective de-icing process approved by the Swedish Transport Agency and the Civil Aviation Administration.

All project goals have been met and prove that the airborne de-icing system is designed, tested and works well in field conditions and is applicable down to about -20 °C.

The method makes it possible to de-ice a turbine in about 1.5 h. In order to be cost effective, the goal was that it should not take more than 2 hours.

The project has been presented in conjunction with Winter Wind 2014 and 2015 as well as Wind 2014 and 2015. During the project it’s also been presented during university lectures and seminars.

List of content

1 Background

In recent years, the interest in establishing wind power in cold climates has increased. The establishment of wind power in cold climates is an investment risk in terms of reduced production or, in worst case, downtime due to icing on the blades. The personnel safety risk of ice throw should also be taken into account when implementing wind turbines in a cold climate.

Some turbine suppliers offer turbine blade de-icing technology which some of their customers' have chosen to equip their turbines with. However, as the technology is not without its flaws, several power producers have also deliberately chosen to not equip their turbines with a de-icing system that cannot be guaranteed. Several power suppliers operating in cold climates (Vattenfall, Skellefteå Kraft AB) have suffered unnecessary downtime costs due to icing event.

With experiments conducted in Canada, there are now opportunities to avoid this type of downtime. The experiments showed that it is possible to de-ice a turbine blade with the use of a helicopter and hot water (without chemicals). The hot water is sprayed onto the blades in the same way as when de-icing an aircraft to remove the ice build-up – a simple yet effective method where Alpine Helicopter AB saw opportunities for further development to expedite the process. At own initiative, Alpine has developed a prototype for de-icing solution equipment for wind turbine blades, with significantly faster results compared to the Canadian method. This prototype was demonstrated in autumn 2013 for the operators at Skellefteå Kraft AB. While they were impressed with the technology, the method required further development.

As a result, a project was initiated and has been running between 2014-2016, supported by the Swedish Energy Agency and Vindforsk in collaboration with Skellefteå Kraft and Alpine Helicopter AB. This report describes the work carried through to further develop this technology.

2 Method

This project has been implemented as an applied project.

The method to de-ice wind turbines by helicopter and hot water originates from Canada. They used a system developed by Simplex Aerospace, which was initially developed and intended for cleaning power line insulators, however the method was too slow to be interesting as a de-icing solution for wind turbines. This depended on the water supply being too small, which, together with a high water pressure, worked more like a high-pressure washer.

A plastic tank was mounted below the helicopter, however the tank deformed when water temperatures went above 50 °C. The water was sprayed onto the blade with a long tube which led to problems at temperatures below -10 °C. The de-icing system worked more or less like a snow-making machine as the water was dispersed under high pressure and froze. See Figure 1 below, from tests performed in Canada in 2011.

Taking up to eight hours to de-ice a turbine, the project was cancelled due to high costs.

Figure 1. De-icing of a Vestas V90 in Canada 2011

2.1 PROVEN TECHNOLOGY FOR NEW APPLICTION

Since it is possible to de-ice an aircraft within fifteen minutes, there was great interest to further develop this method. Reasonably, it should be possible to implement the de-icing of a wind turbine with similar equipment used when de-icing an aircraft. The difference is that the only de-icing fluid allowed is hot water; chemicals or other additives such as salt are not allowed due to environmental directives.

Figure 2. De-icing demonstration at Uljabuouda Oct 2013

The first prototype equipment was developed by Alpine Helicopter (ALP-system).

The main difference between the Simplex and the ALP system is:

- The water tank hanging below the helicopter is connected with steel wires.
- The water jet is controlled with a joystick.
- The water pressure is lower.
- The water flow is higher.

This made it possible to de-ice a turbine in a similar manner as when de-icing an aircraft and showed to be much more effective compared to the Simplex system.

Some of the first demonstrations of the system were made in cooperation with Skellefteå Kraft on site Uljabuouda, located in the municipality of Arjeplog. The test was conducted in mid-October 2013 before there was any risk of iced blades to show that the method was useful and feasible.

Those who attended the demonstration, personnel from Skellefteå Kraft AB, were convinced that the method would work but needed further improvement, development and testing in a cold climate during winter.

A project application was submitted to the Swedish Energy Agency for support to develop the ALP-system, a method for de-icing wind turbine blades with warm water in a similar way as when de-icing an aircraft.

2.2 STAGES

The project has been divided into four stages, which are based mainly on weather conditions, as on-site testing can only be performed during the winter months. Stage 1 and 3, which took place between April and September, mainly consisted of equipment testing and development, preparing reports and attending conferences. Stage 2 and 4 consisted of testing in Uljabuouda and Boden during the weather conditions needed for this project. Despite this, there have been longer periods with no ice formation, which was the case with the tests planned to perform at Uljabuouda wind farm in January 2015. Some of the tests and evaluations have been conducted in the surroundings of Boden and Riksgränsen.

Project reports have been shared regularly within the steering group and Vindforsk. The first steering committee meeting was held in mid-June 2014 in Skellefteå where the

project plan was presented to the steering committee appointed at the time. The project began by reviewing the results that emerged during the winter of 2013-2014.
These results have been the basis for further development. With the first prototype ALP system, it was possible to de-ice a wind turbine in three hours. This was still deemed a too lengthy and costly de-icing process to be of interest. A review of necessary changes / improvements started, with the purpose of being a competitive alternative compared to waiting for thaw. Initially the most important measures of improvement were:

- The weight of the equipment – the water tank in particular – must be reduced.
- The water consumption must be reduced.
- The water capacity needs to be increased. A total capacity of 45 m^3 is necessary to de-ice at least three turbines daily.
- Streamline the de-icing process for a quick and safe procedure.
- Develop an operations manual and a basis for the Safety Operation Procedure (SOP).
- Receive permission from the Civil Aviation Authority (Luftfartsverket).

Figure 3. The old prototype tank

2.3 EQUIPMENT

2.3.1 Water tank review

When filled with water, the prototype tank (see figure 3 above) was close to reaching the helicopter's total lift capacity, another reason to reduce the weight. The only options available were to either reduce the tank weight or use a helicopter with higher load capacity. The later was assessed uninteresting, as it would increase flight time – and costs for the same – leading to a lack of interest.

Based on previous experience, some suggestions for a new tank design were discussed. Weight reduction was essential, as well as ensuring that the pump housing was placed beneath the water level to avoid pump air suction. On the old prototype tank, where the pump house was mounted high, filling water directly into the pump housing solved this problem. The material options available for the manufacturing of new tanks were plastic or aluminium. Aluminium became the final choice, mainly as the material can be welded and that constructional changes are possible, which are more difficult to implement with plastic. Water left in a tank made of plastic freezes and can cause frost damage. Plastic also softens at higher temperatures. The requirements were:

- A robust, strong and lightweight construction.
- Protected mounting for the pump housing and pump motor (compared to the prototype tank).
- Must be able to be filled with 800 litres of water in a short period of time.

Several layouts were discussed and all connections were considered when looking for low weight materials. Icing in pipes and water nozzles had to be minimized. It was also important to consider the aero dynamical properties in the design as the old tank swayed more than desired. A number of changes and improvements were made until a satisfactory result was reached. The final tank layout is shown in figure 4 below.

Figure 4. Final tank layout

As can be seen in the figure above, a number of changes are done compared to the prototype tank in figure 3. Tubes and connections are more protected and the pumps are positioned below the water level when the tank is filled. The total weight reduction is roughly 150 kg – a considerable amount in this context.

2.3.2 Increased water capacity

In order to create a cost effective method, it is necessary to ensure the water volume capacity is enough to de-ice three turbines daily, approximately 45m^3 at 50 °C. The total water volume available in the truck is 16m^3, enough to de-ice one turbine, hence not meeting the requirements. Since de-icing will occur during cold weather conditions, it is important to adapt all equipment to fill up, heat and transfer the water from truck to trailer and vice versa. Pumping, heating and handling water in severe cold conditions has been one of the project's biggest challenges.

A trailer was adapted to meet the requirements for water heating and transport. The requirement was that the trailer should be able to serve the water needs without the presence of the truck. The truck must be able to leave the site for water refill if necessary.

The trailer (see figure below) was rebuilt and provided with

- An oil burner.
- 240 V/24V fuel genset generator for battery charging and for heating of vital components in the helicopter during the night.
- All lights were swapped for LED to decrease power need when parked.
- Flashlights were mounted for visibility when parked on the site.
- Separate tanks were mounted for both petrol and oil.
- Work lights were mounted.
- Larger pipes were installed for quick water handling.
- Fasteners were fixed to the sides for tube transportation.

Figure 5. Adapted trailer at Uljabuouda January 2015

Test and development

Several tests have been conducted to secure the equipment's accessibility. Most testing was carried out in the vicinity of Boden, where a huge old military training ground was used for activities demanding enough space to fit the truck, trailer and helicopter at the same time. The training ground is located close to Luleå River, which was essential for good water access. After completed attempts, leftover water was emptied back into the river.

Figure 6. Water filling in progress

It takes 20 minutes to completely fill up the trailer with water and 6h to warm the water from 0 °C to 60 °C.

2.3.3 Water pump, temperature and cavitation

The water quantity needed for the de-icing process, as well as the water temperature was reviewed. In order to be effective, it required using the smallest amount of water possible at the lowest possible temperature. The blade manufacturer recommendations were that the blade can withstand a temperature of no more than 65-70 °C.

During one test session, there were problems with the length of the water jet as it was halved compared to the experiments conducted the previous day. At first an error with the pump engine was suspected, but once concluding that was not the case, the pump, nozzles and other attachments were replaced without success. After several hours of troubleshooting, the team was forced to discontinue. With plenty of 75 °C water available, it was decided to conduct a new attempt the following day.

Surprisingly, everything worked perfectly the next day. However, as the underlying causes were not known, it was important to understand what had happened to avoid this problem in the future. After a few days of research, cavitation in the pump house was diagnosed as the issue.

Cavitation may occur when local static pressure in a fluid reaches a level below the vapour pressure of the liquid at the actual temperature. According the Bernoulli Equation, this may happen when the fluid accelerates in a controlled valve or around a pump impeller. Generally, cavitation can be avoided by increasing the distance (pressure difference) between the actual local static pressure in the fluid and the vapour pressure of the fluid at the actual temperature. This can be done by reengineering components initiating at high-speed velocities and low static pressures, increasing the total or local static pressure in the system or reducing the temperature of the fluid.

The solution is simple: reduce the water temperature. The guideline for the maximum water temperature is set to 55 °C to avoid cavitation. Another benefit of lowering the water temperature is a decreased risk of burns for the de-icing team.

2.3.4 Water Pump

A gasoline engine driven pump with controllable pressure and capacity is the solution that works best together with the two pump housings tested.

After several tests, both on the ground and with equipment hanging below the helicopter, a combination was found that was used during de-icing tests. An important part of this was also the cable length between the helicopter and the water tank. A number of wires were tested – short, medium and long, finding that with long wires gave the best results, namely:

- The water tank did not sway as much.
- The movement that did occur was easier to adjust compared to the prototype tank.

The expected problems with an increase of oscillation with long wires did not occur, the theory being that the rotor wind that passes around the water tank's sides also stabilises it. If the water tank was hanging higher up, then the rotor wind would not pass the sides of the tank, making it more turbulent. It is the same phenomenon as if driving closely behind a truck at higher speed – it will cause turbulence.
Much of this work was carried out in Riksgränsen where a helicopter was stationed during the latter part of the winter season 2014 and 2015. This is also where maximum flight speed, search speed range to minimize vibrations, and appropriate wire length were tested. The weight difference between an empty and full tank is 800 kg, which also influences the movement. Some of this information is used in the safety operation of procedures, e.g. max flight speed.

Part of the development included looking over the connections between the helicopter and tank. The requirement is that the process of replacing water tanks should be quick and easy. The connections must have good contact for transmission of signals from the joystick, to control the water jet. At the same time, the requirement for a quick release in the case of emergency must be reached. The flight safety regulations state that the load must be able to release if problems arise with the equipment or helicopter.

Figure 7. Test activity in Riksgränsen

2.3.5 Nozzels

Even the nozzles have been subject to a review as the pump capacity has increased compared to the prototype equipment. Some of the nozzles tested are featured in the figure below.

Figure 8.Selection of nozzle for test

Nozzle No. 5 from the left became the final choice for de-icing. It is a flexible nozzle as it is very easy to change the inserts, the black part of the nozzle, to change the water jet image, see figure 9 below. The requirement was an overall hit range of the water that holds together without being too affected by the rotor wind. The nozzle should also be self-drained when directed downwards to reduce the risk of icing.

Figure 9. Final nozzle choice

A number of nozzles were tested with regards to the length of the jets, how fast they empty the tank and what temperature the water is expected to have when it hits the blade.

The water temperature drops fast after it leaves the nozzle. At a water outlet temperature of 63 °C when it leaves the nozzle, the temperature could be measured to 33 °C at a distance of 20 m after the nozzle outlet and at 30 m, the temperature had dropped to about 18 °C. The water was easily captured in a bucket where the temperature was measured with a digital thermometer. The ambient temperature was -

20 °C at this occasion. The ambient temperature ranged from -5 °C to -20 °C at the different test occasions.

For transportation of water tanks and other equipment such as engine ice drill and snow mobile, a covered trailer was used. When not used for transportation, it worked as a mobile workshop for repair and overhaul of equipment due to the need of a sheltered place when it was windy and cold. In the future the trailer will be equipped with heating facilities.

The wind chill effect is important to take into account for personnel working in cold climate. When it is windy, the experienced temperature is colder than the actual temperature. The rate at which the body is cooled down does not only depend on the temperature of the air but also on the wind speed.

Table 1. Wind chill effect

	10°C	5°C	0°C	-5°C	-10°C	-15°C
2,5 m/s	8	4	-3	-9	-14	-19
5,0 m/s	6	2	-6	-13	-18	-23
7,5 m/s	4	0	-9	-17	-22	-27
10,0 m/s	2	-3	-12	-21	-26	-31
13,0 m/s	0	-6	-15	-25	-30	-35
18,0 m/s	-4	-12	-21	-33	-38	-43
20,5 m/s	-6	-15	-24	-37	-42	-47

The stronger the wind the colder it will feel. Squares colored red indicate actual temperatures where unexposed skin will suffer from frostbite in just a few minutes. In other words, you may suffer from frostbite at temperatures that are only just below zero Celsius if the wind is strong enough.

Figure 10. To the right in the figure, combined trailer and mobile workshop.

2.4 DE-ICING TEST AT ULJABUOUDA WIND FARM

The team has been at Uljabuouda Wind Farm three times since the project was initiated. The first time was in 2013, when the technology, the opportunities and the advantages that this method provides, were demonstrated. The second time was in 2014 when two de-icing tests were carried out and the last time was in the beginning of 2016.

In mid-January, Skellefteå Kraft AB informed that their production was reduced since a week ago. This was due to icing on the blades and their existing de-icing system was not able to remove the ice from the turbine blades. The weather forecast was good: sunshine, good wind availability and around -20 °C. The conditions were the best thinkable to show that the method works when there are no other solutions available than to wait for thaw.

A de-icing team of four members and one photographer were put together. The mission was to carry out and document de-icing tests at Uljabuouda.

Figure 11. The whole de-icing team at Uljabuouda

The temperature at Uljabuouda was about -16 °C, which is the perfect condition to test all the equipment. The equipment is deemed to be operational down to -20 °C, which is also the lowest allowed temperature to operate in according to the SOP (Safety Operating Procedure).

Two turbines were de-iced during the tests. The first turbine to de-ice was Uljabuouda No 8, which delivered approximately 460-500 kW at a wind speed of about 9-11 mps. This is approximately 20 % of expected power production according to the P / W curve, see Figure 12 below.

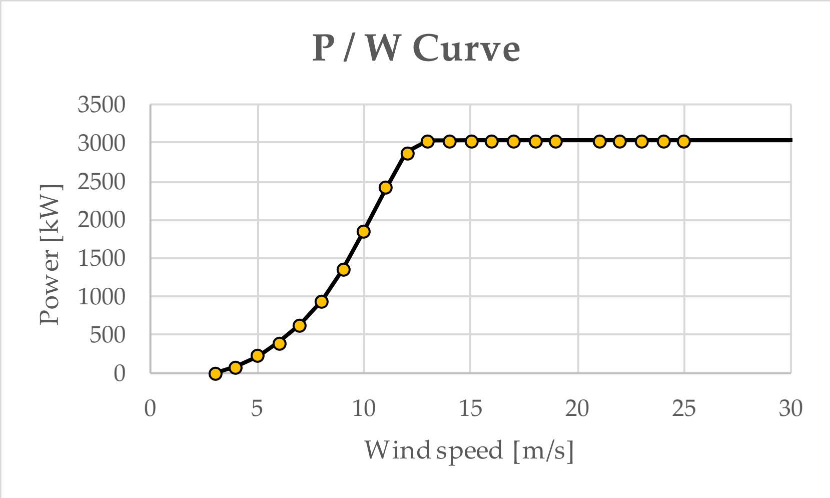

Figure 12. P/W Curve WinWind 3MW

According to the turbine power curve it should deliver around 2.5 MW at a wind speed of 9-11 m/s. The de-icing process was completed in 1,5 h, during which two thirds of the total blade length was de-iced.

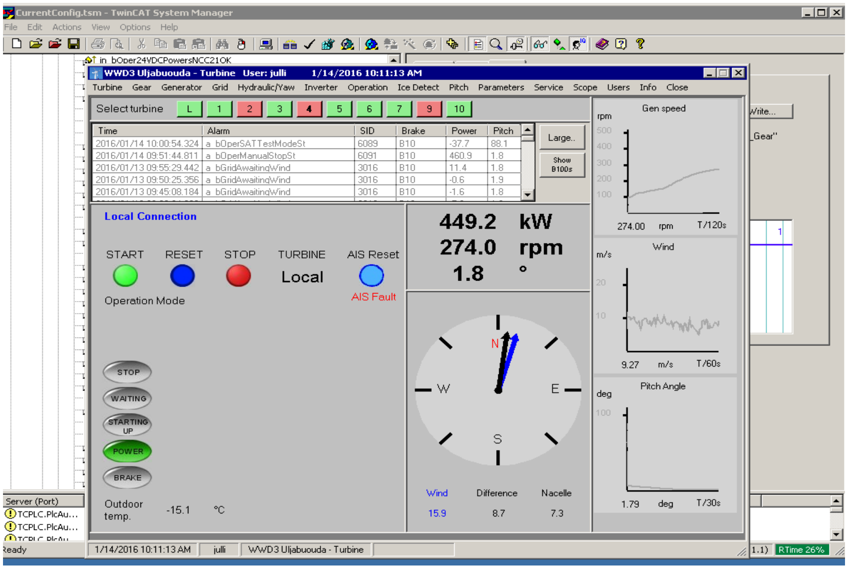

Figure 13. Production WTG 8 before de-icing 450-500 kW

After completed de-icing, the wind had reduced to around 6-7 m/s. In spite of this, the turbine produced 550-600 kW, slightly more than at the beginning of the de-icing process, but at a much lower wind speed. Later in the evening, the wind speed increased to 10-11 m/s; increasing production to 1.5 MW, see Figure 14 below.

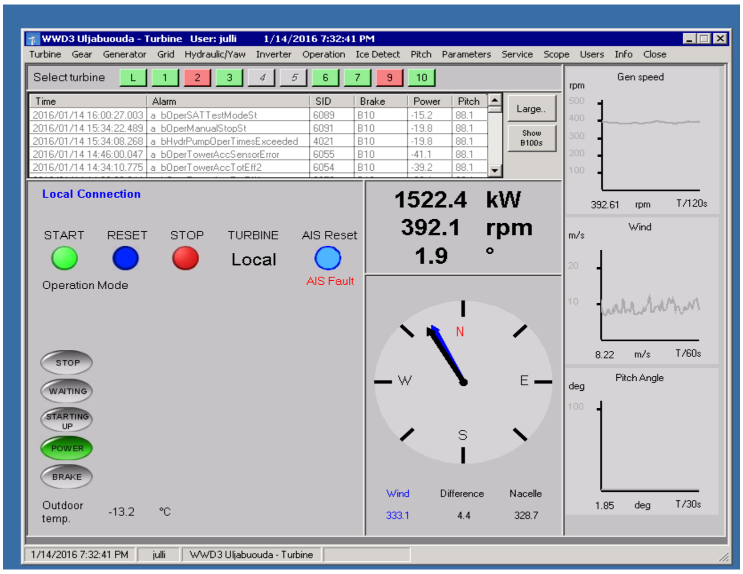

Figure 14. Production WTG 8 after de-icing

During the night, the wind speed increased to 13-16 m/s and the power production increased to about 3 MW, which is what the turbine should be able to produce.

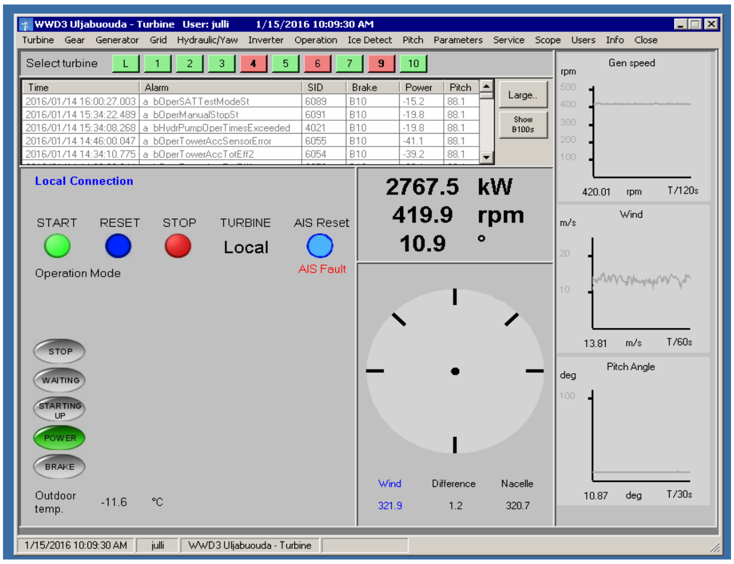

Figure 15. Full production WTG 8.

The next day WTG 9 was de-iced.

Turbine status before de-icing:

- Power production: 2-2.1 MW, about 66 % of expected production according to the P / W curve.
- A temperature of -12 °C; wind speed 13-16 m/s.

Immediately after completed de-icing, production went up to 3 MW, which is the maximal power the turbine can deliver, see Figure 16 below.

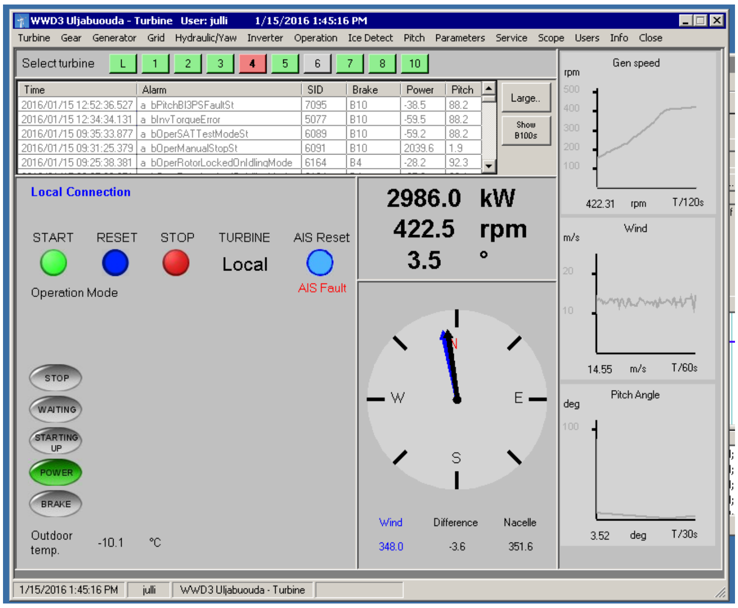

Figure 16. Full production WTG 9

2.5 AVAILABILITY AND GUIDELINES TO DE-ICING

There is currently only one complete de-icing system ready for use. Time for establishment at site in northern Sweden is estimated at about 24 hours from request until a team is established at site. It should be possible to de-ice about three turbines daily during the darkest period during December and January. During November and February, it should be possible to de-ice a total of four turbines a day when the sun sets later. At the same time, demand for water will increase by approximately 15m³ to cover the accumulated need. The trailer's water capacity is sufficient to de-ice two turbines. The truck can leave the site to be refilled with water, which means that the increased water demand can be met provided that the day starts by emptying water from the truck's tank.

The biggest problem is not that the system is suspended below the helicopter, but rather that it is adapted to different helicopter types. The biggest challenge, particularly in winter, is to heat and transport the water and related management. You can also buy hot water from a local district heating plants and fill the truck and trailer tanks. This is a better alternative from an environmental perspective compared to heating the water with oil. Another aspect to be taken into account is the distance between the site and the district heating plants. This method was considered for this project but unfortunately the water cost was double the price of heating it. Water prices may vary in different locations.

As there is no protocol as to when – and under which conditions – de-icing should be implemented, the decision is based solely on an agreement between the customer and supplier. The basis for this is cost-related issues, as well as a safety and environmental perspective, as de-icing with a helicopter is not a first choice method. There is also no recommendation on when to carry out de-icing with this method. It is therefore important to conduct a thorough analysis before de-icing. There are, however, four important guidelines to take into account if considering de-icing:

1. The turbine generates power with greatly reduced production or no production at all

It is important to make a careful analysis of the conditions you expect over the next few days:

- the risk of new ice formation on the blades
- the expected wind availability for the next 72 hours
- energy prices

SMHI or Kjeller Vindteknik can provide weather-related forecasts. Kjeller can deliver daily forecasts of icing events for the next 48 hours during winter, information that is updated four times daily. A map shows a forecast of where icing can be expected to occur, its intensity and the expected ice accumulation.

Short-term prognosis can be used to indicate when there is a risk of ice throw from the turbines during operation. This is valuable information related to the security of personnel, but also for the general public that's sometimes is present at site.

These forecasts are developed by Kjeller Wind Technology and are based on a development that has taken place in close cooperation with VTT in the Wind Pilot Projects. With these models, Kjeller provides a forecast of losses caused by icing, making it a useful tool for us, but also for turbine owners to assess when to initiate de-icing. Within the project the team has had some contact with Kjeller but also with others such as SMHI. These forecasts then become a useful tool in the process of deciding when it is justifiable to use this type of de-icing method.

2. From a safety perspective, any ice on the blades must be removed due to the danger of harming personnel or persons of the public staying in the vicinity of the turbines.


Figure 17. Damage to the roof of the building and the car, caused by ice throw on the site

In cases when there is a risk of personal injury or property damage, the wind turbine owners are utmost responsible for the safety. There have been reports of wind farms being forced to close down, due to the safety not being guaranteed. The most noted incident caused by icing was the downtime of a Swedish wind turbine during the period November 2002 - January 2003. For about two months the turbine was at a standstill with ice on the blades and without the owners being able to do anything to resume operations.

For the wind power industry in general, the main issue isn't the value of production losses. To be able to guarantee supply when there are prerequisites for operation, i.e. during good wind conditions, is a far more significant question. Unless the industry itself takes on a responsibility for the opportunity to de-ice within a reasonable time, the Swedish Energy Agency should consider a future governed requirement for a large-scale deployment of wind energy in cold climates.

3. The risk of mechanical damage to the bearings and gearboxes.
The ice doesn't form symmetrically on the turbine blades, which can cause imbalance, which in turn can cause damages to the gearboxes. If the turbines are at a standstill for a longer period, at least five to six weeks, damages can also be caused to the bearing.

4. Ice can loosen and damage other blades.
There have been several reports of ice striking blades going upwards, which has caused damage to the turbine blades. This is another reason to remove the ice in as a controlled manner as possible.

2.5.1 Increased availability

There has been recent interest in the possibility to use the de-icing equipment for washing the blades, which is possible if you replace the water nozzle. Using an environmentally friendly detergent to dissolve the dirt and insects, you then replace the nozzle again to rinse off with warm water. In light of this, more systems will be probably be made available for use of both de-icing and cleaning, thus increasing the availability. Together with Dalavind, tests for washing turbine blades were carried through in the beginning of June 2016.

2.6 THE ENVIRONMENTAL IMPACT OF CO_2 AND ENERGY CONSUMPTIONS

Estimations for CO_2 in a de-icing project is unique as the calculation is dependent on factors related, but not limited, to:

- The distance to the wind park
- The distance between the site and night's rest location
- Prognosis for ice and wind
- The current cost of fuel

With this method now available, it will be easier to find finances and stakeholders for projects in the future. Insurance companies have also shown an interest in wind farm owners using this method if it is deemed necessary.

Calculation of de-icing ten turbines at Uljabuouda (3 days)

The round trip Boden-Uljabuouda is 500 km, anticipating it would take three days to de-icing ten turbines. Additionally there are transports between Arjeplog and the site – about 50 km / day – for night's rest. Apart from the truck, the de-icing team uses a van for transporting personnel and equipment.

Flight time Boden-Uljabuouda-Boden is approximately 1.6h. Flight time on the site is estimated to roughly 4 hours / day. The helicopter consumes 178 litres/hour and emits about 450 kg CO_2 /h. Total flying time for the assignment is: 1.6 + 4 * 3 = 13.6 flight hours.

The total distance travelled by truck and van in the example would be:
500 km + 50 km * 3 = 650 km.
Fuel consumption for the truck is 0.28 l / km, calculated emissions is 0.76 kg CO_2 / km.

The van, a VW Pickup, consumes 0.086 l / km, calculated emissions of 0.225 kg CO_2 / km.

The oil burner's power output is 260 kW. Fuel consumption is approximately 30 l / h. The incineration of 1m³ fuel oil produces about 2,661 kg of CO_2, providing 2,661 kg CO_2 / litre fuel oil. The incineration of fuel oil produces about 69 kg CO_2 / h at an output of 260 kW. It takes about 6 hours to heat 15m³ of water from 6° to 55°. The total amount of water to heat for the example becomes 15m³ * 3 * 3 = 133m³. Total time to heat the water is 6 hours * 3 * 3 = 54h for the entire period.

Table 2. CO_2 emissions to de-ice Uljabuouda wind farm

Vehicle/Equipment		Total emissions CO^2 kg	Fuel consumptions total litres
Truck	650*0,76	494	0,28*650 = 182
Van	650*0,225	146,3	0,086*650 = 55,9
Helicopter	13.6*450	6,120	178*13.6 = 2,421
Water heating	54h*80	3,726	54*30 = 1,620
Total		**11,080**	**4,279**

The energy content is similar for all input fuels, about 9.8 kWh / litre.

Total energy used in the form of fuel is 9.8 * 4,279 = 41,934 kWh = 41.9 MWh.

Overall, it provides a release of about 1,100 kg CO_2 / turbine for the example above with ten turbines. De-icing should only be performed when there are high expectations for good wind access without the risk of icing.

In the Nordic system, emissions-intensive coal power plants are currently valued as marginal electricity. When demand is high, these power plants start up when other productions (mainly hydro, nuclear, cogeneration plants and wind power) are not sufficient to cover demand. In the production of marginal electricity, a coal power plants releases (coal condensing) between .75 to 0.97 kg of CO_2, depending on the efficiency of each kWh produced, according to the Swedish Environmental Research Institute.

A wind turbine of 3 MW = 3,000 kW produces about 33 % of installed capacity over the year, giving an average of 3,000 * 0.33 ≈ 1000 kW / h.

When producing marginal electricity, emissions of CO_2 are between 750-970 kg / h in a coal power plant to cover the shortfall of a standstill plant. With a gas turbine, the corresponding emissions are about 500 kg / h.

To reduce the emission of CO_2, the method to de-ice the wind turbines by helicopter, is a better option than not doing anything at all. This is both from a financial and environmental perspective, as the wind turbines otherwise would have been at a standstill with no production at all. The energy consumption for de-icing ten turbines is about 41.9 MWh.

After about 4.2 hours of production, these turbines – with 33% availability – have delivered the energy required for de-icing. This means that benefits of de-icing with this method are greater, as it should only be implemented if expecting good wind access over the next few days.

If reducing the number of turbines to de-ice, or if the travel distance to other sites is much farther, the method will outcompete all power generation from coal power or gas turbine (marginal electricity production) within a few hours in reference to greenhouse gases, CO_2 and power consumption.

2.6.1 Fuels

Oil is used to heat water and clean diesel fuel for trucks and other vehicles. Other options, such as making use of fuel with a mixture of rapeseed oil, were examined. A mixture of rapeseed oil works well down to a temperature of about -20 °C, below that temperature the fuel becomes slow flowing. This caused major problems last winter when the temperature dropped to -34 °C. Diesel vehicles and the fuel burner stopped working. In this context it should be mentioned that during the final tests on Uljabuouda it was -32 °C in Arjeplog, but "only" about -16 °C on site. It is not unusual that it is warmer at higher altitudes during the winter. When travelling long distances, making overnight stops where it is usually significantly cooler than on site, it was decided not to use fuels that can cause problems. When environmentally friendly alternative fuels that can handle extreme cold are made available, they will replace the fuel used today.

2.7 PARALLEL ACTIVITIES WITHIN THE PROJECT

In parallel with the on-going work during the project, it was necessary to develop routines and design documents, namely:

- Safe Job analysis Risk assessment
- Standard Operational Procedure (SOP)

These documents are required to carry out this type of mission. The SOP is written in Norwegian and approved by Luftfarttillsynet in Norway. An approval in Norway also gives approval in Sweden.

Being such an extensive operation, there are plenty of things to take into consideration before carrying out a project of this size. Here are a few examples of important routines that have been verified:

- Positioning of the blade.
- The helicopters position against the wind direction.
- In and out flight from the turbine.
- Personnel security in and around the helicopter and water filling process.

The project has been in contact with several wind energy companies operating in cold climates, as well as with the wind turbine manufacturers to receive approval for the application of this method. Unfortunately the attempts have not been as successful as desired; hence this is still an on-going pursuit.

It had been easier to get attention for this method during the project if the seasons 2015-2016 had resulted in as much difficulty with icing as in 2010-2011 and 2013-2014.

However, severe ice formation followed by long periods without risk of further icing will come and then also an interest in this method.

It is also important to remember that this method should only be used when the turbines are standing still due to icing and one expects good wind conditions in the next three days without the risk of new ice formation. Production loss of a turbine during normal wind conditions is about 20,000 SEK / day.

The project has received considerable attention, both nationally and internationally in newspapers and on the radio.

The coming icing season, Norrbotten Media and Swedish Television (SVT) are planning news coverage on the method in the winter season 2016-2017.

3 Results

This project shows that by using this method, costs will be recovered within 48 hours compared to a reduced or no production. From an environmental perspective, this is also a better option than a turbine at standstill where the energy source needs to be replaced with marginal electricity such as coal or gas. As this method is not recommended as a first choice, careful consideration should be made before attempting this process. The project contributes to the development of new services and the profitability will improve for the wind turbine owner.

Project goals:

- Method and equipment for de-icing with warm water should be developed and tested during field conditions in cold climates.
- Demonstrate that the method is applicable and cost efficient.
- The technology should be presented at conferences and seminars.
- Develop a manual and routines of how to carry out a safe and effective de-icing process approved by the Swedish Transport Agency and the Civil Aviation Administration.

While there is space for smaller improvements, all project goals have been met and it has been proven that the airborne de-icing system is designed, tested and works well in field conditions and is applicable down to about -20 °C.

The method makes it possible to de-ice a turbine in about 1.5 h. In order to be cost effective, the goal was that it should not take more than 2 hours.

The project has been presented in conjunction with Winter Wind 2014 and 2015 as well as Wind 2014 and 2015. During the project it's also been presented during university lectures and seminars.

AIRBORNE DE-ICING SOLUTIONS FOR WIND TURBINES

Method and equipment for de-icing with warm water is developed and tested during field conditions in cold climates. The technology is applicable and cost efficient. The technology is presented at conferences and seminars. The Swedish Transport Agency and the Civil Aviation Administration approve manual and routines of how to carry out a safe and effective de-icing process. This airborne de-icing system is designed, tested and works well in field conditions and is applicable down to about -20 °C.