Siemens Blade De-icing

Improving output in harsh conditions

Agenda

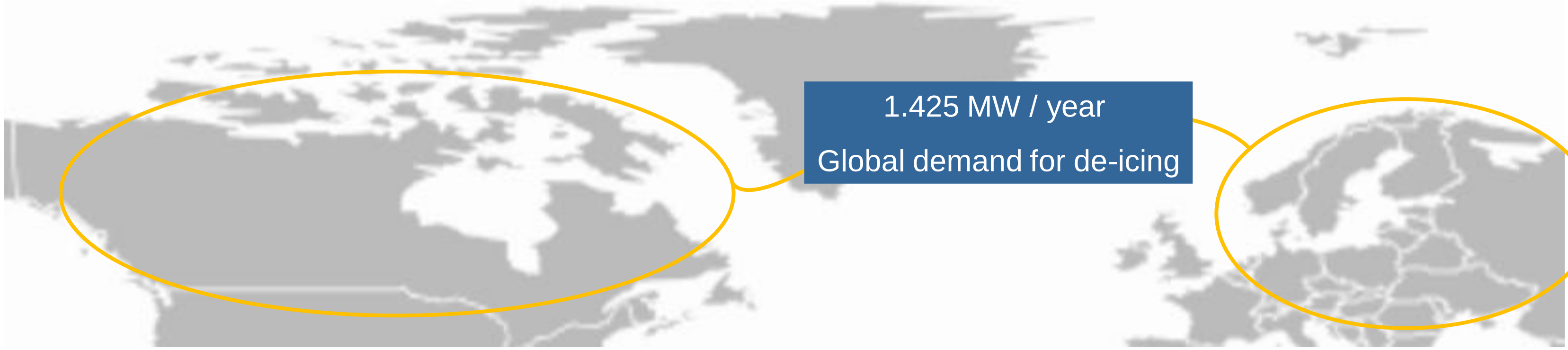
- Impact of Ice and De-icing Market Potential
- Siemens Wind Power De-icing System
- Prototype Sites and Data
- Cold Climate Package
- Operation with Ice
- Performance Warranty

Ice build-up impacts performance and availabilty

- Depending on the degree of ice build-up, areaodynamic performance of the blade is reduced.
- Ice build-up can cause a rotor imbalance and lead to a shut down event, thereby decreasing availabilty.
- Increased risk of ice throw incidents that can possibly cause damages to the surrounding environment.
- Siemens Wind Power offers a blade de-icing solution for:
  - SWT-2.3-101
  - SWT-3.0-101, SWT-3.0-113
  - SWT-3.2-101, SWT-3.2-113
  - SWT-3.4-101

Capturing the market potential for blade de-icing

A well-functioning de-icing system is a *must* across the globe



Required:

- approx. 75 % of the Swedish projects => 450 MW per annum
- approx. 50 % of the Finnish projects => 100 MW per annum
- approx. 33 % of the Norwegian projects => 200 MW per annum

Requested:

- approx. 25% of the Belgian projects => 100MW
- approx. 25% of the Austrian projects => 75MW
- approx. 25% of the Canadian projects => 200 MW
- approx. 10% of the German projects => 300MW

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The selection of SWP De-icing System

SOLUTION	PRO	CONS
Blades Painted Black	Proven technology in sunny areas – USA	Efficient only where sun radiation is available
Change Air Flow by Pitching	Cheap	Not efficient regarding power production; not able to work as stand alone solution
Mechanical Solution (expanding foils, “bug wipers”, inflating balloons)		Maintenance / Service
Shaking the Blades	Cheap	Not proven to work; SWP blades fatigue test - not strong enough to brake the ice
Spray-on Chemicals	No extra equipment needed in blades / hub	Environmental unfriendly
Microwaves		EMC protection – High price
Nanotechnology / hydrophobic	Does not effect other components	Not tested – not proven to work.
Heated Air Inside the Blades	Protected by blade structure during transport	“Only working at standstill / idling slow – blades are thermally isolating components
Hydraulic Heated Hoses	The losses from the nacelle can be used to heat up the hydraulics	Add a lot of weight on the blade - critical
Electrical Heated Foils	Fast working – on the surface	Wiring in/at blade structure, Transportation problems, Exposed for lightning / erosion

Improving performance by detecting icing conditions

SWP Ice detector system provides the turbine controller information about potential risk for ice on the turbine blades.

System:

- Ice sensor and controller unit
- Interface to Siemens turbine controller
- Interface to Siemens SCADA

Ice alarm:

- Can trigger turbine shutdown
- Activate an acoustic or visual site warning indication
- Initiate blade de-icing

Control Unit	
Material	Polycarbonate
Degree of protection	IP 66/67
Operating temperature	-30^{oC} to +60^{oC}
Power consumption	7 V
Fuse:	50 mAT, IEC 127 5 x 20 mm

Ice Sensor	
Dimensions	350 x 100 x 25 mm (h x w x d)
Material	Aluminium
Degree of protection	IP 65
Operating temperature	-40^{oC} to +60^{oC}

Low torque ice detector: a software based solution used to detect ice accretion on the blades

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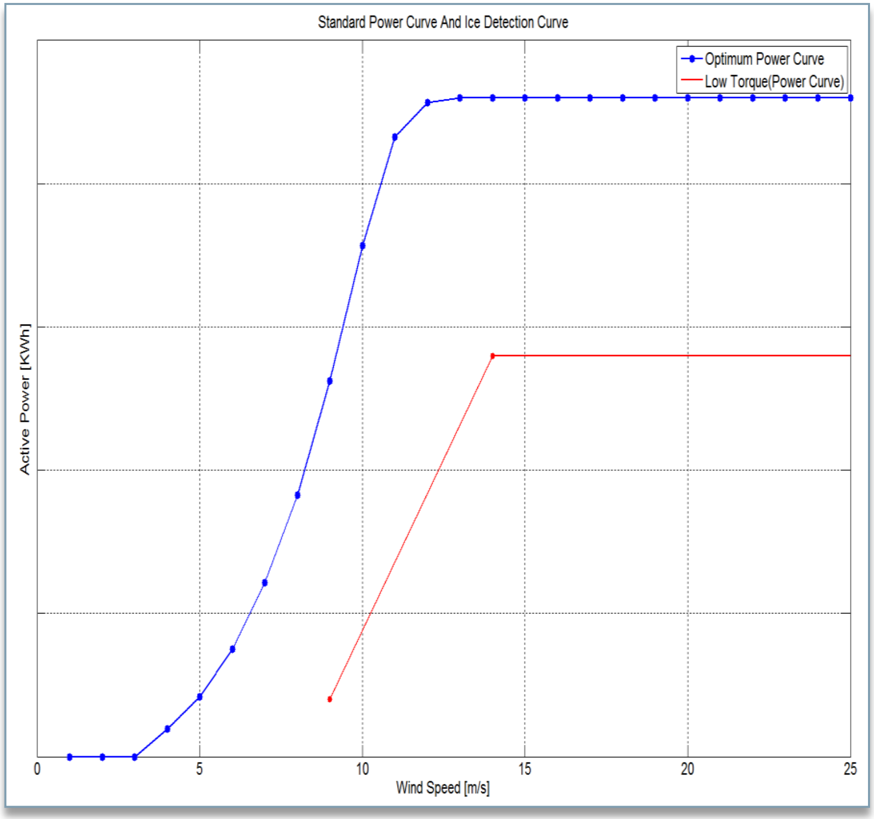
- Part of the Siemens turbine controller.
- An ice power limit is continuously calculated based on an ice power curve using 10 minute averages of wind speed.
- When power production degrades due to ice build-up on the blades in cold weather, and the turbine power production is below a determined ice power curve, then it is reasonable to assume that the lower power production is caused by ice build-up on the blades.
- The figure to the right illustrates the comparison between the low torque power curve and the optimum power curve.

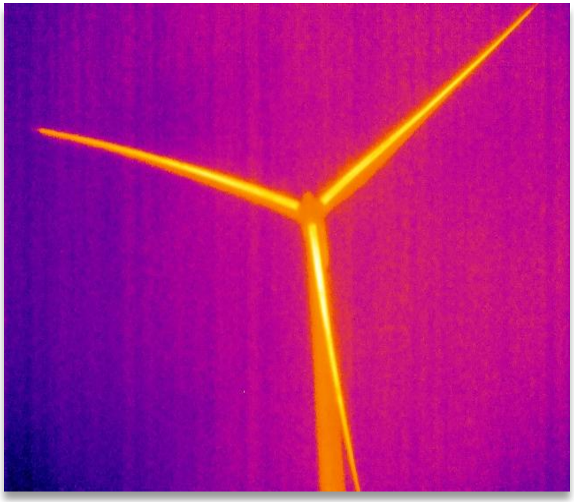


Reliable solution for removing ice

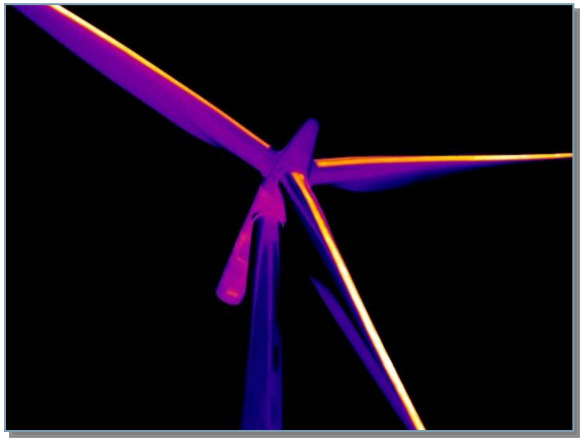
Siemens Wind Power De-icing Strategy

- Ice detected (through power curve deterioration, ice detection sensor or low toque ice detector).
- The turbine is stopped, in static or idle mode (0-2 Rotor rpm).
- The nacelle yaws so the rotor is in ”back-wind” or in ”safe angle of rotor disc vs. nearby objects”.
- De-icing is activated on all three blades.
- After x min, the nacelle yaws back into the wind.
- Once the turbine is producing again, de-icing is deactivated.

Parameters for blade de-icing	
Temperature	+5^{oC} to -15^{oC}
Liquid water content	0 - 60 g/m3
Droplet diameter	0 - 60 µm
Wind Speed	0 - 25 m/s



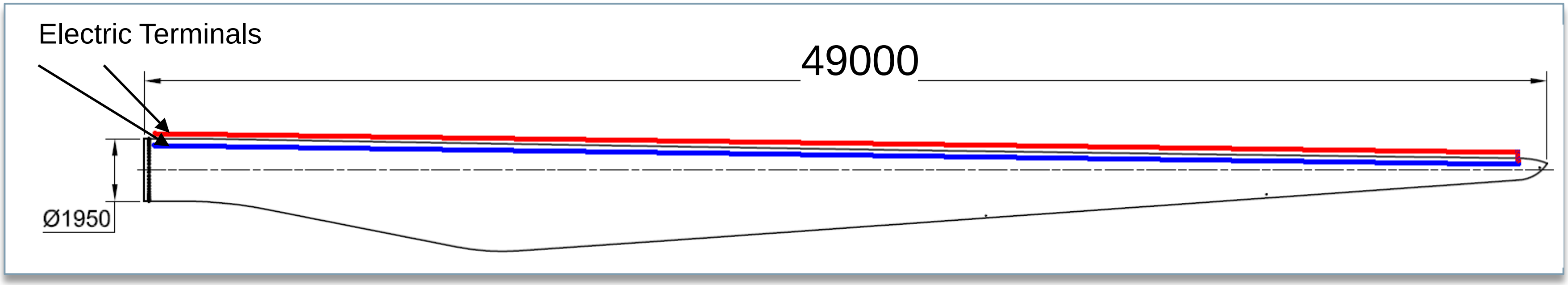
SWT-2.3-101 de-icing activated



SWT-2.3-101 de-icing activated

Siemens Wind Power De-icing System: carbon fiber heating elements integrated in the blade

- Carbon fiber heating element
- The two heating strips cover the leading edge of the blade from the root to approximately the tip. The tip cannot be covered due to the presence of lightning receptors.
- The two lanes are connected, forming a continuous electrical loop from the root connection on the pressure side to the root connection on the lee side.
- The two strips are electrically insulated through a narrow filled gap on the leading edge of the tip of the blade and increase to a larger width for the rest of the leading edge to the root.
- The turbine controller prevents the blades from overheating by automatically checking that the ambient temperature at hub height is below +5^{oC} before de-icing is activated.



Integrated design offers distinct advantages

Designing toward minimum risk…

- Heating elements secured from contamination, loading, loosening & displacement.
- No wiring on the outside of the blade, reducing risk of lightning strikes.
- Factory assembled system, increasing reliability while minimizing risk of transport damage.

Blade with mounted carbon layer

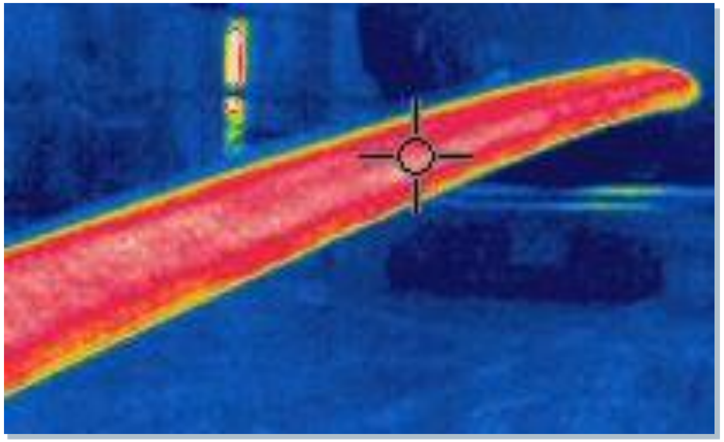
…and optimized performance

- Heating element adjacent to surface for optimized heat transfer and minimum power losses.
- Full retention of the aerodynamic profile.
- No effect on noise levels.

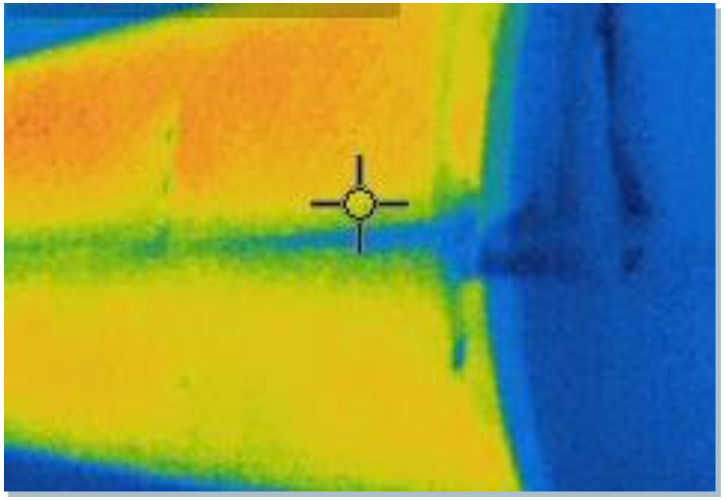
Finished blade with de-icing

Extensive and rigorous testing before serial installation validates the design

- Heat distribution test
- Thermocycling test (1600 cycles)
- Uneven thermal expansion test (glass vs carbon)
- Lightning reception test



Test set-up for heat distribution test (carbon element)



Infra-red camera picture showing even heat distribution

De-icing power connections and consumption

- The power is taken from a power unit outlet at the tower base, wired through the tower to the nacelle and into the hub through a slip-ring system.
- Cables connect a hub control cabinet to terminal boxes in the blade with lightning protection. The slip-ring system is the only moving part in the system.
- All cables, slip rings, and other electrical components are dimensioned to supply power to the blades continuously at nominal grid voltage of 690 V at 50 or 60 Hz.
- The average heat generated per m2 de-icing carbon mat (approximately 0.6m wide per side of the blade from the front of the leading edge starting at 1m from the root up to1.5 m before the tip) is 0.48 kW/m2.
- Note that the general +/- 10% tolerance band on grid voltage will affect the blade power correspondingly.

Protection and turbine safety

- Circuit breakers in the AA33 cabinet placed in the nacelle protect the system against short circuit and ground fault.
- An additional circuit breaker is located in the power unit.
- Overload protection is performed by the turbine controller.
- Over voltage protection devices are located in the hub.

De-icing design and maintenance

- All components in the system are designed in accordance with engineering standards EN 60364 and EN 61439.
- The system is covered by the defects warranty as set out in the conditions of contract of the turbine supply agreement.
- Maintenance is limited to annual visual inspection of the carbon mats.
- In case of failure the function loss will be detected by the control software, alarm codes will be generated, and turbine operation will return to nominal operation without de-icing.
- The breakers in the power unit or nacelle can be manually switched off and locked for safe inspection and maintenance.
- All system components can be replaced or repaired on site.

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Successful prototype installations in Sweden confirm the system performance

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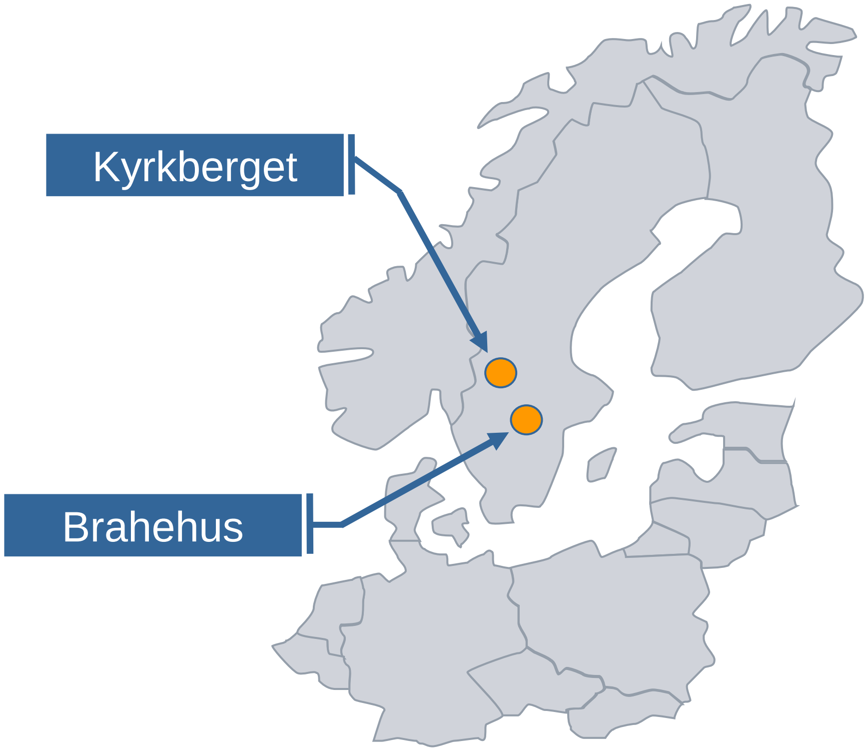
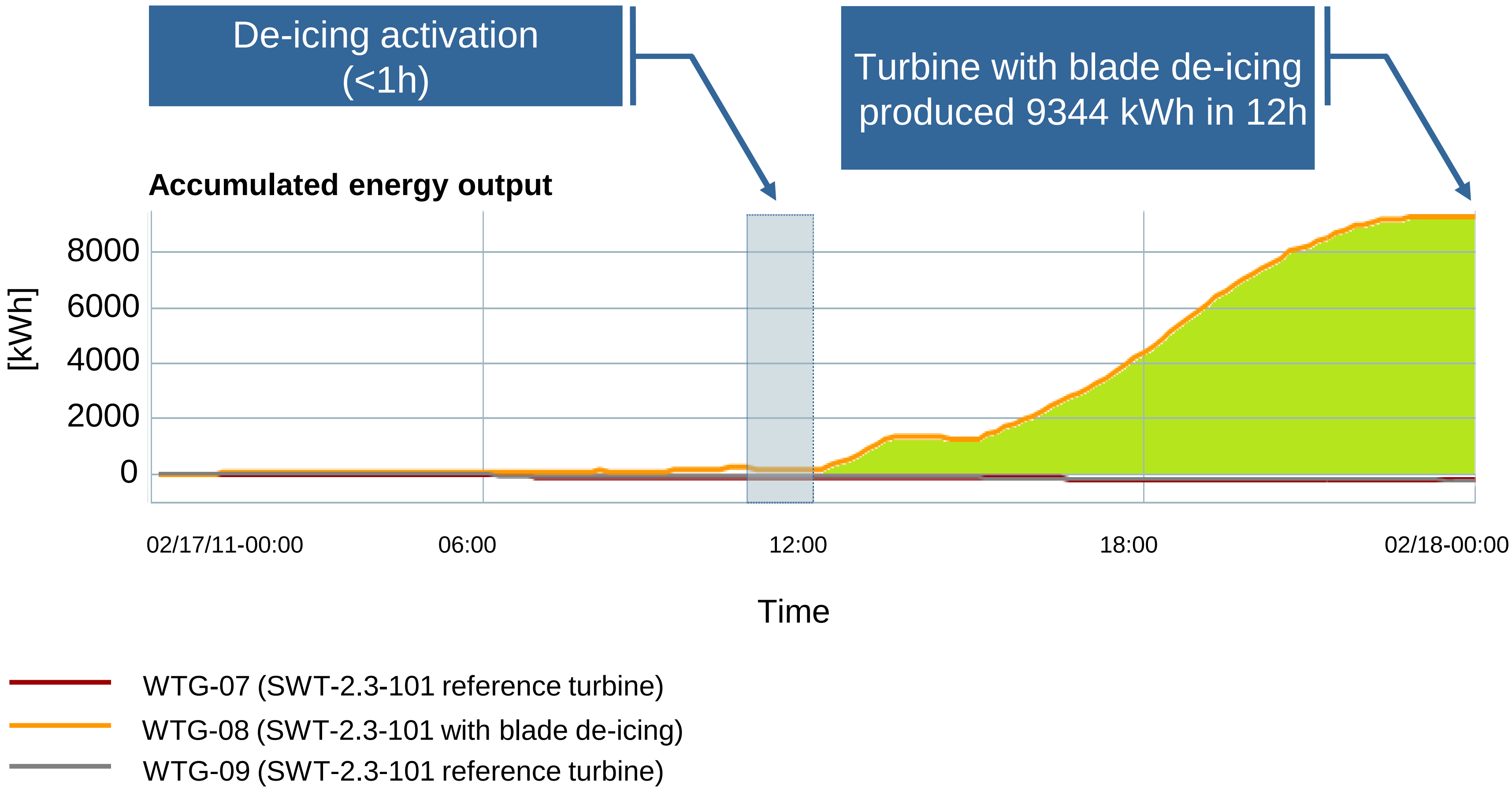
Site testing with early success:

- Prototype installations on two SWT-2.3-101 wind turbines.
    - Tests started in Q1 2011
    - Testing continued on 13 WTGs in winter 2011-2012 for further optimizations
- Tests have demonstrated significant increase in power production during winter, across all test sites.
- All prototypes have been in full operation since day one.
- Continuous data analysis and continual improvements of control system.



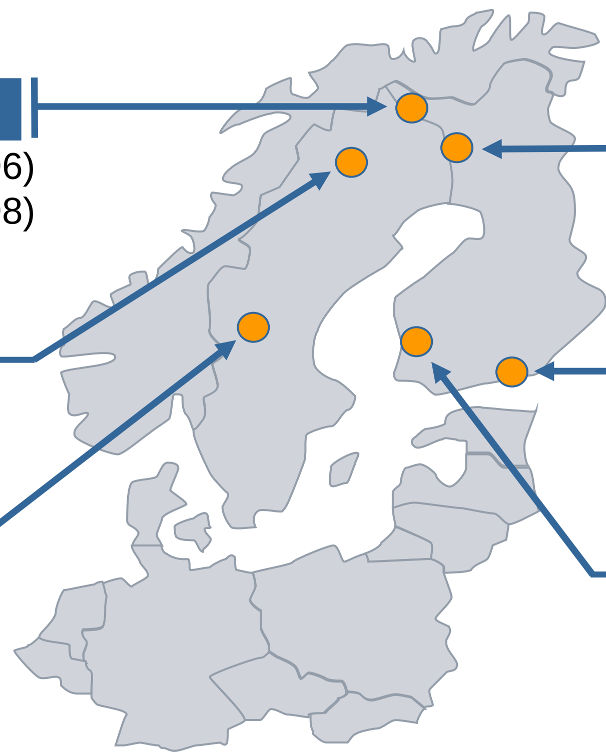
Successful prototype installations in Sweden confirm the system performance



Long experience in cold climates and icing conditions since Bonus era

Bonus as a pioneer wind turbine manufacturer in cold climates & icing conditions:

- First cold weather package in 1986 (Quebec, Canada).
- First de-icing system implemented on a 150kW Bonus turbine in 1994 (Yukon, Canada).



Lammasoaivi
- 2 x Bonus 450kW (1996)
- 1 x Bonus 600kW (1998)

Olos
- 2 x Bonus 600kW (1998)
- 3 x Bonus 600kW (1999)

Suorva
- 1 x Bonus 600kW (1998)

Kotka
- 2 x Bonus 1MW (1999)

Vemhån
- 1 x Bonus 600kW (1998)

Pori
- 4 x Bonus 1MW (1999)

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Siemens cold climate package complements blade de-icing for continued operation

Extended lower temperatures:

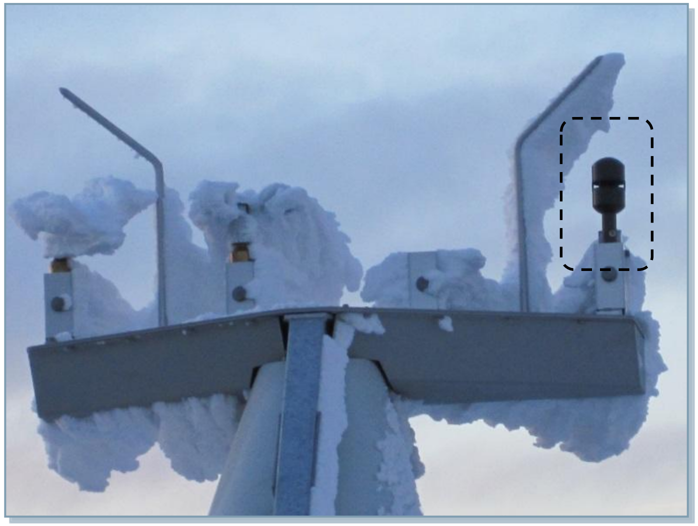
- Standstill: -45^{oC} (standard: -20^{oC})
- Operation: -25^{oC} (standard: -10^{oC})

Special material features:

- Cold-resistant steel for turbine tower according to EN 1933-1-10:2005 where needed
- Low temperature varieties for damper and cooling liquids

Additional heating elements:

- Heating elements for gearbox and hydraulic unit
- Sonic wind sensor with integrated heating



Ice-free sonic wind sensor with integrated heating (dotted line)

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Increasing production and availabilty in icing conditions through adaptive operation

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Operation with Ice

- Functionality that extends the range of operation in cold climates.
- Adaptive operation that finds the optimal operational set-upf through pitch angle and speed-power modifications or maximum power production in icing conditions.
- Increases production and availability without compromising operational safety.

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How can we increase employer value?

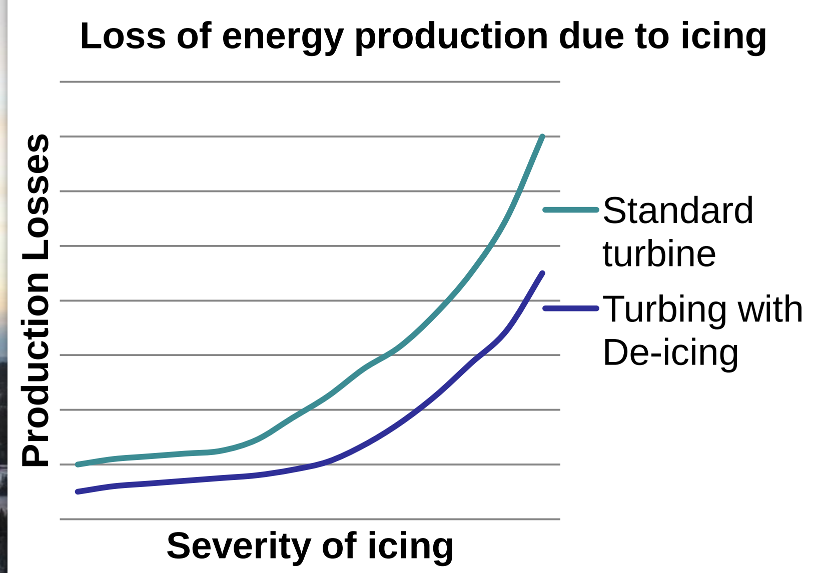
Current employer value of blade de-icing

- Allows operation in harsh climatic conditions
- Increases energy production (reduces losses)
- Decreases repair costs

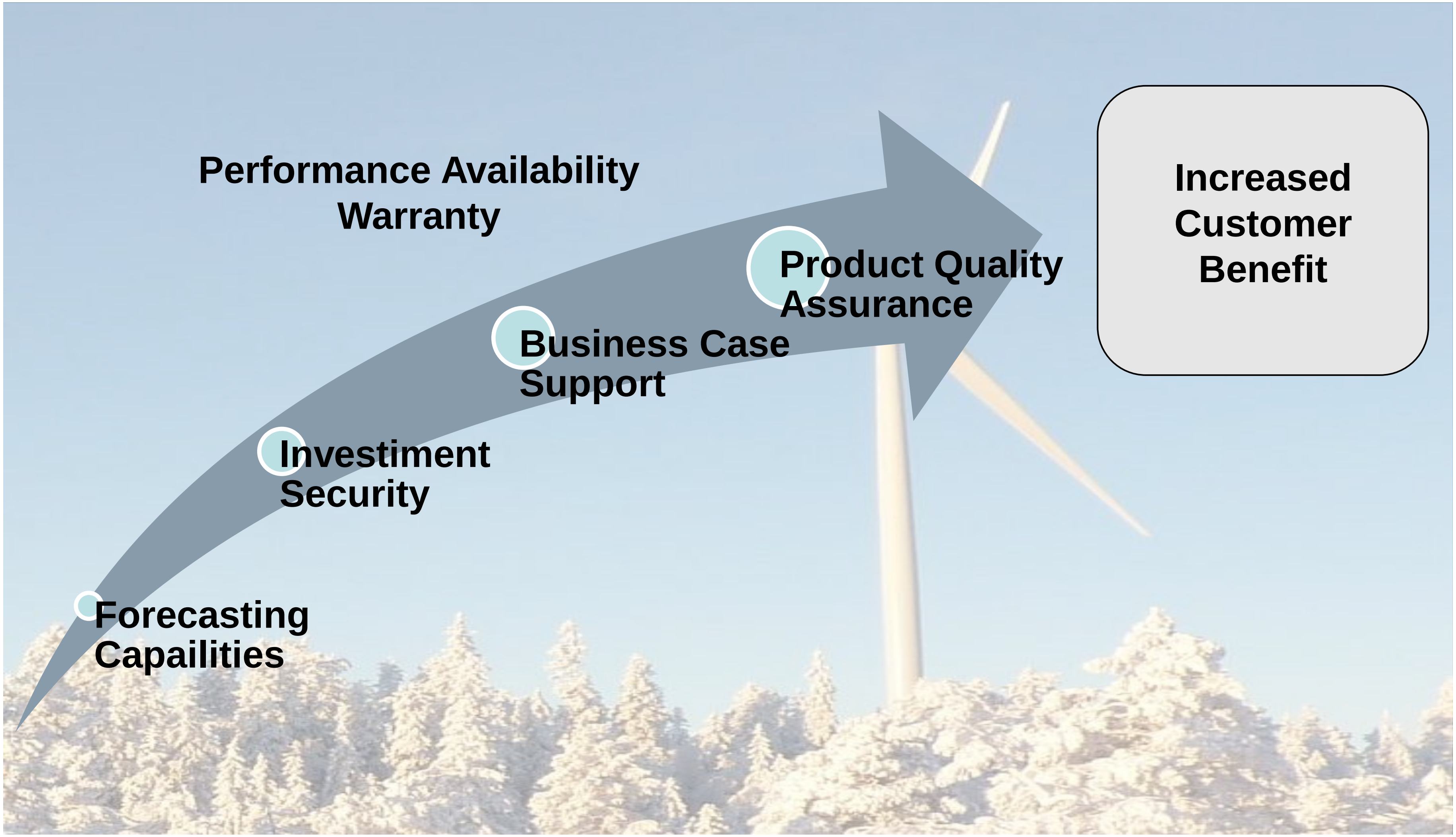
How can we add value?

- Increase knowledge of ice characteristics and behavior
- Standardized methods of describing icing conditions, de-icing systems and de-icing efficiency
- Performance Availability Warranty

Reduce employer risk of contingency



Providing performance availability warranty increases customer benefit



Increasing employer benefit may increase contractor risk

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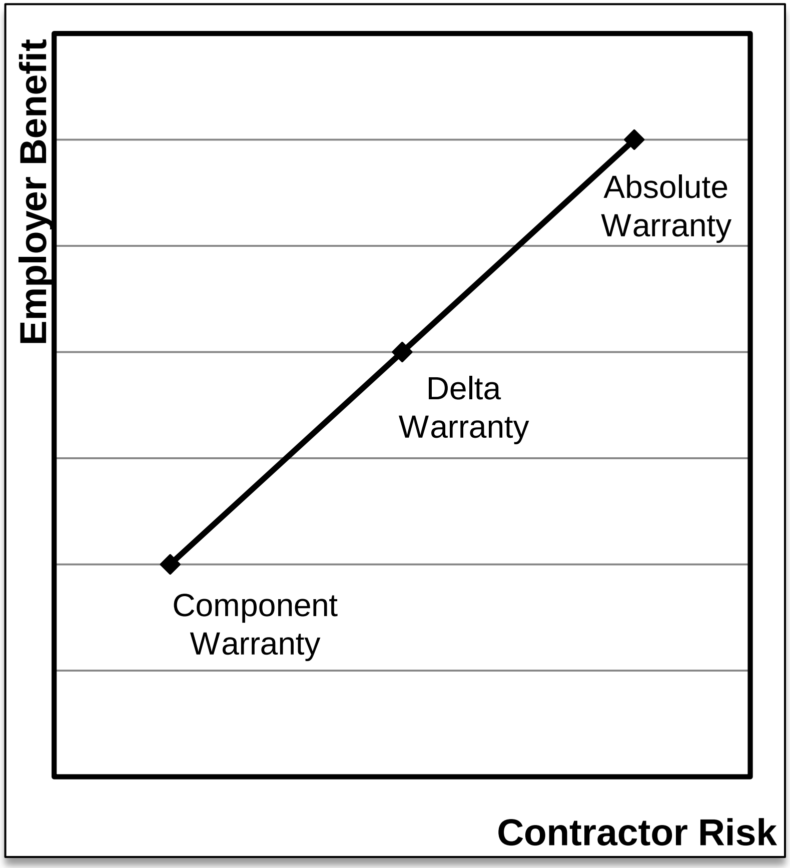
Present
Warrant the functionality of the de-icing system

Challenges to address:

- Many variables to consider (e.g. wind speed, temperature, air moisture)
- Little knowledge of ice characteristics and behavior
- No standardized way for evaluating icing conditions

Future
Warrant performance of de-icing system (e.g. in terms of decreased downtime caused by icing, increased energy production or decreased energy loss)



Going from niche to industrialized solutions with high volume, lower cost, and improved quality

Installed and contracted projects*

- Previous platforms: 18 units (1994 -1999)

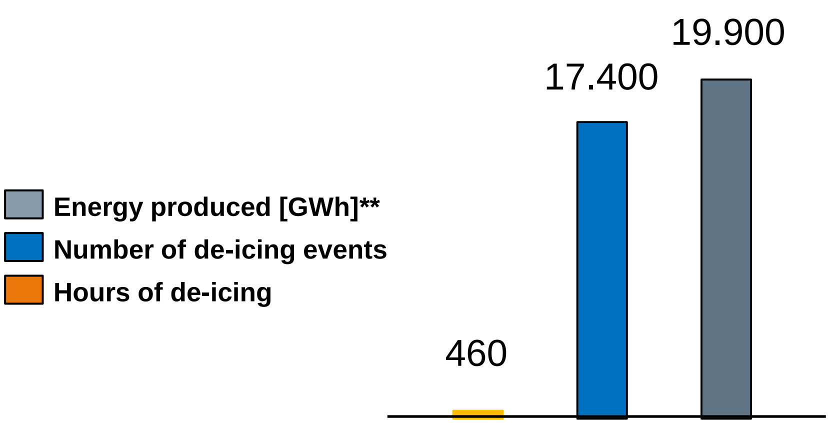
  Bonus 150kW, Bonus 450kW, Bonus 600kW, Bonus 1MW

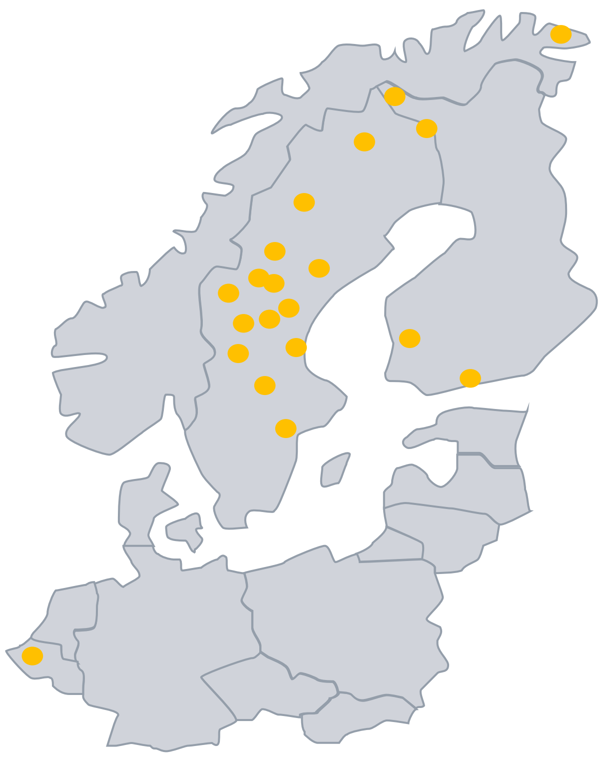
- Geared platform: 61 units (2011 - 2013)

  SWT-2.3-101

- Direct Drive platform: 221 units (2013 -2015)

  SWT-2.3-113, SWT-3.0-101, SWT-3.0-113, SWT-3.2-113





* Accumulated numbers during winter 2013 and 2014

** Gigawatt-hour

Siemens Blade De-icing System: Improving output in harsh conditions

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Summary

- Blade de-icing allows Siemens wind turbines to operate under harsh icing conditions.
- Integrated design increases reliability while completely retaining the aerodynamic profile and noise levels.
- SWP experience and rigorous testing complement the design to minimize the risk of un-scheduled service in remote areas.
- By improvement through years of experience we can offer customers a solution to minimize production losses and increase environmental safety.
- Further investigation of icing characteristics and behavior is necessary in order to increase customer benefit through performance warranty.

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Thank you for your attention

www.siemens.com/wind