VTT

PHYS-E6572 Advanced Wind Power TechnologyL09

Timo Karlsson, material contributed by Esa Peltola, Ville Lehtomäki and others.

Contents

Operation and maintenance

Operation and maintenance

- Goal: Maximize
  - Turbine lifetime
  - Turbine availability
  - Wind farm revenue
- 10 – 20 % of lifetime costs onshore are from O&M
- Plan maintenance properly, to ensure long lifetime and minimum disruption to operations

Wind turbine availability definitions

- **Time-based availability**

$$\text{Time-based availability} = \frac{\text{Time available (in hours)}}{\text{Total time in consideration (in hours)}}$$

$$\text{Production-based availability} = \frac{\text{Energy actually produced (in kWh)}}{\text{Energy potentially expected (in kWh)}}$$

- **Contractual availability**.
  - Defined in the Turbine Supply agreement.
  - Monitored with the wind turbine SCADA reports.
  - Has “carve-outs” or negotiated provisions for scheduled maintenance (~40 hours per year)

- **Technical or effective availability**.
  - Annual % of time that the turbine is in operation, ready for energy production (even if it is just standing still due to low wind).
  - It is a faithful measure of technology performance

- Full period availability vs wind-in-limits availability

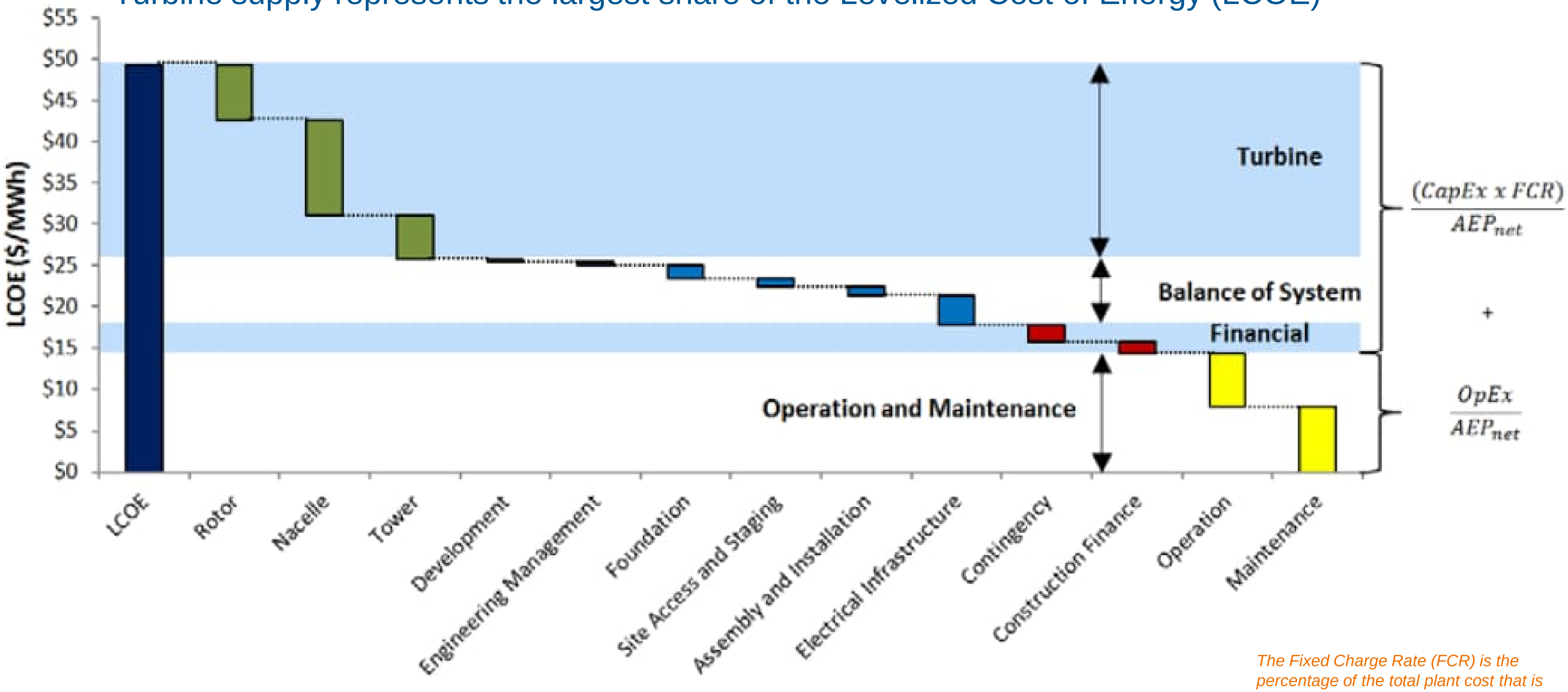
$$\text{Full-period availability} = \frac{\text{Number of hours available}}{\text{8,760 hours/year}}$$

$$\text{Wind-in-limits availability} = \frac{\text{Number of hours generating kW}}{\text{Number of hours that the wind is between cut-in and cut-out}^{3}}$$

Source: DNVGL EEA-WP-15 (2017)

Wind farm costs

- Turbine supply represents the largest share of the Levelized Cost of Energy (LCOE)



Component-level cost breakdown for the 2016 land-based wind reference project (NREL 2017)

The Fixed Charge Rate (FCR) is the percentage of the total plant cost that is required over the project life per year to cover the minimal annual revenue requirements.

Field operations

- Field operations involve planned and unplanned maintenance, and manual restart following faults
- Accredited **safety training** is a must for participating in field operations.
- Access to wind turbines requires, as a minimum the Global Wind Organization Basic Safety Training (**GWO BST**)
- Also work requiring rope access, such as blade maintenance, requires Industrial Rope Access Trade Association (**IRATA**) rope access accreditations
- In addition to safety accreditations, a technical qualification is also required (electrical works, hydraulic works, composite repairs)

Source: Altitec

Inspection and field monitoring

- Erosion and in cold climates icing can damage the blades
- Bad enough erosion can result in reduced aerodynamic efficiency
- Periodic inspection
- These days increasingly photgraphing the blades with drones
- Some repairs, even blade surface and coating repairs can also be done with robots today

Source:https://www.windpowerengineering.com/tips-choosing-right-drone-inspection-service/

Source: IEA Wind Task 46

Maintenance checks

- Periodic checks
  - **Bolt tension**: tower, gearbox mounting, main frame to tower, electrc terminals etc.
  - **Gearbox:** oil levels, check oil quality
  - **Hydraulics:** hose condition
  - **Power cables:** cable condition, connections
  - **Generator:** alignment, electric conditions
  - **Lightning protection:** check conductivity
  - **Blades:** leading edge condition, erosion tape, drain holes

Image Source: Bladefence

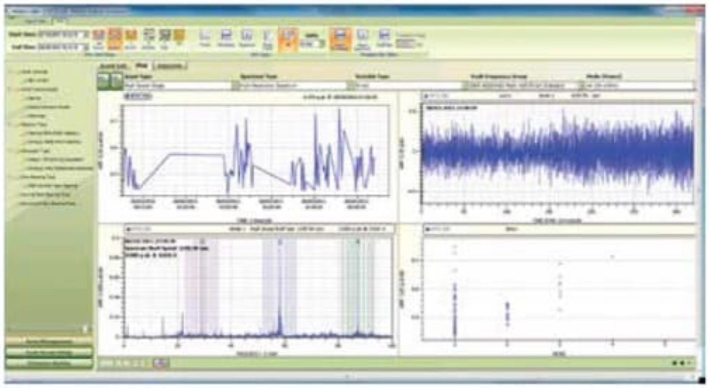
Condition monitoring system

- Condition monitoring combines **data acquisition** and processing to **diagnose** the status of the system and **prognose** its future status

- It enables a shift from **corrective / scheduled** maintenance towards **predictive or condition based maintenance**

- Typical CMS installed in wind turbines include:
  - Gearbox accelerometers
  - Gearbox oil particle sensors
  - Nacelle accelerometers
  - Signal processing hardware
  - Diagnostic software combining sensors with SCADA data

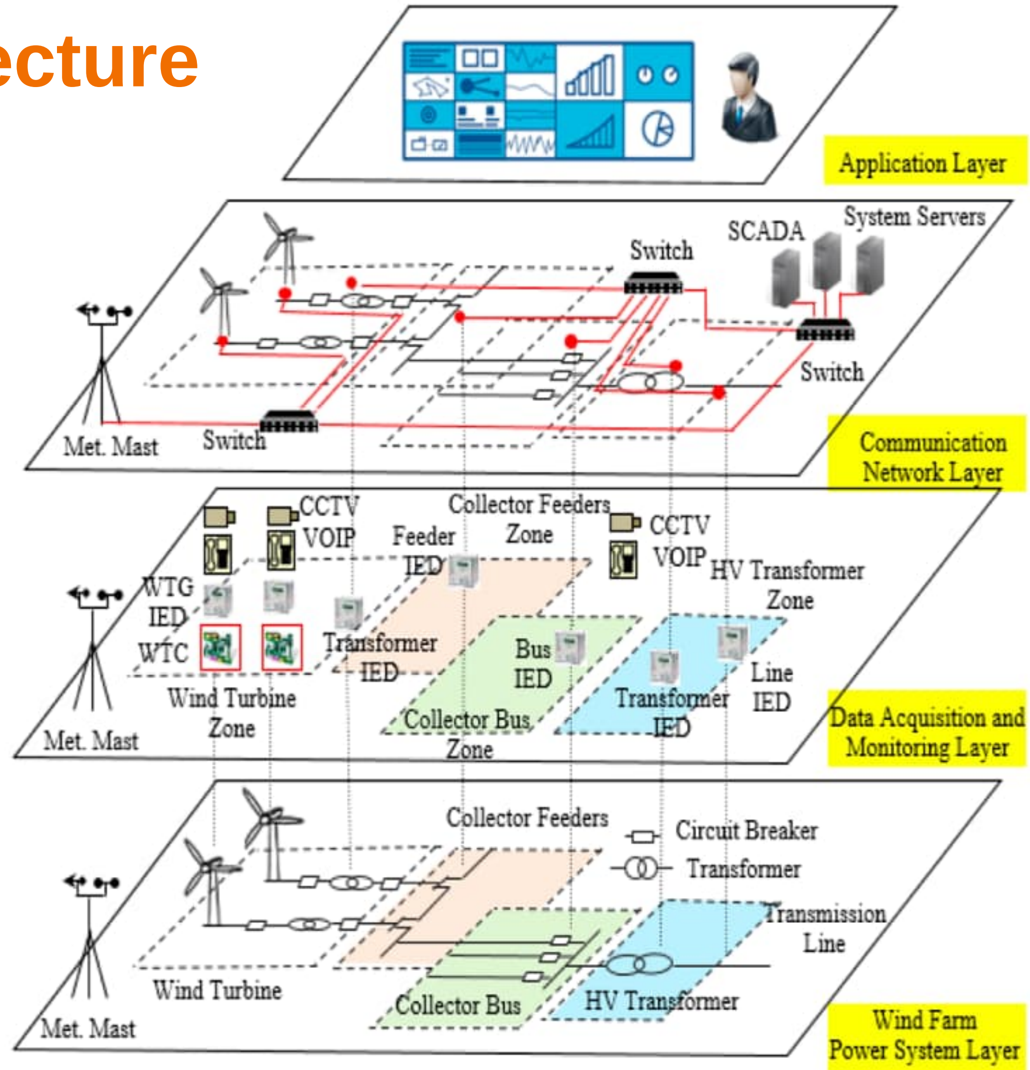
- Also the following sensors may be included: Temperature of gearbox oil and gearbox bearings



Source: General Electric Measurement

Wind farm SCADA architecture

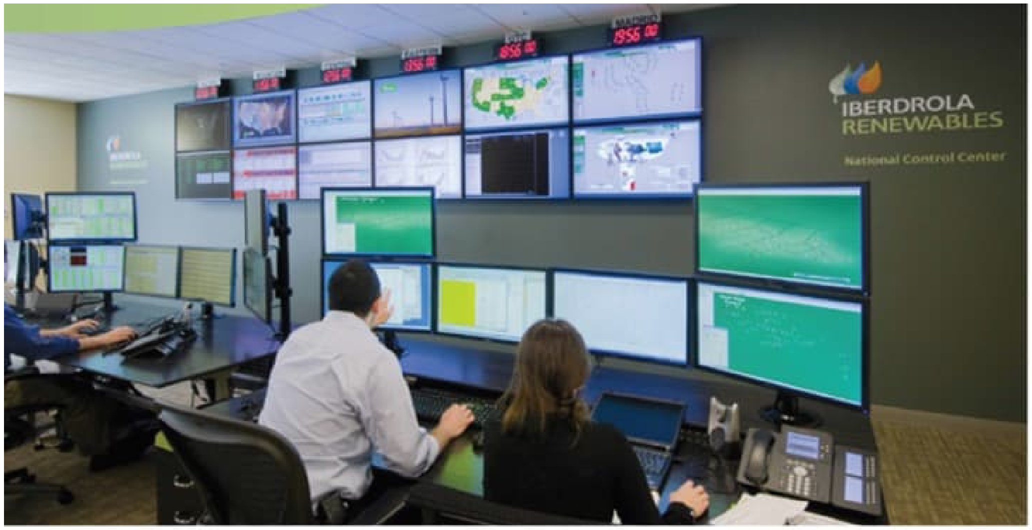
- The wind farm power system layer is supported by a SCADA system formed by three layers:
  - **Data acquisition & monitoring** : array of sensors and Intelligent Electronic Devices (IEDs) for protection & control, which are installed in the Wind Turbine Generators (WTGs), the Met Mast and the Electrical substation
  - **Communication network** : linking the data acquisition with the SCADA servers (field bus, industrial ethernet, fiber-optic, RS-232, satellite)
  - **Applications**: SCADA software
- The **control centre**, hosting the SCADA servers and the team of operators, may be local (co-located at the substation) or remote, controlling one or more wind farms



Source: Ahmed, M. " Communication Architecture for Grid Integration of Cyber Physical Wind Energy Sys Appl. Sci. 2017, 7(10), 1034

The Control Centre

- A remote control centre, such as the NCC of Iberdrola in US (Oregon) manages ~6000 MW of combined Wind, solar, biomass, termal and hydro, including some 1300 wind turbines. Typical operations include:
- Operate in compliance with standards, including generation and voltage set points, maintaining communications, and data systems
- Operators troubleshoot alarm/error codes to adjust turbine activity to comply with local grid demands, direct technicians in the field to respond to faults or get out of harm's way if severe weather approaches.
- Acts as a point of contact and information flow when emergencies occur in the field.
- Provides field services to remotely operate and reset wind turbines in compliance with prescribed protocols.
- Handles planned and unplanned outages



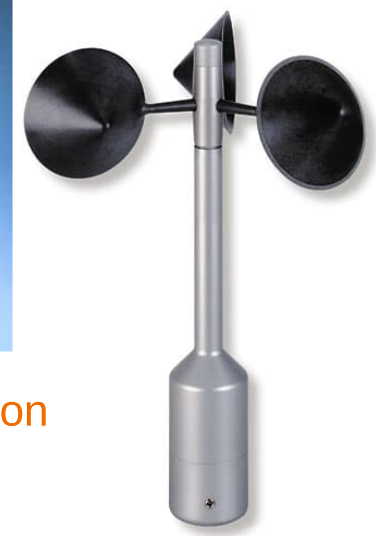
Source: Iberdrola - Avangrid

Measurements

Cup Anemometers

- Measures the scalar wind speed
- Classification
- Calibration
- Heating: shaft or fully!

Vaisala 252



Thies first class

- Wind vanes for wind direction measurements

NRG 40

Sonic Anemometers

- Sonic anemometers measure the wind velocity by sensing the changes in the speed of sound in air.
- It can measure the wind vector (3D) or the component of the wind vector on the horizontal plane (2D)

+ Direction included ☺

+ No moving parts

+ Extremely fast sample rate (good for turbulence studies)

+ Heating is easier to implement than in cups

- Heavy (mounting issue)

- No classification so far

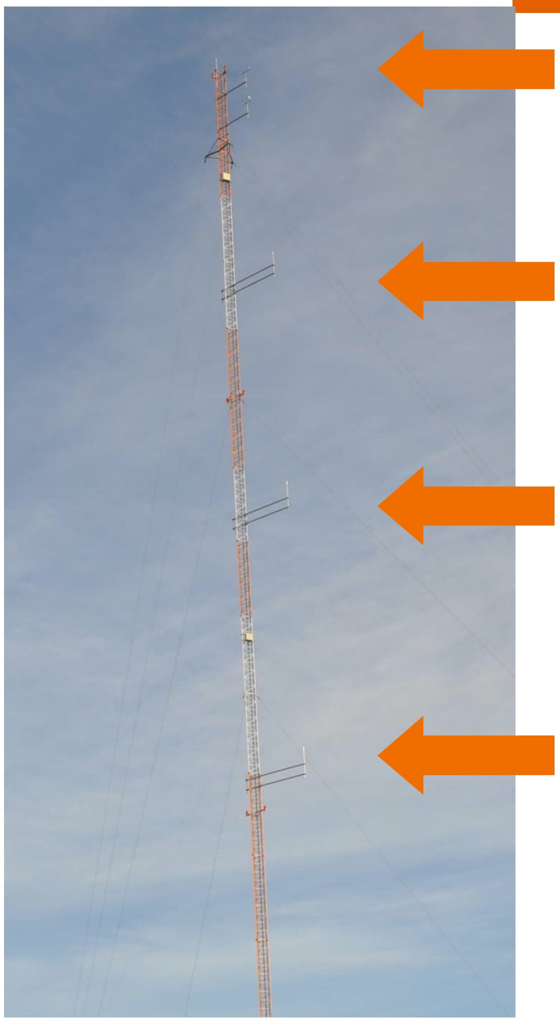
Other Relevant Metereological Sensors

- Temperature
- Pressure
- Humidity
- Ice detectors
- Radiation
- Rain

- Webcam

Wind measurements with Multiple Levels

- Vertical Profiles
  - Wind speed → shear
  - Direction → veer
  - Temperature → stability
- Backup in case of failure



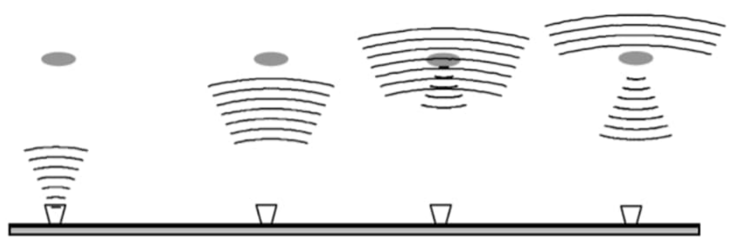
Remote Sensing

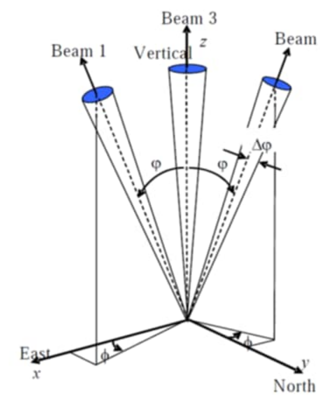
SODARS

- Wind vector measurement by sending and receiving successive pulses of sound
- Scattered sound from turbulent temperature variations
- Doppler effect in the backscattered signal
- Several measurement height from 10m up to 300m for wind energy application

+ Low consumption

+ Cheap ≈ €40 k





Remote Sensing

LIDARS

- Wind vector measured by sending beams of light and detecting the Doppler shift in the backscattered signal from the atmosphere
- Scattered light from aerosol

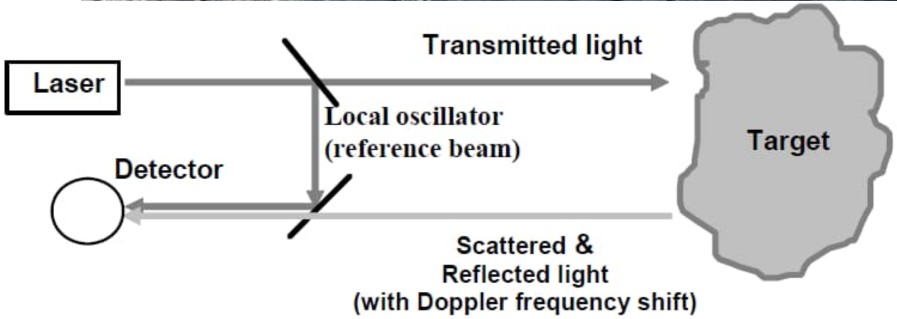
+ Silent

+ No background noise problems

+ Precise and Accurate

+ Only option in offshore

- Expensive ≈ €150 k



Be aware of bad mounting and icing conditions!

Safety and reliability of measurements

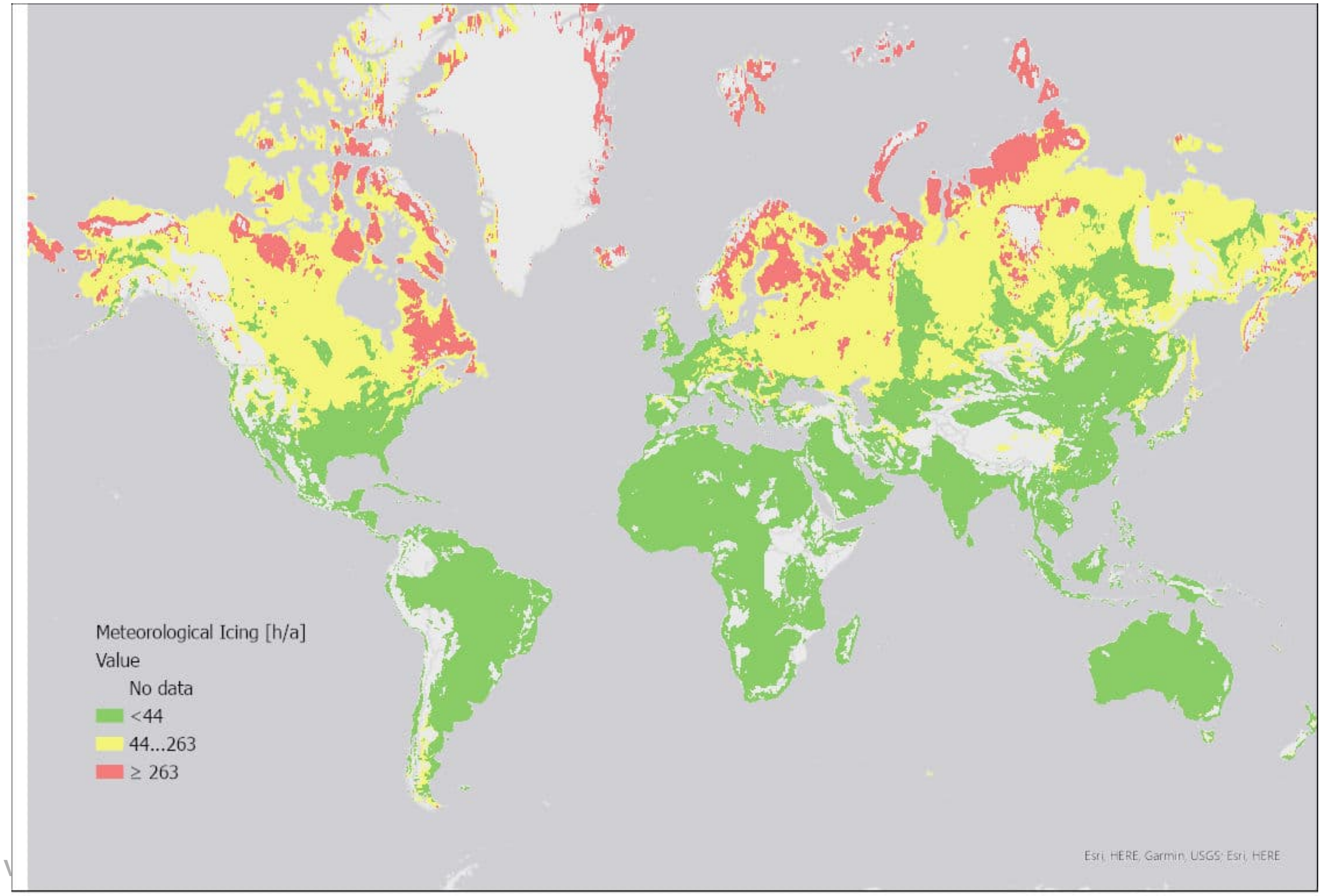
Cold Climate wind

Cold climate wind

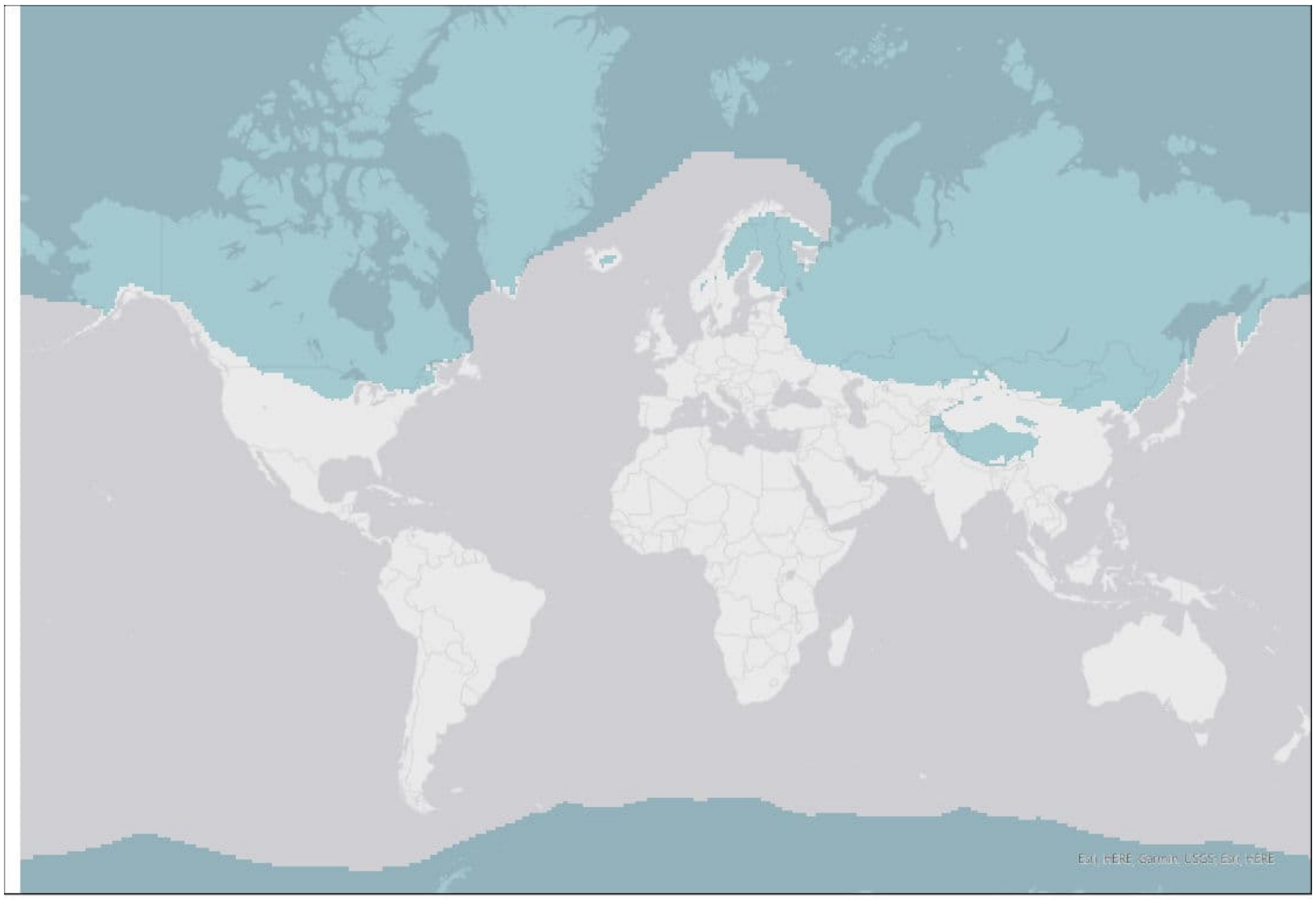
- Why arctic / cold climate wind as separate issue?
- Technical challenges
  - Blade icing
  - Cold temperatures
- Advantages
  - Sparsely populated areas
  - Good wind conditions
  - Higher yield due to higher air density

$$P = C_p \frac{1}{2} \rho A v^3$$

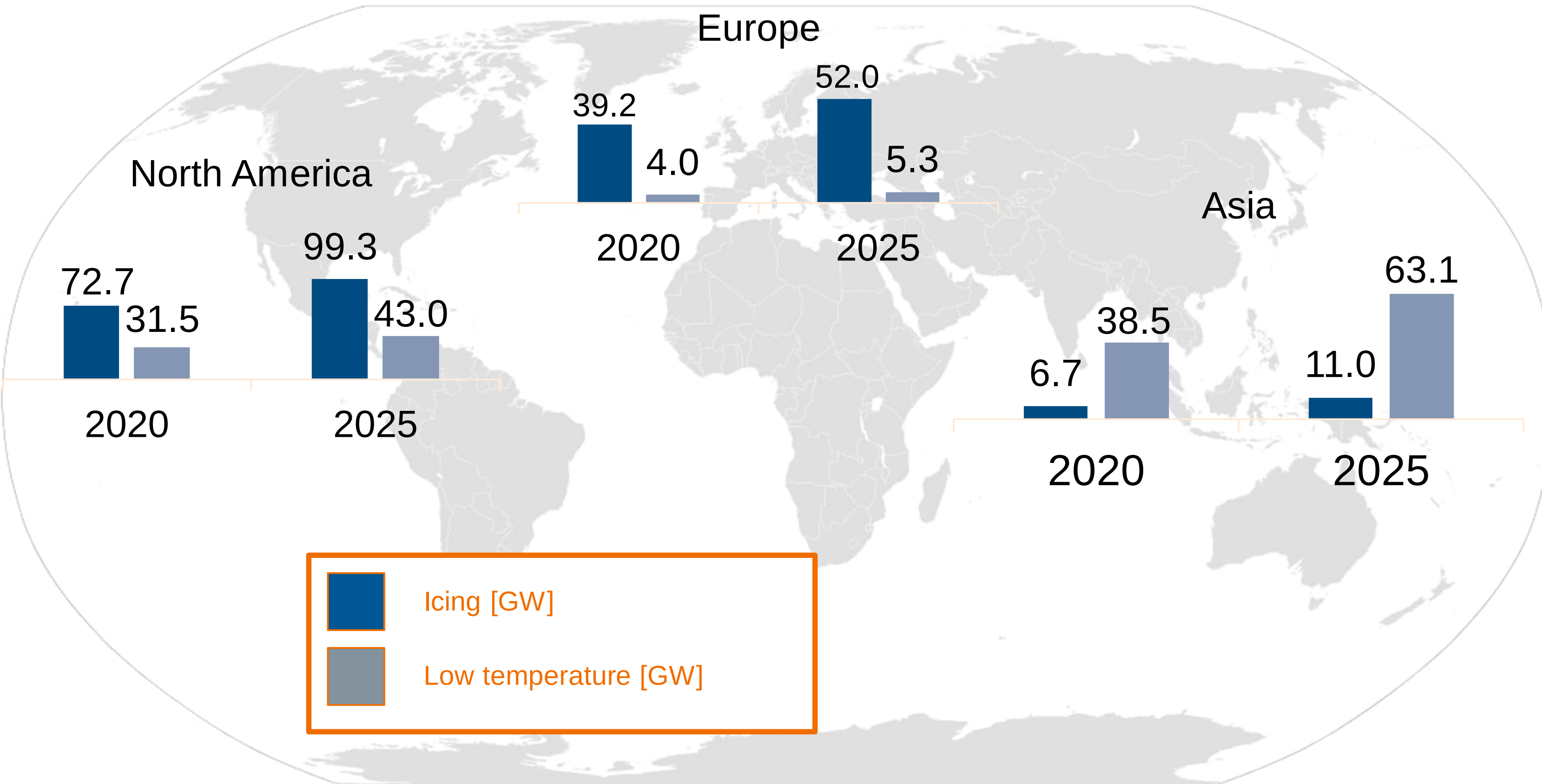
Icing climate



Cold Climate



Forecast of cold cliamte market 2020-2025



Cold climate market size

Estimated cold climate wind market size in GW in 2020		Forecast for Cold climate wind market in GW for 2025	
Icing climate	Low temperature	Icing Climate	Low Temperature
118.6	74.0	162.2	111.4
Total 156.2		Total 223.6	

Growth estimates assume that the local share of cold climate remains similar through the forecast period.

Year-over-year growth, average	
Icing climate	8.7
Low Temperature	7.5
Cold Climate total	13.5

Two main issues with cold climate wind

Cold weather

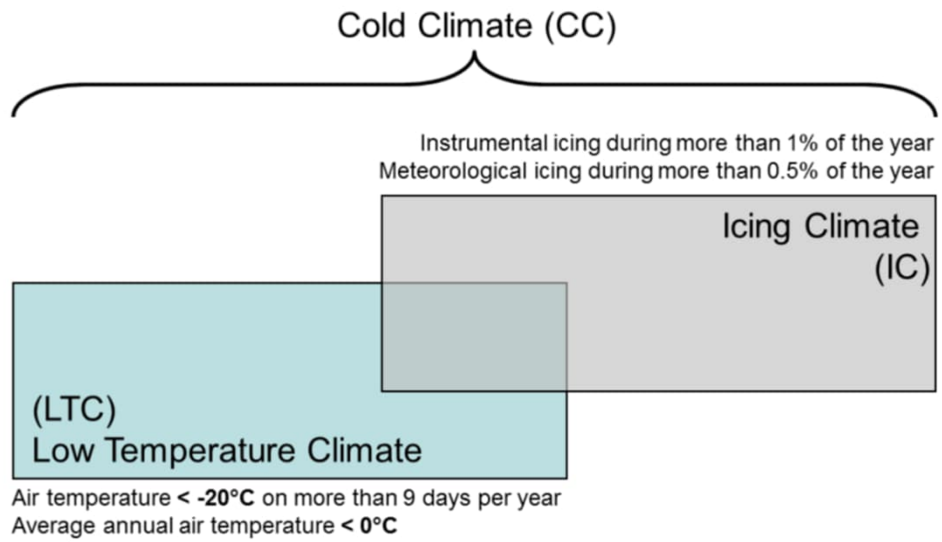
- Hydraulics
- Lubricants
- Materials
- All need to have low enough operating temperatures
- Heating for electronics
- Cold start

Icing

- Ice collected on the blades
- Reduced lift, increased drag due to icing
- Reduced production
- Ice can fall from turbines
- Safety risk

Cold Climate*

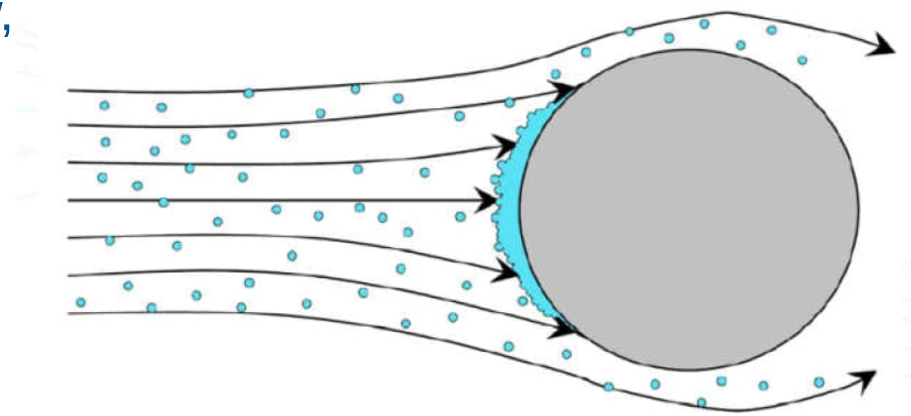
- In wind power there are two issues with cold climate
- Low temperature
- Icing
  - Ice can form on components



*Source: IEA Wind Task 19 Available Technologies report of Wind Energy in Cold Climates (2016 edition): http://www.ieawind.org/task_19.html

Icing

- Blade icing can be caused by wet snow, freezing rain or in-cloud icing
- In-cloud icing most common here
  - Supercooled cloud droplets
  - Temperature < 0 °C, but still liquid
  - When droplets hit a surface, ice will form



Ice growth

- ISO 12494, Makkonen formula
- Ice growth rate relative to wind speed
  - Wind speed at the collision point
  - Tip speed ratio ~7 → higher wind speed at the blade

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$

α_1- collision efficiency, $\alpha_1 = f(V,d,D)$
α_2- sticking efficiency, $\alpha_2 \approx 1$
α_3- accretion efficiency, $\alpha_3 = f(V,d,w,T,e,D,\alpha_1)$
w – cloud liquid water content
A – collision area, perpendicular to flow
V – Wind speed

Icing effects

- Ice forms on blades and insruments

Images courtesy of VTT

Blade icing: 2D-simulation

Param.	Value
Temp	-5 °C
Speed	60 m/s
LWC	0.25 g/m3
MVD	15 µm
Time	4 hours

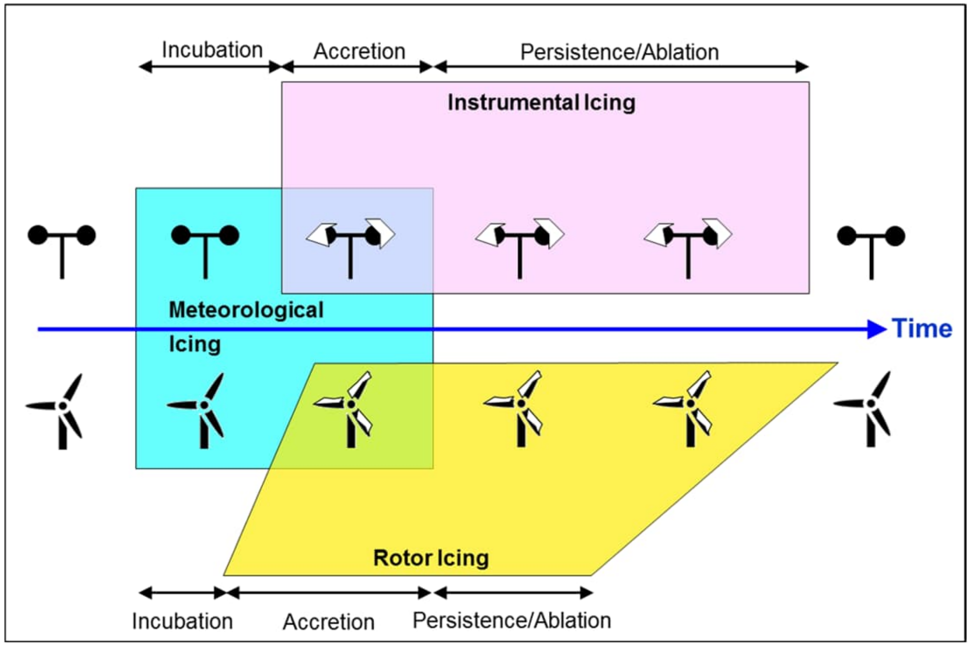
TURBICE™ simulation video

Case: typical icing conditions for turbine blade section

TURBICE™: VTT ice accretion software
Saara Kaija & Simo Rissanen
VTT Technical Research Centre of Finland Ltd

Icing event*

- Meteorological icing
  - Weather conditions are favorable for ice accretion
- Instrumental icing
  - Ice is present on instruments or structures
  - Longer than meteorological icing
  - Length depends on conditions after meteorological icing event has ended
- Rotor icing
  - Ice on the actual blades of a wind turbine
  - Can be shorter than instrumental icing



*Source: IEA Wind Task 19 Available Technologies report of Wind Energy in Cold Climates
(2016 edition): http://www.ieawind.org/task_19.html

Impact on production

- Icing impacted aerodynamics results in underproduction
- Can also lead to unwanted stops
- Missed production is economic loss to operator

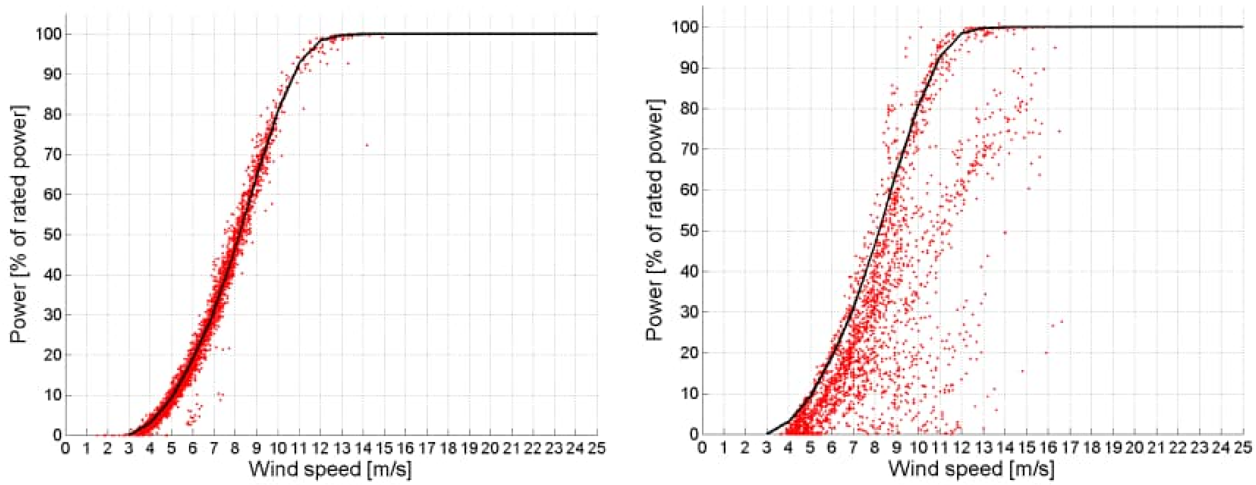


Figure 7-3: Power (% of rated power) as a function of wind speed in two cases. On the left: A power curve registered in May 2010. On the right: An ice-impacted power curve registered in November 2009.

Source: IEA Wind Recommended Practices for wind energy projects in cold climates edition 2017

IEA Ice Classification[1]

IEA Ice Class	Duration of Meteorological Icing [% of Year]	Duration of Instrumental Icing [% of Year]	Production Loss [% of AEP]
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0-0.5

[1]: IEA Wind Recommended Practices for wind energy projects in cold climates edition 2011

Loads

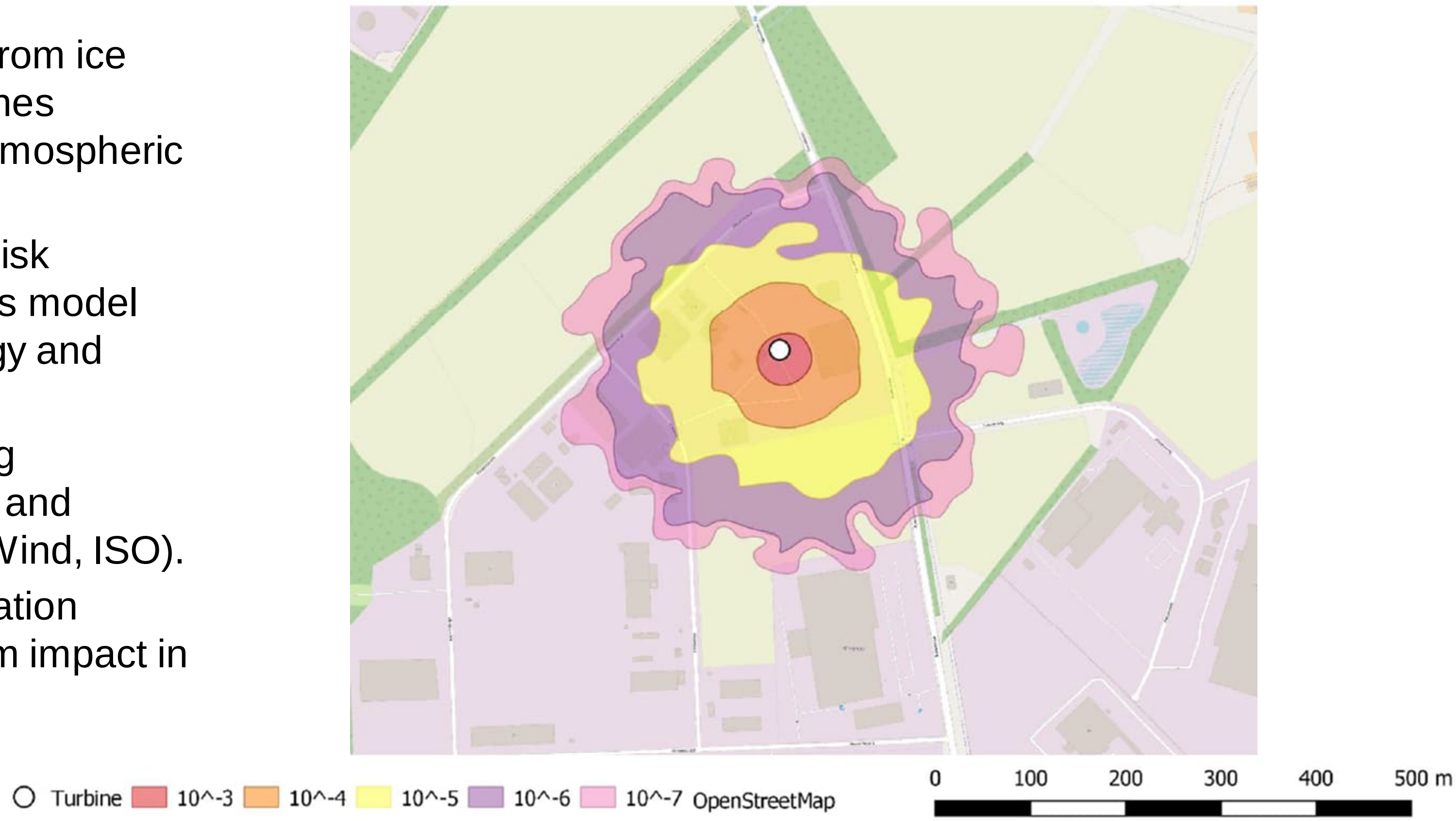
- Aerodynamic loads increase as well as rotor mass
- Imbalance of rotor
  - Increase in fatigue loads
  - Vibrations increase
- Difficulties starting the rotor
- Condition monitoring system might stop the turbine due to vibrations

Health & safety

- Ice throw can be a risk
- Ice on the blades can fall from a turbine, or be thrown
- Safety risk for workes or for people passing by turbines

Risk due to ice fall & ice throw

- Quantification of risk from ice falling from wind turbines following periods of atmospheric icing.
- Localized Individual Risk Analysis from statistics model combining meteorology and ballistics.
- Assessment according recognized standards and guidelines (IEA TCP Wind, ISO).
- Selection of risk mitigation measures for minimum impact in operations.



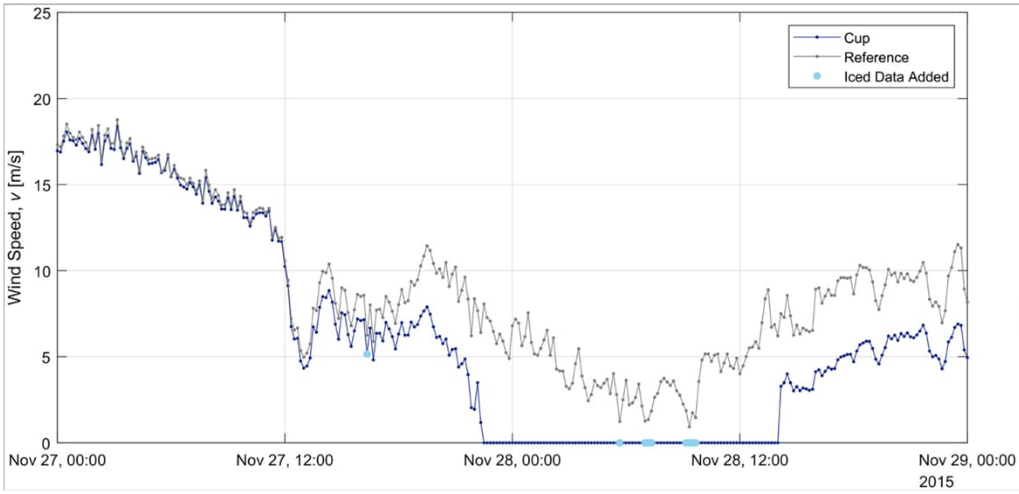
Ice Detection

- For safety and blade heating
- Different technologies:
  - Dedicated ice detectors
  - Installed either on nacelle or directly on blade
  - Blade vibrations
- Indirect sources
  - Deviation from power curve
  - Icing of anemometers

Labkotec ice detector

Indirect ice detection

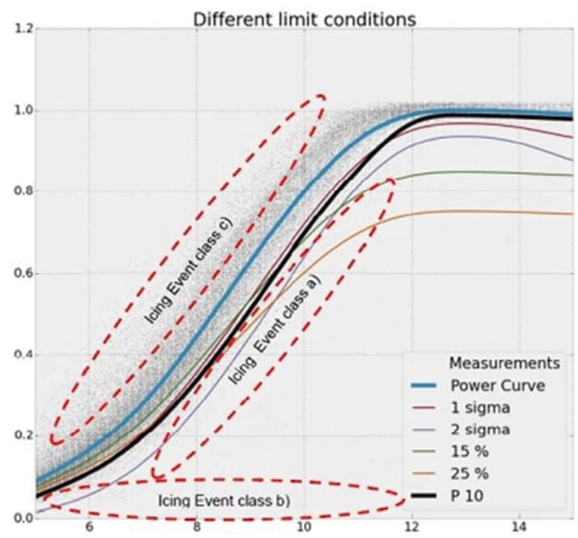
- Double anemometry (common in site assesment)
  - Use a cup anemometer and a heated wind sensor
    - Cup or ultrasonic
  - Unheated anemometer starts to slow down in cold, humid weather → evidence of instrumental icing



Swytink-Binnema, N., Godreau, C., & Arbez, C. (2019). Detecting instrumental icing using automated double anemometry. *Wind Energy*, *22*(1), 80–88. https://doi.org/10.1002/we.2271

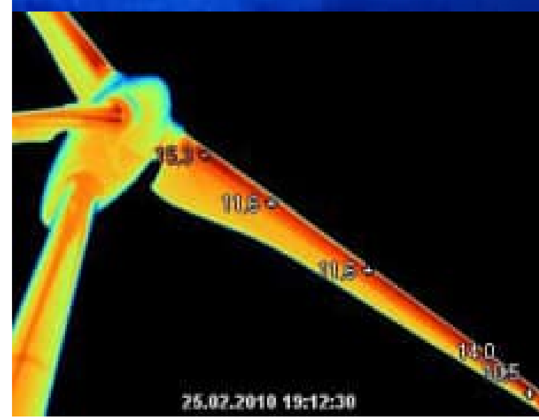
Power curve based ice detection

- Output power deviating too much from the power curve during cold weather can be evidence of ice on the blades
- Used for blade heating control
- assesment of icing losses of operating wind turbines



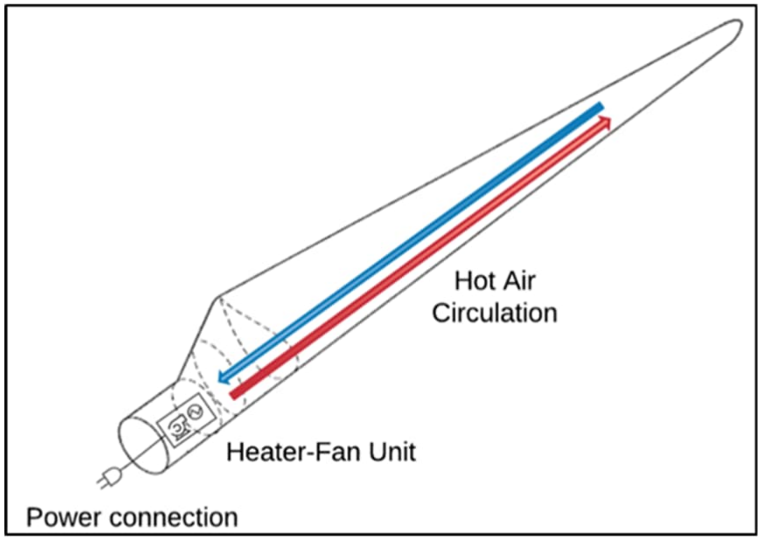
Blade heating

- Heat the blades to remove ice and prevent new ice from forming
- De-icing:
  - Stop the turbine → heat the blades → melt the ice → restart
  - Smaller power draw, stopping the turbine results in production loss
- Anti-icing:
  - Heat the blades during operation
  - Requires more power, but no additional stops



Blade heating with hot air

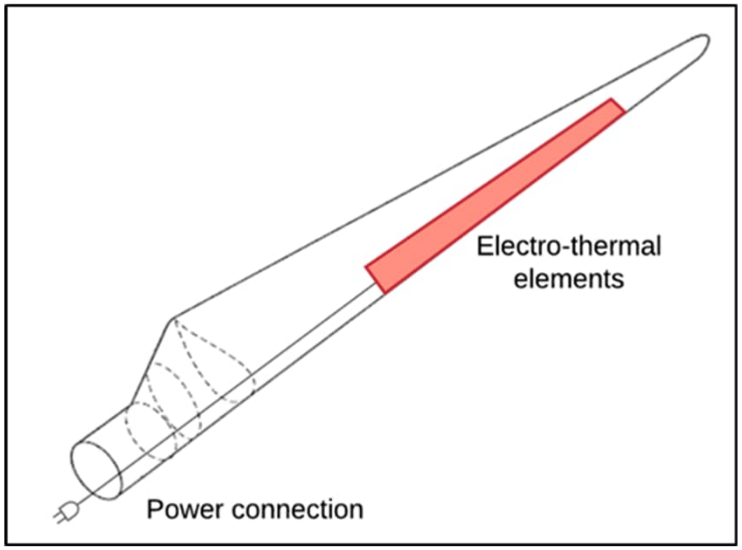
- One solution is to heat the air inside the blade
- Benefits:
  - All active parts installed at blade root
  - Few modification to the blade
- Drawbacks
  - Blade material good insulator, hurting efficiency
- Usually a de-icing solution



Wickman, H., Godreau, C., Karlsson, T., & Söderberg, S. (2020). *Performance Warranty Guidelines for Wind Turbines in Icing Climates*.

Blade heating with integrated electro-thermal elements

- Heating element laminated inside the blade
  - 1-2 mm below the top coating
- Significant modifications to the blade
- Instrumentation and power almost to the tip of the blade
- Maintenance
- Lightning protection



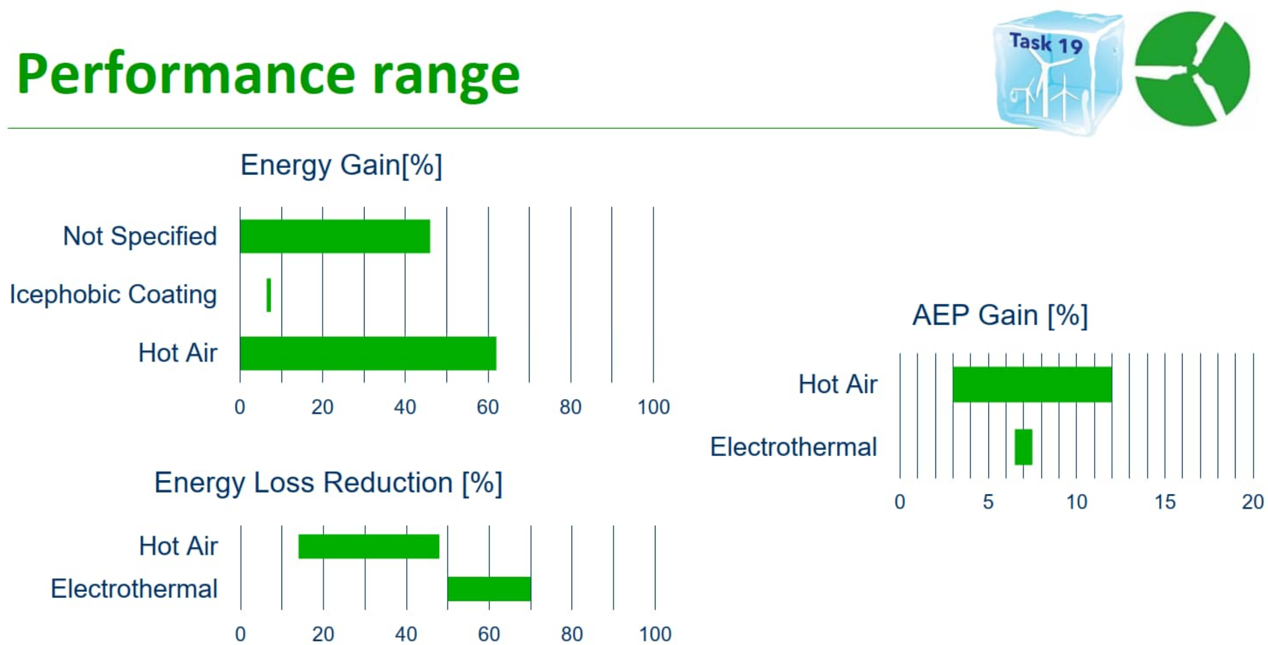
Wickman, H., Godreau, C., Karlsson, T., & Söderberg, S. (2020).
Performance Warranty Guidelines for Wind Turbines in Icing Climates.

Ice Prevention System in Operation

Video: Raimo Huuhtanen, Vapo

Blade heating benefits

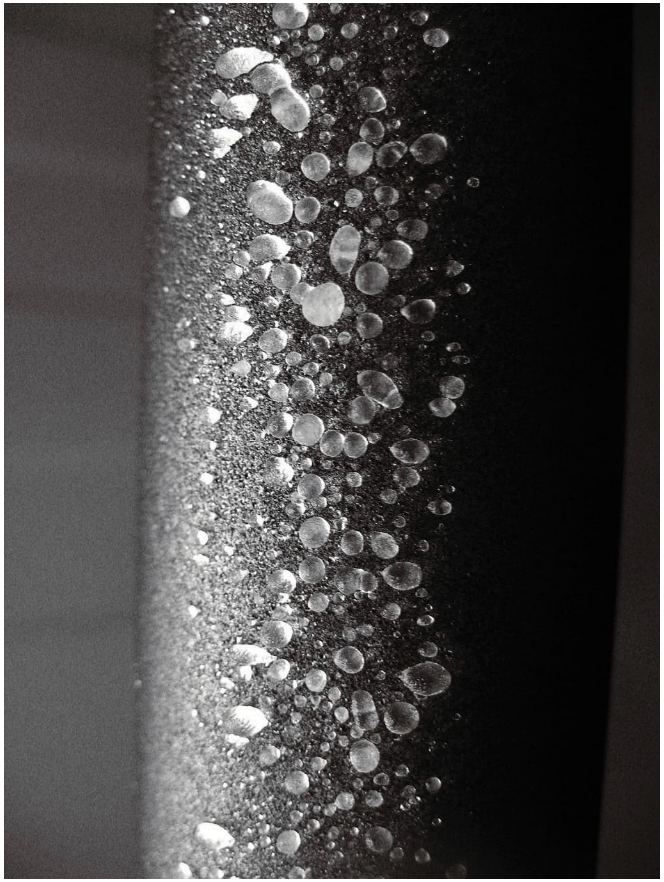
- Heated turbine can gain back 50 -70 % of lost production
- Gains depend on site
  - Site conditions
    - Temperature
    - Wind speed during icing



Godreau, C., & Tete, K. (2020, May). *Ice protection systems and retrofits: Performance and experiences*. https://windren.se/WW2020/13_4_39_Godreau_Ice_protection_systems_and_retrofits_Performance_and_experiences_Pub.pdf

Coatings

- Icefobic coating
  - prevent ice from forming
  - reduces adhesion between ice and blade
- Research still ongoing
- Durability main issue
  - Erosion
  - Mechanical stress
  - Also icophobicity difficult to reach and maintain



Qualitative Benefits of Ice Prevention Systems

No system	Hot air / de-icing	Anti-icing with electrothermal heaters
Up to loss 20 % of AEP	Loss of production due start/stops and system use	Loss of production < 1% of AEP (system consumption)
Extensive standstill during wintermonths	Turbine stopped due to system inefficiency	No standstill due to icing or IPS operation
Up to 60% decrease in fatigue design life[1]	Additional stop/start-cycles loading the turbine	Loads close to normal operational conditions
Risk of damage or injury due to ice throw (large ice pieces)	Somewhat reduced risk of damage or injury due to ice throw	Small risk of damage or injury due to ice throw
No need for additional investment	Not proven or available for turbine suppliers	Customizable, opportunity for independent supplier

[1]: IcedBlades - Modelling of ice accretion on rotor blades in a coupled wind turbine tool, WinterWind 2012 conference

Offshore in cold climate

- Sea ice will require different types of foundations
- Increased loads and vibrations from sea ice pushing at the tower
- Structures can freeze due to sea spray
- Access difficult during winter

Project planning in arctic conditions

First estimate of icing severity -> icing maps

Icing measurements included in site assessment

- Site classification & detailed analysis of expected icing losses

Assess need for ice protection system

- Estimate the energy gained with anti- or de-icing system
- Compare the ENERGY used for heating
- Consider the reliability and lifetime of the systems

Consider the local rules and regulations of operating wind turbines in icing conditions

Need for shut down during icing event?

beyond
the obvious

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