1,500 operational Years of Icing on Wind Turbines – A Long Term Study

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Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

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Content

- The essence out of over 1500 machine year of rotor blade monitoring and ice detection
- Comparison between different icing situations
- Quantified measurements and examples
- Different requirements for ice detection

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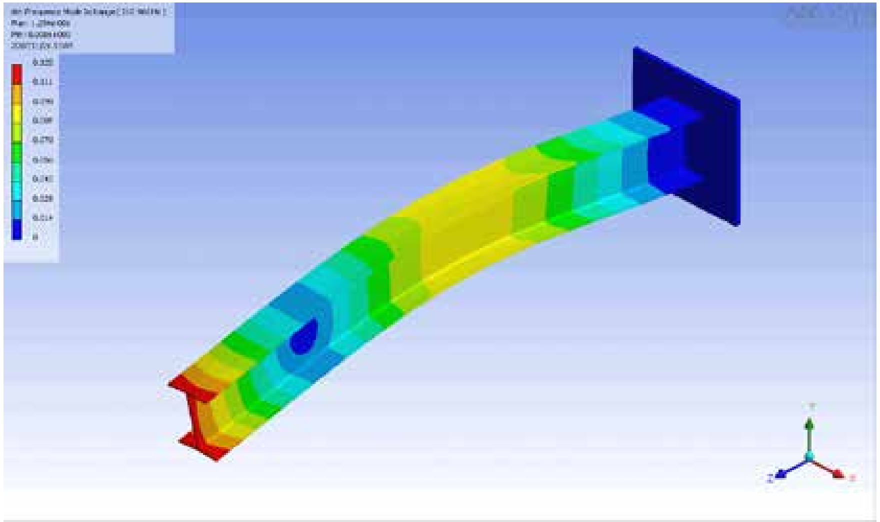
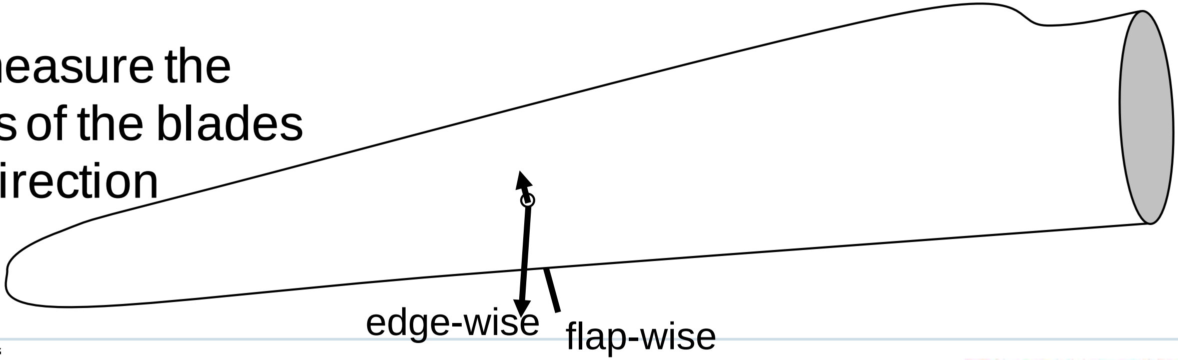
Measurement Principal: Natural Oscillations



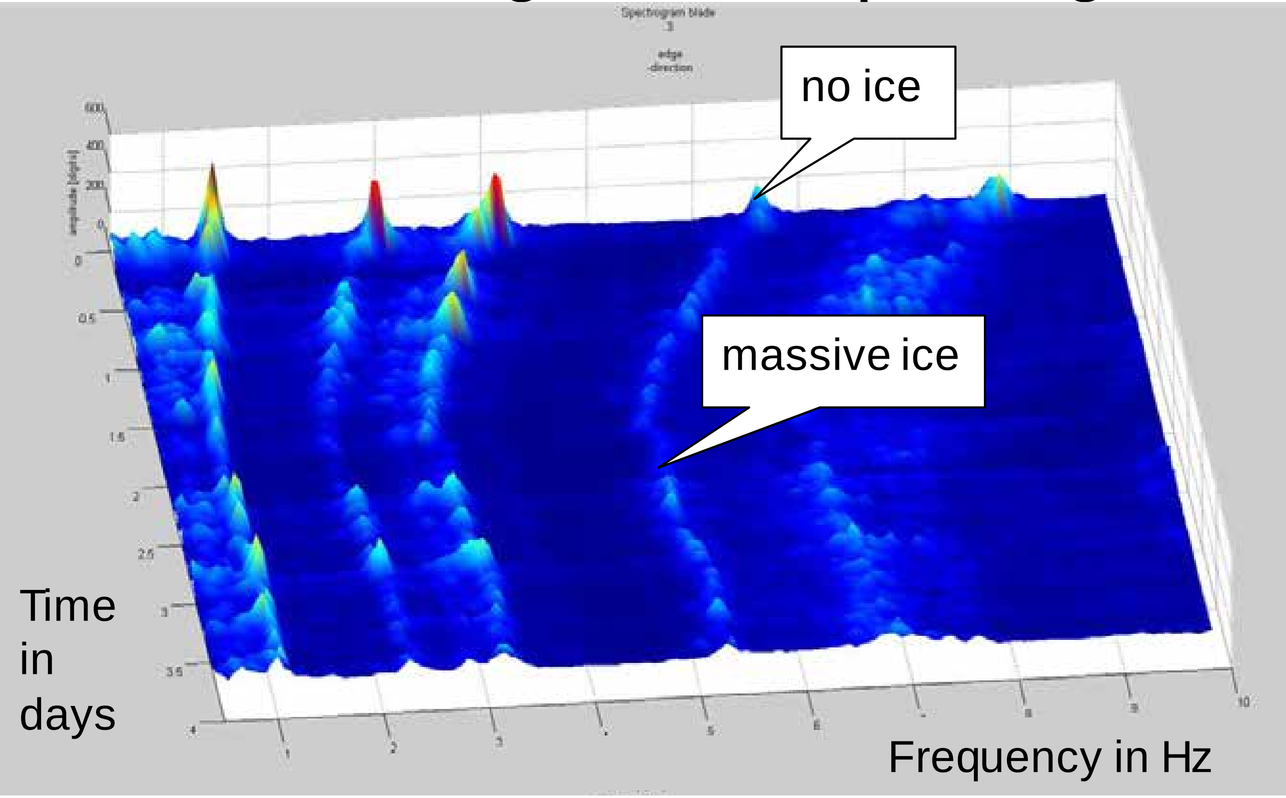
- Blades are regarded as flexural oscillator
- The natural frequencies decrease with accumulated ice mass
- Frequency deviation is an indicator for the amount of the ice formation
    - Calibration via test with artificial mass on real turbine

- Accelerometers measure the natural oscillations of the blades in edge and flap direction



Source: Wikipedia, „Biegeschwinger“

Extreme icing event - spectrogram



no ice

massive ice

Time in days

Frequency in Hz

Icing event with over 250 kg ice per blade

- All natural oscillations decrease due to ice
  - Blades natural frequencies as well as whole rotor natural frequencies

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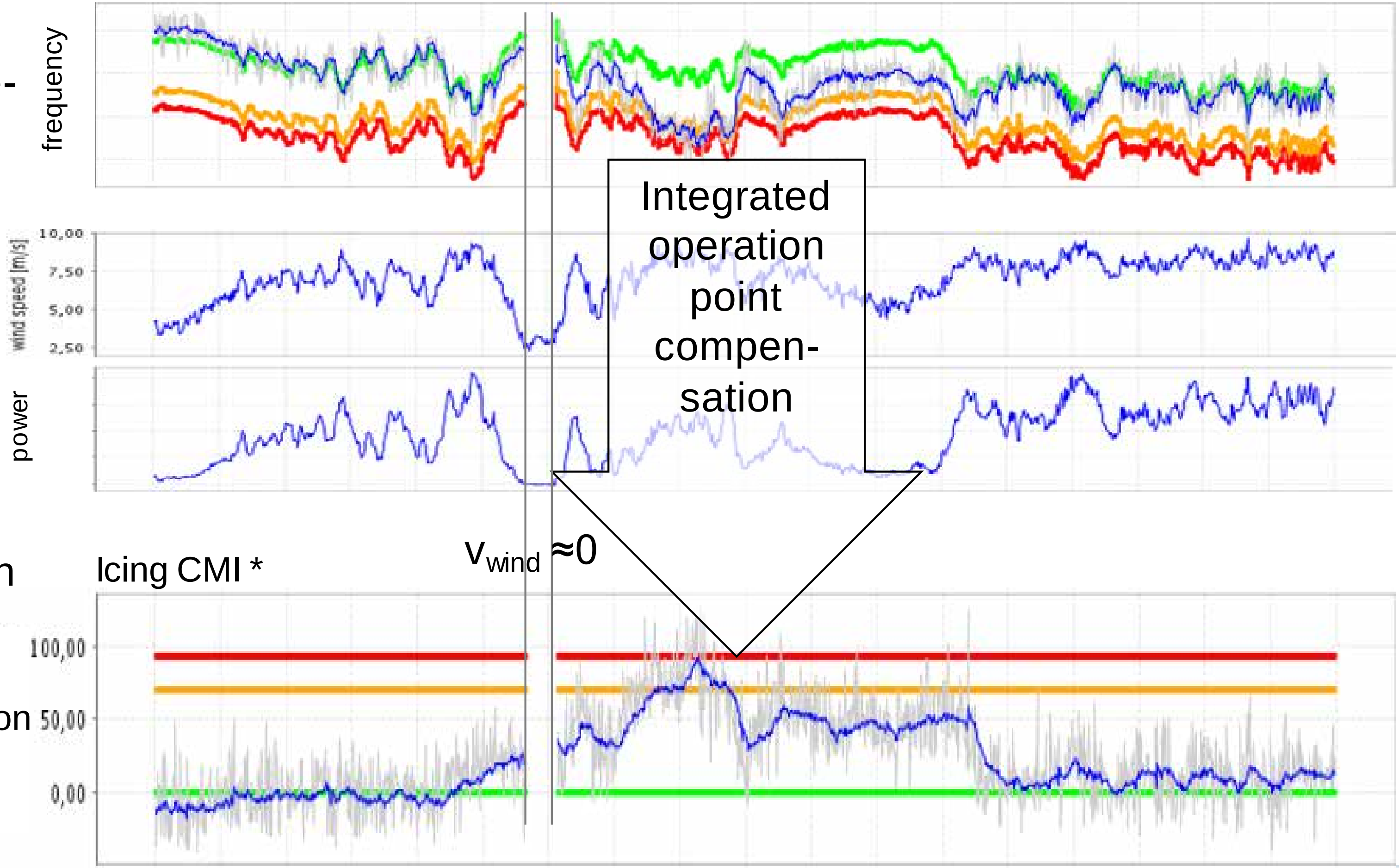
Compensation of operational influences

Measure-
ment



Integrated operation point compen-
sation

Utilization

Visualization

blue – measurement data; green – no ice, yellow – slight ice formation, warning; red – ice formation, alarm

* Condition Monitoring Index

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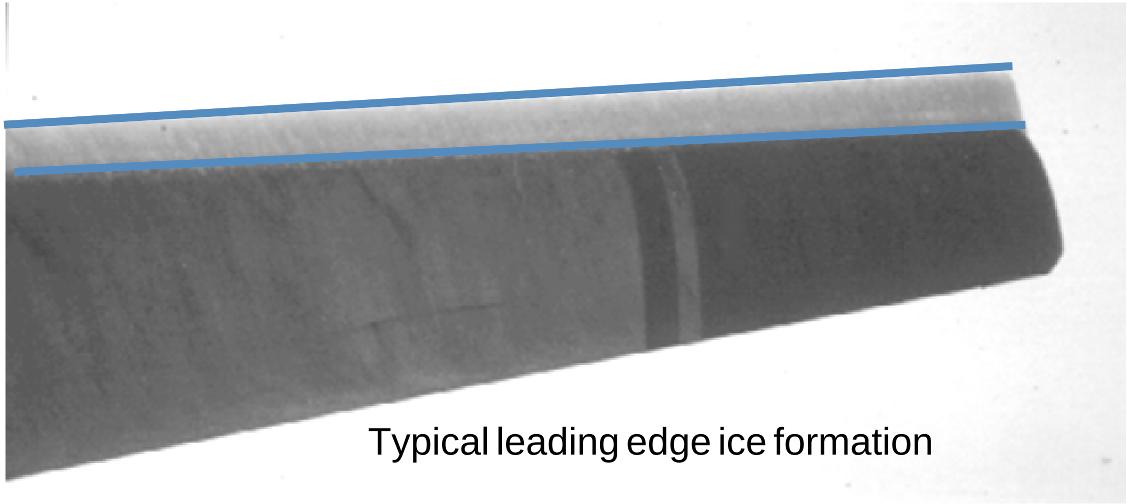
Ice build-up: Running vs. stopped turbine

- § Blade of running turbine sweeps bigger surface in same time than stopped turbine
- § Ice build up of the running turbine is faster than for the stopped turbine
- § Measurement of ice build up on the nacelle can be misleading and
  à **Alarm too late**



Typical leading edge ice formation

Thickness of ice formation increases along the blade radius due to circumferential velocity

Source: H. Seifert, AERODYNAMICS OF ICED AIRFOILS, presented at the European Wind Energy Conference, October 1997, Dublin Castle, Ireland

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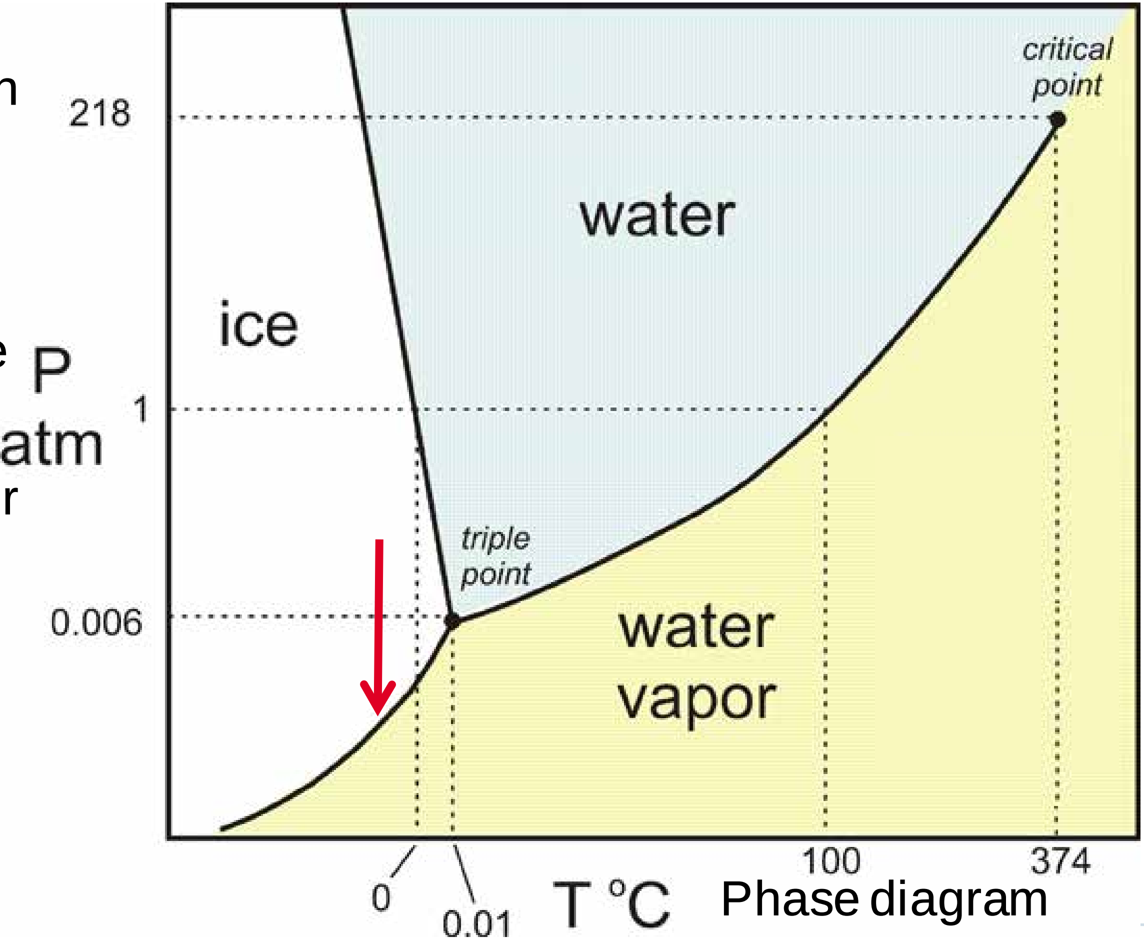
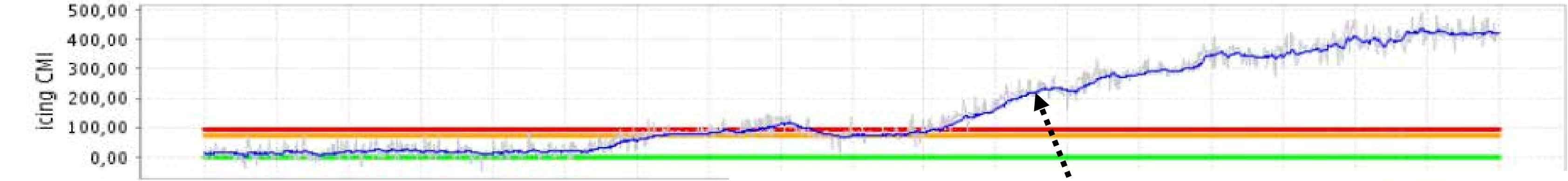
Sublimation: Low temperature + high wind speed

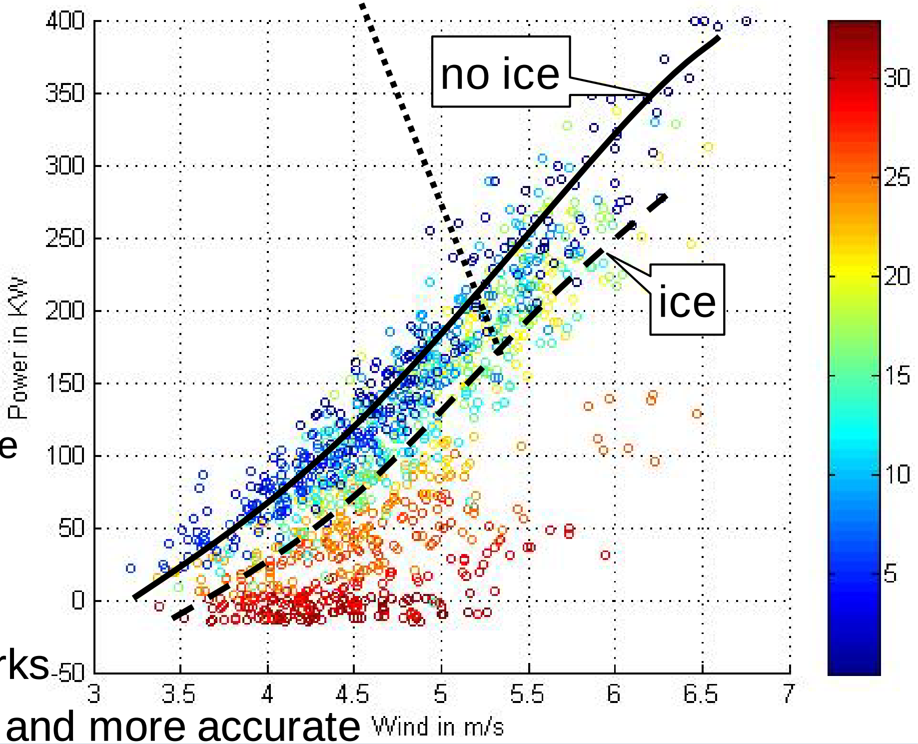
- Low pressure on blade suction side due to high wind speed and high blade tip speed
- Sublimation of ice due to decreasing pressure
- Ice loss on the running turbine is faster than for the stopped turbine
- Measurement of ice build-up on the nacelle can be misleading and
  à **Alarm too long**



Phase diagram

Icing trendline vs. operational parameters





- Aerodynamic problems start at 200 – 300% icing CMI

Alternatively

- Deviation in power curve

- Power curve based ice monitoring works
- Natural frequency monitoring is faster and more accurate

Typical Ice Formation: On the leading edge

Ice formation with high density

Ice throw critical at a thickness of about 2 cm

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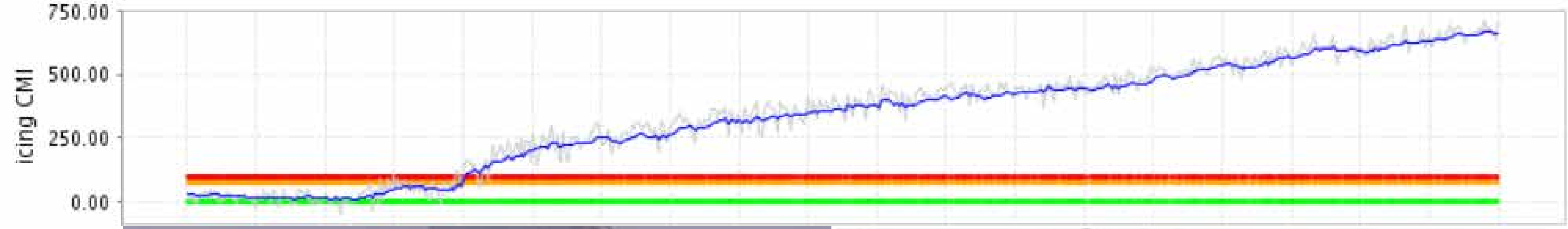
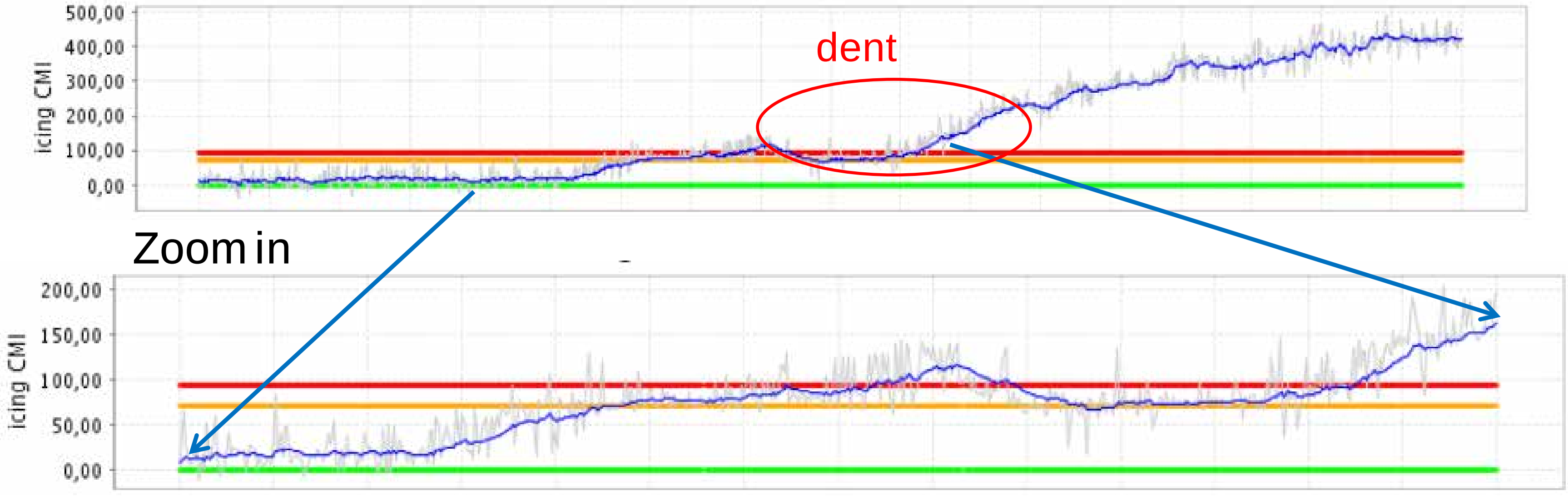
Extreme icing event, example



- Turbine still running, low power and huge change in rotor speed

Ice throw



- No turbine reaction on ice alarm
- Thrown ice detected by dent in the icing trendline
- Ice endangers the environment and turbine itself due to the sudden change in the moment of inertia

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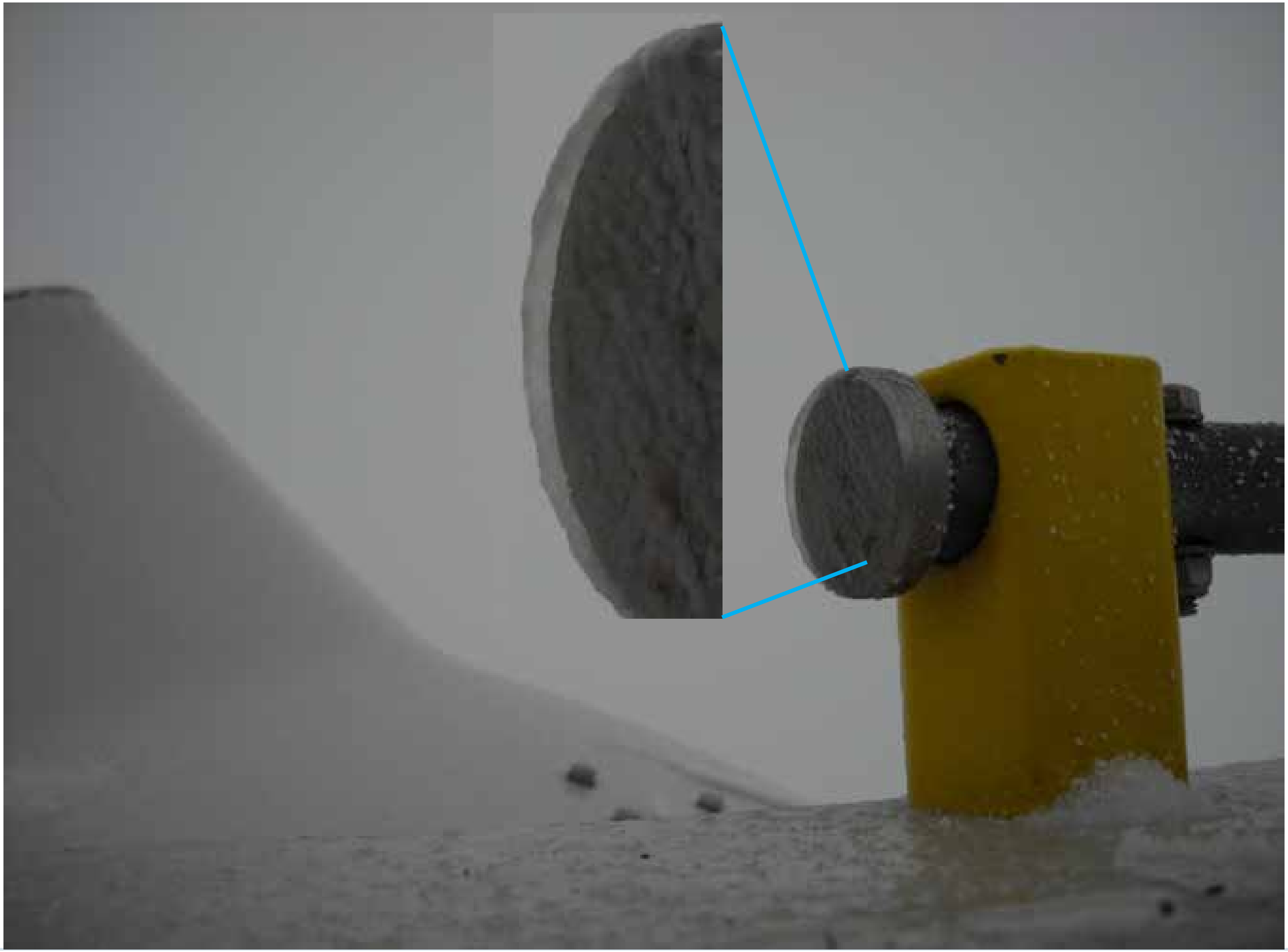
Ice rain



Transparent ice, invisible from the ground

Thickness ≈ 1,5 mm

Ice mass > 150 kg

No risk to people due to low thickness but huge additional mass stresses the turbine

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Extreme icing condition and counter strategy

- Some climate zones facilitate heavy icing situations
- Maximum thickness up to 40 cm
- faster ice build-up at running turbine
- Strategy:
  - Stop the turbine with little ice
  - wait for weather changes to accelerate ice shed and reduce downtime

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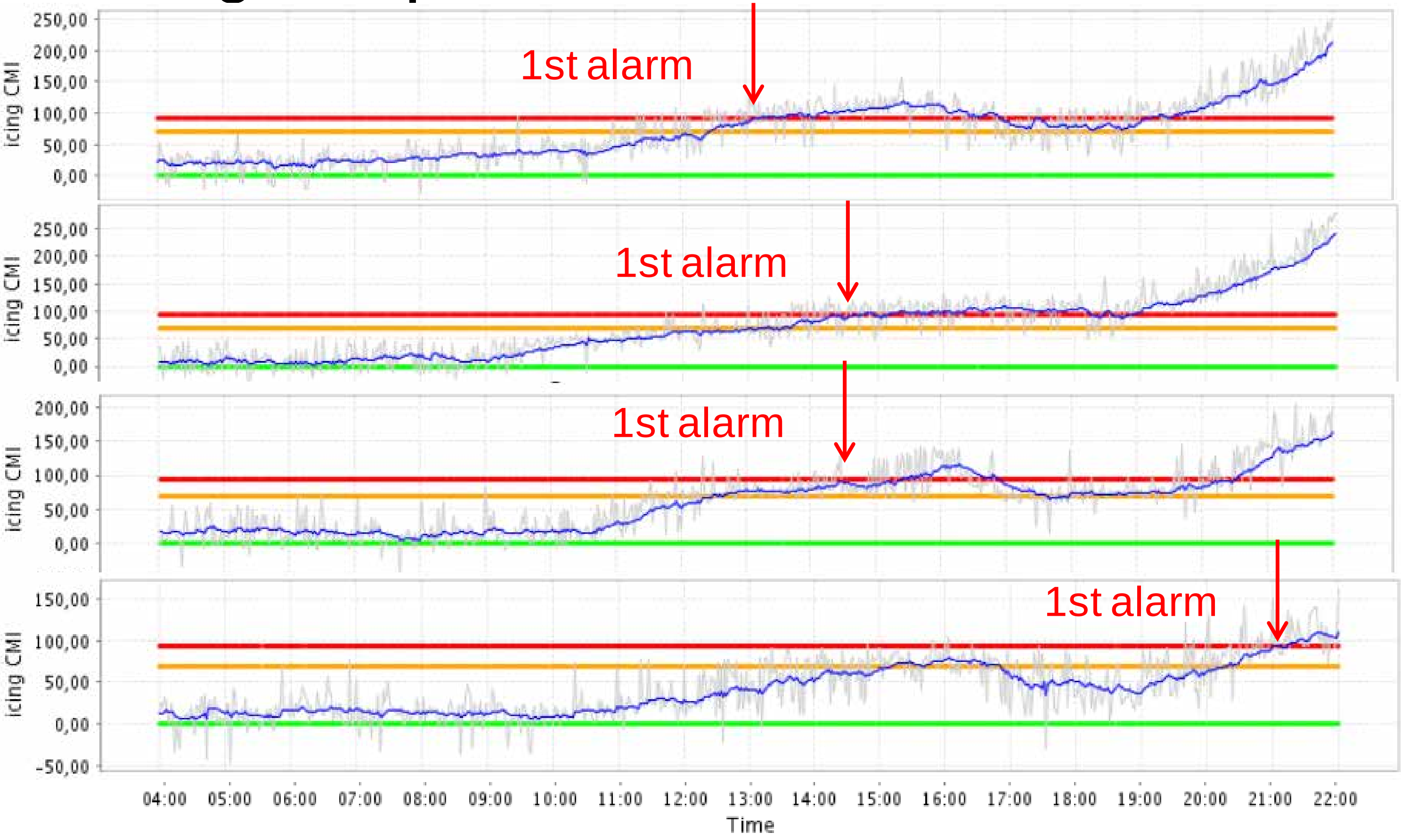
Icing comparison within windfarm, 4 turbines



Moment of 1^{st} ice alarm differs from turbine to turbine => equip each turbine

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Sensitive sites

- Close to highways
- industrial areas

Special demand for sensitive ice detection at stopped turbine to yaw the rotor in safe position and flash warning lights

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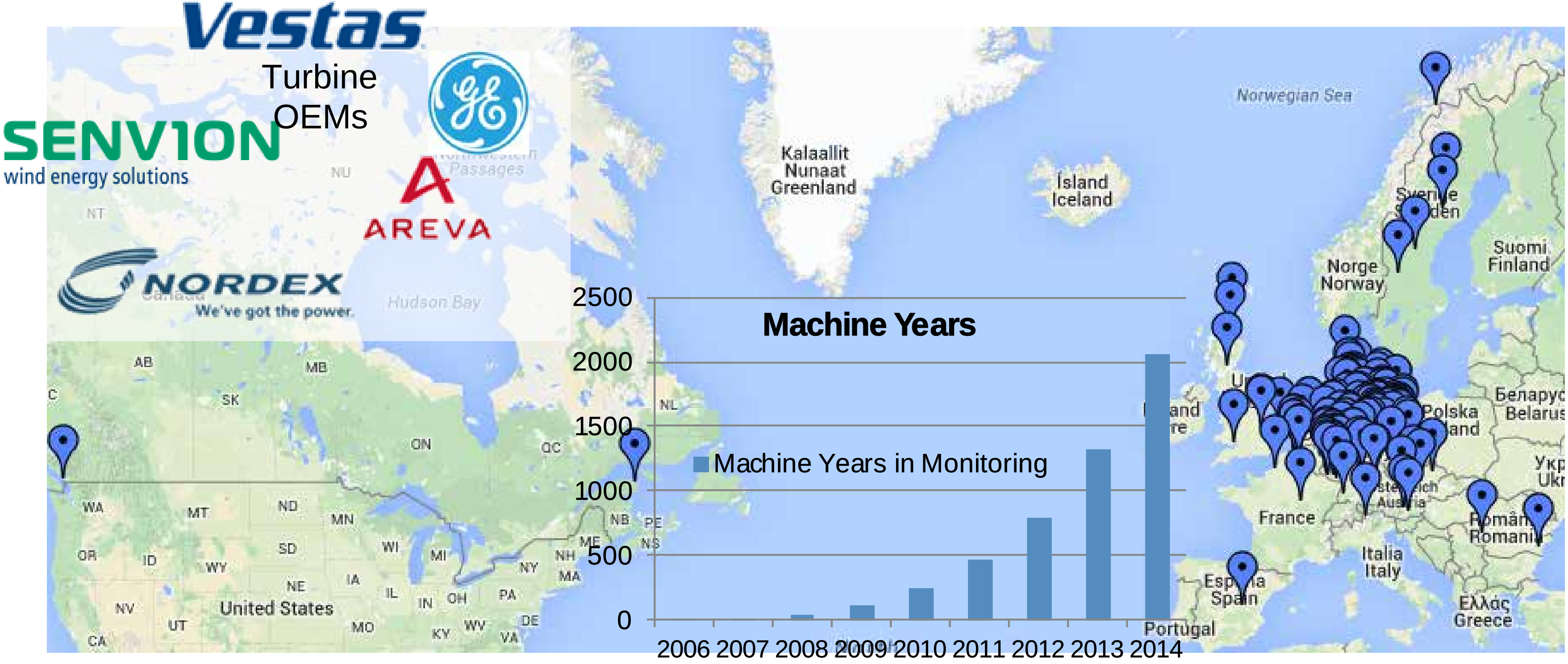
System Deployments northern hemisphere



- Ice detection, main focus:
  - Central Europe as well as Scandinavia and Canada

Summary

- Nacelle based ice detection results may differ from the actual icing situations on the blades
- Different requirements for ice detection exist in different regions
- Most accurate detection results are gained by the natural vibration evaluation and the power curve method
- Natural vibration method is also capable of measuring at turbine standstill

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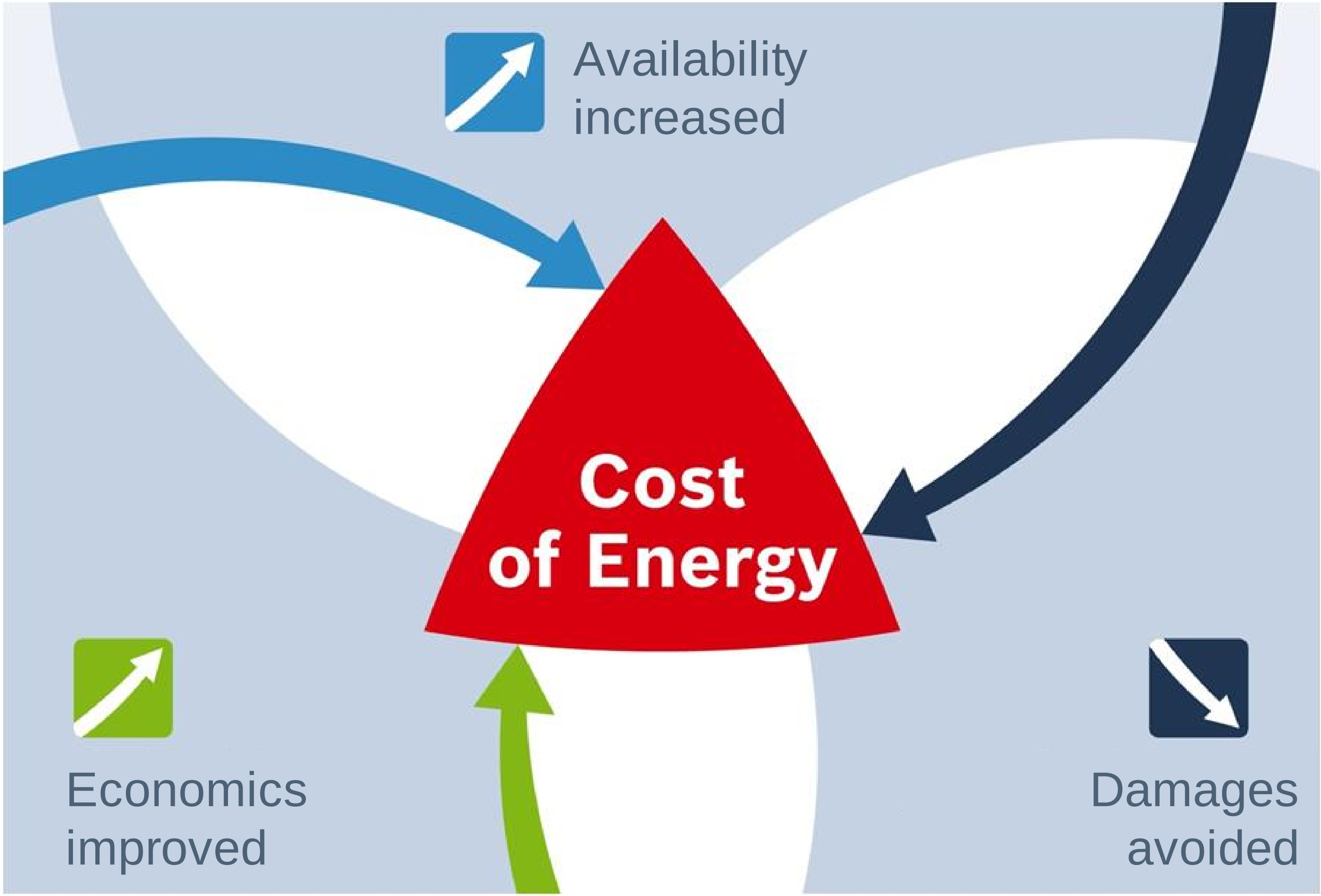

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