Determination of the actual ice mass on wind turbine blades
Measurements and methods for avoiding excessive icing loads and threads

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Determination of the actual ice mass on wind turbine blades

Ice throw

-> heavy impact on drive train due to change of moment of inertia
Determination of the actual ice mass on wind turbine blades

Typical Ice Formation: On leading edge
Determination of the actual ice mass on wind turbine blades

Typical Ice Formation: On leading edge

Ice formation with high density

Ice throw critical at a thickness of about 2 cm
Measurement of blade vibration with accelerometers

- Precise detection of icing for automated turbine shutdown and restart

Installation on the turbine

HMU = Hub Measurement Unit
ECU = Evaluation & Communication Unit
Measurement of blade vibration with accelerometers

- Precise detection of icing for automated turbine shutdown and restart
- Early detection of rotor blade damages → repair possible at relatively low costs
- Automated turbine shutdown in case of detected severe structural damages

HMU = Hub Measurement Unit
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Determination of the actual ice mass on wind turbine blades

Natural vibration at blades shown after FFT

Blades 1\textsuperscript{st} and 2\textsuperscript{nd} natural frequency
Determination of the actual ice mass on wind turbine blades

Extreme icing event - spectrogram

- **Ice growth**
- **no ice**
- **massive ice**

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<th>Time in days</th>
<th>Frequency in Hz</th>
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Extreme icing event - spectrogram

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

Icing event with over 250 kg ice per blade
Determining the actual ice mass on wind turbine blades

conversion: frequency deviation in Hz $\leftrightarrow$ ice mass in kg

- $M$ – blade mass
- $m$ – mass of ice
- $df$ – frequency deviation
- $f$ – frequency without ice accretion
- $k$ – conversion factor

\[
m = \frac{M}{k} \cdot \frac{df}{f}
\]

Note:
Frequency deviation $df$ has to be compensated for influences of the current operation point of the turbine.
Determining the ice mass

**conversion**: frequency deviation in Hz ↔ ice mass in kg

- $M$ – blade mass
- $m$ – mass of ice
- $df$ – frequency deviation
- $f$ – frequency without ice accretion
- $k$ – conversion factor

$$m = \frac{M}{k} \cdot \frac{df}{f}$$

But Ice mass no indicator for risk!

-> **Ice thickness more reasonable**
Determining the ice thickness

**Conversion**: ice mass in kg ↔ ice thickness in mm

- $m$ – ice mass in kg
- $l$ – length of the iced surface in m
- $w$ – width of the iced surface in m
- $\rho$ – density of ice in kg / m$^3$
- $th$ – ice thickness in m

$$th = \frac{m}{\rho \cdot l \cdot w}$$

Maximum ice thickness 1,5 – 2 cm until turbine shutdown necessary
Determination of the actual ice mass on wind turbine blades

Example for ice mass estimation

Most critical ice accretion **only** on **outer third** of the **leading edge**

- \( l = \frac{1}{3} \) blade length
- \( w = 0,1 \) m
- \( th = 0,02 \) m
- \( \rho = 900 \) kg / m\(^3\)

\[
th = \frac{m}{\rho \cdot l \cdot w}
\]

Example:

- **Blade length** = 45 m
- **Maximum ice mass** = 27 kg

-> **ice mass needed for overload estimation**
Conversion frequency deviation into ice mass?

- Relation between frequency deviation and ice mass depends on ice distribution across the blade
- Tests on a running turbine with extra masses of lead glued to the blade fullfilled
Conversion frequency deviation into ice mass?

- Relation between frequency deviation and ice mass depends on ice distribution across the blade.
- Tests on a running turbine with extra masses of lead glued to the blade fullfilled.

- Ice thickness more reasonable indicator for risk assessment of Ice.
- Ice at the tip is more risky than ice at the root due to higher speed.
- Ice mass in kg no indicator for risk!