Forecasting ice accretion on rotor blades validation against webcam and ice detectors

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Abstract
Ice accretion on rotor blades causes production losses. The ice can also potentially damage the mechanics of the turbine and represent safety risks for passers-by and service personnel. Reliable forecasts of blade icing several hours or days in advance are therefore valuable for the operation of wind parks in cold climates.

Last winter, we used a weather model combined with an ice accretion model to forecast ice loads on a wind turbine in the wind park Ellern (a hilly region close to Frankfurt, Germany). We validated the forecast with on-site ice load measurements.

Objectives
This work is embedded in the ICE CONTROL¹ research project.
The ICE CONTROL project aims at identifying and quantifying the main uncertainties associated with the forecasting of icing on wind turbines by comparing forecasts with in-situ measurements. We also aim at reducing the uncertainties and eventually improving forecasts by adapting the limited-area weather model and the ice accretion model. We compare results from different model chains and icing measurements from different sensors and manufacturers.

Methods

- **Global weather model**
  - GFS
  - ~ 25km

- **Initial and boundary conditions**
  - 3D meteorological variables

- **Limited-area weather model**
  - WRF
  - ~ 6km

- **Ice-accretion model**
  - “Mäkkonen”
  - 3cm cylinder
  - Ice load [kg/m²]
  - Ice growth rate [kg/m²/hour]
  - Ice melt rate [kg/m²/hour]
  - Ice density [kg/m³]

- **Nacelle measurements**
  - Ice load, icing, wind, T° C, RH, hydrometeors webcam

The ice accretion model²,³ is based on physical equations representing liquid droplets flowing against/around a rotating cylinder. Currently, the cylinder (3cm diameter) represents the ice load sensor on the nacelle. We are working on adaptations in order to represent a rotating blade.

Processes currently accounted for (✔) or not accounted for (❌):

- Ice growth due to cloud droplets ✔
- Rain droplets ✔
- Wet snow ❌
- Ice removal due to melting ✔
- Sublimation ❌
- Shedding ❌

Results

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- Ice load model [kg/m²]
- Ice load observed [kg/m²]
- Wind speed model [m/s]
- Wind speed observed [m/s]
- Temperature model [°C]
- Temperature observed [°C]
- Relative humidity model [%]
- Relative humidity observed [%]
- Rainwater model [mm]
- Rainwater observed [mm]
- Cloud water model [g/m³]
- Cloud water observed [g/m³]
- Ice nuclei model [m²/m³]
- Ice nuclei observed [m²/m³]

Very rapid melt measured on the ice load sensor
Webcam (below) indicates melt + shedding

Conclusions

The model captures the main icing events observed by the ice load sensor and the webcam. Ice growth is almost exclusively due to cloud water. The main uncertainty is linked to the forecasting of fog at nacelle height, e.g. getting timing and intensity of cloud water events correctly. The modeled ice growth rate is very sensitive to the input parameters.

Next winter, the experiment goes on with improved ice accretion model and WRF model.

References
1. Ensemble-Verifikationsprognosen als Basis zur innovativen Betriebsführung von Windkraftanlagen unter Veriﬁzierungsberechnungen, FHE Projektber. 833775.

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