IcedBlades - Modelling of ice accretion on rotor blades in a coupled wind turbine tool

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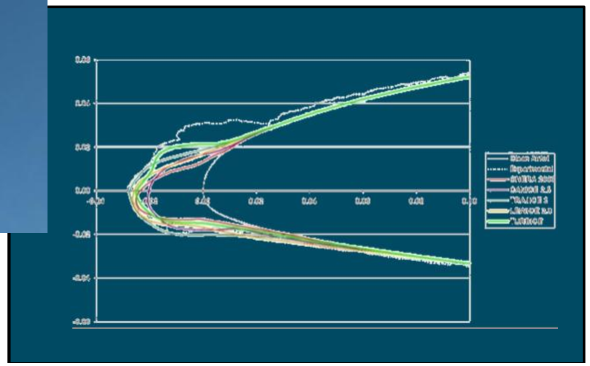

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VTT Fraunhofer IWES

Outline

- Project Motivation
- Project Objectives
- Cooperation and Partners
- Work Packages and Schedule
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- Summary

Project Motivation

Northern areas like Scandinavia as well as areas with high altitude feature a high potential for large capacity wind farms thanks to favourable wind conditions and mostly low populated areas.

- Expansion of a common European research area by combining different research backgrounds
- WinterWind 2011: R&D Priorities for cold climate (Jos Beurskens, ECN)
  - Impact on loading (aerodynamically and mechanical/aerodynamically induced loads, scale effects)
  - Impact on performance (how big are "hidden" energy losses)
  - Field test facilities for problem definition and verification of models
- Demand for independent technical note on icing (Mike Wöbbeking, GL, WinterWind 2011)

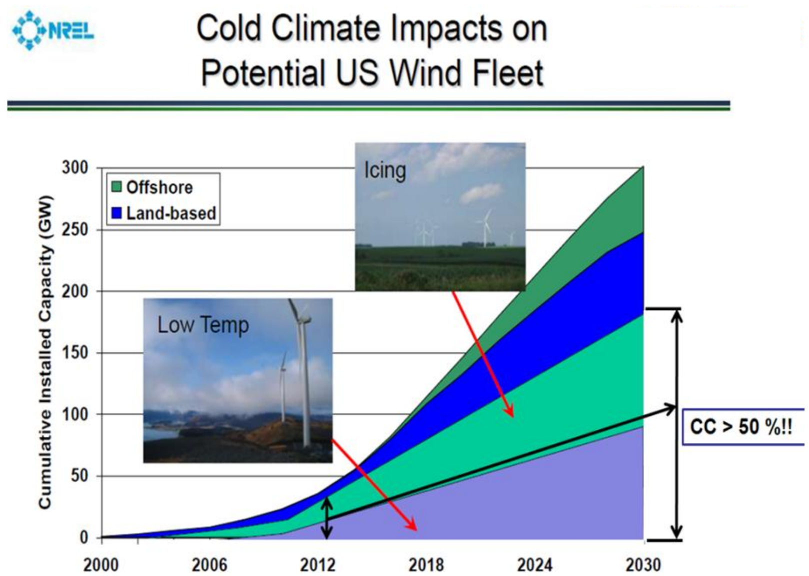

Figure 1: Wind energy capacity in the USA [NREL]

Project Objectives

Within the project scope a new and updated simulation tools for ice accretion on rotor blades and coupling of this tool to an aero-servo-elastic simulation tool will be developed.

1. Predicting the power losses resulting from ice accretion on rotor blades.
2. Gain a better understanding of dynamic loading effects resulting from ice accretion on rotor blades via a validated numerical models.
3. Developing a new technical note for icing sites to help wind turbine designers to take into account icing effects of rotor blades more accurately than current guidelines.
4. Development of icing classes for new edition of IEC 61400-1 Ed3 → Ed4
5. Developing a method to forecast the risk of icing for single wind turbines and geographical sites
6. Forecasting power production in cold climate conditions

Cooperation and Partners

VTT: VTT Technical Research Centre of Finland is the biggest multitechnological applied research organisation in Northern Europe. VTT provides high-end technology solutions and innovation services.

Fraunhofer IWES: Fraunhofer IWES is the leading German research institute in the field of wind energy and energy system technologies and offers a wide research spectrum from material development to grid optimization.

GL: GL Renewables Certification is the leading certification body in the wind energy sector, offering project and type certifications, also in the other fields of renewable energy exploitation.

WinWinD: WinWinD is an international wind energy solutions provider with a strong position in the global multi-megawatt market.

Work Packages during 2012-2014

Site Conditions & Certification Regulation	Software Development & Simulation	Full-Scale Measurements	Software Validation & Technical Note	Forecasting of Icing Risks
- Assessing appropriate site conditions - Decision of test turbine(s) - Evaluation of current certification guidelines	- Adapting of TURBICE & OneWind to project requirements - Creating an iced airfoil database with TURBICE & CFD - Dyn. overall WT simulation utilizing iced rotor blades	- Power and load measurements from multi-MW WT in icing conditions - Measuring of environmental conditions and ice accretion at FhG IWES met mast	- Validation & improving of simulation models - Developing of Ice classes - Developing of new "Technical Note on Icing"	- Developing a method to forecast the risk of icing for WT outside normal environmental conditions - Expanding forecast to local site
VTT, Fraunhofer IWES, WinWinD, GL	Fraunhofer IWES, VTT	VTT, Fraunhofer IWES, WinWinD	VTT, Fraunhofer IWES, WinWinD, GL	VTT, Fraunhofer IWES

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Work Packages during 2012-2014

GL Renewables Certification intends to issue a technical note which will include modelling criteria for ice aggregation on the rotor blades, design load cases and ice classes for different durations of homogeneous and inhomogeneous ice aggregation.

Therefore, large scale measurements will be used to consider the following issues :

- Thickness and local distribution of the ice aggregation along the blade radius and chord line resulting in changed mass distributions of the rotor blades.
- Changed aerodynamics of the blade profiles due to ice aggregation resulting in altered aerodynamic loads on the rotor blade.
- Inhomogeneous ice aggregation on the rotor (some blades iced, some not) leading to significant mass and aerodynamic imbalances on the rotor and thus high periodic loads.
- Temporal distribution of homogeneous and inhomogeneous ice aggregation, depending on the climatic conditions.

Preliminary Study on Icing

Overall model

- NREL – 5 MW baseline wind turbine
- Widely used in the research community

Table 1: Gross Properties Chosen for the NREL 5-MW Baseline Wind Turbine

Rated power	5 MW
Rotor Orientation, Configuration	Upwind, 3Blades
Rotor, Hub Diameter	126 m, 3 m

Icing Conditions

Table 2: Typical rime ice conditions in Scandinavia

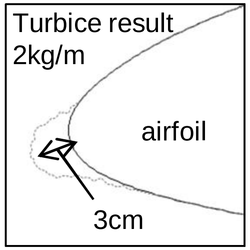
Temperature	-7°C
Median Volume Diameter (MVD)	25 µm
Liquid Water Content (LWC)	25 g/m^3
Icing time	3.5 h

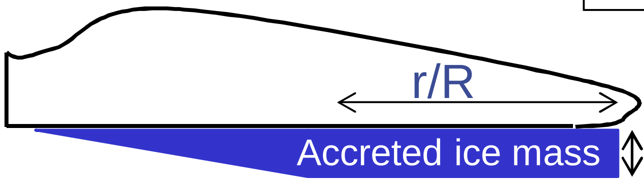
Simulation

- Ice shape from verified VTT code TURBICE and iced airfoil performance CFD results from Fluent
- Iced airfoil C_l and C_d tables as input for NREL FAST
- Results focusing on fatigue loads were calculated with NREL MLife
  - Weibull-Rayleigh distribution of wind, V_{ave}=8.5 m/s

Preliminary Study on Icing

Results: Ice accretion withTurbice & CFD

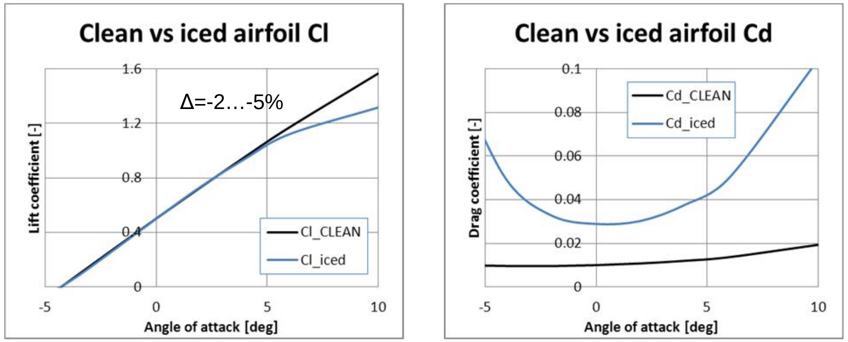




Ice on blades causes:

- Reduction of aerodynamic performance (CFD results)
  - Small effect to airfoil lift coefficient
  - Larger impact on airfoil drag
  - Iced C_l and C_d on outer third of the blade r/R = 0.7…1.0

Moderate icing (CFD results)



Additional ice mass on blades by GL Guideline 2010:

( )

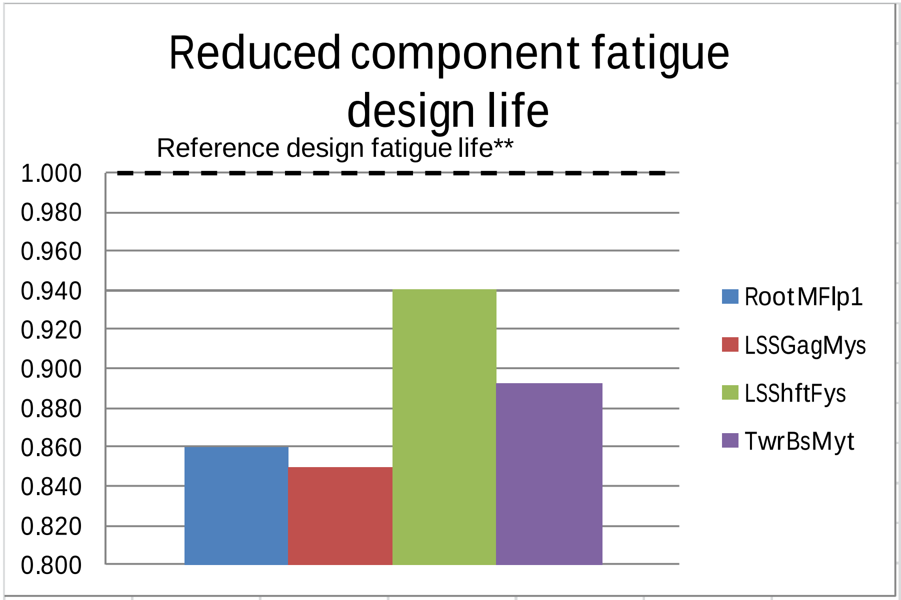
- Only ice mass in the current certification design load cases (no aerodynamic effects)!
- For NREL blade, max ice mass with GL formula would be 40kg/m
- Simulation with down-scaled GL ice mass formula according to TURBICE result

> ➢ These results are used as input for FAST simulations

Preliminary Study on Icing

Case 1: Air density increase from = 1.225 to 1.292 kg/m^3, 55days/year*

- Air density of 1.292 kg/m^3 at 0°C and 0 m above sea level
- No ice accretion on blades
- Figure below present the components that were mostly effected by air density increase



RootMFlp1	= Blade 1 flapwise moment at the blade root
LSSGagMys	= Nonrotating main bearing tilt moment
LSShftFys	= Nonrotating low speed shatf shear force
TwrBsMyt	= Tower base fore-aft moment

* Component Ice class III determined by IEA Task 19, Recommended Practices for Wind Energy Projects in Cold Climates, Draft, 2011

** Reference component Miner cumulative damage , designed for 20-years of operation

Preliminary Study on Icing

Case 2: Comparison of Rotor ice mass and aerodynamic effects

- The icing on the rotor is symmetric (all blades have same ice shape) or asymmetric (1 blade is ice-free while two other blades are iced)
- Fatigue loads from aerodynamic effects are bigger than ice mass effect **

Component		Component fatigue loads* vs clean [%]	
		Mass effects	Mass + Aero. effects
RootMzb1	Sym.	+2	+25
	Asym.	+1	+25
RotThrust	Sym.	+1	+22
	Asym.	0	+22
TwrBsMyt	Sym.	0	+20
	Asym.	0	+19

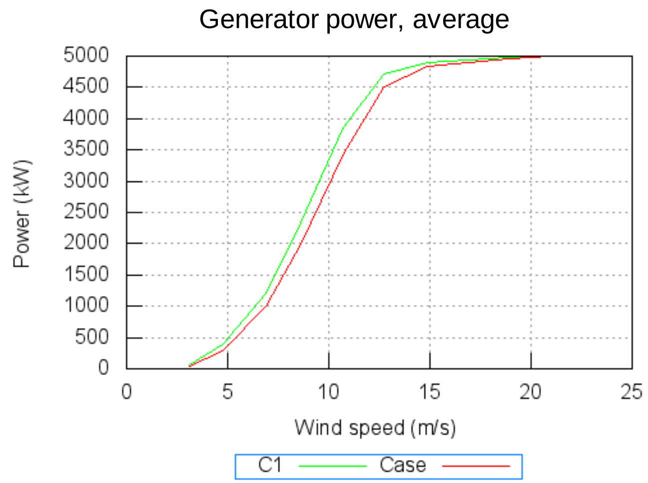
RootMzb1 = Blade 1 pitching moment at the blade root
RotThrust = Rotor thrust force
TwrBsMyt = Tower base fore-aft moment

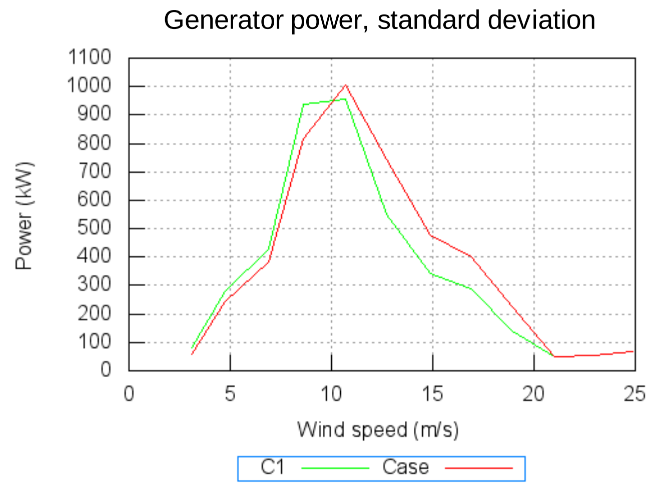
*: Fatigue loads represent Damage Equivalent Loads (DELs) from load Rainflow Cycle Counting (RCC) method
**: Assuming that the same ice shape will stay on the blade for the whole duration

Preliminary Study on Icing

Case 3: Moderate icing, symmetric icing 30days/year*, asymmetric 1day/year,

- Assumtion: The ice same shape will stay on the blade for the whole duration (31 days/year)
- -10…-20 % power output loss at low winds AND reduced power output quality





C1=Clean (no ice)
Case=Case 3

- Annual Energy Production (AEP): -13 %

*: Component Ice class II determined by IEA Task 19, Recommended Practices for Wind Energy Projects in Cold Climates, Draft, 2011

Preliminary Study on Icing

Case 3: Moderate icing, symmetric icing 30days/year*, asymmetric 1day/year,

- Even a small amount of ice for a short period of time can effect component fatigue loads and component design life
  - ➢ Blade root design life reduced up to -55 %

Component	Component design life iced vs clean airfoil
RootMzb1	**0.45**
RotThrust	0.76
TwrBsMyt	0.79

RootMzb1 = Blade 1 pitching moment at the blade root
RotThrust = Rotor thrust force
TwrBsMyt = Tower base fore-aft moment

Increased load level at blade root (excess vibration levels)
→ more stop-start sequences
→ increased fatigue loads

Summary

- Icing of blades causes additional wear and tear on different components
- The aerodynamic effects from iced blades are more significant for the fatigue loads than accreted ice mass
- Even small amounts of ice can decrease the wind turbines main component's fatigue design life
- In icing climate sites, a substantial decrease in fatigue design life (up to -55 %) is seen if no measures are taken to prevent ice accretion on rotor blades

Thank you for your attention!

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