Input to new IEC 61400-1 design standards:

Two case studies of iced turbine load analysis

Presented by:

Ville Lehtomäki, VTT Technical Research Centre of Finland

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Winterwind INTERNATIONAL WIND ENERGY CONFERENCE

NORDEX

Co-authors & Collaborators

K. Sandel, Senvion (REpower), Germany

W. Moser, Nordex

S. Rissanen, VTT, Finland

M. Wadham-Gagnon TCE , QC, Canada

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Motivation

- Problems surrounding wind turbine production losses caused by iced blades are getting more and more attention in Cold and Icing Climates (CIC)

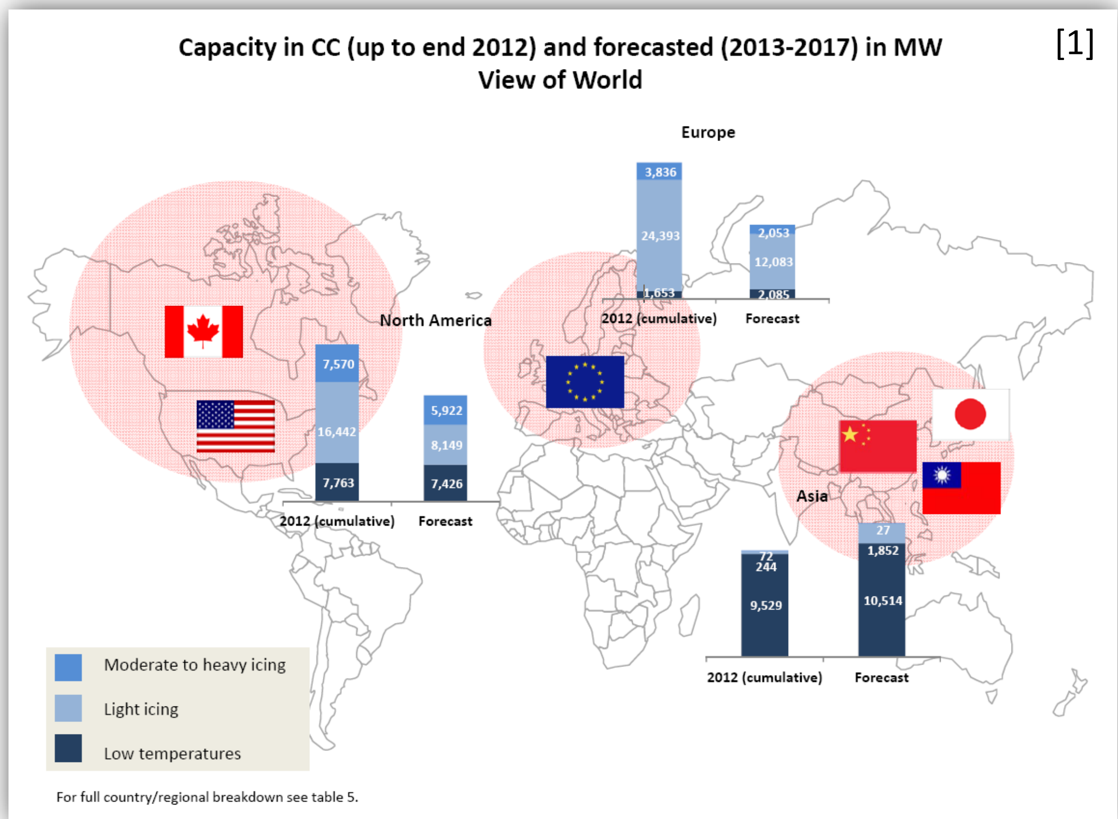
- **BUT no clear idea, how turbine lifetime is affected by iced blades.**

- **Thesis: Are premature failure of main components e.g. gearboxes & towers resulting to “hidden” financial penalties BIGGER than production losses?**

- ULTIMATE GOAL: Increase knowledge & improve wind energy reliability in CIC.

Market status

- 60-70 GW (24% of total) currently installed in cold and icing climate (CIC) [1,2]
- Global wind energy in CIC ≈ 3 x global offshore! [3]
- <u>**45-50GW of new installations by 2017 in CIC [1]**</u>



[1]: BTW WMU2012
[2]: Task19 report, 2011
[3]: T19 EWEA 2011

Site descriptions

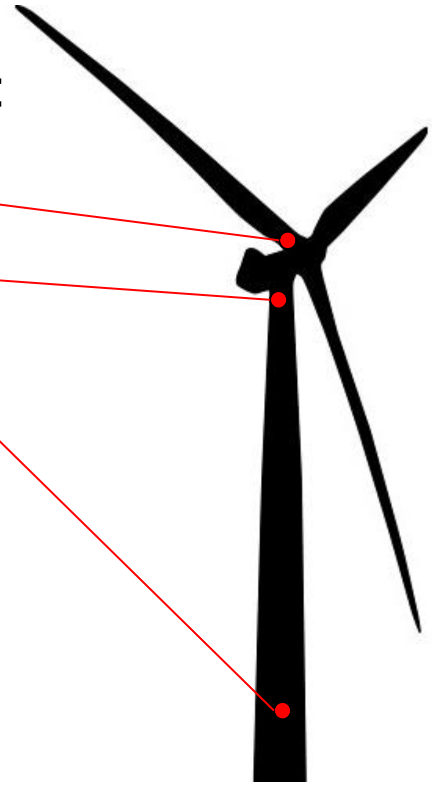
Case 

Case 

Case CAN
Site & measurement system description

- Site location: Riviere-au-Renard, Quebec, Canada
- Senvion MM92 2MW (D=92m, hh=80m)
- Load measurement campaign: 12/2012-5/2013

- Load measurements from (GL coord.):
  - Blade#1 root (flap&edge)
  - Tower top (TTMy,TTMx)
  - Tower base (TBMy,TBMx)

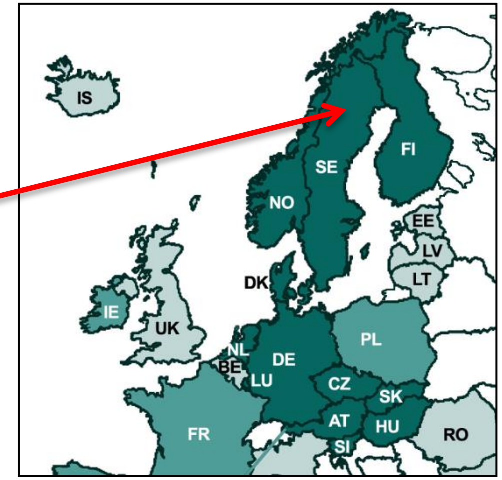


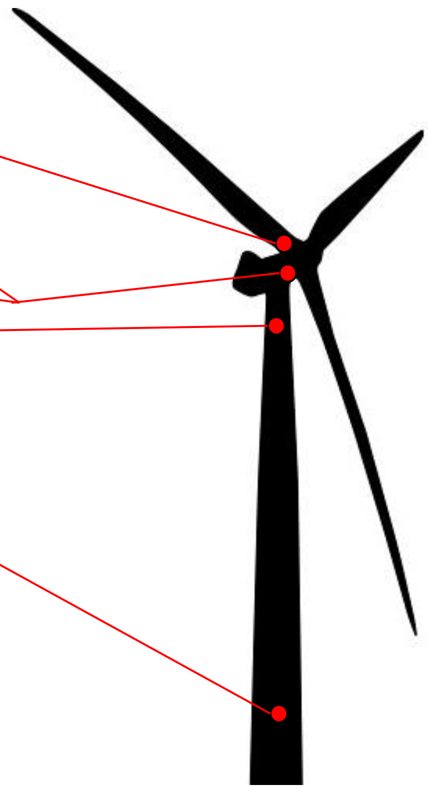
- 126m met mast (5 levels every 30m):
  - 4 x heated & unheated cup anemo
  - 4 x temperature measurements
  - 1 x Holo-Optic
  - 1 x cloud base height sensor

Case SWE
Site & measurement system description

- Site location: Jokkmokksliden, Sweden
- Nordex N100 2.5MW (D=100, hh=100m)
- Load meas. campaign: 2/2013-5/2013
- Load measurements from (GL coord.):
  - Blade#1-3 root (flap&edge)
  - Rotor bearing (RBMy,RBMx)
  - Shaft torque (LSSTq)
  - Tower top (TTMy,TTMx)
  - Tower base (TBMy,TBMx)

- 80m met mast
  - Labco ice sensor + webcam
  - Saab Ice monitor@56m (too low…)





Analysis method

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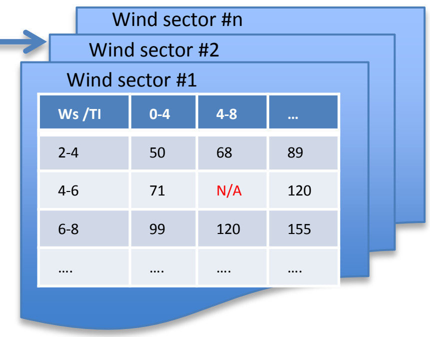
Analysis Method

- Create non-iced dataset of 10min values: baseline values.
- Compare baseline to Icing Event (IE) values -> Relative values.
- For loads: focus on fatigue (Damage Equivalent Loads)

1. Calculate baseline (non-iced) values for:
   - External wind conditions f(ws,TI,wdir): 3-D baseline matrix
   - To reduce data scatter, exclude < 5 m/s winds
   - Power production only

Capture matrices for operational turbine



2. Calculate relative values for icing events (IE) using formula (1)

$$Relative = \frac{Iced}{Baseline} \qquad (1)$$

- If *relative* = *1.3*, then IE values are 30% above baseline values.

Ice detection

- Percentiles of P10-P50-P90 as “min-ave-max” for baseline power production and mechanical loads
- Icing Events (IEs) detected in two different ways:

Case CAN

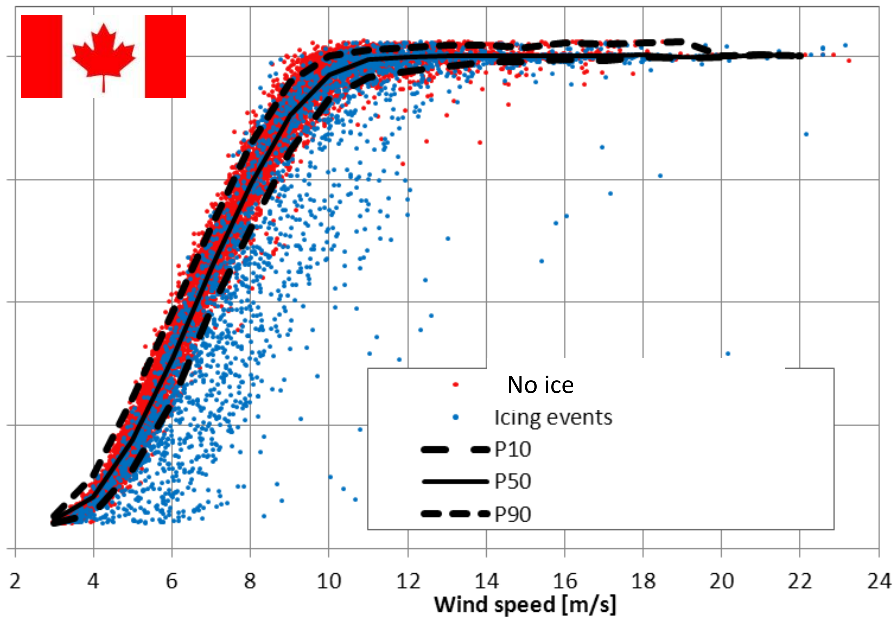
1. Instrumental icing to detect start-stop IE time
2. If power < P10 baseline: power loss
3. If loads > P90 baseline: ice induced vibrations

Case SWE

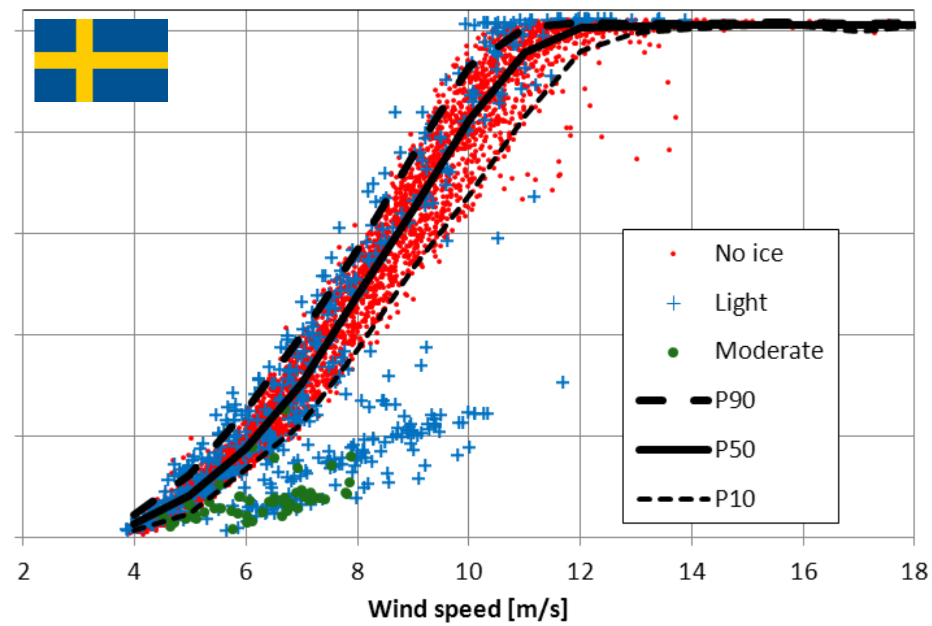
1. Blade CAM pics (root-tip) to detect start-stop IE time
2. If power < P10 baseline: power loss
3. If loads > P90 baseline: ice induced vibrations

Example: Baseline power vs iced

Case CAN



Case SWE



Instrumental icing after data filter: 250h

- Below P10: 160h

Camera icing 1Feb2013->: 210h tot (root or tip)

- tip =120 h, root = 190h
- Below P10: 90h

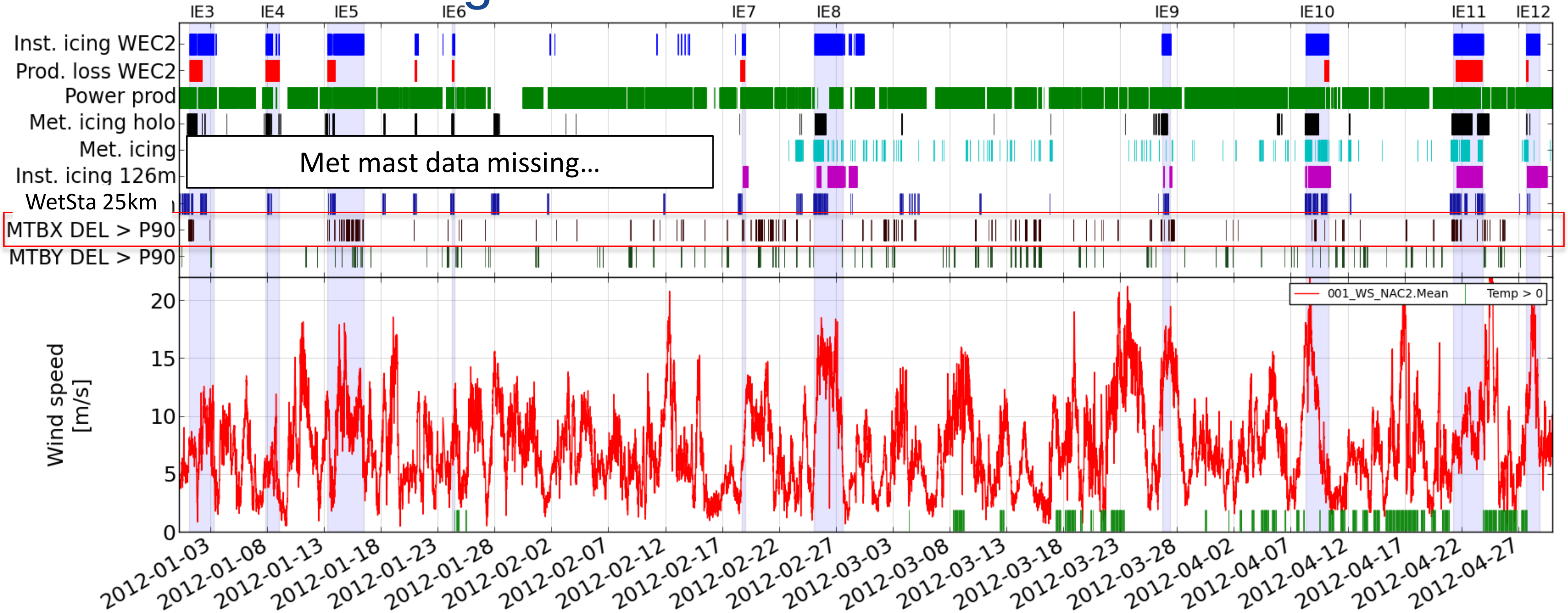
More severe power drops in SWE!

Summary of winters

CAN (2011-2012) &

SWE (2012-2013)

Case CAN
Icing events of winter 2011-2012



Winter 2011-2012 statistics [4]:

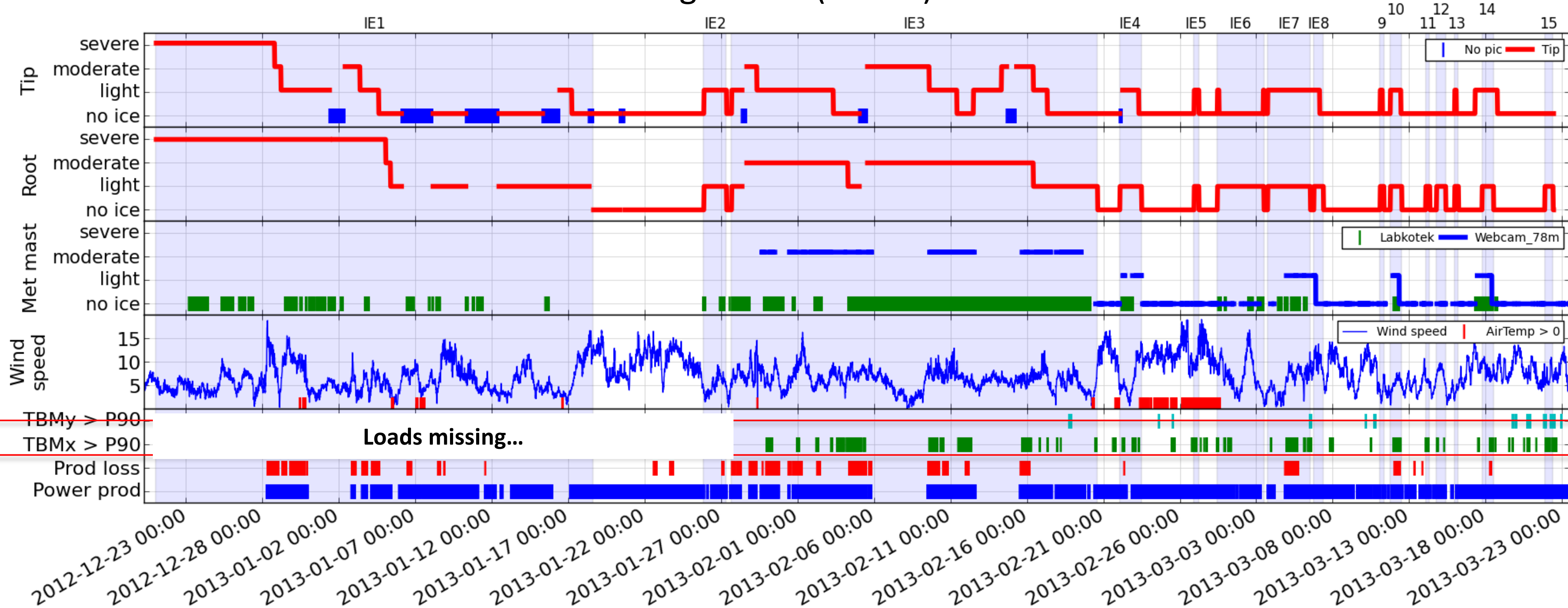
Icing event lenghts	5-60h
Meteorological icing	200h
Instrumental icing	400h
Production loss	160h

Most TBMx vibrations during IEs!

7 of 10 IE end when T<0°C: ice erosion!

Case SWE
Icing events of winter 2012-2013

Icing events (IE1-15)



Winter 2012-2013 statistics:

Icing event lenghts	6-**700h**
Meteorological icing	?
Blade root icing	190h
Production loss	90h

Most TBMx vibrations during IEs!

12 of 15 IE end when T<0°C: ice erosion!

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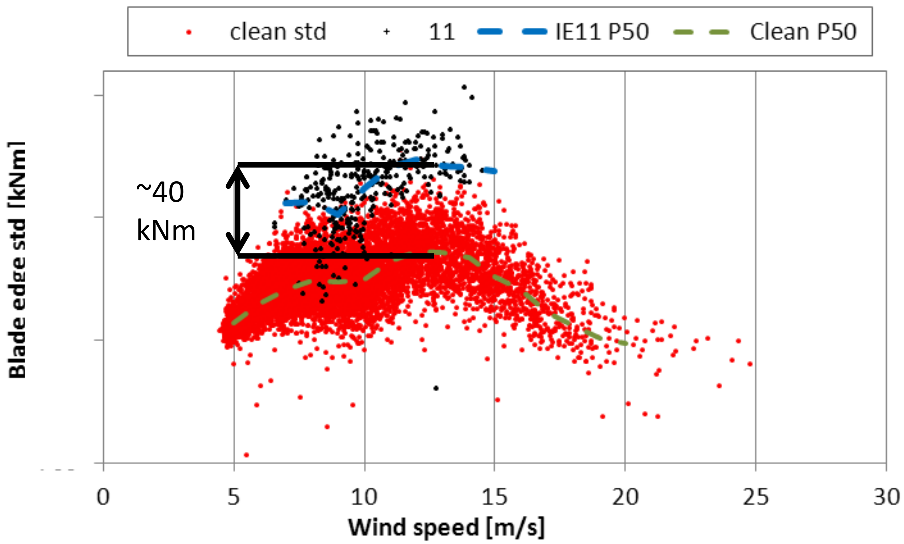
Key observations:
CAN vs SWE

1. SWE ice VERY persistent: max IEs= 480-720h! (CAN max 60h) -> WHY?
2. SWE: Ice erosion faster in blade tip than root
3. SWE & CAN: Ice erodes from blades often below 0°C! No melting!
4. SWE: Multiple “small” IEs inside within IE classification
5. SWE & CAN: Production losses and ice induced tower vibrations start-stop unpredictably during IEs -> Ice shedding???
6. **Most tower side-to-side vibrations occur during IEs!**

Blade ice mass

Case CAN

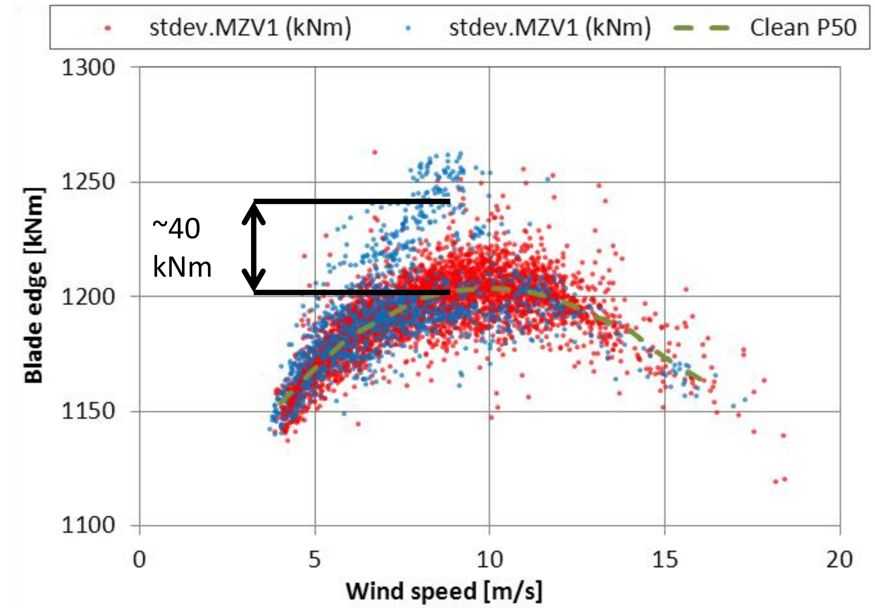


For sinusoidal signal:
standard deviation = amplitude/sqrt(2)

$$40kNm \times \sqrt{2} = 57kNm$$

IEC Ice COG = 2/3R -> Ice mass = <u>190 kg</u>

Case SWE



IEC Ice COG = 2/3R -> Ice mass = <u>180 kg</u>

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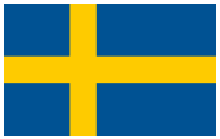
Component fatigue loads

P90 DEL (Relative lifetime fatigue loads, 100% = baseline)



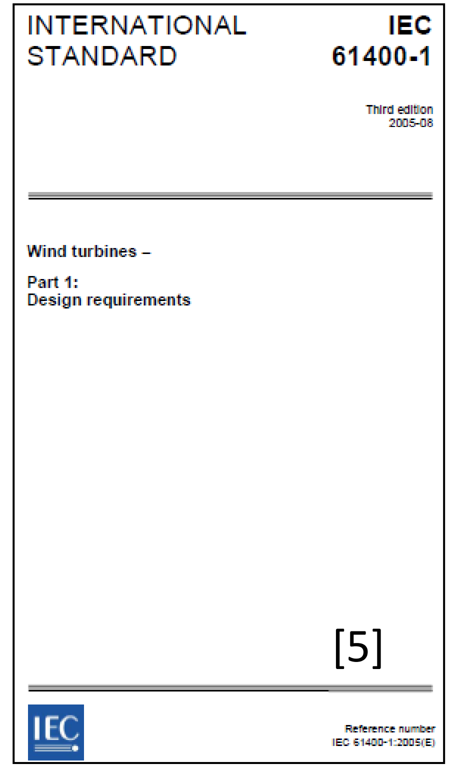
icing h/a	Edge	Flap	TBMX	TBMY	TTMX	TTMY	RBMx	RBMy	RotTq
8760	100 %	97 %	120 %	98 %	77 %	102 %	107 %	107 %	110 %
750	100 %	100 %	102 %	100 %	99 %	100 %	101 %	101 %	101 %
0	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %

icing h/a	Edge	Flap	TBMX	TBMY	TTMX	TTMY
8760	101 %	100 %	115 %	103 %	101 %	103 %
750	100 %	100 %	102 %	100 %	100 %	100 %
0	100 %	100 %	100 %	100 %	100 %	100 %

- 750h/a icing “reasonable” -> proposed to new 61400-1 standard
- Similar results: Tower base side-to-side (TBMx) most clearly affected
- ➢ **These results used as target values for load simulations!**

International standard IEC 61400-1 ed3->ed4
NEW: Cold Climate

- Very important for turbine manufacturers!
- Proposed: <u>a cold climate class turbine </u>eg **IEC 2A CC** (release Q1/2016)
- <u>Dedicated chapter & Annex for Cold Climate</u>
- VTT as Coordinator of international Cold Climate Sub-Committee making text additions
- New cold climate design load cases (DLCs) are also proposed
  - Aerodynamic penalty: reduced lift, increased drag
  - New ice mass formula for blades


INTERNATIONAL STANDARD

IEC 61400-1

Third edition 2005-08

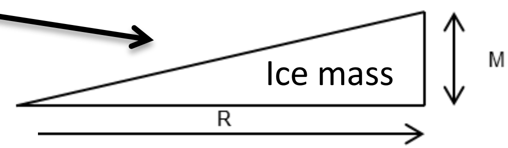
Wind turbines –

Part 1: Design requirements

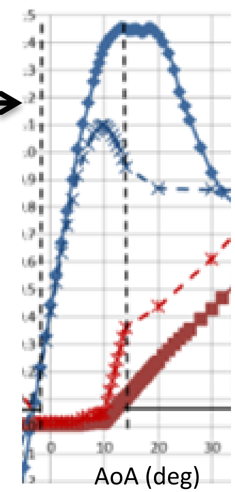
[5]

IEC

Reference number IEC 61400-1:2005(E)



$$M\left[\frac{kg}{m}\right] = 0.125 \cdot A \cdot C_{85\%} \cdot r$$



- Main goal of CC DLCs:
  <u>Verify turbine controller safety with iced blades</u>

Cold climate design load cases
Simulations vs measurements

- Target values from case CAN & SWE to IEC CC DLC simulations
- OBS! New CC Class turbines will be designed with CC DLCs!

Table. Measurements vs simulations for fatigue (100 % = ref).

		Ice on blade	TBMx	TBMy	TTMx	TTMy	Edge	Flap	Power
SWE	Measured	8760 h/a	120 %	98 %	77 %	102 %	100 %	97 %	~70 %
SWE	IEC simu	8760 h/a	128 %						100 %
CAN	**Measured**	8760 h/a	115 %	103 %	101 %	103 %	101 %	100 %	**86 %**
CAN	IEC simu	8760 h/a	150 %	106 %	128 %	93 %	101 %	93 %	89 %
CAN	**IEC simu**	**750 h/a**	**110 %**	101 %	104 %	100 %	100 %	100 %	99 %

Only ice mass

Conservative but realistic!

Table. TBMx Ultimate loads

	Blade ice model	Max blade ice mass [kg]	min	max
CAN	measured	190	-	-
CAN	GL x 0.5	300	187 %	143 %
CAN	IEC x 2	330	217 %	157 %
CAN	GL	590	338 %	205 %

Reasonable!

➢ Soft tower concepts might require additional CC design effort!

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Conclusions (1/2)

- More reliable ice detection achieved with multiple methods
- Measured blade ice mass during operation ≈ 200kg
- Very different sites (CAN & SWE) but similar results:
  - Icing reduces power output
  - Icing increases tower base side-to-side loads
  - Other component loads not largely effect BUT remember: data only from 1.5 winters!!
  - ➢ Icing much more persistent in SWE than CAN, factor ≈ 10 !
- For CC site assessment (loads & power): blade ice erosion important to understand!

Conclusions (2/2)

- **Major breakthrough** with international standard IEC 61400-1:

  - Dedicated CC chapter & Annex
  - New Cold Climate class turbine eg IEC 2A CC
    - ➢ **more reliable turbines in future in CC!**

  - New cold climate design load cases (CC DLC) have been validated with load measurements from case CAN & SWE

  - New CC DLCs have mild effects to component lifetime (mainly tower base) but are primarily targeted to:
    - ➢ **Investigate turbine controller safety with iced blades**

    - Soft tower concepts might require additional design effort

Tack, Danke, Merci, Thank you, Kiitos!

Ville Lehtomäki, M.Sc. (Tech)
Research Scientist
Ville.Lehtomaki@vtt.fi

Vuorimiehentie 5, Espoo, P.O. Box 1000, FI-02044 VTT Finland
Tél. : +358 40 176 3147

Finnish Funding Agency for Technology and Innovation
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References

[1] BTM World Market Update 2012, Special Chapter: Cold Climate Turbines, Navigant Research, Copenhagen, Denmark

[2] IEA WIND TASK 19, EXPERT GROUP STUDY ON RECOMMENDED PRACTICES: *13. WIND ENERGY PROJECTS IN COLD CLIMATES*, 1. EDITION 2011, Approved by the Executive Committee of IEA Wind May 22, 2012.

[3] Laakso, T. et al., *IEA WIND TASK 19 WIND ENERGY IN COLD CLIMATES: Cold Climate Challenges*, EWEA 2011 side event, Brussels, Belgium

[4] Wadham-Gagnon, M., et. al., Ice profile classification, based on ISO 12949, WinterWind 2013, Ostersund, Sweden

[5] IEC 61400-1:2005 ed3, *Wind Turbines – Part 1: Design requirements*, International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland