EXHIBIT A

ICE LOADS, CASE STUDY

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ABSTRACT: Three different ice cases were measured in similar wind conditions. Effects of icing are presented as a reduction of a lifetime compared to a clean situation in similar wind conditions. Same situations were also simulated with ADAMS-model. The results presented here implicate serious hazard to the turbine's lifetime or power production due to unbalanced ice build-up.

1 BACKGROUND

Measurements were carried in Pyhätunturi test station. The turbine is Wind World 220kW. Site is 500 meters above the sea level and the elevation from surroundings is about 300 meters. Icing conditions occur frequently during the wintertime.

2 METHOD

These measurements were carried as a campaign. Time series of meteorological and load measurements were recorded as usual. When icing conditions started blade heating was turned off. Ice build-up on turbine was observed and at the same time icing conditions measured by using a special rotating multicylinder device (RMC) /1/. The RMC-device collects ice, ice build-up is measured and results with wind speed (V), temperature (T) and accretion time (t) are used as input to the RMC code, which gives liquid water content (LWC) and droplet size (MVD) as a result. All these are used as input data to TURBICE /2/ code that is used to calculate ice build-up. Calculated ice shape and amount is compared to observations and calculated ice mass distribution in radial direction is used as an input to dynamic simulation codes (mostly ADAMS). Results from dynamic calculations were compared to measurements. In ADAMS approximated iced ClCd values were used. The approximation was made using experience,references /3, 4/ and by fitting power curve to measured cases.

In all cases wind speed was 11 m/s and turbulence intensity (hydrotech) was 11%.

From measured tower root loads turbine lifetime was calculated and compared to the calculated lifetime based on load measurements on a not-iced turbine operating in similar wind conditions. Note: this is not a real lifetime, just a calculated lifetime for tower if turbine would be running all the time in these wind conditions. The results are presented as a ratio, lifetime reduction.

This turbine does not have a vibration censor so the results presented here can be interpreted as a loss of power production on turbines which have vibration sensors and would stop in case of serious vibrations.

In simulations comparison is made to a simulated clean case, not to a measured case.

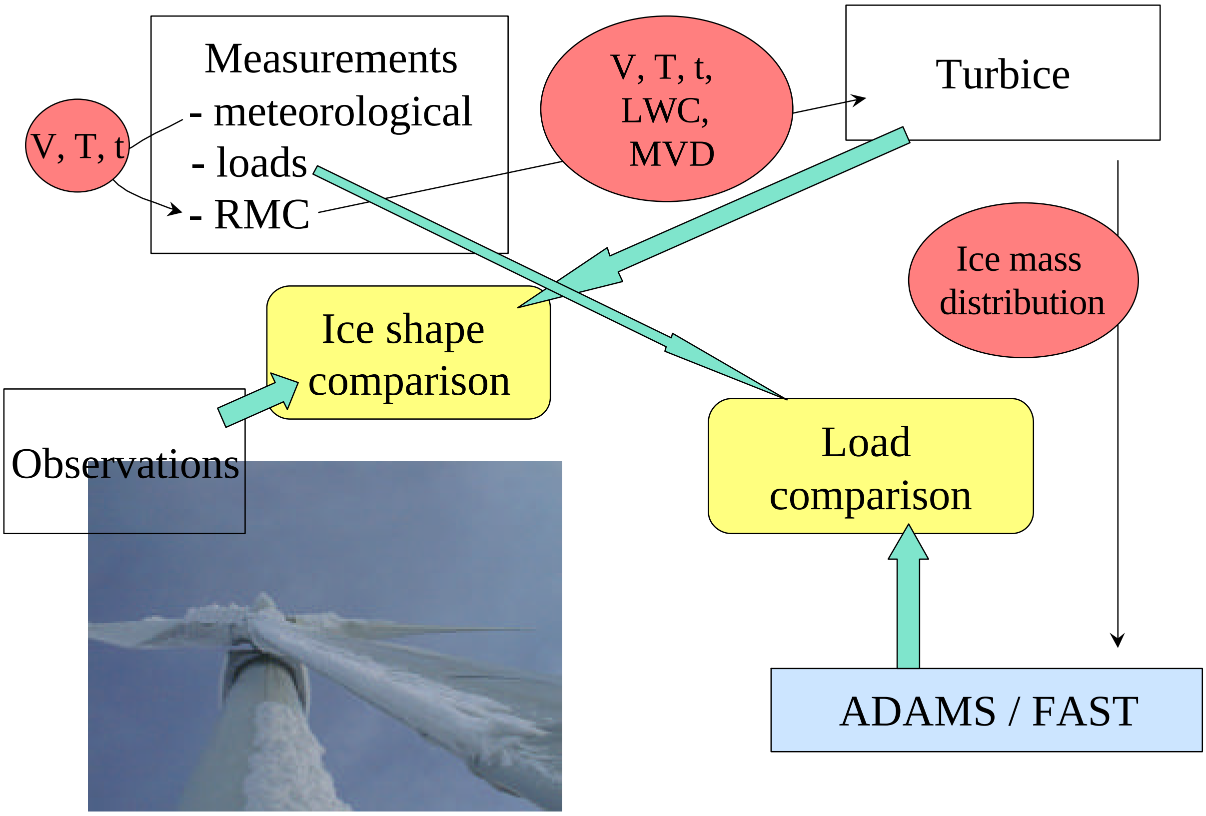

Figure 1. Method.

3 CASE 1, BEGINNING

This case was recorded 25.4.2000 11pm. In the beginning the turbine was clean. The blade heating was switched off and the turbine accreted ice for two hours. The ice build-up was on the leading edge and the shape was triangular in radial direction, as usual. In the tip ice build-up was 7 cm (14 %) in chord direction. Iced profile has an interesting two-peak shape. All the blades look similar, there is no visible imbalance.

Measured lifetime change is -50% and simulated change is +50%. In simulation there is no imbalance, only added mass and iced ClCd-curves so result is predictable, but difference to measurement indicates that there is imbalance. Is it mass imbalance or aerodynamic imbalance? Either one, but the surprising finding is that there is imbalance, even that it can not be noticed visually.

Measured -50% in lifetime is not alarming. In this case a long exposure time to these loads would be required to make a difference. If this kind of icing is all that turbine would have to face, this kind of icing probably wouldn't last for several months annually.

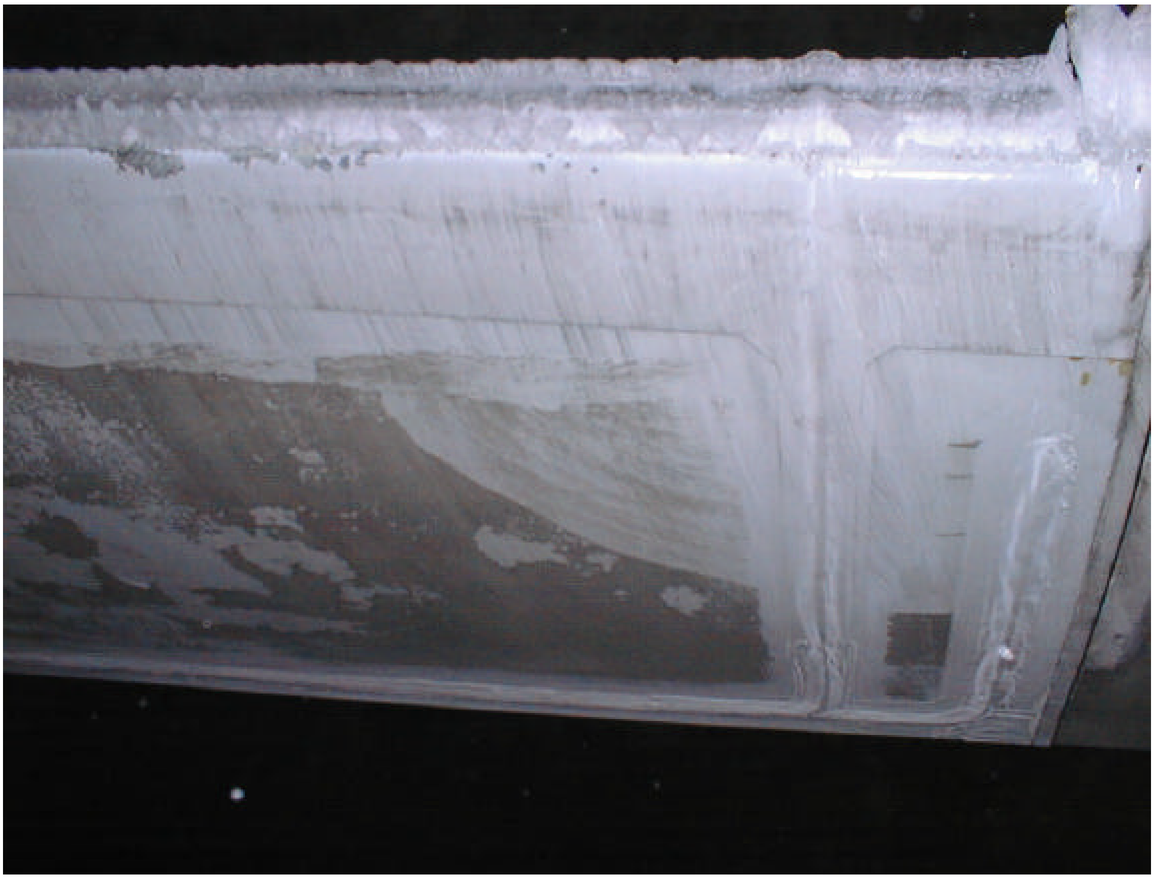

Figure 2. Two peaked ice on leading edge

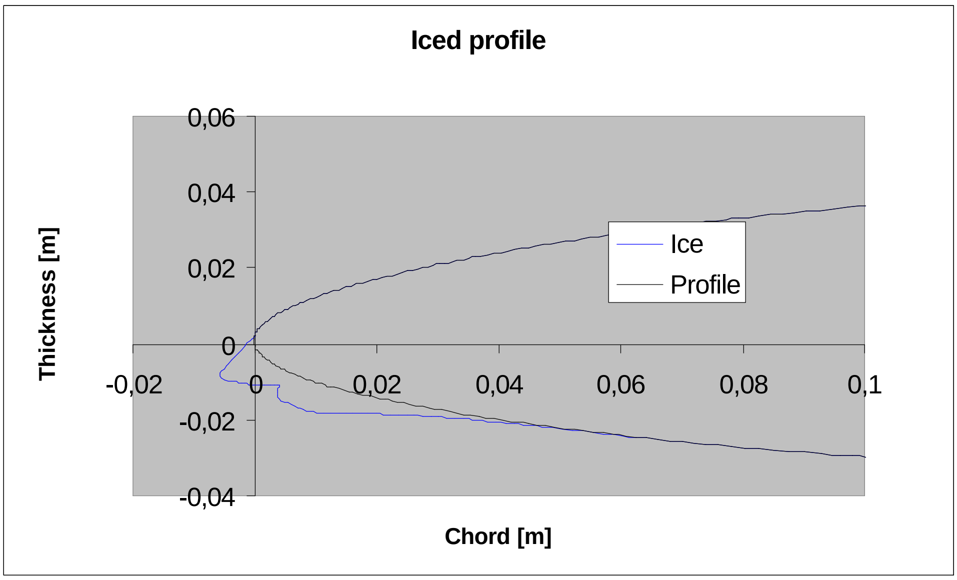

Figure 3. Ice shape from TURBICE.

4 CASE 2, MORE ICE

This case was recorded 26.4.2000, 2.30 am. Icing continued from the previous case for two more hours. One of the blades collected more ice than other blades. In blade number one ice build-up in tip was 20cm (40%) and in other blades 12 cm. 30 cm of the tip of the blade 3 was clean. In the tips ice is no longer in “two peak“ shape, peaks have grown to form just one peak. Near the blade root shape is more like two-peak shaped.

Measured lifetime reduction was from 70 % to 90%. In simulation reduction was up to 98%. This kind of vibrations are something that must be considered.

Figure 4. Ice distribution.

Figure 5. 12 cm of ice on tip.

5 CASE 5, ICE RESIDUES

This case was recorded 9.2.2000 3pm. This case differs from previous cases. Wind conditions were similar but weather was not icing, instead it was a nice sunny winter day. There was not much ice on the blades, just some residues. The tip f the Blade 2 had 5 cm and other two tips 2 cm. Note that the tip that has most ice is different to the previous case.

Measured lifetime reduction was from 80% to 90%. In simulations change was from +10% to -20%. Surprisingly this was found to be most severe case. And the most important aspect is that this kind of situations may last often, possibly months. Clearly it is not mass imbalance that causes this, aerodynamic imbalance is the main factor here.

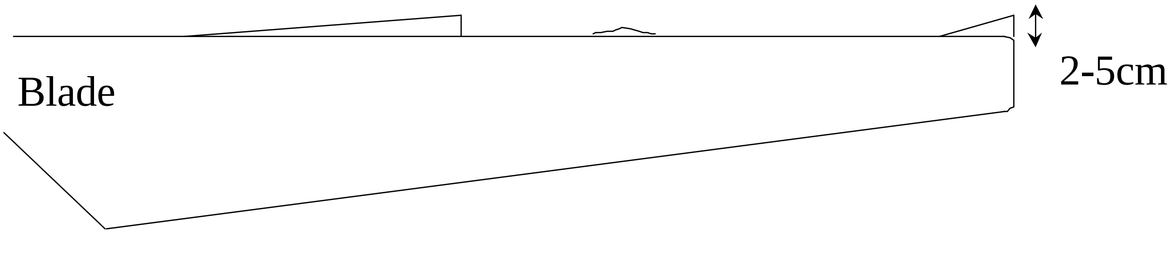

Figure 6. Ice residues.

Figure 7. Nice sunny day.

Table 1 Summary

	Meas.	Simu.	Explanation
Case1	-50%	+50%	No aerodynamic imbalance
Case2	-70%…-90%	-98%	Serious imbalance may lead to serious loads
Case3	-80%…-90%	+10…-20%	No aerodynamic imbalance

6 CONCLUSIONS

Measurements

If icing conditions last a long time (i.e. hours) there will almost always be mass (and aerodynamic) imbalance.

If imbalanced situations last a long time (i.e. days or weeks) there might be significant reduction in turbine lifetime (or in power prouction).

Simulations

Aerodynamic imbalance was not included, because codes ADAMS and FAST have only one set of ClCd values which is used to all of the blades. This leads to unsatisfactory results. This small improvement shoud be made to the codes.

Results were quite predictable´because only mass imbalance and iced ClCd values were included. Small differences in mass imbalance cause big differences in tower root loads.

REFERENCES:

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3. Per Vølund and Petteri Antikainen: Ice induced loads on wind turbines, proceedings of EWEA conference in Dublin 1997

4. Bengt Tammelin et.al. Wind energy production in cold climate (WECO). Final Report, JOR3-CT95-0014. 1998.

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