IceRisk: Assessment of risks associated with ice throw from wind turbine blades

Rolv Erlend Bredesen, Kjeller Vindteknikk, Norway
Michael Pedersen, Dag Haaheim, Niklas Sondell, Statkraft, Norway
Simo Rissanen, Ville Lehtomäki, VTT, Finland
Hicham Farid, Université du Québec à Chicoutimi, Québec, Canada
Gaute Gruben, SINTEF Materials and Chemistry, Norway
Arve Sandve, Lloyds Register Consulting, Norway

EWEA 2016 abstract,

Topic: Environmental impacts & social acceptance, Health & safety, Resource assessment.

Introduction

Uncertainties are large and empirical data is scarce when considering the risk assessment associated with ice throw from the blades of operational wind turbines. In order to assure a realistic risk assessment and to avoid an overly conservative risk picture, one should strive to make realistic assumptions at each sub-step in the risk assessment process. When early ballistic models of ice throw didn't include air drag, the extent of hazard zones around turbines was exaggerated. On the other hand, if one only uses empirical data of shape, size and density of ice debris collected from the ground in the vicinity of turbines, the risk assessment could become overly opportunistic as ice is a very brittle material and a large fraction of ice debris thrown from the turbines would be omitted in the statistics. When building a database of thrown ice debris one should therefore also take into account larger craters in the snow (assuming a snow cover exists). The safety distances of the furthest possible throws should also be inspected/included as far as possible.

> In this paper, the IceRisk methodology [1] is presented. Sub-steps in the risk assessment are addressed and improvements are presented. In the current IceRisk methodology, ice throw databases are only used for validation purposes. The ice accretions and shedding events are directly calculated from hindcasts of weather data together with Kuroiwa/Makkonen [5] type ice accretion models for: 1) simplified rotational blade cylinder models for the reference analysis and 2) advanced blade models including potential flow around the turbine blade such as the TurbIce model [6] for more detailed studies. A sound method for calculating the ice debris size distribution suitable for inspecting the extent of the risk zones has been employed.

Approach

A ballistic trajectory model is used together with the energy limit of 40 J to differentiate between dangerous ice throw and fall from other ice debris. Safety zones based on calculated risks were previously suggested [1] based on similar criteria for other industries. For the icefall, a generic shape of freely rotating ice cubes, of density 500 kg/m^3 where the length of the ice piece (l) in each class is dimensioned after the accreted ice load (L) and density (ρ), $l = (L/\rho)^{0.5}$ was employed and compared favorably with observations. For ice throw, the safety zones have been calculated using a density of 800 kg/m^3, since dense ice pieces can be thrown further than lighter ones. Based on current observations of differently shaped ice pieces with varying densities, the safety distances calculated for the freely rotating ice cube holds and we consider the calculated ice fall risk zones as accurate.

Note that the assumption of freely rotating cubes is suited for inspecting the furthest ice drift and throw distances. For more detailed analysis on the maximum possible damage in the vicinity of the turbine we recommend tuning the size distribution to more elongated ice pieces, especially for analysis of shedding associated with the deicing of a stopped wind turbine.

Main Body of Abstract

A general methodology to assess risks related to ice throw from turbines and falling ice debris was presented in [1] and applied on wind farms and turbines, tall masts, and fjord crossing power lines in Norway. Operational forecasts of risk zones relevant for maintenance purposes for the wind farm Stamåsen in Sweden has also been presented [2]. Here, we scrutinize the method at the windfarm of Stamåsen by comparing forecasts issued for the winter season 2015-2016 with empirical data in form of turbine operational (SCADA) data, ceilometer measurements of cloud base heights from within the wind farm, evidence of ice debris and other sources. A review is given on ongoing and suggested improvements to the methodology.

Conclusion

We present an applicable method, which enables identification of where and how the best risk reducing measures are to be applied.

Novel improvements:

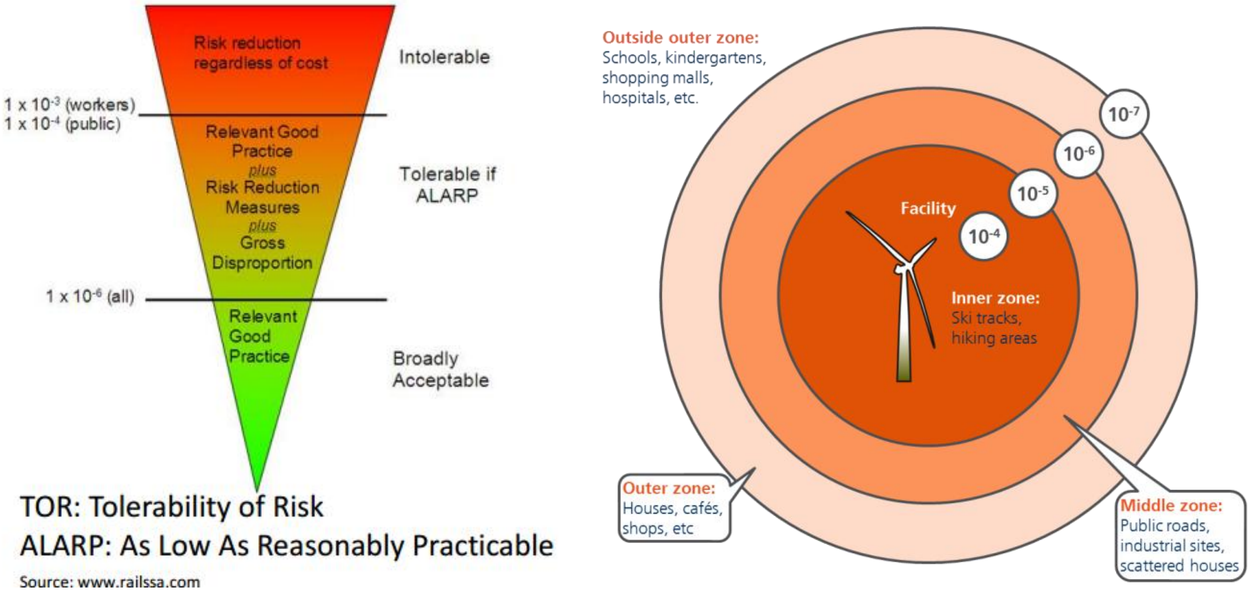
- Improvements are made to the ice debris size distribution by utilizing the TurbIce model [6] for detailed blade ice accretion calculation.
- Review of material properties of ice at different densities and temperatures relevant for i) impact studies, and ii) modeling of shedding [3], [4] .
- Review of damage criteria for blunt impacts against the human body [8].
- Improvements for impact analysis beyond using the 40 J limit for possibly fatal ice debris as the assumption becomes conservative with decreasing ice densities [8].
- Standardized method of risk communication (see figure).

Key questions for ongoing and future work:

- What is the largest ice accretion expected in the wind farm and what is the maximum throw distance associated with this ice accretion?
- At which ice load is the turbine influenced in the form of a penalty on the performance and rotational speed. What is the reduced rate of further ice accretions on the blade?
- What is the long-term size and density distribution of ice accretion on a blade for a site specific turbine?
- How much energy is absorbed on impact for snow/ice debris of varying density?
- How effective are detection, deicing and anti-icing systems with respect to the prevention of buildup of dangerous ice amounts?
- How effective are de-icing systems with respect to not attempting start-ups when dangerous ice amounts are still present after a failed deicing cycle?

Learning objectives

The furthest ice throw distances suggested by ballistic models have not yet been confirmed, however with increasing empirical evidence we expect the safety distances to be addressed with a higher level of certainty. Uncertainties and simplifications still exist in the presented IceRisk methodology, though with incremental improvements and increasing empirical evidence the precision in such analyses will increase. The advantages of using the presented assumptions are evident: 1) the method enables comparison of the risk related to falling and thrown ice, between sites and different installations and 2) the method could be applied by others in the community to compare with their own models and experience, especially regarding the size of and risk level associated with the ice throw risk zones around turbines. Such a scrutiny is welcome and wanted as the community improves the awareness and knowledge with respect to the safety issue.



Left: Risk reduction according to the ALARP principle as presented by IEA Task 19 suggestion [7]. **Right:** Lloyd's Register Consulting's suggested safety zones around installation that may case risk of ice throw or ice fall. The numbers indicate the iso-risk contours for localised individual risk (LIRA), the probability that an average unprotected person, permanently present at a specified location, is killed during one year due to ice fall or throw from the facility. [1][7]

Bibliography

[1] R. E. Bredesen and H. Refsum, "Methods for evaluating risk caused by ice throw and ice fall from wind turbines and other tall structures," in *IWAIS 2015*. 16th International workshop on atmospheric icing of structures. ISBN 978-91-637-8552-8.

[2] R. E. Bredesen, "Ice risk forecast system for operational wind farms," in *WinterWind*, 2016.

[3] H. Farid, M. Farzaneh, A. Saeidi, and F. Erchiqui, "A contribution to the study of the compressive behavior of atmospheric ice," *Cold Reg. Sci. Technol.*, vol. 121, pp. 60–65, Jan. 2016.

[4] H. Farid, "Experiments on atmospheric ice under different conditions," 2016.

[5] ISO/TC98/SC3/WG6: Atmospheric icing of structures, International Standard, ISO 12494, 2000

[6] Makkonen, L., Laakso, T., Marjaniemi, M., and Finstad, K. J. Modelling and prevention of ice accretion on wind turbines. Wind Engineering, 25:3-21, 2001.

[7] Wadham-Gagnon et al., 2015. IEA Task 19 - Ice Throw Guidelines. Winterwind 2015.

[8] Bredesen, R.E., 2015. IceRisk - Damage Criteria. Literature study on the damage potential for falling ice debris. KVT Memorandum. KVT/REB/2015/N071.