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Understanding Icing Losses and Risk of Ice Throw at Operating Wind Farms

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Renewable Energy Experts
worldwide

Losses

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Overview

- Effects of icing
- Types of icing
- Identifying icing events
- Losses: production & availability
- Conclusions

Production losses due to icing

1. Power performance loss due to deteriorated airfoil (ice on the blades)
2. (Availability loss due to increased turbine faulting in cold conditions)
3. Safety shutdown when turbine controller or operator detects icing and vibration faults
4. Access disruption due to icy or snowy access roads
5. Collections network down due to ice on above-ground power cables
6. Turbine shut down due to erroneously low wind speeds from iced anemometers

Two types of icing: Rime and Glaze

Rime:

- Supercooled water vapour deposited on turbine structure
- Forms in dry conditions at temperatures below 0 degC
- Opaque or white like snow

Two types of icing: Rime and Glaze

Glaze:

- Freezing rain, clear and smooth
- Occurs in wet conditions near freezing point

Identifying icing events: data

- GH **database** of 14 wind-farm years in North America compiled and analysed
- Turbines in database: 1.5 MW or greater, pitch regulated
- Content: detailed operational information

Identifying icing events

Blade icing:

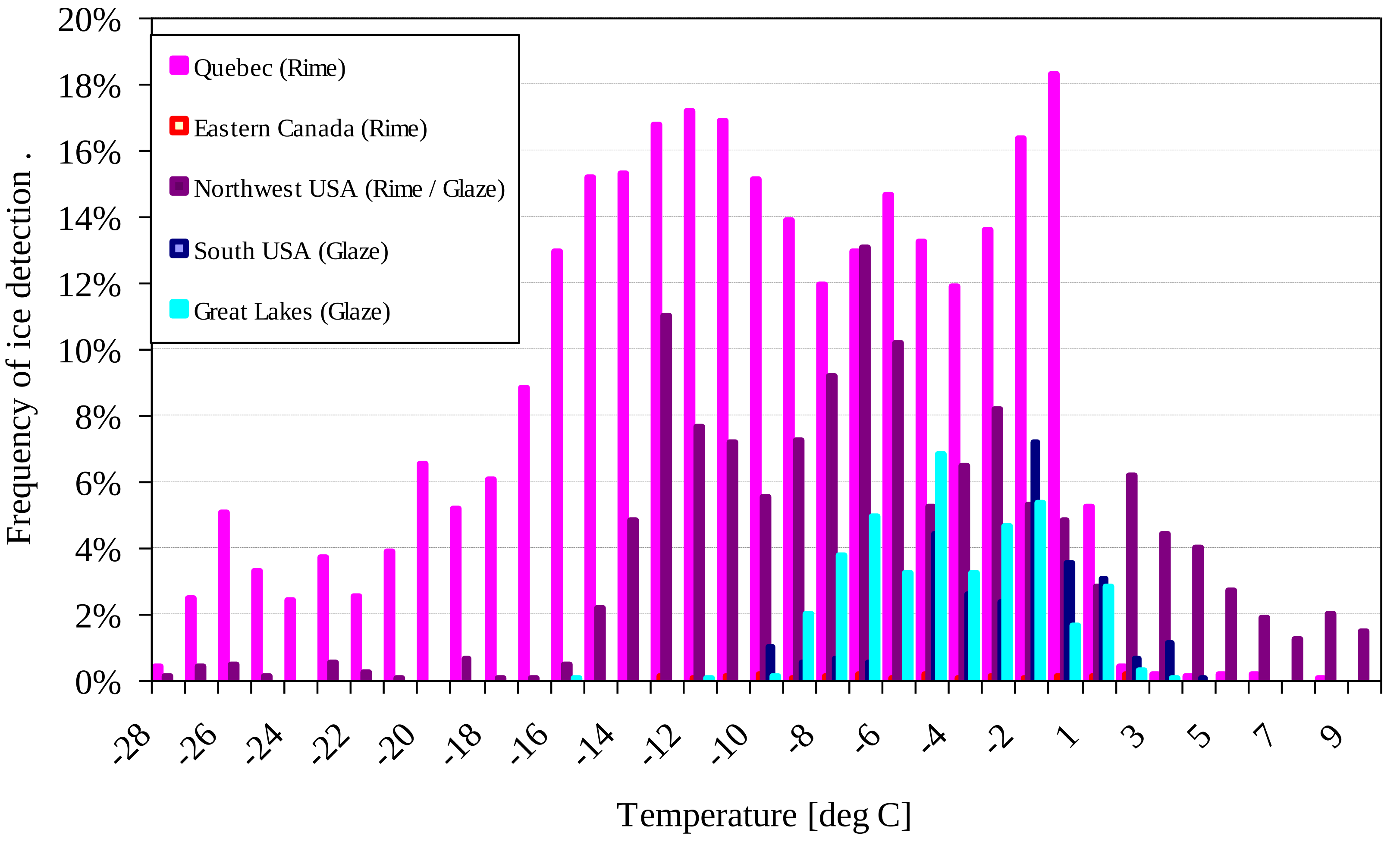
- Detected through detection of power performance deterioration while atmospheric conditions were conducive to icing
- Production loss due to power curve deterioration was calculated at the iced turbines by constructing a density-corrected nacelle anemometer power curve for each turbine during non-icing conditions

Identifying icing events

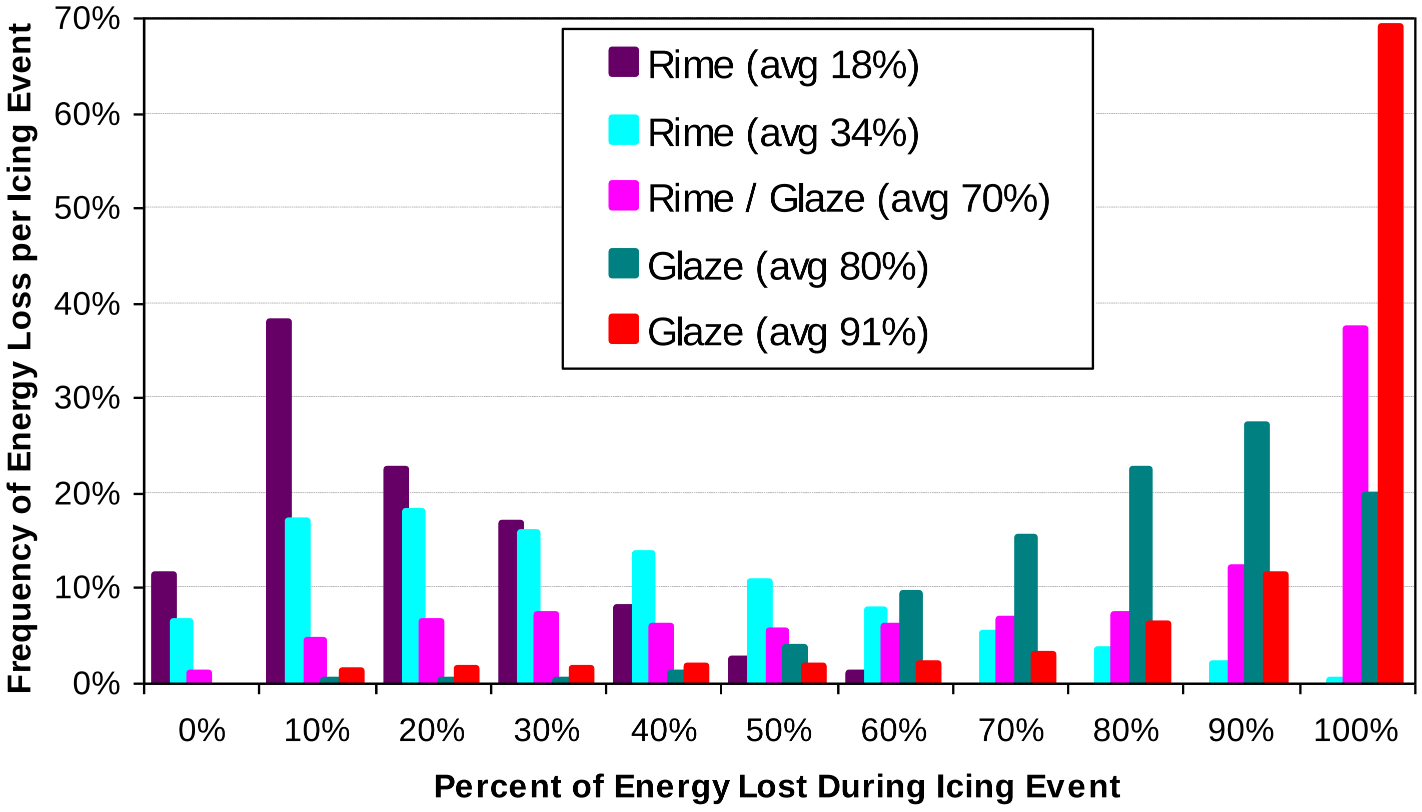
Anemometer icing:

- Detected through inspection of the power curves and correlation of nacelle anemometer signals with the wind farm average
- Estimated by calculating the expected energy which would have been produced at the turbine given the average nacelle anemometer wind speed of the other turbines at the wind farm

Icing frequency: more rime than ice



Power curve degradation:
Glaze strong effect



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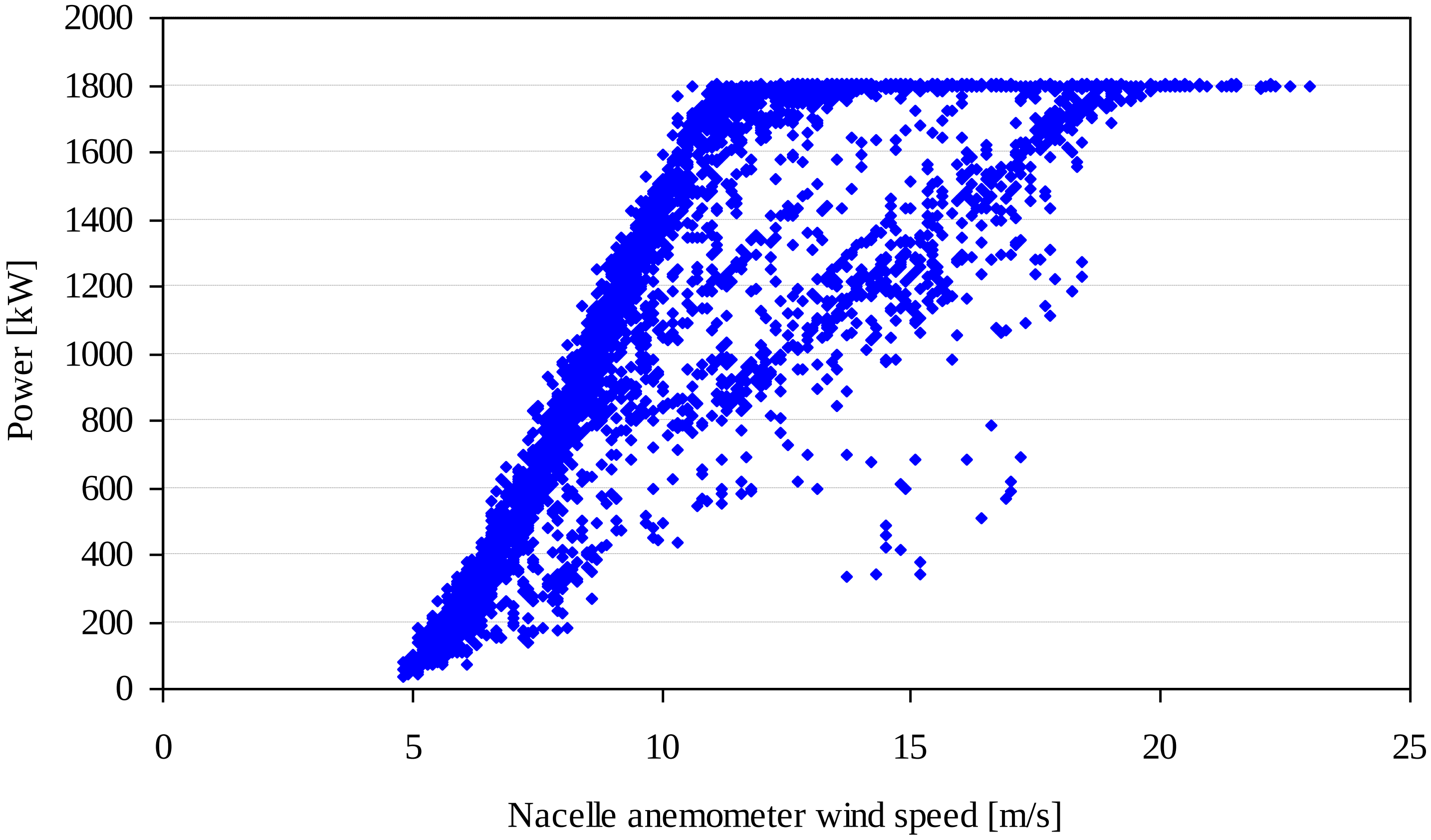
Results: Rime

- Temperature: from -20 ˚C to 0 ˚C.
- Ice was observed on at least one turbine between 8% and 18% of the time.

- Average power curve performance degradation due to a rime icing event is between 18% and 34%.
- The average energy loss per icing event is approximately one third of the energy expected from the normal power curve.

Rime Icing - typical example

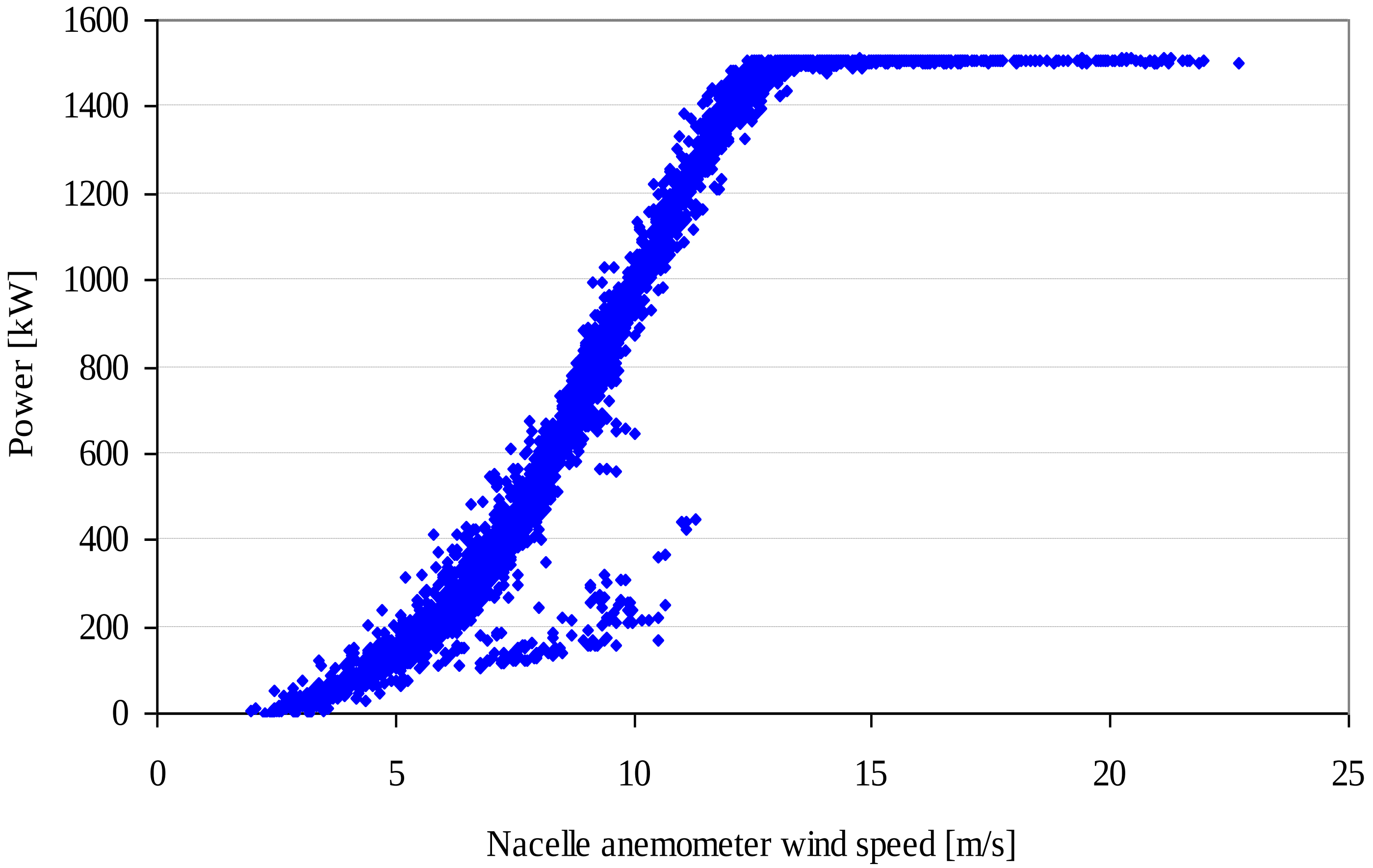


Losses: power curve degradation

- Temperatures: -8 ˚C to 2 ˚C
- Ice was observed on one or more turbines between 2% and 7% of the time when the temperature was within the range. In many cases coincident with known ice storms which lasted for several days.

- Average power curve performance degradation due to glaze ice is much higher: between 80% and 91%.
- Average loss of 80% of the expected energy during that 10-minute period.

Glaze Icing - typical example



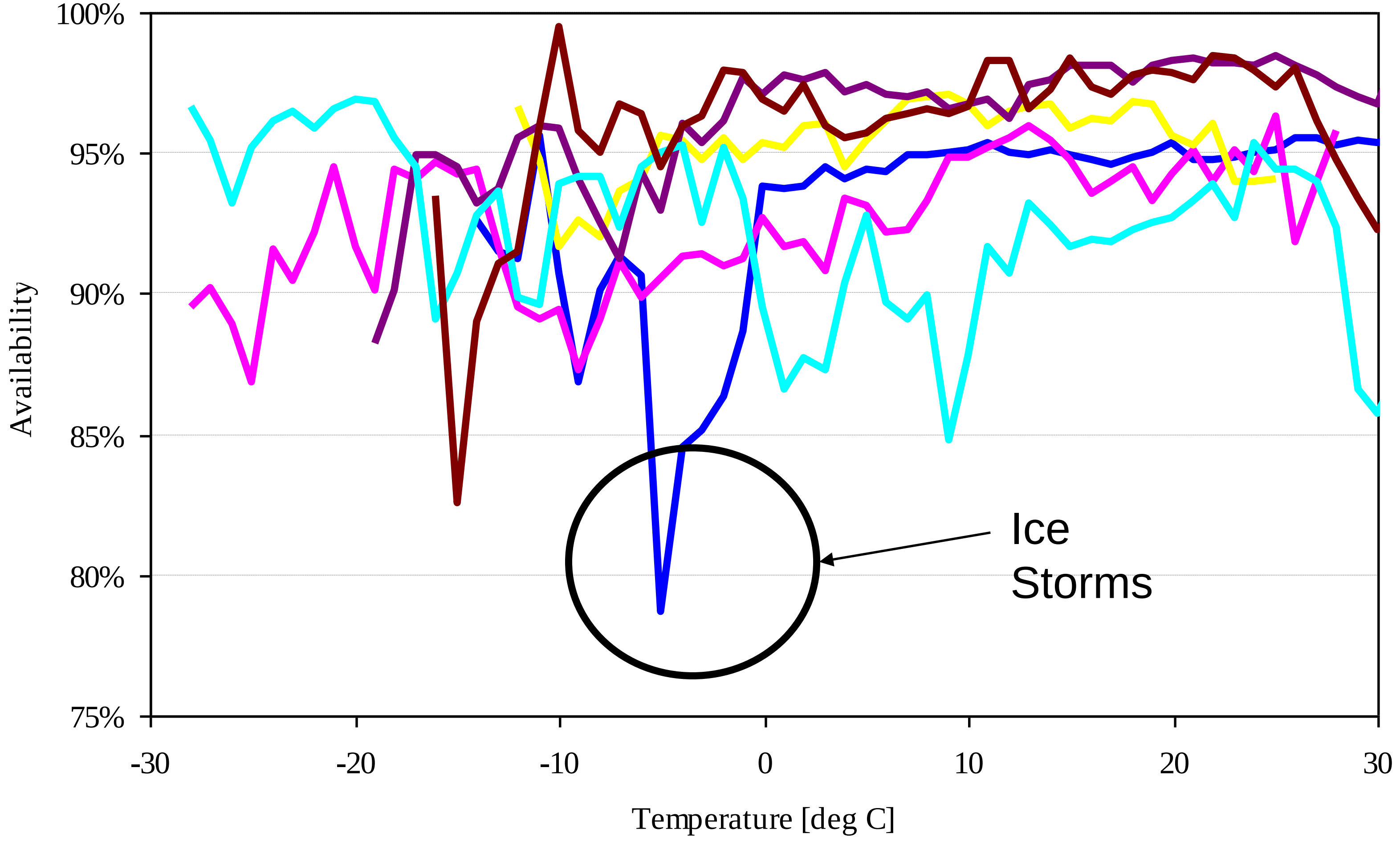
Losses: power curve degradation

- Total production losses due to power curve degradation were found to range from 0.01% to 4.2% of the expected energy capture per annum.

Losses due to *Availability*

- Beware of fault chaining!
- **Availability trends during detected icing periods:**
  - Availability on icing days found to range from 1% to 5.3%
  - Since the number of icing days per year varies from 4% to 46%
- Production loss due to the low availability observed through detected icing events is estimated to range from **0.1% to 2%**
- Production loss due to low availability was not found to be dependent on the icing mechanism.

Availability vs Temperature



Conclusion: icing (NA)

An initial quantification of icing the losses due to icing at operational wind farms indicates that:

- It is possible to reliably identify icing events from a detailed analysis of operational data.
- Rime ice is observed more frequently and at a wider range of temperatures than glaze ice.
- Where glaze ice is detected, it results in a larger (80% - 90%) deterioration of the power curve relative to rime ice (18%-34%).
- Observations suggest a dependence of turbine availability with temperature.

>> Better predictions in pre-construction estimates required: by region and by icing mechanism

Ice throw risk

Overview

- Wind Turbine Icing
- Ice Throw Risk Assessment
- Guidelines
- Example Calculation
- Additional Factors
- Ice Throw Observations
- Control Mitigation Strategies

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LIVE BBC NEWS CHANNEL

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Ice shards rain down from turbine

A giant wind turbine near Peterborough has been switched off after its frozen blades threw off shards of ice - many crashing into nearby homes.

Resident collected some of the smaller shards of ice that fell

The Cornwall Light and Power 80m (262ft) turbine was put up in August, near an industrial estate and close to homes in King's Dyke, Whittlesey.

But it was switched off when big chunks of ice started crashing into gardens on Saturday morning.

Cornwall Light and Power said it was investigating the incident.

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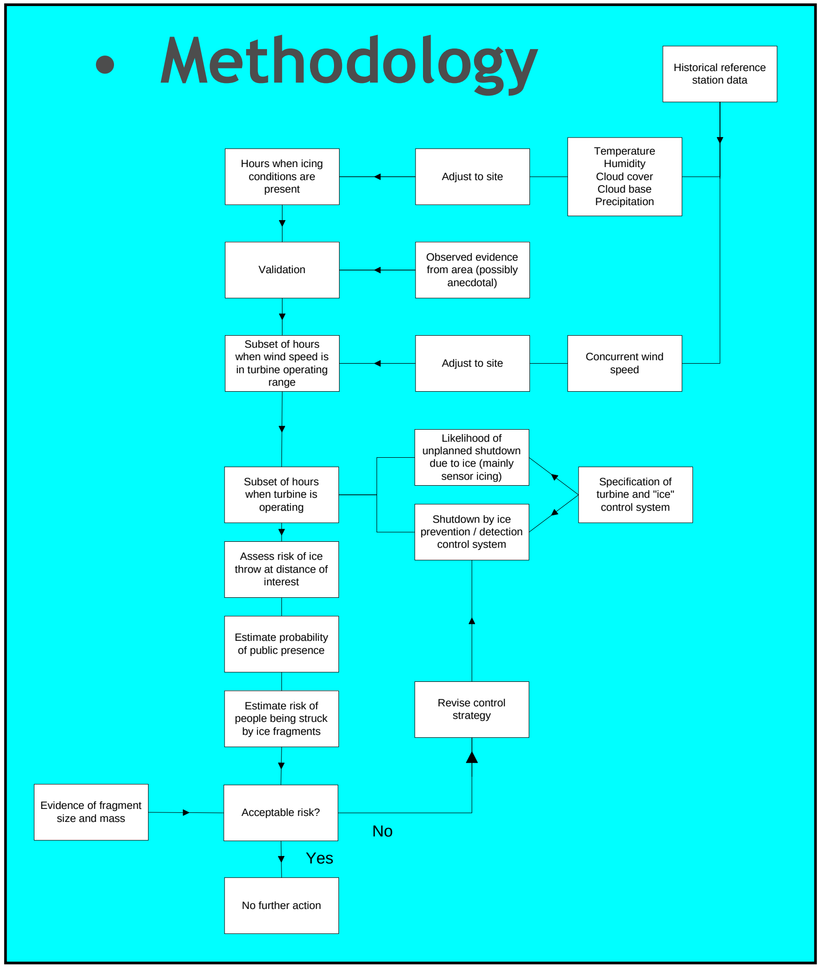
Wind Turbine Icing

- Ice can build up on wind turbine rotor blades when appropriate conditions of temperature and humidity exist.

- Stationary turbine:
  - Ice accretion rate same as a buildings, trees or power line.
  - Ice will eventually be released and fall to the ground.

Ice Throw Risk Assessment

- **Methodology**



WECO research project (1999)

Main steps to follow:

1. Determine Ice accretion periods when wind turbines are operational
2. Exclude periods when wind turbines will be shut down automatically by the control system or by remote operators
3. Use **guidelines** to arrive at probability of fragments landing at the distances from the turbines
4. Estimate probability of members of the public being present within the distances from the turbine which are being considered.
5. Arrive at combined probability of members of the public being hit by ice fragments

Guidelines

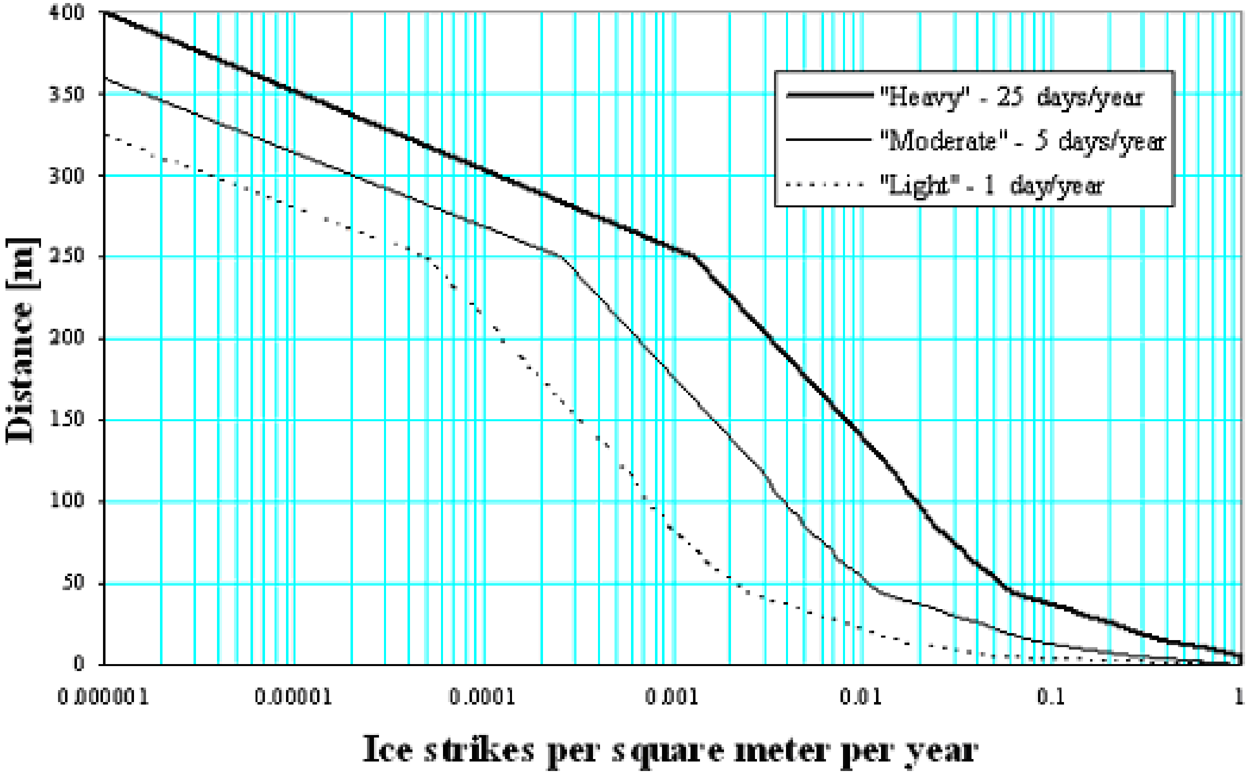
Developed for a generic modern wind turbine:

Rotor diameter =	80 m	Cut-in wind speed =	4 m/s
Hub height =	80 m	Cut-out wind speed =	25 m/s
Nominal rotor speed =	15 rpm (fixed)	Nominal tip speed =	62.8 m/s (fixed)

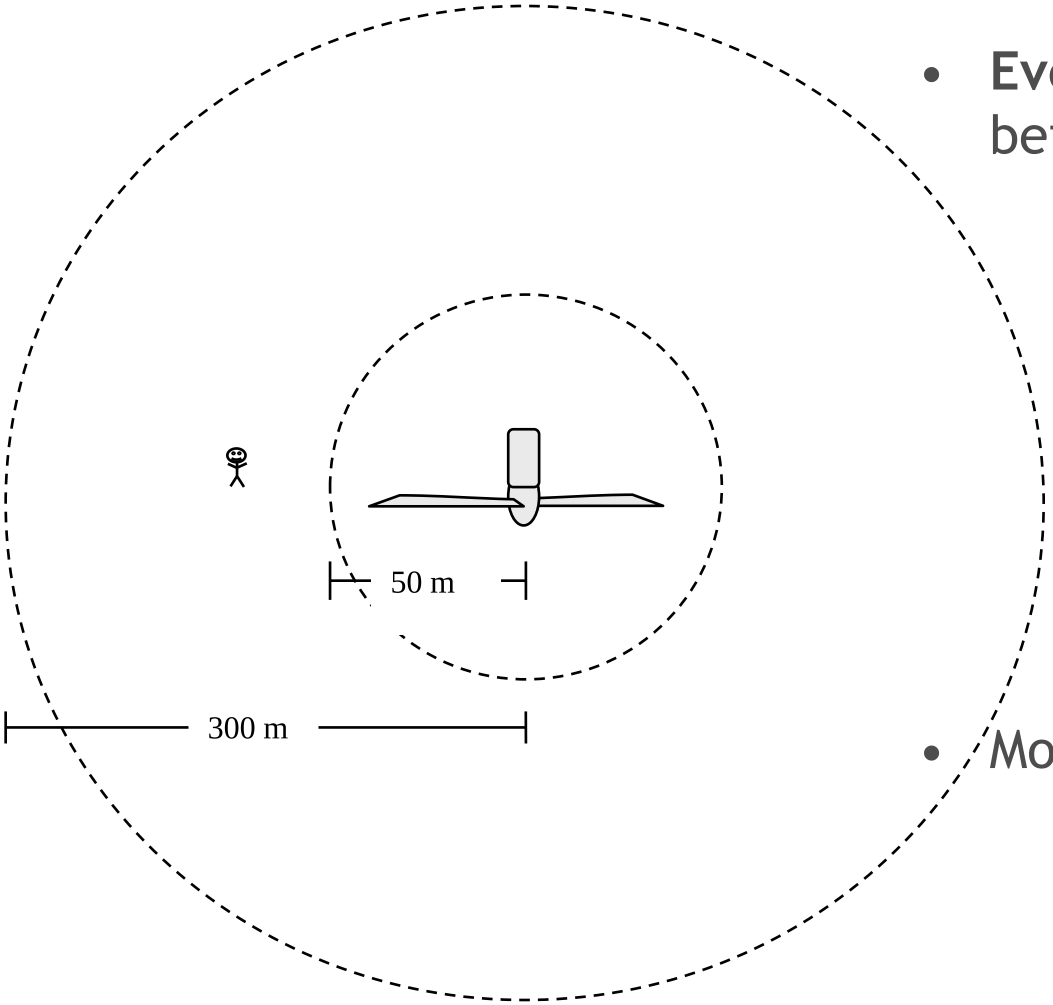
- Based on a Monte-Carlo simulation of 100,000 ice throws
- Key assumptions:
  - Ice fragment is equally likely to detach at any blade azimuth angle and 3 times more likely from the blade tip than the rotor
  - Ice fragments have mass of 1 kg and frontal area 0.01 m^2
  - Wind speeds follow a Rayleigh distribution of 8 m/s
  - All wind directions are equally likely

Guidelines

Probabilities for 3 ice accretion levels per m^2 per year



Example Calculation



- **Ever-present individual** between 50 m and 300 m
- Individual equally likely in any given 1 m^2 within area
- Moderate icing conditions

Example Calculation

- Area between 300 m and 50 m is ~275,000 m^2
- Calculate distance weighted area under the 50 m to 300 m risk profile of guidelines (Moderate)
- **Individual Risk** (IR) probability for an ever present individual:

- IR = 0.002 x (1 m^2 / 275,000 m^2) x 275,000 m^2
- IR = 0.002 strikes per year

- Equivalent to **1 strike in 500 years**

Additional Factors

- **Presence of individuals in the unpleasant weather necessary for icing conditions**
- Specific parameters of the wind turbine model
- Frequency of the wind direction
- Trees or other structures – may provide shelter
- Terrain slope – significant for hills or ridgelines
- **Control mitigation strategies implementation**

Control Mitigation Strategies

Where public ice throw risk is believed to exist, the following strategies are recommended:

- Curtail turbine operation during periods of icing
- Implementing special turbine features which prevent ice accretion or operation during icing periods
- Posting warning signs and/or gated access ways alerting anyone in the area of risk.
- Protocols and procedures for operational staff to take appropriate action when ice accretion is likely to occur

In the planning stage, re-siting of turbines to remove them from areas of risk should also be considered where possible.

Conclusions, ice throw

- Risk associated with ice throw needs to be understood in design phase of project
- Mitigation measures and proper siting of turbines can reduce risk associated with ice throw

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THANK YOU!

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