



**RECOMMENDATIONS FOR RISK
ASSESSMENTS OF ICE THROW AND
BLADE FAILURE IN ONTARIO**

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CONTENTS

	Page
1 INTRODUCTION	1
1.1 Scope and objective	1
2 WIND TURBINE ICING	2
3 RECOMMENDED ICE THROW RISK ASSESSMENT METHODOLOGY	3
3.1 Methodology overview	3
3.2 Guidelines	3
3.3 Example calculations	5
3.4 Additional factors to consider	7
4 ICE THROW OBSERVATIONS IN ONTARIO	8
5 TYPICAL CONTROL MITIGATION STRATEGIES	9
5.1 Automated ice detection systems	9
6 LITERATURE REVIEW OF ROTOR BLADE FAILURES	11
6.1 Publicly available lists of wind turbine failure events	11
6.2 General comments	12
REFERENCES	14
LIST OF TABLES	15
LIST OF FIGURES	16
APPENDIX I	Wind farm operator survey
APPENDIX II	Wind turbine certification process

1 INTRODUCTION

1.1 Scope and objective

Garrad Hassan Canada Inc. (GHC) has been contracted by the Canadian Wind Energy Association (CanWEA) to (i) provide recommendations for assessing the risk of ice fragments shed from wind turbines striking members of the public in the vicinity of wind farm projects in Ontario and (ii) provide a literature review of wind turbine rotor blade failures based on publicly available information.

The work reported here has been performed in accordance with the proposal provided to CanWEA [1.1]. This report presents the findings of the work undertaken by GHC.

2 WIND TURBINE ICING

Ice can build up on wind turbine rotor blades when appropriate conditions of temperature and humidity exist, as it will on any structure which is exposed to the elements. When a wind turbine is stationary, it is no more likely to suffer from ice accretion than any other large stationary structure such as a building, tree or power line. As for such other structures, accreted ice will eventually be released and fall to the ground.

When a wind turbine is operating, which will typically be when the wind speed at the wind turbine hub height is in the range 4 m/s to 25 m/s, ice can still accrete on the rotor blades in appropriate conditions of temperature and humidity. In this case, observations suggest that higher ice accretion rates occur due to the relative velocity of the rotor blades but that accretion is retarded by the flexing of the blades. Ice fragments which detach from the rotor blades can be thrown from the wind turbine. Any fragments will land in the plane of the wind turbine rotor or downwind.

In situations for which a risk is perceived due to icing of rotor blades, mitigation measures are often taken in terms of automated or (remote) manual shutdown of the wind turbines. It should be noted that remote monitoring and operation of wind farms is now standard in the industry.

Certification requirements detail the load cases which must be used in the design of a wind turbine and these load cases include iced blades in order to ensure that adequate strength is provided in the structure. It is generally accepted in the wind industry that ice build up on the blades of an operating turbine will lead to additional vibration caused by both mass and aerodynamic imbalance. All commercial machines include vibration monitors, which will shut the machine down when vibrations exceed a pre-set level.

As with a large stationary structure, the risk remains of ice forming at a slow rate on the structure and dropping from the stationary turbine. As this thaws, there will be some wind blow effect although that will be small on all but the lightest particles. GHC estimates that only very high winds may cause fragments of any significant mass to be blown beyond 50 m of the base of a modern 2 MW turbine which is stationary. Operating staff will be well briefed on this situation and the risk will be minimal.

Risks associated with an operational turbine are larger than those associated with a stationary one. When a turbine re-starts after a prolonged period of shutdown ice particles may be thrown from the blade. Further ice may form during operation and will eventually also be thrown. Typically there are operational procedures designed to minimise risk to staff which are adopted by projects which include wind turbines which may experience icing.

This report addresses the behaviour of ice thrown from an operating turbine.

3 RECOMMENDED ICE THROW RISK ASSESSMENT METHODOLOGY

3.1 Methodology overview

The assessment methodology recommended is based on that developed by Garrad Hassan and Partners Ltd (GHP) in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut as part of a research project on the implementation of wind energy in cold climates (WECO) primarily funded by the European Union and also supported, in part, by the United Kingdom Department of Trade and Industry [3.1]. The overall approach is presented schematically in Figure 3.1 and is based on a staged approach:

- Determine the periods when ice accretion on structures is technically possible, based on historical climatic observations.
- Within those periods, determine when the wind speed conditions are within the operational range of the wind turbines.
- Within the resultant periods, exclude those periods when the wind turbines will be shut down automatically by the wind turbine control system or by remote operators.
- Based on an estimate from the above of the amount of icing, use guidelines (see Section 3.2) to arrive at probability of fragments landing at the distances from the turbines which are of interest.
- Estimate probability of members of the public being present within the distances from the turbine which are being considered.
- Arrive at combined probability of members of the public being hit by ice fragments.
- Compare that probability to a suitable benchmark risk – the most commonly used one being the risk of being struck by lightning.

It is considered that the methodology is applicable to wind farm projects in Ontario by considering the proposed turbine type, the terrain of the site and surrounding area, and assumptions for human presence in the surrounding area.

3.2 Guidelines

The guidelines for safety assessments in relation to ice throw were developed by GHP in the WECO project and that work was summarized in a series of conference papers [3.2,3.3,3.4].

The guidelines produced in the WECO project were based on a combination of numerical modelling and observations. Similarly to the WECO project, the calculation methods described in [3.2] have been extended to make estimates of the probability of any particular ice fragment landing in a given square meter area of ground. This is considered to be representative of the risk of a person standing in one particular point being struck. In the absence of field data, an assumption is required on the relative probability of the ice fragment becoming detached as a function of its radial position on the blade, and the azimuthal position of the blade. The following assumptions have been made:

- The fragment is equally likely to become detached at any blade azimuth angle.
- The probability of ice detachment at the tip is three times greater than at the hub, with linear interpolation used for other radial positions.

- Ice fragments have mass of 1 kg and frontal area 0.01 m².
- Wind speeds are distributed according to a Rayleigh distribution with a mean of 8 m/s, and there is no correlation between wind speed and the occurrence of icing conditions.
- All wind directions are equally likely, with no correlation between wind direction and the occurrence of icing conditions, and the turbine nacelle is aligned with the wind.
- The turbine rotor speed is zero when the wind speed is outside the operation wind speed range of the wind turbine considered.
- Parameters for the wind turbine considered are:

Wind turbine model	Generic – 2.0 MW
Rotor diameter	80 m
Hub height	80 m
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Nominal rotor speed (fixed)	15 rpm
Nominal tip speed (fixed)	62.8 m/s

Table 3.1 Wind turbine parameters

A Monte Carlo analysis has been used, in which 100,000 ice fragments are shed from the rotor. The initial radial and azimuthal position and the wind speed and direction conform to the assumed probability distributions. The ranges of the fragments are binned to obtain the distribution of landing probability per unit ground area.

The results are shown in Figure 3.2. This represents the probability, given an ice fragment has been released, that any one ice fragment lands in one square metre of ground area, as a function of distance from the turbine. Clearly the risk per square metre per year is obtained by multiplying by this probability by the probability of a fragment being released, which in turn depends on the number of ice fragments thrown from the turbine per year.

From these results it would appear that there is a critical distance of approximately 220 m from a turbine, at greater distances the probability falls off rapidly. The critical distance can effectively be regarded as a ‘safe’ distance, beyond which there is negligible risk of injury from ice throw. The critical distance depends mainly on the tip speed of the turbine, not on its size. The maximum tip speeds of commercially available turbines are all quite similar.

In the modelling, further assumptions are required in regard to the aerodynamic properties of ice fragments. These assumptions were verified during the course of the WECO project by measuring the lift and drag characteristics of models of typical ice fragments in wind tunnels. Those coherent fragments collected from various icing events were irregular blocks shed from the leading edge of the rotor blades. Moulds were produced from these and replicas cast for wind tunnel testing. No stable lifting situation was measured leading to a conclusion that the lift coefficient could be ignored. The drag coefficient meanwhile was measured to fall in the same range as was assumed in the modelling described above.

In the EU WECO study [3.4], the observations of ice build-up on rotor blades and fragments shed from rotor blades were gathered from wind farms throughout Europe. The data gathered are presented in Figure 3.3, which shows that fragments typically land within 100 m of the wind turbine. Ice fragments with masses up to 1 kg were found although most were much smaller.

When considering the results above and assuming three categories of icing conditions for this Ontario study, the chart in Figure 3.4 is proposed for use in risk assessment where detailed assessment is required. It will be noted that the critical distance of 220 m referred to above is significantly exceeded in the data presented in Figure 3.4. The curves provided for distances in excess of 250 m have been included on a pragmatic basis to add a level of conservatism at low probability values and are not based purely on the data presented in Figure 3.2.

The results are based on “sample conditions” as listed above. It may be necessary to consider more specific site conditions. For example the actual wind rose could be included. Many turbines are now variable speed but, as a conservative assumption, the example used here uses a fixed speed turbine. In a variable speed turbine the tip speed of the blades is lower than assumed here and hence the distance travelled by any ice is likely to be smaller.

3.3 Example calculations

To demonstrate the recommended methodology, three example calculations are presented:

- Scenario A – Fixed dwelling
- Scenario B – Road
- Scenario C – Individual

They have been designed to represent a typical wind farm project in rural Southern Ontario.

For the purpose of the example calculations, the sites for all three scenarios are represented by the assumptions listed above. Moderate icing conditions (5 days per year) in flat open terrain have been assumed. The relevant distances for each scenario are presented in Figures 3.5 to 3.7. It is also assumed that there are no mitigation strategies as discussed Section 5 in place to prevent an ice throw event from occurring.

The result for each calculation is presented in term of Individual Risk (IR) which is defined in this case as the probability of being struck by ice fragment per year. This value can be compared to other natural hazards such as being struck by lightning. For example, the average annual *per capita* lightning strike rate in the United States is approximately 1 in 600,000 [3.5].

3.3.1 Scenario A – Fixed dwelling

In this scenario, a 100 m² dwelling is situated at a distance of 300 m from a turbine, see Figure 3.5. Based on the general assumptions, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk is approximately 0.00002 strikes per square meter per year for a distance of 300 m.
- This risk is for all wind directions. However we are only concerned with wind directions resulting in a turbine rotor alignment with the dwelling. Assuming that these wind directions occurs 80% of the time during icing conditions, the resulting probability for a 100 m² dwelling would be:

$$0.00002 \times 100 \text{ m}^2 \times 0.8 = 0.0016 \text{ strikes per year}$$

- To calculate the IR probability, it is further assumed that the dwelling is always occupied during icing conditions, the dwelling affords no protection to the inhabitant and that there is a

1 in 100 chance that any ice throw event striking the dwelling will result in an individual being struck i.e. the individual's "cross section" is 1 m². The resulting IR would be:

$$IR = 0.0016 \times 0.01 = 0.000016 \text{ strikes per year.}$$

This is equivalent to 1 strike per 62,500 years.

3.3.2 Scenario B – Road

In this scenario, a north-south road is situated directly west of a turbine at a minimum distance of 200 m. With this condition, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk profile on the road can be plotted as presented in Figure 3.8.
- It is assumed in a rural setting that 100 vehicles traveling at 60 kilometer per hour will pass the turbine during the 5 days of icing events. From Figure 3.8, a vehicle would be exposed to hazard for a conservative 600 m segment of the road. Therefore, the fraction of time that a vehicle would be exposed to hazard is:

$$100 \text{ vehicles} \times 600 \text{ m} / 60 \text{ km/hr} / (5 \text{ days} \times 24 \text{ hours}) = 0.008$$

- Calculating the area weighted average under the risk profile of Figure 3.8 and assuming that wind directions resulting in a turbine rotor alignment with the road occur 80% of the time during icing conditions, the resulting IR for a vehicle with a plan area of 10 m² would be:

$$IR = 0.00016 \times 0.008 \times 0.8 \times 10 \text{ m}^2 = 0.000010 \text{ strikes per year.}$$

This is equivalent to 1 vehicle strike per 100,000 years

3.3.3 Scenario C – Individual

For this scenario, it is assumed that one ever-present individual is present within 300 m of a turbine and that individual is equally likely to be in any given 1 m² within that area but does not impinge within 50 m of the turbine base. It is also assumed that the wind blows in all directions equally during icing conditions when wind speed levels are in the operational range of the wind turbine. With this scenario, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk profile for distances between 50 m and 300 m can be obtained.
- Given that the area between 300 m and 50 m is approximately 275,000 m² and calculating the distance weighted area under the 50 m to 300 m risk profile, the resulting IR probability for an individual with a plan area of 1 m² would be:

$$IR = 0.002 \times (1 \text{ m}^2 / 275,000 \text{ m}^2) \times 275,000 \text{ m}^2 = 0.002 \text{ strikes per year.}$$

This is equivalent to 1 strike in 500 years.

3.4 Additional factors to consider

While the above example scenarios are indicative, it is recommended that the importance of the following additional factors be considered with any risk assessment of ice throw hazards:

- Accounting for the presence of individual in the unpleasant weather conditions necessary for icing conditions;
- Specific parameters of the wind turbine model considered in the assessment;
- Presence of tree coverage or other structures that may provide shelter;
- Frequency of the wind direction in relation to the risk area under assessment;
- Terrain slope – may be a significant factor if a turbine is sited on an elevated hill or ridge; and
- Implementation of control mitigation strategies as discussed in Section 5.

4 ICE THROW OBSERVATIONS IN ONTARIO

To offer further support to the methodology described in the previous section for Ontario, it is recommended that a publicly available data base of ice throw observations from wind farms in Ontario is produced. A suggested wind farm operator survey has been provided in the Appendix for this purpose.

The only known recorded and publicly available example of such observations in Ontario is from an existing Tacke TW600 wind turbine near Kincardine. The operator monitored the operation of that turbine since its installation in December 1995 until March 2001 [4.1]. In that period, approximately 1000 inspections were made, a manual note was made on each occasion. In these notes, some form of ice build-up on the wind turbine was recorded on 13 occasions during the December 1995 and March 2001 observation period, as reproduced in Table 4.1.

Record date	Event date	Comment
1 Apr 2001	2 Mar 2001	"Minor icing event, only a few pieces of ice on the ground"
1 Apr 1999	3 Mar 1999	"One icing event, found only a few pieces of ice on ground"
1 Jan 1999	Not noted	"...minor icing on one day"
10 Jan 1998	Not noted	"There was some ice build up on blades during a freezing rain event, all ice fell off and unit ran OK" "Many ice pieces, largest piece was 12x12x2 inches, pieces up to 100 m from tower"
17 Mar 1997	13-14 Mar 1997	"Ice storm, winds up to 20m/s, ice on blades after 4 hrs, the ice got off slowly found only a few pieces of ice on the ground"
1 Mar 1997	Feb 1997	"5 icing events ... only a few pieces on ground"
23 Feb 1996	23 Feb 1996	"About 1 ton of ice on ground. During my weekly inspection, found many pieces of ice at base of windmill. Pieces of ice had same curve as blade therefore these pieces of ice came from the leading edge of the blade. Estimated about 1000 pieces on ground. The largest pieces were 5 inches long 2 inches thick and 2 inches wide. The pieces were scattered up to 100 meters from base of windmill in same direction as blade arms were pointing – this was in the north-south direction as the wind was coming from the east. Most pieces were found within 50 meters from tower base"
27 Jan 1996	27 Jan 1996	"Ice on wings Found some ice pieces on ground"
14 Dec 1995	14 Dec 1995	"Freezing rain but good wind ... anemometer slowed down, ice build up ...found a few pieces of ice on ground"

Table 4.1 Observations of icing at Tacke TW600 wind turbine

There was no event recorded by the operator in which the ice that was thrown from the Tacke TW600 turbine struck any property or person.

5 TYPICAL CONTROL MITIGATION STRATEGIES

While the risk to the public from ice throws can be assessed as demonstrated by the worked examples in Section 3.3, in a situation where a significant risk to the public or operational staff due to ice throw is believed to exist, the following control mitigation strategies are suggested:

- Curtailing operation of turbines during periods of ice accretion.
- Implementing special turbine features which prevent ice accretion or operation during periods of ice accretion.
- The use of warning signs and/or gated access ways alerting anyone in the area of risk.
- Through established protocols and procedures, operational staff should be aware and take appropriate action when the conditions likely to lead to ice accretion on the turbine are present which could lead to the risk of ice falling from the rotor in areas of risk.

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

Reduction of icing on a wind turbine operating under icing conditions can significantly be improved by using blade heating system to avoid ice accretion on blades. Such an approach is however prohibitively expensive and is not used on a commercial basis.

5.1 Automated ice detection systems

Reliable detection of icing conditions in order to allow automated turbine curtailment and/or activation of blade heating systems during unattended operation is commonly desired by owners.

While ice detection systems are a continued area of research, ice detectors are commercially being used for this purpose. The most widely available and common type found in practice are ultrasonic ice detectors which detect icing with an ultrasonically-vibrating probe (frequencies between 40-70 kHz). Ice adhering to the probe decreases its resonant frequency due to the increase in mass.

In practice, it is important to measure not only whether there is ice on a detector, but also to monitor the persistence of icing conditions. Therefore a device having heating elements which are switched on after ice accumulation is detected beyond a certain threshold is also desirable. The accumulated ice is quickly melted, the sensor cools in a few seconds, and the device is ready to measure ice again. The frequency of heating can roughly be called an “icing rate”, consequently these types of devices are sometimes marketed as “icing rate sensors”.

Ice detectors are typically mounted on the nacelle of a turbine and monitored by the wind farm control system, trigger an automatic or remote manual shutdown of the wind farm control system in the event that icing conditions are detected. Given the flexing action of the blades experience suggests that the nacelle icing is more common than blade icing and hence such an approach is conservative.

In addition to ice detectors, the use of web cams, indirect signals such as power curve “plausibility”, ratio between heated and unheated anemometer readings, and audible performance of the blades have been proposed. While these alternative methods or combinations of these

methods may increase reliability and redundancy of ice detection systems, they largely remain at the early development stage for commercial use.

6 LITERATURE REVIEW OF ROTOR BLADE FAILURES

GH has undertaken a review of publicly-available literature on turbine failures, in particular turbine rotor failures resulting in full or partial blade throws.

6.1 Publicly available lists of wind turbine failure events

A recent report prepared by the California Wind Energy Collaborative (CWEC) in November 2006 [6.1] provides a brief literature review of turbine failures rates and provides recommendations for assessing the risk of full or partial blade throws.

Such events are very rare and hence data describing them are scarce. CWEC states that reporting on turbine failures is very limited providing very few publicly available accounts. The main types of blade failures are listed by CWEC as:

- Full blade failure at root connection,
- Partial blade failure from lightning damage, defect or extreme load buckling,
- Failure at outboard aerodynamic device, and
- Failure from tower strike.

Factors attributed to these failures are:

- Unforeseen environmental events outside the design envelope,
- Incorrect design for ultimate or fatigue loads,
- Poor manufacturing quality,
- Failure of turbine control/safety system, and
- Human error.

Most failures are actually reported to be a combination of the above factors and it is reported that the probabilities of some failure events are highly correlated with each other [6.1].

The main source listed in the CWEC report [6.1] is a Dutch Handbook [6.2] which compiles the information of two large databases of wind turbines in Denmark and Germany covering turbine operation from the 1980s until 2001. The authors of the handbook analyzed the data and recommended the following risk values for blade failure rates:

- Full blade failure at nominal rotor speed – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~1.25 times nominal rotor speed) – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~2.0 time nominal rotor speed) – 1 in 20,000 turbines per year
- Failure of tip or piece of blade – 1 in 4,000 turbines per year

Documented blade failures and distances were also reported in the handbook with the maximum distance reported for an entire blade as 150 m and for a blade fragment 500 m.

The handbook authors have compared these recommended blade failure rates to earlier ones developed by European agencies in the earlier 1990s, and state that the overall blade failure rate has declined by a factor of three. The authors of [6.2] have commented that “with the maturity of the industry blade failures will continue to decrease”.

The most recent list of publicly available wind turbine accident reports, last updated in February 2007, has been compiled by the Caithness Windfarms Information Forum (CWIF) [6.3]. The list states that from the 257 accidents listed since 2000, 74 were reported as blade failures.

6.2 General comments

GH considers that the failure rate values recommended by the Dutch Handbook [6.3] are particularly conservative in the context of current-day commercial wind turbines as the various root-causes of blade failure have been continuously addressed through developments in best practice in design, testing, manufacture and operation. Much of this development has been captured in the IEC standards series with which all current large wind turbines comply. Background on the turbine certification process is provided in Appendix 2. Use of the Handbook values for present day turbines can therefore be considered as inappropriate.

The reduction in blade failures referred to in the above reports coincides with the widespread introduction of turbine design certification and type approval. In addition to certifying compliance with standards, this process requires full scale strength testing of every certified design of turbine blade. In addition, it typically requires a dynamic test that simulates the complete life loading on the blade. The certification body will also perform a quality audit of the blade manufacturing facilities and perform strength testing of construction materials. This approach has effectively eliminated blade design as a root cause of failures.

The main causes of blade failure are now a human interference with a control system leading to an over-speed situation, a lightning strike or a manufacturing defect in the blade. The latter cause does not often lead to detachment of blade fragments.

Turbine control systems are the subject of rigorous specification in the design standards for wind turbines (IEC 61400-1) and exhaustive analysis in the certification process, hence most systems operate in a safe and reliable manner. Turbines with industry certification must have a safety system completely independent of the control system. The safety system must also have two mutually independent braking systems capable of bringing the rotor speed under control in the event of loss of reaction torque – which happens in the event of failure of the utility grid connection. Usually the blades pitch to remove the aerodynamic driving torque and provide a braking torque in its place, redundancy is usually provided through the provision of two separate pitching systems and some times it is provided in the form of a mechanical brake applied to the high speed shaft. In the event of a failure in one system, the other system must be able to control the rotor speed.

Anecdotal information now suggests that the most common cause of a control system failure is human error; where an operator makes an unauthorized adjustment. Many manufacturers have recognized this risk and are now limiting the adjustments that can be made in the field.

Lightning protection systems for wind turbines have developed significantly over the past decade and best practice has been captured in industry standards to which all modern turbines comply. This has led to a significant reduction in events where lightning causes structural damage.

The occurrence of structural manufacturing defects in rotor blades has also diminished significantly due to improved experience and quality control in the industry, centered on a small number of companies who make blade manufacture their main or sole business. Design practice has also evolved to improve structural margins against any manufacturing deficiencies. Even in the rare event of blade failure in modern machines, it is much more likely that the damaged structure will remain attached to the turbine than to separate.

It is considered that the above developments have substantially reduced the probabilities of blade failure from those represented in the Dutch Handbook [6.3]. This has been necessitated by the increasing trend of locating wind turbines in very close proximity to population – most notably in Northern Europe. GHC is not aware of any member of the public having been injured by a blade or blade fragment from a wind turbine.

REFERENCES

- 1.1 “Assessment of risks associated with ice throw and blade failures from utility-scale wind turbines in Ontario”, GHC proposal 86120/OP/01 Issue A, 5 May 2007 .
- 3.1 C Morgan et al, “Wind energy production in cold climate (WECO)”, ETSU contractor’s report W/11/00452/REP, UK DTI, 1999.
- 3.2 C Morgan and E Bossanyi, “Wind turbine icing and public safety - a quantifiable risk?”, Proceedings of Boreas III conference, Sariselka, Finland 1996.
- 3.3 E Bossanyi and C Morgan, “Wind turbine icing – its implications for public safety”, Proceedings of European Union Wind Energy Conference 1996.
- 3.4 C Morgan, E Bossanyi and H Seifert, “Assessment of safety risks arising from wind turbine icing”, Proceedings of EWEC ‘97 conference, Dublin 1997.
- 3.5 National weather service, http://www.srh.noaa.gov/jetstream/lightning/lightning_faq.htm
- 4.1 C Morgan, “Assessment of Ice Throw Risk for the Proposed Huron Wind Farm”, GH report 3174/BR/01 Issue A, 30 April 2002.
- 6.1 “Permitting Setback Requirements for Wind Turbines in California”, PIER Interim Project Report, November 2006.
- 6.2 H Braam et al., “Hanboek Risicozonering Windturbines”, 2nd Edition, January 2005.
- 6.3 Caithness Wind Farm Information Forum, <http://www.caithnesswindfarms.co.uk>

LIST OF TABLES

- 3.1 Wind turbine parameters.
- 4.1 Observations of icing at Tacke TW600 wind turbine.

LIST OF FIGURES

- 3.1 Ice throw risk assessment procedure
- 3.2 Calculated probability of ice fragment throw distances
- 3.3 Recorded ice throw data (from [3.4])
- 3.4 Recommended probability for ice fragment strikes in Ontario
- 3.5 Scenario A – Fixed dwelling
- 3.6 Scenario B – Road
- 3.7 Scenario C – Individual
- 3.8 Risk profile for Scenario B

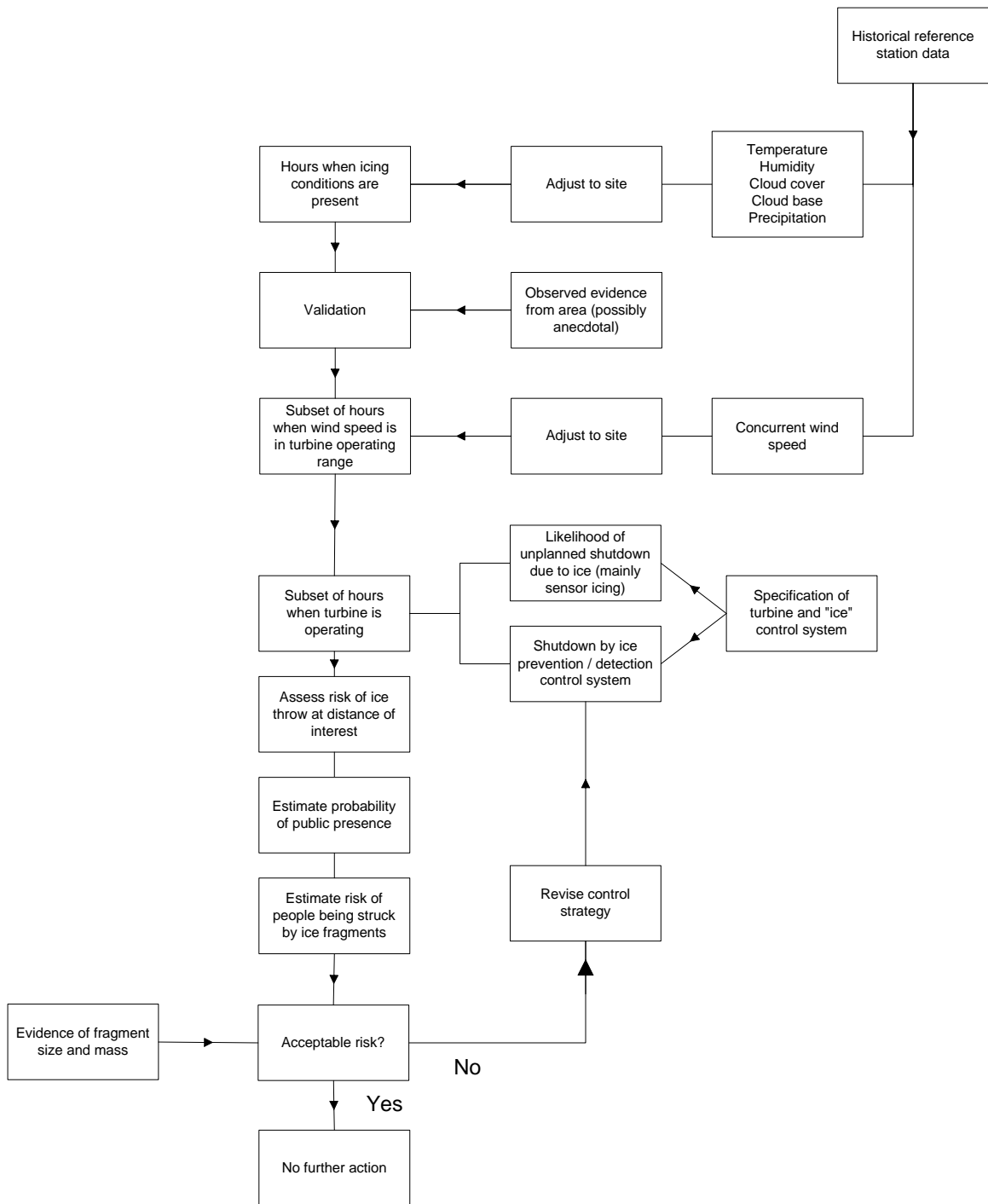


Figure 3.1 Ice throw risk assessment procedure

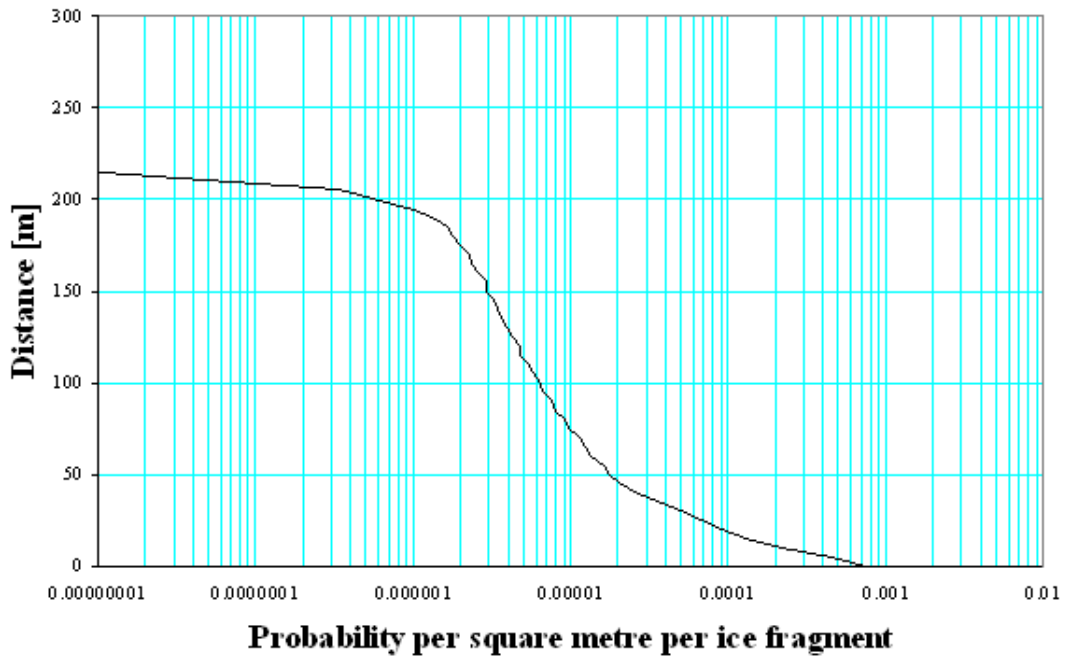


Figure 3.2 Calculated probability of ice fragment throw distances

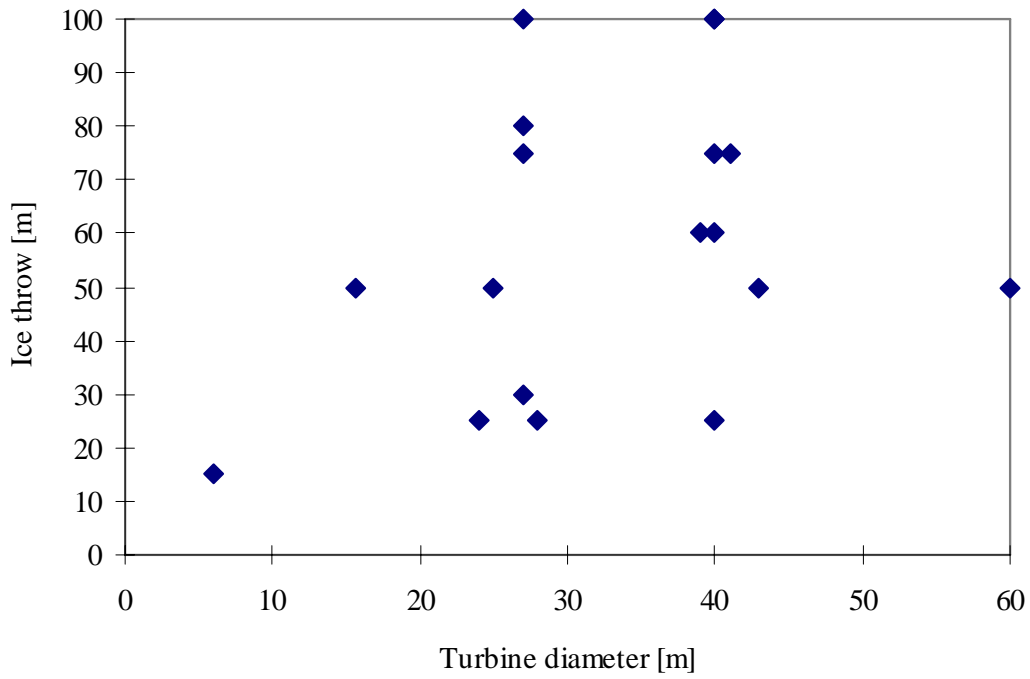


Figure 3.3 Recorded ice throw data (from [3.4])

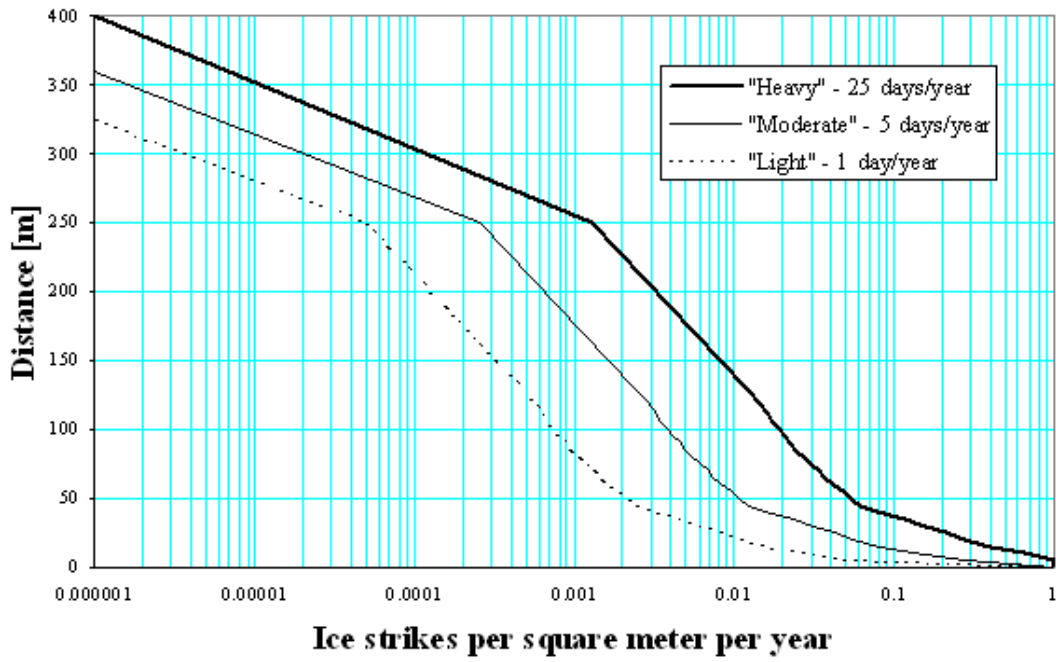


Figure 3.4 Recommended probability for ice fragment strikes in Ontario

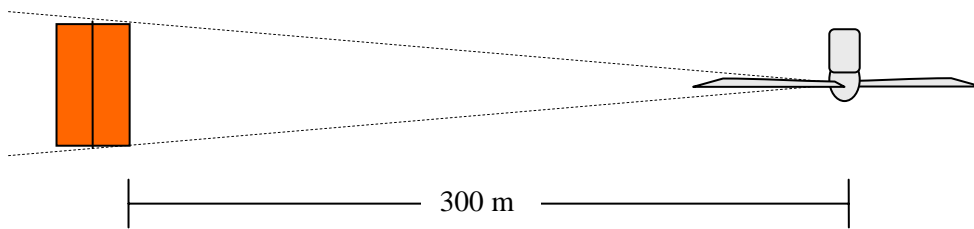


Figure 3.5 Scenario A – Fixed dwelling

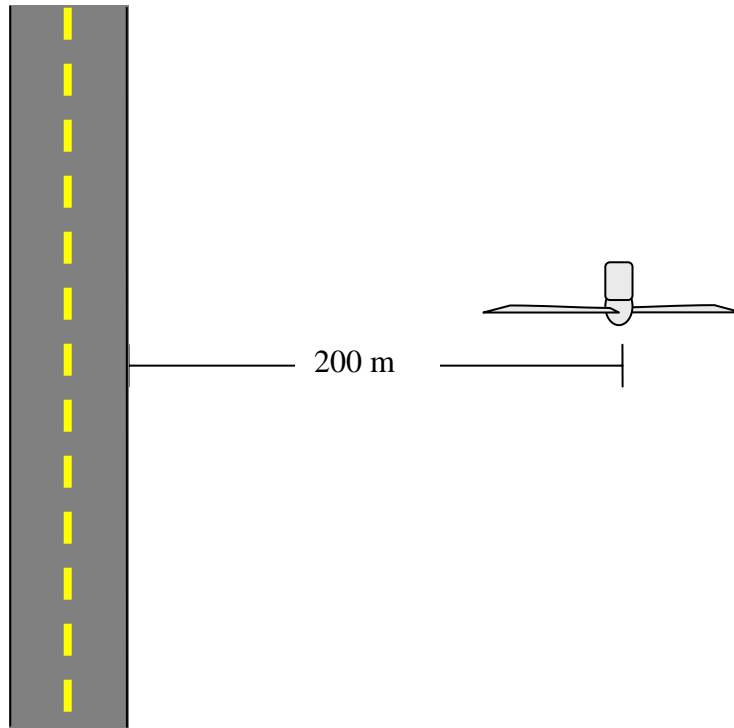


Figure 3.6 Scenario B – Road

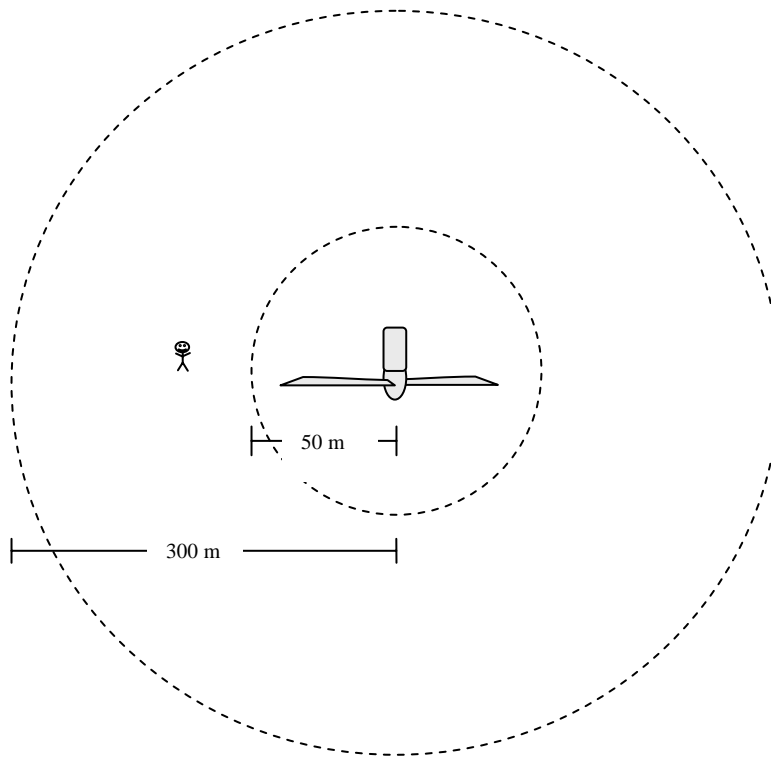


Figure 3.7 Scenario C – Individual

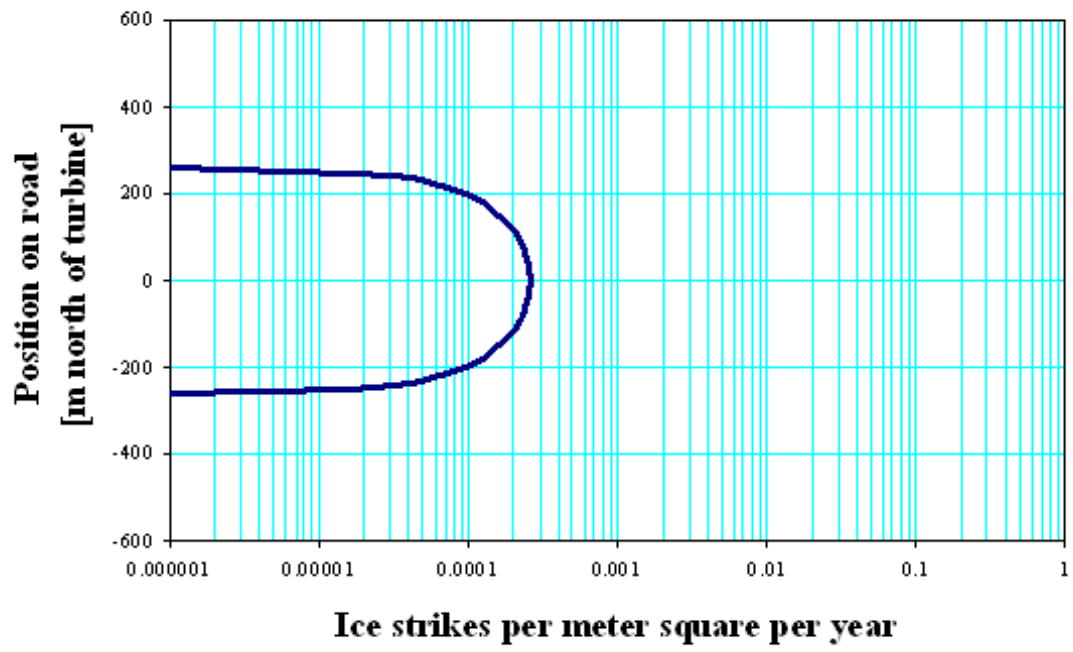


Figure 3.8 Risk profile for Scenario B

APPENDIX I

Wind farm operator survey

ONTARIO WIND TURBINE ICING EVENT SURVEY

GENERAL PROJECT INFORMATION

Date: _____

Site name: _____

Location: _____

Elevation: _____ (meters or feet above sea level)

Terrain: Lakeshore Flat Hilly Forested (tick all that apply)

Turbine type: _____ Cold weather package? Yes / No

Number of turbines: _____ Heated nacelle anemometers? Yes / No

Number of winter seasons: _____ Blade heating system? Yes / No

TYPICAL ICING EVENTS

Number of icing events per year: none 1 to 5 5 to 10 10 to 25 > 25

Typical duration of events: < 1 hour 1 to 5 hours 5 to 12 hours > 12 hours Unknown

Most frequent type of ice found: Glaze (clear) Rime (white) Other: _____

Condition(s) for typical icing events: Freezing Rain Fog Both Other: _____

Typical turbine reaction during icing: Shutdown Fault only No reaction Other: _____

MOST SIGNIFICANT ICING EVENT

Approximate date: Year: _____ Month: _____ Day: _____ Time: _____

Duration: < 1 hour 1 to 5 hours 5 to 12 hours > 12 hours Unknown

Type of ice found: Glaze (clear) Rime (white) Other: _____

Condition(s) for icing event: Freezing Rain Fog Both Other: _____

Turbine reaction during icing event: Shutdown Fault only No reaction Other: _____

ICE THROW

Have you witnessed ice thrown from a turbine? Yes / No

Have you ever found ice fragment(s) around a turbine? Yes / No

If YES to either question:

How far was the ice thrown? _____ (meters or feet)

Size of ice fragment: _____

Approximate weight: < 250 g 250g -1kg > 1kg Unknown

Additional comments: _____

APPENDIX II

Wind turbine certification process

The wind industry de facto standard calls for a turbine to be certified by a recognized certification agency. There are a couple of different types of certifications that are commonly referred to by manufacturers selling into North America:

- Statement of Compliance for Design Assessment of a turbine in compliance with an edition of IEC 61400-1 rules for safe design.
- Type certificate according to IEC WT01:2001

The “Type” certification scheme according to IEC WT01:2001 is divided into three modules. It is possible to obtain certification for each of these modules. The certificates are normally called Statements of Compliance and a Type certification includes a Statement of Compliance for Design Assessment.

The Design Assessment is a thorough review of the design documentation from the turbine manufacturer carried out by the selected certification agency. The design documentation must cover the whole turbine. When evaluating the certification of a turbine one should note the following:

- A Type certification is far more comprehensive than a Design Assessment and therefore Type certification is to be preferred.
- The certification body has to be accredited to perform certification in accordance with the standard used.
- In some cases there are a number of conditions to a given certification. It can more or less undermine the value of the certification.

The Statement of Compliance and associated verification report are issued after review of the machine design using specified components. In order to maintain a valid certificate the machines delivered to site must consist of an assembly of these components. The turbine supplier cannot vary these components and maintain certification. It is therefore important to check that the machines delivered are, indeed, consistent with the certificate and hence with the specification. It is also important to establish, and to check during the manufacturing process, that the turbines delivered are consistent with the certified specification.

This procedure has to be followed throughout the life of the machine. The providers of operation and maintenance service must either ensure that all components used for repair or enhancement are in accordance with the original certification or have the certification modified to reflect any alternative components.

The certification process also requires the inspection of the wind turbine on a periodic basis. This would be generally every two years but this may be extended in certain circumstances. Such inspections should include a detailed inspection of the blades.