Information Brief

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Large Wind Energy Turbines and Icing

Considering Ice Shed and Throw Arising from Utility Grade Wind Turbines

Key Findings:

The SSCRPC finds that under certain conditions and climates ice can form on wind turbine structures and blades. The potential is highest in areas with more severe cold weather than that found in central Illinois.

The nature of the risk comes from two events: *ice shed* and *ice throw.* The possibility of ice shed is most often a risk for those working in and around the base of the turbines, usually when it is stationary or idling.

Ice throw can extend beyond the base, but the distance at which throw occurs does not appear to be so great that it cannot be addressed though proper setbacks. Studies at wind farm sites and computations that modeled ice shed and throw risk indicate that they are not significant at current Sangamon County WECS ordinance setback distances.

In addition, there are realistic mitigation actions that can be taken by the wind farm operator to reduce the risk of ice shed and throw. These could be included in WECS safety plans.

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Utility-grade wind turbines are large outdoor structures that can be affected by the elements, including icing during inclement weather. As questions have been raised concerning the risk to public safety that might be caused by icing on wind turbines, the Springfield-Sangamon County Regional Planning Commission (SSCRPC) looked to the existing literature in an attempt to help the Sangamon County Board better assess this issue.

Considering the implications of wind turbine icing is important for a number of public policy reasons, not the least of which is to determine the degree to which 'setbacks' might eliminate or mitigate any risk to public safety. Setbacks generally refer to the space requirements established around structures or uses that prescribes the distance a structure or use must be from another. Often setbacks are designed to address matters of public health and safety; such as the side-yard setback requirements in residential zoning areas that are intended to address access to air and light as well as aid in fire safety.

The SSCRPC found that while the risk due to wind turbine icing is known, the literature is limited in three ways. First, not as much scholarly research exists related to icing compared to other issues associated with wind turbines (e.g., property values and sound). Second, much of this research relates to the modeling of anticipated risk, which may or may not duplicate real-world applications. Some evidence even exists that modeling may overstate the risk, particularly in less harsh climates. Third, the field research that has been done has tended to look at operations in much harsher climates than one finds in central Illinois. This leads us to believe that any hazards resulting from wind turbine icing would be less problematic in this area than is found in the climates most often studied or modeled.

Even with these limitations, the SSCRPC found the literature to be informative. The following pages discuss the issue.

The nature of wind turbine icing

As with many other structures, ice may form on wind turbines. The accumulation of ice on wind turbines and their structures is important to the wind energy industry itself since ice formation may affect efficient turbine operation (see for example, Durstwitz, et al., NDG), but it is also important to the general public in terms of any safety or property risks it might pose.

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", and like these other structures, this "accreted ice will eventually be released and fall to the ground" (LeBlanc, 2007, p. 2). However, wind turbines are not always stationary. When a wind turbine is operating, which will typically be when the wind speed at the wind turbine hub height is in the range of 4 m/s (13 ft/sec[1] or about 9 mi/hr) to 24 m/s (79 ft/sec or about 53.7 mi/hr), ice can still accumulate on the rotor blades in appropriate conditions of temperature and humidity, with accumulation occurring in relation to the speed at which the blades are turning and lessened by the flexing of the blades (LeBlanc, p. 2).

The Canadian National Centre for Environmental Health reports that two types of ice can form on the blades of wind turbines:

> Glaze ice is smooth, transparent, and highly adhesive; it forms when moisture contacts surfaces colder than 0°C (e.g., ice storms at low elevation). It normally falls straight down shortly after formation. Rime ice, which is granular and opaque, forms at colder temperatures and is less adhesive. It is sometimes thrown from moving turbines, but often breaks into smaller pieces. (Rideout, et al., 2010, p. 3)

The reader should note the distinctions concerning the forms of ice and their nature reported by the Centre in relationship to temperature. This is because the potential for ice to accumulate on a turbine and the nature of the ice depends upon the presence and degree of low temperatures, cloud cover, precipitation and heavy fog. In the presence of icing, and when the right conditions occur, ice and ice fragments can break loose from the structure and fall to the ground, or can be thrown from moving turbine blades. The fragments from the blades of an operating turbine are thrown off due to aerodynamic and centrifugal forces, or they fall down from the turbine when it is shut down or idling (Seifert, et al., 2003).

For the purpose of this SSCRPC *Information Brief*, we will term the situation in which ice falls off of the turbine when it is shut down or idling, *ice shed,* and the second, in which ice is thrown from moving turbine blades, *ice throw*. This is consistent with the literature reviewed. As noted by the Centre for Environmental Health (Rideout et al., p. 3), "Ice throw (i.e., ice projected off the turbine blade) presents a potentially severe public hazard since the ice may be launched far from the turbine. In contrast, ice that sheds or drops from stationary components places service personnel near the wind farm most at risk."

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[1] Most of the research cited throughout this *Information Brief* provided speed, distance, weight and length in metric measures in the original work. This SSCRPC *Information Brief* maintains these measures but to assist the reader provides conversions to English system measures in all cases. The reader should be aware, however, that the English system measures provided are approximate as they are rounded.

However, the critical questions for wind turbine regulation is not whether ice may form on wind turbine structures and fall or be thrown from it, but the risk that falling or thrown ice offers and whether regulatory approaches – such as setbacks – ameliorate this risk.

The nature of the risk

Assessing the likelihood of ice forming and being thrown from a turbine is not simple as it is dependent upon a number of variables, including: climate conditions, wind speed and the operational range of the turbine, direction of the blades in relation to people or structures, turbine dimensions, terrain, and such structural factors as anti-adhesive coatings and the color of the blades (dark colors are heat absorbing). In addition, for human injuries to occur several other conditions must exist simultaneously. These include a sustained weather condition conducive to icing, the ice dislodging from the turbine or turbine blade, the ice involving pieces large enough to remain intact through the air, these pieces traveling in a particular direction beyond setback lines, and someone being in its path when it lands (Canadian Wind Energy Association, 2007, as reported by Chatham-Kent Public Health Unit, 2008).

As reported above, ice shed primarily relates to the risk of ice forming on a stationary wind turbine structure. This involves ice forming and then falling or being blown as the ice thaws. As one might guess, ice dropping from the structure itself presents a risk for those immediately under the structure: wind farm employees and maintenance workers, for example. But there is the potential for ice forming on a stationary or idling turbine to be blown by the wind, although the ice particles shed in this way are likely to be small. As LeBlanc reports concerning ice accumulation on turbines, “[a]s this thaws, there will be some wind blow effect although that will be small on all but the lightest particles” (2007, p. 2). LeBlanc estimates that only very high winds would cause ice fragments of any significant mass to be blown beyond 50 m (164 ft) of the base of a stationary modern wind turbine.

As one might also guess, risks associated with ice throw from an operating turbine are greater than those from 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. (LeBlanc, 2007, p. 2)

So what is the degree of this risk to people and property? This has been considered in two ways: studies of actual ice shed and throw from turbines, and the mathematical modeling of wind turbine icing risk based upon accumulated data. While the SSCRPC found the literature limited, particularly for moderate climates like that in central Illinois, it was informative.

Ellenbogen, et al., (2012, p. AC-3) reports on a study by Seifert, et al., (2003) that showed the maximum distance that ice was observed to fall from a turbine with a rotor diameter of 20 m (66 ft) during operation was approximately 100 m (328 ft). Ellenbogen compares this to a calculation used to predict the maximum throwing distance of a piece of ice from a hypothetical turbine with a rotor radius of 20 m (66 ft) installed on a tower 50 m (164 ft) high, which found the maximum distance to be 135 m (443 ft). The difference was considered reasonable given the assumptions the calculation required. The Ellenbogen study concluded that, “[i]n general, it appears that ice is unlikely to land farther from the turbine than its maximum vertical extent (tower height plus the radius)” (p. AC-5). If the Ellenbogen conclusion is correct, this would imply that a turbine 500 ft in height, with a rotor radius of 66 ft, would have a maximum ice fragment area of about 566 ft, all things being equal. But unlike the Seifert study, the Ellenbogen calculation is based upon a hypothetical tower, so it is relevant to look to other real world studies of ice shed and throw.

In one study reported by Morgan, et al. (1997, also 1998), observations of ice build up, shed and throw were collected from wind farms throughout Europe. This research found that the fragments typically landed within 100 m (328 ft) of the turbine. Fragments of up to 1 kg (2.2 lbs) were found, although most were much smaller. There was a wide variance reported in the weight of fragments shed from the blades of the turbines studied – 0.1 kg (3.5 oz) to 1.0 kg (2.2 lbs) – and the distance from the base of the turbine where they were found – 15 m (49 ft) to 100 m (328 ft). To put this in some common context, five US quarters weigh about 1 oz. and a US gallon of whole milk weighs about 8.6 lbs, so the ice fragments found within about 328 ft of the turbine ranged from particles with a weight of about 17.5 quarters to a bit more than a quart of whole milk, with most tending toward the lesser weight.

A Canadian study (LeBlanc, 2007, p. 8) reviewed 1,000 inspections of a single wind turbine located in Ontario, Canada, conducted between 1995 and 2001. During this period some form of ice build-up was recorded on the turbine on 13 occasions, however in none of these events was ice thrown striking any property or person. On average, ice fragments were found mostly within 100m (328 ft) of the turbine, including the largest fragment (12x12x2 inches). On one occasion representing a major icing event, in which an estimated 1,000 pieces were found on the ground at the base of the turbine, the largest piece found was 5x2x2 inches. LeBlanc contends that the results of this study lend credence to a risk assessment he conducted for Garrad Hassan, Inc., for Ontario, Canada.

Based upon his modeling of the risk, LeBlanc provided (p. 6) the following estimations of risk due to ice throw in Ontario based upon the three scenarios modeled:

- For a fixed dwelling - Estimate that any ice throw event striking a dwelling will result in an individual being struck: 1 strike per 62,500 years.
- For a road - Estimate that an ice throw event will strike a vehicle at a minimum distance of 200 m (656 ft): 1 strike per 100,000 years.
- For an individual – Estimate that an ice throw event will strike a person within 300 m (984 ft) of a turbine – 1 strike per 500 years.

As LeBlanc notes in his report:

> 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 lightening. For example, the average annual per capita lightning strike rate in the United States is approximately 1 in 600,000. (LeBlanc, 2007, p. 5)[2]

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[2] The SSCRPC attempted to validate this result through a review of wind farm accident/fatality data. Unfortunately we did not find any authoritative source to exist. One individual (Paul Gipe, Wind-Works.org) attempts to collect such data on an informal basis, but the data he maintains is significantly limited in scope, appears to not rely on primary sources, and includes fatalities for all sizes of wind turbines. For the period of 1975 to 2006, he reports 32 wind farm related fatalities world-wide. Only one he reports as being associated with icing. In this 1994 case a worker was killed by ice knocked off of the *interior* of a tubular tower in Minnesota.

LeBlanc estimated the probability per square meter per ice fragment beyond 200 m (656 ft) at 0.00000001, and within 50 m (64 ft) at about 0.00001 (see LeBlanc figure 3.2). So the risk of getting struck by an ice fragment, though small, would significantly increase as one gets closer to the turbine. That leads us to believe that ice shed and throw risk can be significantly reduced through setbacks of some reasonable distance.

One of the difficulties of the LeBlanc work is that his assessment is based upon the risk potential of a single turbine. This was reasonable for the purpose of the study – to provide some general insight for a province – but does not address how risk might increase or decrease in multi-turbine situations. A similar analysis done by GL Garrad Hassan (Boucetta & Heraud, 2010) for a proposed wind farm site (the Kingdom Community Wind Power Project southwest of Orleans, Vermont) helps to fill this void.

Unlike the LeBlanc assessment, this analysis looked at a specific multi-turbine project to calculate the risk of ice throw prior to development. Using a methodology similar to that used by LeBlanc and data recorded from sensors mounted on a meteorological tower, the analysis found that the typical range of ice throw from the turbines would be approximately 150 m (494 ft), and the typical range (within 90% of time) of ice drop – shed – approximately 45 m (148 ft). The results of the ice drop case analysis indicated that the risk of a fragment dropping and landing in a square meter away from any turbine structure drops sharply beyond 60 m (197 ft) (p. 11). This would seem to confirm LeBlanc's distance findings related to the probability per square meter per ice fragment.

The authors conclude:

> ...that only very high winds in a specific direction may cause fragments of any significant mass to be blown beyond 60 m of the turbine base with a probability of fragment strike per square meter of approximately once in 65,000 years. Assuming 25 days of icing per year, this amounts to an individual risk for a stationary person present for all icing events located 60 m of the turbine base of once in 10 years. (Boucetta & Heraud, 2010, p. 17)

Of course, sites in climates that experience fewer than 25 icing days per year would be expected to present a lower risk factor on some declining scale than that offered in the case above.

The distances suggested by the modeling appear to be supported by other real-world studies, such as that previously reported by Morgan, et al., (1998), noted above. The researchers write:

> In addition to this objective information, anecdotal evidence suggests that the tendency is for ice fragments to be dropped off, rather than thrown off, the rotor. Also, it tends to be shed off the tips in preference to other parts of the blade and large pieces of debris tend to fragment in flight. There is significant evidence that rime ice continues to form when the turbine is operating and is not shaken off by blade flexing, even though this may be the case for other types of ice formation. Also, rime ice formation appears to occur with remarkable symmetry on all turbine blades with the result that no imbalance occurs and the turbine continues to operate. (Morgan, et al., p. 117)

When research is limited it is often useful to look to cases where the event would most likely occur. In terms of wind turbine icing and the risk of ice shed and throw, one might assume that the degree of shed and throw in central Illinois would be less than one would find in a location or locations where turbine icing is much more likely. In this regard a study (Cattin, et al., 2008) conducted at a test site in Switzerland may be particularly meaningful, as this test site was subject to much more severe weather and the conditions that lead to icing (both glaze and rime) than one finds in central Illinois.

The site that was the subject of the study is located on a ridge in the Swiss Alps at an elevation of 2,300 m (7,546 ft, or about 1.4 mi). Wind speeds at the site can reach 120 km/h (75 m/h) and above, and the long term monthly air temperature varies from -6.9°C (19.6° F) in February to 7.3°C (45° F) in July, dropping to below 0°C (32° F) from November through April. Midwinter temperatures can fall below -20°C (-4° F) and icing can occur throughout the year.

During the study periods (the winters of 2005-06 and 2006-07) the researchers found 121 ice fragments with a maximum length of more than 100 cm (39 in) and a maximum weight of up to 1800 g (4 lbs) at distances up to 92 m (302 ft) from the wind turbine. Almost 40% of the ice fragments were found within 20 m (66 ft, or the length of a rotor blade) of the turbine, with about 6% found between 80 m (263 ft) and 92 m (302 ft). Almost 50% of the fragments weighed 50 g (1.76 oz) or less, with less than 5% having a weight of more than 500 g (1.1 lbs).

The study concluded that: most ice throw occurred underneath the blades of the turbine; the distance ice was thrown was less than the empirical models predicted; most of the fragments were rather small in weight, though they did find some fragments as large as 1.8kg (4 lbs); and there was no relationship between the weight of the ice fragment and throwing distance, yet the throwing distance was dependent of wind speed when ice fell from the blade. This indicates to us that the speed of the wind at the moment of throw has an effect beyond that of the aerodynamic and centrifugal forces arising from the movement of the blade itself; that is, the fragment may be ‘blown’ as well as ‘thrown’ under the right conditions. This appears to be consistent with their finding that the distance the ice was thrown was less than predicted by mathematical modeling and that few of the pieces were found at the longer distances from the tower.

The SSCRPC believes that this particular case is especially revealing. In a harsher winter climate than we find in central Illinois, the ice loss from the turbine due to throw and shed did not exceed about 302 feet, including the largest and heaviest fragments. Only 6% of the fragments were found at the furthest distances from the turbine (between about 263 ft and 302 ft), and since 40% were found within about 66 feet of the structure, one can assume that the remaining 54% fell between 67 feet and 263 feet of the structure. Our supposition is that the 40% of the fragments that fell within 66 feet were the result of ice shed, while those beyond this distance resulted from either wind blown ice shed (based upon other research noted above, most likely smaller fragments) or wind assisted ice throw. In any event, in this severe weather case, where cold temperatures, many icing days, and high winds are often present, ice throw only slightly exceeded 300 feet.

Options for mitigation

The reduction or mitigation of the risk of ice shed and throw can be accomplished in several ways. The first is inherent to the design and operation of the wind turbines themselves. This market-driven improvement should not be discounted as it accrues from direct interests of the wind turbine operator on both the short and long-term.

As Durstewitz, et al., write:

> The effects of cold climate to wind turbines are quite similar and not site specific. This means that components of the turbine e.g. rotor blades, wind sensors, nacelle etc. collect particles like freezing rain, rime or snow which might adhere to the surface of the wind turbine. This often results in reduced aerodynamic performance, faulty readings of wind gauges, which again might cause wrong yaw angles and further reduction of aerodynamic properties. Finally, the wind turbine will operate with significantly reduced efficiency or it will stop completely. (p. 2)

They go on to write:

> Cold climate and low temperature issues have to be seen from different viewpoints. From a designers point of view turbines enduring ambient temperatures down to -20° C and ice loads up to 30 mm has to be considered "normal" for a standard wind turbine design. From an operators point of view these "normal" influences might not be acceptable in terms of a profitable business. (p. 6)

The first implication of this is that the industry has a financial interest in improving turbine technology, at least in harsh climates where icing is more likely to occur making such improvements cost effective. These design improvements should decrease both ice shed and throw. Unfortunately it is not likely that such improvements will be of benefit to central Illinois in the near term as it takes time from technological innovations to be adopted in the market place and we do not believe that central Illinois has the harsh climate necessary to make some of the contemplated improvements (such as blade heating) cost effective.

The second implication may be more important locally: there are disincentives for the operator to run turbines in icing conditions as the machines are less efficient in these situations absent improvements in the technology. We believe that this reduction in efficiency under significant icing conditions would likely lead to the turbines being shut down. This could potentially lead to ice shed occurring near the structure at turbine start-up, but reduce periods of ice throw overall.

The second way of reducing the risk of ice shed and throw is through the use of setbacks. As the research appears to indicate, ice shed most often occurs immediately below the turbine and is primarily a risk to maintenance workers, particularly when the turbine is at rest and not rotating (AMEC Earth and Environmental, 2008). The risk to those who must work in and around turbines during icing periods could be addressed by safety protocols and other procedures established by the operator and encompassed in a facility safety plan. We will mention aspects of this again below.

Setbacks can also be used to reduce the risk of ice throw and wind blown ice shed to those not working in close proximity to a turbine. Currently the Sangamon County Wind Energy Conversion Systems (WECS) ordinance establishes the following setbacks for utility grade wind turbines:

- 1,200 feet from the project perimeter;
- 1,000 feet or three times the rotor diameter, whichever is greater, from a principal structure;
- 1.1 times the system height from third-party utility lines;
- 1.1 times the system height from a public road.

The actual setbacks from places where people live, work or congregate may effectively be larger depending upon how other conditions required by the ordinance are met.

None of the research found by the SSCRPC and reported above would indicate a public safety risk arising from ice shed or throw within these ranges, as the largest throw distance found was about 494 feet (150 m). In the modeling reported by LeBlanc, risk beyond 656 feet (200 m) was judged to be quite low. To the extent that distances are at issue, the setback distances for utility lines and public roads are closer to the shed and throw limits reported. Assuming a turbine tower height of 500 ft, for example, the setback would be 550 feet from both utility lines and roads. But even this distance is greater than the shed and throw distances reported in the literature reviewed. While setback distances could be increased for any number of reasons, it appears that there is a diminishing return on increasing the distance for the purpose of decreasing ice shed and throw risks.

While setback distance is often seen as a way to mitigate safety risks associated with icing, wind farm operators have mitigation methods they can use as well. For example they may employ automated or remote manual shut down of the turbines during periods of icing, and remote monitoring and shutdown is now standard in the industry. It is also accepted in the industry that ice build up on the blades of an operating turbine leads to additional vibration, and all commercial turbines include vibration monitors that shut down the turbine when vibrations exceed a preset level (LeBlanc, 2007, p.2; see also, Ellenbogen, et al., 2012).

LeBlanc suggested the following mitigation strategies that can be implemented by the wind farm operator (p. 9):

- Curtailing operations 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 the risk.
- Establishing protocols and procedures that make operational staff 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.
- Using automated ice detection systems.

A report done by the Chatham-Kent Public Health Unit (2008, p. 10) further recommends mandatory icing training for all construction and maintenance workers, signage of the potential for icing, and that tourist information kiosks should be set far enough away from turbines to reduce risk.

Conclusion

After reviewing the literature on wind turbine icing, the SSCRPC finds that under certain conditions and climates ice can form on wind turbine structures and blades. The potential is highest in areas with more severe cold weather than that found in central Illinois, such as that found in northern climes or in mountain ranges. However these areas are often remote from people.

The nature of the risk from turbine icing comes from two events: ice shed and ice throw. The possibility of ice shed is most often a risk for those working in and around the base of the turbines, particularly while the turbine is stationary or idling, and immediately after start-up.

Ice throw can extend well beyond the base of the turbine, but it appears that the size, weight and amount of the ice shed or thrown significantly diminish with distance from the turbine. The distances at which throw occurs do not appear to be so great that they cannot be addressed though proper setbacks, and are well within the setback ranges established in the current Sangamon County WECS ordinance.

We also conclude that the problem of ice throw may be mitigated by the equipment itself, in that severe ice buildup will lead to automatic turbine shutdown. This may become part of a required wind farm safety plan, as we found there to be realistic mitigation actions that can be taken by the wind farm operator to reduce the risk of shed and throw that could be included in such a plan.

This report prepared by E. Norman Sims, SSCRPC, Executive Director

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The Springfield-Sangamon County Regional Planning Commission (SCRPC) serves as the joint planning body for Sangamon County and the City of Springfield, as well as the Metropolitan Planning Organization for transportation planning in the region.

The Commission has 17 members including representatives from the Sangamon County Board, Springfield City Council, special units of government, and six appointed citizens from the city and county. The Executive Director is appointed by the Executive Board of the Commission and confirmed by the Sangamon County Board.

The Commission works with other public and semi-public agencies throughout the area to promote orderly growth and redevelopment, and assists other Sangamon County communities with their planning needs. Through its professional staff, the SSCRPC provides overall planning services related to land use, housing, recreation, transportation, economics, environment, and special projects. Its Executive Director also oversees the Sangamon County Department of Zoning which oversees the zoning code and liquor licensing for the County.

The Commission prepares area-wide planning documents and assists the County, cities, and villages, as well as special districts, with planning activities. The staff reviews all proposed subdivisions and makes recommendations on all Springfield and Sangamon County zoning and variance requests. The agency serves as the county's Plat Officer, Floodplain Administrator, and local A-95 review clearinghouse to process and review all federally funded applications for the county.

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