association to protect
AMHERST ISLAND

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Submission to the MOECC Technical Review Team Concerning Ice Throw from the Amherst Island Windlectric Wind Energy Development.

Introduction

The MOECC has no regulation for ice throw by industrial-scale wind turbines. Nevertheless, ice throw, like shadow-flicker, is a recognized hazard associated with wind turbine operation.

As island residents and stake-holders in the Windlectric proposal, we have been lulled into complacency by the assurance that icing monitors will detect ice on the blades and that the turbines will be shut down. No longer can we be so sure!

A very recent article[1] in *Wind Energy Update*, a wind industry publication, has drawn attention to the very real safety concerns with ice throw. This article has stimulated this submission to the Technical Review Team reviewing the Windlectric REA documents.

Our conclusion is that ice throw from the proposed Siemens 2.3-113 turbines can reach out to 300 metres and that ice fragments will land with a speed of 100 to 200 km/h. The proposed turbines S08, S13, S18, S26, S30 and S37 are within 300 metres of a travelled road and therefore present a winter ice-throw hazard. Furthermore, there are 27 turbines proposed to be located within 300 metres of non-participating residents lot lines; this infringes on the freedom of these residents to fully enjoy their property during the winter season.

Reality of Ice Monitoring and Control

We can do no better than quote from the Wind Energy Update article:

"If you want to get an idea of the negative impact of ice build-up on turbines then just head to YouTube. What is worrying is not just that amateur video makers have captured ice throw situations that the industry says should not happen, but also that these images are being used to convince the public that cold-climate wind farms could be dangerous. Worst of all, that might be true.

"A lot of research work and development is underway in this context," says Andreas Krenn, a project manager at the Austrian renewable energy consulting engineering firm Energiewerkstatt.

"But most ice detection sensors still do not work very reliably."

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[1] Jason Deign, "Cold-Climate Operations: Why OEMs Must Avoid Icy Situations", Wind Energy Update, August 7th, 2014 (see attached).

Furthermore, he adds, the systems that original equipment manufacturers (OEMs) have developed to get rid of ice have yet to be rigorously tested by independent bodies out in the field."

Additionally, to quote from General Electric[2]:

"rotating turbine blades may propel ice fragments some distance from the turbine - up to several hundred meters if conditions are right", and

"ice detection is not highly reliable"

Modelling Ice Throw

Two years or so ago, on behalf of APAI, an ice-throw model was developed. It is realistic, in contrast to models used by consultants to the wind industry, as outlined in the attached model description. The model was tested against measured ice throw from two turbines and proved itself. The result of applying the model to the Siemens 2.3-113 turbine is that under icing conditions there needs to be an exclusion zone of 300 metres. This agrees with the General Electric remark noted above. Furthermore, with a realistic 5 mm covering of ice, the mass of ice on the blades of one turbine will be 2000 kg or over 2000 one-kilogram ice fragments.

Conclusion for the Windlectric Project

Just as with turbine noise and shadow flicker, ice-throw is a threat to the health and safety of island residents and visitors. Ice throw from the 156 metre high Siemens 2.3-113 turbines can be out to 300 metres from the base. There are no homes within 300 metres of a turbine. However, there are 6 turbines planned to be within 300 metres of travelled roadway (S08, S13, S18, S26, S30 and S37). These are a potential hazard in the winter season. Shut-down of these turbines should not depend upon icing sensors. In addition, there are 27 turbines within 300 metres of a non-participating neighbour's lot line. No resident should have access to his or her own land limited because of the hazard of ice throw. And of course, the school playground is within 550 metres of turbine S06!

Ice throw is another example of why the Windlectric project, with its high turbine density and proximity of so many turbines to homes, is wrong for Amherst Island. The winter threat of ice-throw is yet one more reason why this project should never have been proposed, never given a contract by the Ontario Power Authority and should never be approved by the Ministry of the Environment and Climate Change.

[2] http://site.ge-energy.com/prod_serv/products/tech_docs/en/downloads/ger4262.pdf

Wind Energy Update – August 2014

Cold-climate operations: why OEMs must avoid icey situations

Aug 7, 2014

Despite growing awareness of the potential for wind power projects in cold climates, turbine manufacturers have yet to deal convincingly with the threat of ice throws.

By Jason Deign

If you want to get an idea of the negative impact of ice build-up on turbines then just head to YouTube. What is worrying is not just that amateur video makers have captured ice throw situations that the industry says should not happen, but also that these images are being used to convince the public that cold-climate wind farms could be dangerous. Worst of all, that might be true.

"A lot of research work and development is underway in this context," says Andreas Krenn, a project manager at the Austrian renewable energy consulting engineering firm Energiewerkstatt.

"But most ice detection sensors still do not work very reliably."

Furthermore, he adds, the systems that original equipment manufacturers (OEMs) have developed to get rid of ice have yet to be rigorously tested by independent bodies out in the field.

Only Enercon, the German turbine maker, seems to have so far taken the icing challenge seriously, with a de-icing system based on circulating hot air inside rotor blades.

However, "even for the Enercon turbine there are just a few examples where results are available," Krenn says. In particular, Enercon turbines' ability to withstand very extreme conditions is largely untested.

De-icing systems

Other EOMs, such as Vestas Wind Systems of Denmark, have introduced de-icing systems, but Krenn points out that their efficacy has yet to be fully verified. So if you buy the turbine, you may be paying extra for a system that does not work as well as you hope.

The problem, Krenn says, is that until recently many turbine manufacturers, with the notable exception of Enercon, have been focusing on technologies for the offshore market.

But addressing cold climate issues is increasingly a priority as demand for wind power in the far northern hemisphere grows.

According to a study by the International Energy Agency's Wind Task 19 group for wind energy in cold climates, by 2017 between 45GW and 50GW of capacity could be installed in areas of low temperature or light to heavy icing.

The distinction between temperature and icing is important because each has different effects on wind turbine operations. Extreme low temperatures can cause stress to some turbine components, and lead to freezing of fluids.

But such effects are relatively easy to deal with on a technical basis. And there are few places in the world, except perhaps regions such as Mongolia, characterised by very low temperatures and dry weather.

Safety risk

Icing, on the other hand, is a much greater concern for wind farm operators, first and foremost because of the safety risk posed by ice throws.

Since this hazard is widely recognised by the authorities, in many cold-weather markets wind farm operators are obliged to shut down turbines as soon as ice is detected on the blades.

This can significantly reduce wind farm profitability: some cold-climate markets can typically experience icy conditions up to 60 days a year. What can project owners do? As with much in the wind industry, it largely depends on the exact nature of the project.

Given that de-icing systems command a premium, in places where the risk of icing is slight then the operator may decide it is cheaper to buy a standard turbine design and write off a percentage of output by curtailing operations whenever ice appears.

Under more severe environments, though, it might pay to invest in Enercon machines and rely on their limited de-icing track record to boost output. Fortunately, however, it is likely only a matter of time before more options appear.

Given a surge in interest in cold-climate market opportunities, OEMs have been paying increasing attention to icing problems since 2010. Many now have de-icing systems on offer, and the availability of improved data can only be a matter of time.

Distributed wind

Meanwhile, some of the turbine makers looking to deal with ice might want to talk to their brethren in the distributed wind energy business. Urban Green Energy (UGE) of New York, USA, has plenty of experience of operating small turbines in freezing conditions, for example.

"UGE has deployed renewable energy solutions in a diverse range of arctic and polar regions including Scandinavia, Alaska, Northern Canada and even Antarctica," says Robin Carol, the company's communications and culture manager.

"Our standard vertical-axis wind turbines will perform at optimum efficiency at temperatures above -25ºC. However, UGE frequently works with customers in very cold climates to solve their specific energy challenges."

In these cases, Carol says, UGE creates custom solutions designed to perform in even more extreme temperatures. "Our turbines have also undergone testing to ensure their performance and durability."

UGE's wind turbines have no stationary horizontal surfaces on which ice can build up, so there is no chance of icing or ice throw. "None of UGE's wind installations in extreme environments have had any issues with ice build up," Carol comments. Large OEMs might want to take note.

Report on Potential Ice Throw by Siemens 2.3-113 Wind Turbines

John Harrison, Research Director, Association to Protect Amherst Island

Summary

A realistic model for ice throw from an operating wind turbine is introduced. The model assumes that the thrown ice is in the form of a thin sheet. It is assumed that, in flight, the ice sheet will align with the velocity with which the sheet is moving through the air. Although modern turbines have protocols for shutting down in icing conditions, the model assumes that the turbine is in fact operating. This is a worst case scenario and is deemed the best approach for safety. The model was tested against measured ice throw from a turbine and found to be satisfactory. The model is applied to the Siemens 2.3-113 turbine proposed for use on Amherst Island. The ice throw is evaluated for a number of drag coefficients, wind speeds and ice sheet thicknesses. The conclusion is that a conservative safe setback from homes, buildings, lot lines and roads is 300 metres.

Introduction

This report models ice throw from turbine blades with specific application to the Siemens 2.3-113 turbine proposed for Amherst Island. This has a hub height of 99.5 m and a blade length of 56.5 m. The blade rotation frequency is 13 rpm.

It is common for consultants for wind energy companies to predict ice throw by assuming cube or similar geometry for the thrown ice, a mass of about 1 kg and a drag coefficient $C_D = 1$. This is not the reality. Ice forms on blades as a thin layer and will come away in the form of thin sheets. It is also common to assume that the protocol for detecting freezing rain and other icing conditions and shutting down the turbines will work. The precautionary principle suggests otherwise. I have also seen a report which claimed that the conservative high for the number of 1 kg ice fragments is 110 to 120, this for a modern turbine with a 113 metre blade diameter and a 128 metre hub height. Finally, reports neglect the wind speed gradient.

This report presents a realistic model for ice throw. At this stage only results for the maximum ice throw for a variety of inputs are given. It is trivial to extend the model to determine a statistical presentation of number of fragments as a function of distance and direction, provided the wind rose for the icing season is known.

Ice Throw Model

Ice throw from a wind turbine is a potential hazard whether the turbine is operating or locked. There are on average 11 days of freezing rain every winter in the Kingston area. There are protocols for locking turbines in icing conditions but these protocols may not be fail-safe.

Therefore the siting of turbines should be done on the basis that they do operate in icing conditions.

Having lived in Eastern Ontario for 40 plus years and through many ice storms it is well known to me that ice forms in a layer rarely beyond 1 cm in thickness. For simplicity, the ice fragment will be taken as a sheet. For such a shape, the drag is defined by a drag coefficient of about 0.1 and operates over the planiform area. For ease of calculation the sheet will be rectangular with a uniform thickness. However, there will be non-uniformity for any real ice sheet and this will ensure that the centre of drag is always behind the centre of mass and that the drag force is directed in the opposite direction to the velocity of the sheet relative to that of the air (or wind). Think of a dart! Very quickly the plane of the ice sheet will be parallel to the relative velocity. Note that this is an assumption in this model.

Although the shape of the sheet will have been formed by a blade with an aerodynamic cross-section, the sheet itself will not have an aerodynamic cross-section. That is, the lift coefficient can be ignored.

It is well known that the wind speed varies with height. If the atmosphere is unstable, the wind speed gradient is small. If stable, the gradient is larger. It is usual to express the wind speed gradient in terms of an exponent α as follows:

$$v(z) = v_{10}(z/10)^{\alpha}$$

where 10 metres is the reference height. For North America, the average value of α is 0.25 but the night-time average is 0.35 corresponding to a stable atmosphere (see appendix A). It is usual for a wind energy developer to measure the variation of α over a period of time as part of the approval process.

For the following, the calculation is performed for ice throw from the blade tip at its highest point. It is trivial to extend the calculation to throw from other blade positions and positions along the blade.

In symbols, the ice sheet has width w, length l and thickness d. The drag force is therefore:

$$F = \tfrac{1}{2}\rho v^2 w l C_D = \tfrac{1}{2} k v^2$$

where $\rho = 1.225\ \text{kg/m}^3$ is the density of air.

A Cartesian co-ordinate system is used, with z the vertical axis, y the wind direction and x the blade tip velocity direction. Therefore,

(0, 0, h) is the initial position of the ice sheet;

$(v_{x0}, 0, 0)$ is the initial velocity of the ice sheet;

$(0, v_{w10}, 0)$ is the wind velocity at a height of 10 metres.

$(0, v_{wz}, 0)$ is the wind speed at height z

At a height z, the wind speed is given by $v_{wz} = v_{w10} (z/10)^{\alpha}$. α averages to about 0.25 but can be in the range from 0.1 to greater than 0.5, depending upon meteorological conditions.

$(F_{x0}, F_{y0}, -mg)$ is the initial force on the ice sheet, where $F_{xo}= -(v_{x0}/v_0)F_0$,

$F_{y0} = (v_{wh}/v_0)F_0$, $F_0 = kv^2$, $v^2 = v_{x0}^2 + v_{wh}^2$, and mg is the weight.

At a later time t,

(x, y, z) is the position,

(v_x, v_y, v_z) is the velocity and

(a_x, a_y, a_z) is the acceleration of the ice sheet;

$(F_x, F_y, F_z - mg)$ is the force acting on the ice sheet, where

$F_x = -(v_x/v)F$; $F_y = -((v_y – v_{wz})/v)F$; $F_z = -(v_z/v)F$; $F = kv^2$; and $v = v_x^2 + (v_y – v_{wz})^2 + v_z^2$.

Then, $a_x = F_x/m$, $a_y = F_y/m$, and $a_y = (F_z – mg)/m$, where m is the mass of the ice-sheet.

The calculation proceeds in increments of time Δt. At each step, the force is calculated from the relative velocity at the previous step, then the acceleration from the force, and hence the new velocity. From the previous velocity, the new position is calculated. That is:

$v_x(t + \Delta t) = v_x(t) + a_x\Delta t$ etc. and $x(t + \Delta t) = x(t) + v_x\Delta t$ etc.

Result for the Siemens 2.3-113 Turbine

Consider the Siemens 2.3-113 turbine, (blade rotation of 13 rpm, blade diameter of 113 m, blade tip height h = 156 m), a drag coefficient $C_D = 0.1$, a 10 metre wind speed = 20 m/s, a wind speed parameter α = 0.2, and ice sheet dimensions of 0.4 x 0.4 x 0.01 m^3. Therefore, m = 1.44 kg, v_{x0} = 77 m/s and k = 0.0098.

The result of the calculation is that when the ice reaches the ground, (z = 0), then

x = 197 m and y = 137 m. That is the ice throw is R = 240 m, where $R^2 = x^2 + y^2$. The speed at which the ice sheet lands is 39 m/s (140 km/h).

The results for a further selection of the drag coefficient, ice sheet thickness, parameter α and 10 metre wind speed are shown in the figures below.

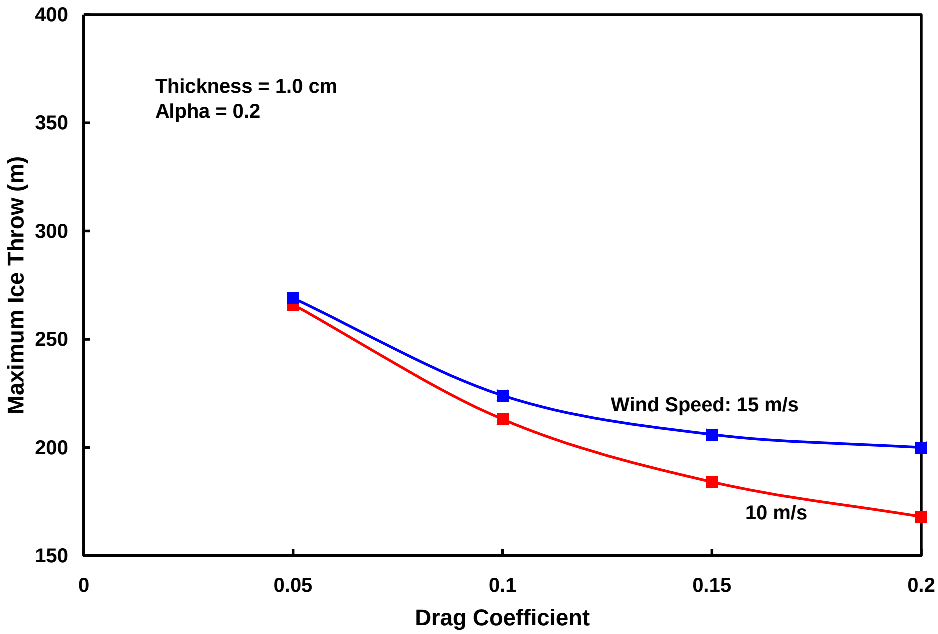

Figure 1: Maximum ice throw as a function of drag coefficient, for α = 0.2, typical for daytime, and ice thickness 1.0 cm. The wind speeds are at a height of 10 metres. For reference, 10 m/s = 36 km/hr.

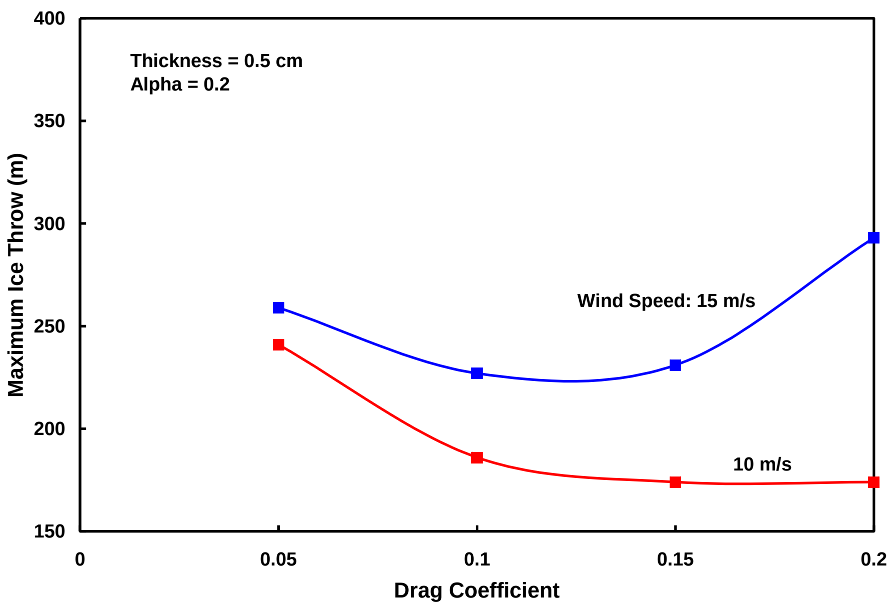

Figure 2: Maximum ice throw as a function of drag coefficient, for α = 0.2 and ice thickness = 0.5 cm.

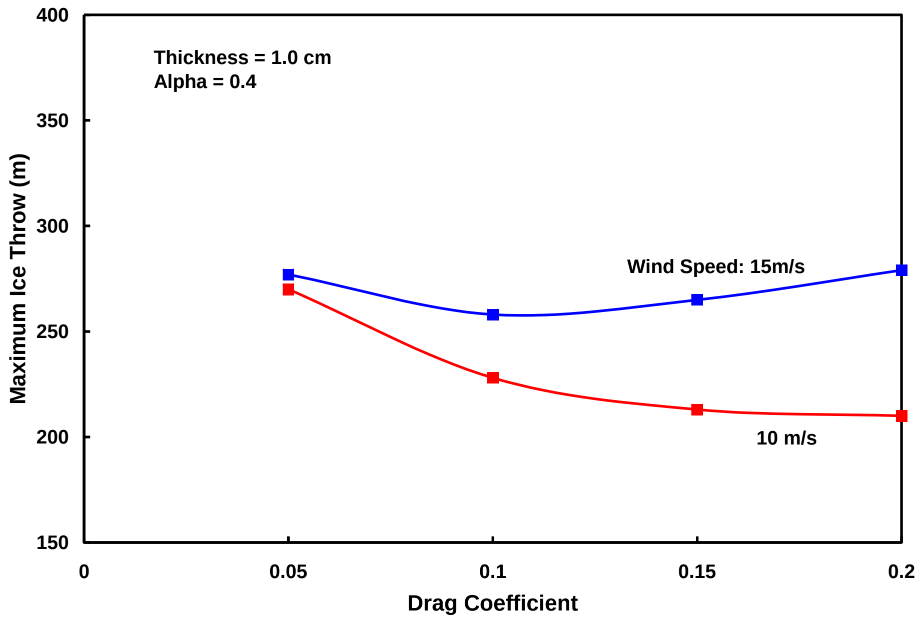

Figure 3: Maximum ice throw as a function of drag coefficient, for α = 0.4, typical for night-time, and ice thickness 1.0 cm.

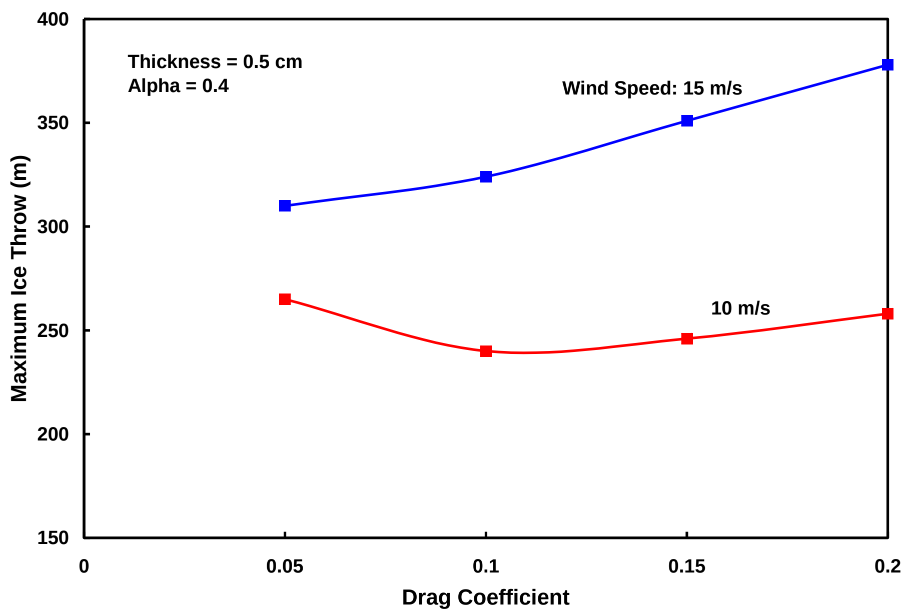

Figure 4: Maximum ice throw as a function of drag coefficient, for α = 0.4 and ice thickness 0.5 cm.

As a conservative precaution it can be seen that a minimum setback from buildings, houses, lot lines and roads needs to be 300 metres.

Test of the Model

In order to test the ice throw model, a comparison has been made with the measurements of Cattin et al.[3] for a 600 kW Enercon E-40 turbine installed on Gütsch Mountain in Switzerland. The hub height was 50 m and the blade length 20 m. The maximum recorded ice throw was 92 metres at an estimated wind speed of 12 m/s.

In the above model the wind speed gradient was assumed to be below average because of the mountainous terrain. The parameter α was taken to be 0.2. The rotation speed was assumed to be 15 rpm. With a drag coefficient $C_D = 0.1$, the ice throw from the blade tip at the top of the rotation was 82 metres, close to that found.

Another report for a similar turbine, a Tacke 600 turbine at the Bruce Nuclear Information Centre, describes the ice throw resulting from an icing event on Feb. 23rd, 1999[4]. There were about 1000 pieces of ice scattered up to 100 metres from the tower. This turbine had a 50 metre tower and 21 metre blade length.

Number of Ice Fragments

Each Siemens 2.3-113 turbine blade is 57 metres long with an average chord length of about 3 metres. With an ice thickness of 0.5 cm, the mass of ice would be over 2000 kg or over 2000 I kg ice fragments.

Conclusion

A realistic model for ice throw has been developed. It takes account of the likely shape of the shedding ice as an ice sheet and of a vertical wind speed gradient. The model has been applied to the Siemens 2.3-113 turbine proposed for the Amherst Island wind project by Algonquin Power Co. It was assumed that the turbine will continue operating during icing, a worst case scenario. To quote General Electric for example, ``ice detection is not highly reliable``. Other evidence of the failure of ice detection has been assembled by Bill Palmer[5]. Ice throw was calculated for 10 metre wind speeds of 10 and 15 m/s, wind speed gradient parameters of 0.2 and 0.4 and a range of drag coefficients. **It is concluded that a conservative setback of turbines from roads, buildings, homes and lot lines is 300 metres.** The ice will strike the ground at a speed in the range 100 to 200 km/h; this will break up the ice so that found fragments will not represent thrown ice.

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[3] R. Cattin, S. Kunz, A. Heimo, G. Russi, M. Tiefgraber, “Wind Turbine Ice Throw Studies in the Swiss Alps” European Wind Energy Conference Milan (2007) Volume: 1, Issue: 1, Pages: 3-7

[4] M.P. Leblanc, Recommendations for Risk Assessments for Ice Throw and Blade Failure in Ontario, Report from Garrad Hassan & Partners to the Canadian Wind Energy Association (2007)

[5] W.K.G. Palmer, Review of Serious Harm to Human Health Caused by South Branch Wind Farm, (2012 unpublished)

Acknowledgement

I would like to thank Bill Palmer for correspondence and for sharing his review of the South Branch Wind Farm ice throw report.

Appendix

The following figure is taken from K. Smith, G. Randall, D. Malcolm, N. Kelley and B.Smith, NREL/CP-500-32492, AWEA WindPower Conference (2002). Ft. Davis is among mountains and not representative of Southern Ontario. This figure is one of many used to generate the averages quoted above[6].

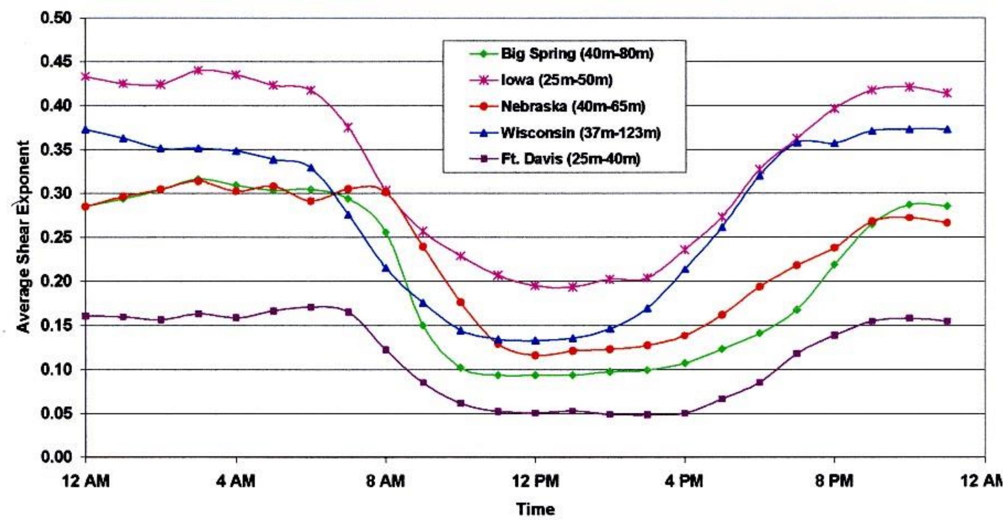

Figure 2. Comparison of Diurnal Wind Shear at TVP Projects

[6] John Harrison, ``Disconnect between Turbine Noise Guidelines and Health Authority Recommendations``, Proceedings of the World Wind Energy Conference, June 2009.