association to protect
AMHERST ISLAND

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Annual Energy Generation for the Windlectric Amherst Island Wind Energy Project[1]

Introduction

In May 2015 Windlectric modified the wind energy project on Amherst Island, proposing to use 26 noise-reduced Siemens 3.2-113 turbines, probably 13 x 2.942 MW and 13 x 2.772 MW turbines. These replace the originally planned mix of 33 Siemens 2.3-113 turbines, probably 21 x 2.3 MW and 12 x 2.224 MW turbines. All four turbine models have a blade circle diameter of 113 metres and a hub height of 100 metres.

Although the nameplate power of the project remains the same, 75 MW, we conclude that the initial capacity factor will be reduced by 13%, from 31.5% for the 33 2.3-113 turbines to 27.5% for the 26 3.2-113 turbines, as demonstrated below.

The project was given conditional approval by the ministry of the Environment and Climate Change on August 24th, 2015.

This report analyses the probable capacity factors of the original proposed turbines and the newly proposed turbines by a detailed comparison with the operating Wolfe Island wind energy project.

Factors Determining Power Output and Capacity Factor

- **Theoretical Maximum Power Output:** First, there is the theoretical maximum power output of a wind generator. This is the Betz limit: 59.3% of the rate at which wind energy blows through the blade circle. The Betz limit follows a cubic dependence upon the wind speed.

- **Idealized Power Output:** Next, there are limitations due to mechanical and electrical losses and the limitation of the generator itself. For low wind speeds, say below a 100-

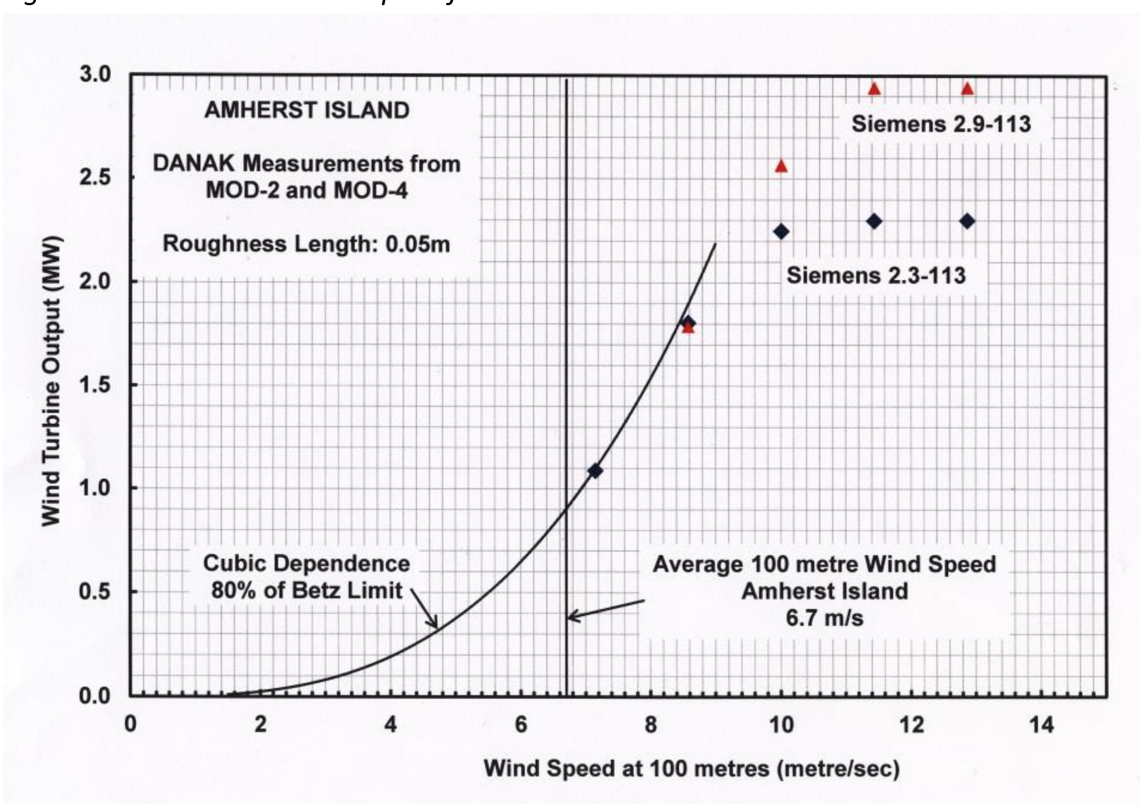
[1] This report is an appendix to the November 2015 letter from APAI to the Directors of Algonquin Power and Emera.

metre-height wind speed of 8 m/s where the generator is not limiting, modern turbines generate 70 to 80% of the Betz limit. Above that wind speed the generator sets the limit. For example, at a 100-metre wind speed of 12 m/s and above, the generator limits are 2.3 MW and 3.2 MW for the Siemens 2.3-113 and 3.2-113 turbines respectively, with their different generators.

Figure 1 below show the idealized power output for the two turbines, the 2.3-113 turbine and the 3.2-113 turbine in its 2.942 MW configuration. The numbers are from the DANAK test measurements of the turbines, presented in the original Hatch noise assessment report and the noise assessment reports accompanying the second and fourth modifications of the Windlectric project[2].

The cubic dependence, which matches onto the data points at higher wind speed, corresponds to 80% of the Betz limit.

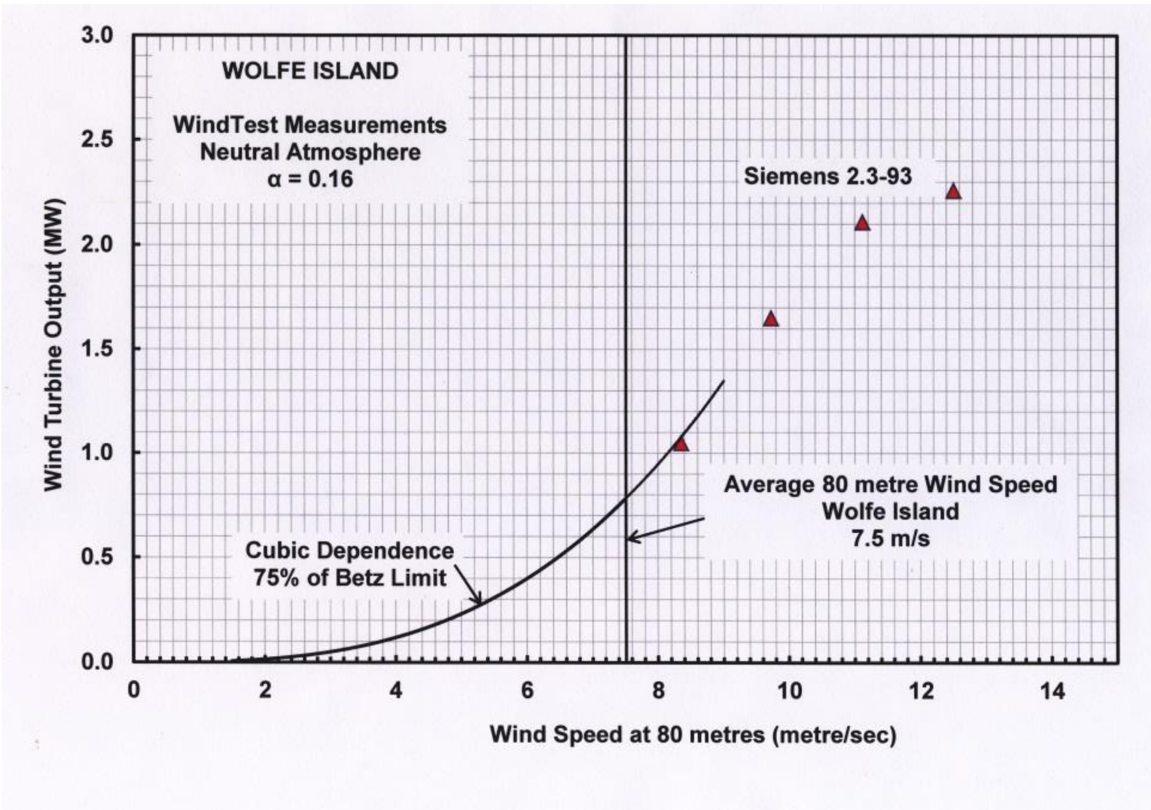
Figure 1: Idealized Power Output of the Modern Siemens 2.3-113 and 2.9-113 Turbines



[2] The measurements were presented in the reports in terms of the 10-metre wind speed. The conversion to the 100 metre hub-height wind speed was made on the basis that the measurements were made with a surface roughness parameter of 0.05 metres; that is, a neutral atmosphere with a wind shear coefficient of $\alpha = 0.16$.

Figure 2 shows the idealized power output of the older Siemens 2.3-93 turbine used on Wolfe Island. The cubic dependence at low wind speed, matching onto the generator-limited power output at higher wind speed, corresponds to 75% of the Betz limit.[3] The increase in efficiency for the turbines proposed for Amherst Island makes sense after almost a decade of research and development and the use of a gearless generator.

Figure 2: Idealized Power Output of the Older Siemens 2.3-93 Turbine



- **Idealized Annual Average Power Output:** The wind speed varies from hour to hour, day to day, month to month and year to year. The annual-average power output depends upon this variation. The conventional wisdom is that the variation in wind speed about the annual average wind speed is described by a Weibull distribution. Also by convention, in the absence of measurements, a particular Weibull distribution, the Raleigh distribution, is used.[4] With this Raleigh distribution, we have used the above power curves to determine the idealized capacity factors for the Siemens 2.3-113,

[3] The Siemens 2.3-93 power curve was derived from the WindTest measurements presented in the Wolfe Island wind energy approval application documents. The hub height is 80 metres.
[4] See for instance: http://www.wind-power-program.com/wind_statistics.htm

2.224-113, 2.772-113 and 2.942-113 turbines on Amherst Island with an annual-average 100-metre wind speed of 6.7 m/s; for comparison, the calculation was repeated for the Siemens 2.3-93 turbine used on Wolfe Island with an annual-average 80-metre wind speed of 7.5 m/s.[5] The reason for including Wolfe Island is that there is an archive of actual wind energy generation for Wolfe Island's wind energy project.

The calculation is straightforward. The idealized annual average power output is given by:

$$P_{average} = \int_0^\infty p\left({}^{u}/_{U}\right) \times P(u)\, d\left({}^{u}/_{U}\right)$$

where $P_{average}$ is the annual-average power output, U is the annual average wind speed at a height of 100 metres, $p\left({}^{u}/_{U}\right)$ is the Raleigh distribution of 100-metre wind speeds u about the annual-average wind speed at a height of 100 metres, $P(u)$ is the idealized power output of the turbine at the 100-metre wind speed u, see Figures 1 and 2. In practice, the upper limit of the numerical integration was 40 m/s (144 km/h) where the Raleigh probability is 10^{-12}.

The result of the computation is summarized in the table below:

Table 1: Idealized Capacity Factors for Several Siemens Wind Turbines

Turbine	2.3-113	2.224-113	2.942-113	2.772-113	2.3-93
Location	A. I.	A. I.	A. I.	A. I.	W. I.
Idealized Average Power (MW)	1.01	0.99	1.12	1.09	0.93
Idealized Capacity Factor (%)	44	45	38	39	41

The idealized capacity factor is the idealized average power divided by the nameplate power. The ideal capacity factors for the newly proposed turbines, with their larger blade circle diameter and increased hub height, just about compensate for the smaller annual average wind speed on Amherst Island when compared to the smaller turbines and higher wind speed on the western end of Wolfe Island.

Two comments can be made:

- The developers of the Wolfe Island wind project were adamant that the annual average capacity factor would be 40% right up to half-way into the first year of energy production. This prediction is very close to the above estimate of 41% for the idealized capacity factor.

[5] The annual average wind speeds were taken from the Ontario wind atlas. This annual average varies across the islands; a site-weighted average was used.

- The idealized annual-average capacity factors for the noise reduced 3.2-113 turbines are significantly less than those of the 2.3-113 turbines. The relative reduction is 13%.

- **Real Annual Average Power Output:** Real annual-average power outputs and capacity factors fall short of the idealized output and capacity factor. There are a number of reasons, including:
    - Turbulence changes the inflow angle locally so that the pitch angle cannot be optimized for maximum power production. Turbulence can occur naturally in the atmosphere and as a result of the turbulent wake of up-wind turbines.

    - The wake from up-wind turbines lowers the wind speed at a turbine. This is obvious: the upwind turbine has taken energy out of the wind. Research has demonstrated that to avoid wake turbulence and wake loss the turbines should be spaced 15 blade diameters in the prevailing wind direction. For the Amherst Island project the site plan shows many turbines aligned in the prevailing wind direction with as little as 5 blade diameter spacing.

    - The capacity factor is reduced in a high wind speed gradient. The idealized capacity factors are determined in a neutral atmosphere. In such a case the wind speed at the top of the blade circle will be about 20% larger than at the bottom of the circle. However, the reality is that the wind speed at the top of the blade circle can be as much as 70% larger than the speed at the bottom of the circle. This makes it impossible to optimize the pitch of the blade. Near-stall conditions can prevail.

The International Energy Commission specifies that power and noise measurements be made in a neutral atmosphere so that fair inter-comparisons can be made between different makes of turbines. The tests will not be made with operating turbines nearby nor in a turbulent atmosphere. The situation is akin to the idealized tests of automobile fuel efficiency – nobody expects to match those numbers under real driving conditions.

To continue:

- Turbines are subject to wear and tear, both the rotating machinery and the blade surfaces (blade erosion), and periodic malfunctions and maintenance shut-downs.

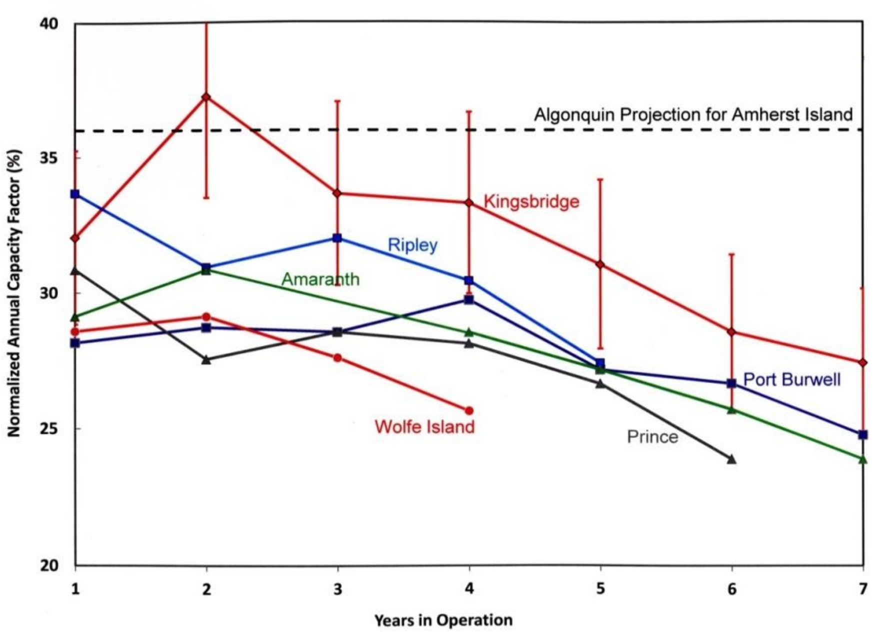
- Icing during the winter months.

The Independent Energy System Operator (IESO) publishes hourly power generation from the major Ontario wind-energy generating systems. The annual average capacity factor for each of these systems has been collected together in Appendix A of an earlier APAI analysis[6], going back as far as 2006 and forward to 2013. There is no value going beyond 2013; it is now government policy that wind energy companies are paid not to dispatch energy to the grid during periods of surplus generating capacity.

The capacity factor is the primary factor in determining the viability of a wind-energy generating system. The annual-average capacity factor is defined as the annual-average power output of the system divided by the nameplate power. In Ontario the maximum over the period 2008 to 2013 was 36%, the minimum was 24% and the average was 30%.

For the wind-energy generating systems there are variations from year to year. This is largely because the annual-average wind speed varies from year to year. In turn, the output of a wind turbine magnifies this variation in average wind speed. The capacity factors can be normalized to remove this variation, as outlined in Appendix B of the same report. Figure 3 shows the normalized capacity factor for those Ontario systems that had been in operation for 5 years or more; the Wolfe Island system has been added because of its proximity to Amherst Island.

Figure 3: Normalized Capacity Factor for Ontario Wind Energy Generating Systems as a Function of Years of Service



[6] http://www.protectamherstisland.ca/wp-content/uploads/2013/08/Economic-Report-March-2013.pdf

Typically, these systems start within the first year or two at a capacity factor of about 30% (Kingsbridge, on the shore of Lake Huron, was an exception). Subsequently the capacity factors decline. This decline is about 1% per year or a relative decline of 3% per year. This of course augurs very badly for a generating system designed for a 20 year life and with capital funding based upon a 20 year life.

Here the focus is on Wolfe Island with, in mind, the prediction of a realistic capacity factor for the Windlectric Amherst Island project. The data points for Wolfe Island indicates an initial capacity factor of 29% followed by the typical 1% per year decrease in capacity factor. This initial capacity factor is 70% of the idealized capacity factor derived above. With similar end of Lake Ontario meteorological conditions it is a reasonable to apply the same 70% multiplier to the Amherst Island project. The resulting realistic capacity factors for the Amherst Island project are shown in Table 2:

Table 2: Comparison of Initial Realistic Capacity Factors and Annual Energy Production for the Originally-Planned 2.3 MW Turbines and the Recently-Proposed Noise-Reduced 3.2 MW Turbines.

Turbine	2.3-113	2.224-113	2.942-113	2.772-113
Location	A. I.	A. I.	A. I.	A. I.
Realistic Capacity Factor (%)	31	32	27	28
Realistic Annual Energy Production (GWh)	205		180	

Note that over the 20-year life of the contract the energy production will dwindle by 3%/year. Over the 20-year contract term the annual average capacity factor becomes 21% and the annual average energy production is 135 GWh. Assuming that continuing research and development will reduce the decline, APAI conservatively estimates that the long term capacity factor will be 23% and the energy production will be 150 GWh/y.

Experience Elsewhere

Wolfe Island is not the only wind project to disappoint. Fitch, a well-known ratings agency, has analyzed the under-performance of 19 wind energy plants in the USA. APAI does not have the resources to buy the Fitch report but the news release that accompanied the report is included as Appendix A to this report.

Perhaps more sobering for APCo, its Directors and its investors is an article from Spiegel Online International, a well-respected German media source.[7] The article was based upon a study by the head of the investment committee at the German Wind Energy Association. The study

[7] http://www.spiegel.de/international/business/wind-power-investments-in-germany-proving-riskier-than-thought-a-946367.html The subtitle reads: “Gone with the Wind: Weak Returns Cripple German Renewables”

looked at the business affairs of over 170 commercial wind parks over the course of 10 years. On average investors received an average return of 2.5%/annum instead of the promised 6 to 8%.

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Appendix A: Fitch Report

US Wind Power Production Underperformance May Continue

Fitch Ratings-New York/Chicago-14 November 2014: Wind power production forecast inaccuracies have dogged the industry and improvements to more recent forecasts remain to be seen, Fitch Ratings says. We believe these issues have taken on more importance in light of a deal to limit greenhouse gases announced Wednesday by Chinese leader Xi Jinping and President Obama, which would accelerate the U.S.'s shift to alternative energy, including wind power.

The majority of 19 operating wind projects we analyzed in a recent report suffered chronic production shortfalls. Actual production only occasionally exceeded base case levels and generally fell between base and rating case levels. On average, actual production was 7.8% below Fitch's base case projections and 6.1% above Fitch's rating case. Going forward volatility is likely. The difference between minimum and maximum annual production in the rated projects is 14% on average and can be higher even in those projects performing relatively well.

In our view, this underperformance is mainly attributable to an overestimation of average wind conditions and underestimating the wake effects between turbines for studies completed prior to construction. Three out of the four Fitch-rated wind projects that used forecasts incorporating actual operating data performed close to base case expectations. Wind resource consultants continue to hone their methodologies and report that more recently completed studies have improved accuracy. Fitch-monitored projects with forecasts prepared in 2003-2006 performed on average only slightly worse than projects with forecasts prepared in 2007-2010. As production data from newer projects becomes available, Fitch will be better able to validate the claims of improved accuracy.

In addition to production shortfalls, wind projects must contend with grid curtailment, technical issues and excess operating costs. Operations and maintenance (O&M) expenses (which include labor, services and replacement parts) can also be significant for some projects. O&M services are often provided by the equipment manufacturers, reducing expense volatility even after original warranties expire. However, the cost of replacement parts and frequency of replacement can increase significantly for projects without service contracts. The impact is deeper when parts availability is strained for weaker manufacturers.

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