Q. Regulated Activities, page 30: Please indicate the firm capacity Hydro considers would be provided by a 25 MW wind development, if any. In the event the exact value for firm capacity has not been determined but Hydro expects it to be greater than zero, please provide an indication of the range Hydro expects for firm capacity from the 25 MW wind development. Provide any calculation, analysis or reports in support of this level of firm capacity.

A. Please refer to the attached paper "Planning for Wind".

PLANNING FOR WIND

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ABSTRACT

Harnessing the energy in wind has taken many forms for thousands of years. In more modern times, the focus of a great deal of research has been directed at wind energy conversion systems for producing electricity. Unlike thermal or dispatchable hydroelectric plants, wind energy cannot be called upon when needed, or relied upon at all periods of the day. Therefore, the capacity (MW) value of wind production remains uncertain. In order to properly assess the merits of wind versus other technologies from a generation planning point of view, it is necessary to estimate the full value (both energy and capacity) that wind generated electricity production brings to the integrated utility system. This paper outlines the analysis undertaken by Newfoundland and Labrador Hydro to estimate the capacity value of wind on the Island Interconnected System and to arrive at an acceptable means of modeling wind for future generation planning analysis.

INTRODUCTION

Newfoundland & Labrador Hydro (NLH) is currently assessing the feasibility of wind energy as a source of future supply. As part of a comprehensive assessment, this analysis has focused on an estimation of the potential value of wind capacity to the Island Interconnected System.

A number of wind production capacity valuation methodologies have been examined in previous industry research. The intent of this study is not to reproduce this past work, but to apply the findings of the research to estimate the capacity value of wind on the Island system.

It should be noted that the estimates developed in this study are considered order-of-magnitude. Should NLH decide to proceed to develop a wind demonstration project, one of the goals of that project will be to more accurately estimate the capacity value of wind energy conversion systems.

BACKGROUND

A widely accepted means of estimating the capacity value of wind generation plants does not exist within the utility industry. Few would argue that wind plants have no capacity value, and similarly, few would argue that a wind farm has the same value as a fully dispatchable thermal or hydroelectric unit. Establishing a position between these extremes, acceptable to both the utility and wind proponents, has proven to be a difficult task. However, since the capacity value of the wind plant has a direct relationship to its economic value, it is an issue that must be addressed.

From a generation planning point of view, which is the focus of this analysis, the value of wind capacity can be related to its potential to offset investments in conventional generating capacity. This being the case, it is important to have an understanding of the planning criteria used to expand the system and its relevance to this analysis.

NLH has established criteria related to the appropriate reliability, at the generation level, for the total Island Interconnected System which sets the timing of generation source additions. These criteria set the minimum level of reserve capacity and energy[1] installed in the system to insure an adequate supply for firm load:

Energy - The Island Interconnected System should have sufficient generating capability to supply all of its firm energy requirements with firm system capability[2]; and

Capacity - The Island Interconnected System should have sufficient generating capacity to satisfy a Loss of Load Hours (LOLH)[3] expectation target of not more than 2.8 hours per year.

Since the goal of the analysis is to identify the capacity value of wind generation, it is the capacity planning criteria that is key to this analysis.

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[1] Energy is the ability to do work and is measured in kilowatt-hours (kWh), while capacity is the amount of electricity required at a point in time and is measured in kilowatts (kW).

[2] Firm capability refers to the maximum annual energy that can be produced under minimum hydraulic inflows.

[3] LOLH is a statistical assessment over all hours of the year of the risk of the system not being capable of serving the load.

On the Island system, as with much of the utility industry, the least cost capacity alternative is the simple cycle combustion turbine (CT). Therefore, the focus of this analysis will be to determine the amount of CT capacity that would provide the same contribution to overall system reliability as a set amount of wind capacity. Based on previous industry research, the following methodologies were used to estimate the capacity value of wind generation on the Island system:

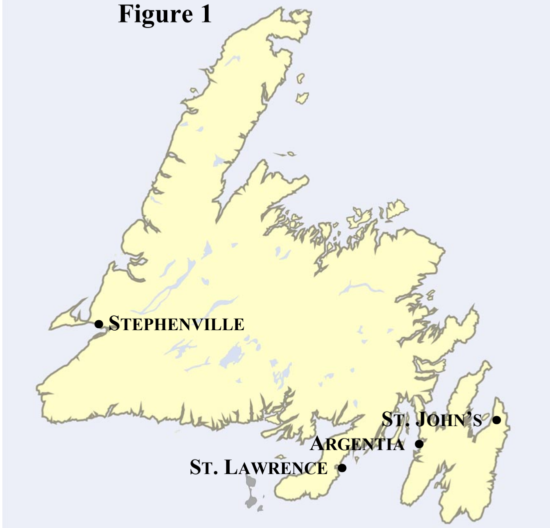
- Annual Capacity Factor;
- Seasonal Capacity Factor (spreadsheet analysis);
- Seasonal Capacity Factor (system simulation analysis); and
- Chronological Analysis.

Each of these methods was applied to a number of hypothetical wind farms, at different locations throughout the Province, to estimate the capacity contributions that would have been assessed had these wind farms been in-service over the period 1996 through 2000. The 5-year period is considered to provide a reasonable balance between the level of computational effort and confidence in the results. The various locations were used to evaluate whether there are regional differences that affect the capacity value of wind.

Wind Farm Models/Assumptions

Based on the availability of suitable wind data from Environment Canada monitoring stations, this study considered four hypothetical wind farms as indicated in Figure 1.

Figure 1



Each of these wind farms consisted of 38 Vestas V47-660 kW wind turbines mounted on 50 meter towers for a total installed capacity at each site of approximately 25 MW. The Vestas V47-660 kW was chosen since it is considered proven technology and in a capacity range that is typical of recent installations. The expected energy production from the wind farms was calculated for each hour of each year of the study period. The average monthly output (MW) from each of the 25 MW wind farms over the 5-year study period is illustrated in Figure 2.

Figure 2
Wind Farm Monthly Production Profile
1996-2000 Study Period

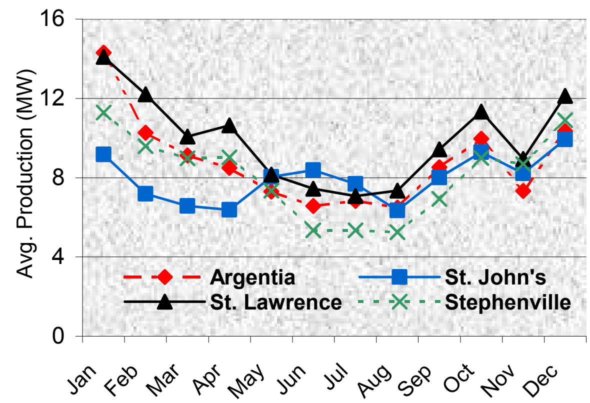


Figure 2 illustrates the generally higher wind speeds experienced during the higher load winter months. Statistical analysis has shown that there is a correlation between wind and load, particularly during periods of higher demand which contribute proportionately more to the assessment of annual LOLH.

Wind Farm Capacity Equivalent Analysis

As previously introduced, a number of methods have been employed to estimate the capacity equivalent (CT) contribution of wind energy conversion systems for system planning purposes. The following examines the range of methods as they would be applied to wind farms on the Island Interconnected System.

<u>Annual Capacity Factor</u>

The simplest estimations of the capacity value of wind energy conversion systems is to calculate the amount of CT capacity required to produce an amount of energy equivalent to the expected average annual energy produced from the wind farm. In addition, since a unit's forced outage rate (FOR) has a direct impact on the value of that unit to the overall reliability of the system, it is necessary to account for differences between the FOR of the wind energy conversion system and that of the capacity equivalent CT. The following formula was used to estimate the capacity value of wind using the annual capacity factor (ACF)[4] method:

MW_{CT} =
$MW_W * ACF_W/ACF_{CT} * (1+FOR_{CT})/(1+FOR_W)$

Where:
MW_{CT} is the equivalent amount of CT capacity;
MW_W is the installed capacity of the wind farm;
ACF_W is the expected annual capacity factor of the wind farm;
ACF_{CT} is the maximum annual capacity factor of a CT unit (89%);
FOR_{CT} is the forced outage rate of a CT unit (7.8%); and
FOR_W is the forced outage rate of the wind farm (2%).

The application of this method to hypothetical 25 MW wind farms at Argentia, St. John's, St. Lawrence and Stephenville yields the following results:

Table 1
Wind Farm Equivalent CT Capacity
Annual Capacity Factor Method

	1996	1997	1998	1999	2000	Avg.
			Argentia			
ACF[1]	36%	38%	37%	30%	n/a	35%
CT[2]	10.8	11.2	10.9	8.9	n/a	10.5
			St. John's			
ACF[1]	33%	33%	32%	31%	29%	32%
CT[2]	9.8	9.9	9.4	9.3	8.7	9.4
			St. Lawrence			
ACF[1]	n/a	n/a	n/a	38%	41%	40%
CT[2]	n/a	n/a	n/a	11.2	12.3	11.8
			Stephenville			
ACF[1]	32%	33%	34%	32%	31%	32%
CT[2]	9.5	9.8	10.1	9.7	9.2	9.7

[1] Annual capacity factor of the wind farm.
[2] Equivalent CT capacity (MW).
n/a Data not available.

Based on this method, the calculated equivalent CT capacity ranges from 9.4 to 11.8 MW, or 38% to 47% of installed wind capacity, depending on location.

[4] Annual Capacity Factor (ACF) =
Annual Energy Production/(Installed Capacity * 8760 hours per year)

<u>Seasonal Capacity Factor (Spreadsheet Analysis)</u>
Similar to the annual capacity factor method, the seasonal capacity factor (spreadsheet analysis) method recognizes that there are greater contributions to the overall system reliability at different times of the year. Therefore, wind energy production during these times is of greater capacity value than that produced during the off-peak times. Based on previous research, a suitable defined peak period may help approximate the capacity value of a wind plant. For the Island Interconnected System, it has been determined that during a typical year the two peak months (usually January and December) make up approximately 85% of the overall annual LOLH.

The application of this method to hypothetical wind farms at Argentia, St. John's, St. Lawrence and Stephenville using the capacity factors of the (combined) two peak months yields the following results:

Table 2
Wind Farm Equivalent CT Capacity
Seasonal Capacity Factor (Spreadsheet) Method

	1996	1997	1998	1999	2000	Avg.
			Argentia			
CF[1]	48%	50%	52%	46%	n/a	49%
CT[2]	14.1	15.0	15.6	13.6	n/a	14.6
			St. John's			
CF[1]	34%	33%	42%	38%	37%	37%
CT[2]	10.0	9.8	12.5	11.5	11.1	11.0
			St. Lawrence			
CF[1]	n/a	n/a	n/a	54%	50%	52%
CT[2]	n/a	n/a	n/a	16.1	15.0	15.6
			Stephenville			
CF[1]	40%	42%	51%	43%	43%	44%
CT[2]	12.0	12.4	15.3	12.9	12.7	13.1

[1] Seasonal capacity factor of the wind farm.
[2] Equivalent CT capacity (MW).
n/a Data not available.

Based on this method, the calculated equivalent CT capacity ranges from 11.0 to 15.6 MW, or 44% to 62% of installed wind capacity, depending on location.

<u>Seasonal Capacity Factor (System Simulation) Method</u>
A further extension of the seasonal capacity factor (spreadsheet analysis) method is to model the wind farm production in STRATEGIST™ similar to the way in which run-of-river hydro units are modeled. STRATEGIST™ is an integrated strategic planning computer model with which NLH simulates the

operation of all generators connected to the Island system. It performs, among other things, generation system reliability analysis, production costing simulation and generation expansion planning analysis.

By modeling the wind farm in this manner, the monthly production from the wind farm is spread evenly over all hours of the month and the average monthly capacity contribution of the wind farm is assessed for all months of the year. The operation of the Island system is then simulated to estimate the capacity value of the wind farm through the application of the capacity planning criteria.

With this approach the wind farm is added to the existing Island system model and then the amount of existing CT capacity is adjusted to achieve the annual LOLH target of 2.8 hours/year. In a subsequent run, the wind farm model is removed and sufficient new CT capacity is added to once again achieve the LOLH target of 2.8 hours/year. The amount of CT capacity that was added in this last simulation is therefore equal to the capacity value of the wind farm. The underlying assumption is that, had the wind farm been present, and NLH had the opportunity, construction of this amount of CT capacity could have been avoided.

The results from the application of this method are summarized in the following table:

Table 3
Wind Farm Equivalent CT Capacity
Seasonal Capacity Factor
(System Simulation) Method

	1996	1997	1998	1999	2000	Avg.
Argentia						
CT[1]	9.9	8.0	9.7	8.3	n/a	9.0
St. John's						
CT[1]	6.0	6.6	6.0	5.6	5.4	5.9
St. Lawrence						
CT[1]	n/a	n/a	n/a	10.0	9.0	9.5
Stephenville						
CT[1]	7.2	6.6	9.0	7.1	7.4	7.5

[1] Equivalent CT capacity (MW).
n/a Data not available.

Based on this method, the estimated equivalent CT capacity ranges from 5.9 to 9.5 MW, or 24% to 38% of installed wind capacity, depending on location.

Chronological Analysis

The most detailed of the wind farm capacity valuation techniques is to simulate the operation of the wind farm over all hours of the year while maintaining the chronological order of all data. Unlike any of the capacity factor methods described previously, this method provides the ability to evaluate the coincidence of wind and load over all hours of the year.

The simulated chronological production data from the wind farm is matched to the system load data for each of the years under evaluation. The wind farm production is then netted off the system load data to produce a new set of wind modified load data. That is, the load that the existing generation plant on the Island system would have had to meet if the wind farm had been present. This modified load data is imported into STRATEGIST™ and the operation of the Island system is simulated to estimate the capacity value of the wind farm through the application of the LOLH planning criteria. This is accomplished using the same approach described in the previous method.

The results from the application of this method are summarized in the following table:

Table 3
Wind Farm Equivalent CT Capacity
Chronological Analysis Method

	1996	1997	1998	1999	2000	Avg.
Argentia						
CT[1]	13.9	8.4	8.9	10.2	n/a	10.3
St. John's						
CT[1]	9.7	4.2	7.8	7.5	8.0	7.4
St. Lawrence						
CT[1]	n/a	n/a	n/a	12.0	10.9	11.4
Stephenville						
CT[1]	12.2	7.1	8.2	8.1	9.1	8.9

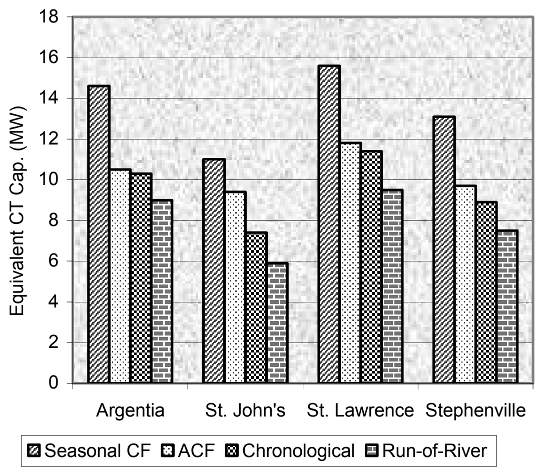
[1] Equivalent CT capacity (MW).
n/a Data not available.

Based on this method, the estimated equivalent CT capacity ranges from 7.4 to 11.4 MW, or 30% to 46% of installed wind capacity, depending on location.

Wind Farm Capacity Equivalent Summary

As can be seen from the results of each of the wind capacity valuation methods presented in this paper and summarized in Figure 3, there is a great deal of variation in the estimated equivalent CT capacity. The chronological analysis is the most detailed and considered to provide the most credible results since, for the years and sites evaluated, these are the values of capacity that would have been assessed had the wind farms been in place. In relation to this method, the simpler annual capacity factor and seasonal capacity factor (spreadsheet analysis) methods tend to produce higher estimates of the capacity value of wind energy. In contrast, the seasonal capacity factor (system simulation) method, or run-of-river model, tends to present a slightly more conservative estimate of the capacity value of wind.

Figure 3
Capacity Equivalent Analysis
Comparison of 5-Year Averages



While the application of the chronological simulation method to historic information is a relatively straightforward, albeit time consuming task, the extension of the technique to future capacity planning is problematic due to the nature of forecasting. It is impossible to predict the magnitude of load and wind speed for all hours of the year for many years into the future.

Recognizing the limitations to the chronological/load modifier approach, an alternative would be to utilize the run-of-river modeling described earlier. Due to the theoretical nature of this investigation, this slightly more conservative estimate of value is considered appropriate as a practical alternative.

CONCLUSIONS

The results of this analysis indicate that there is a correlation between wind speed and load on the Island Interconnected System. The wind speeds are generally higher in the peak winter months and there is evidence from statistical analysis that there is a greater expectation of higher loads at times of higher winds.

A detailed chronological evaluation of hourly system loads and wind speeds indicates that the CT equivalent capacity value of a 25 MW wind farm would range from 7.4 MW to 11.4 MW (or 30% to 46% of installed wind capacity) depending on the location of the wind farm.

In comparison to this full chronological evaluation, a simple analysis of the expected annual or seasonal capacity factors of potential wind farms will generally produce a higher estimate of the capacity value of the wind farm. Modeling the wind farm similar to run-of-river hydro tends to produce a slightly more conservative valuation of wind capacity which is considered an appropriate and practical approach for current generation planning analysis.

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