Q. **Reference: Reliability and Resource Adequacy Study 2022 Update, Volume I, page 5, f.n. 22**

Footnote 22 states: “Hydro is undertaking a third-party study with the goal of determining the amount of wind that can be integrated into Hydro’s system, including preliminary interconnection information for future potential self-supply customers.”

Provide the name of the consultant undertaking this study, the scope and schedule for this study, and explain how Hydro plans to use the results of this study.

A. Please refer to PUB-NLH-232, Attachment 1 for the Wind Power Integration Study, undertaken by Hatch Inc. (“Hatch”), which was completed in October 2022.[1] A copy of the presentation providing a summary of the Wind Integration Study has been provided as PUB-NLH-232, Attachment 2.

The scope of this study was to assess the amount of additional, non-dispatchable wind generation that can be added, economically and technically, to the Newfoundland and Labrador power system for a range of forecast scenarios. Both the ability of the hydroelectric system to operate efficiently with additional wind generation and issues of system stability and voltage regulation were considered.

The results of this study are informative to Newfoundland and Labrador Hydro (“Hydro”) and wind generation proponents as they include a detailed listing of technical requirements and general considerations for potential wind interconnections. While detailed system studies will ultimately be required to confirm system upgrade requirements for final project proposals, proponents can avail of this information to help ensure the technical viability of conceptual designs.

The study results are also helpful in that they provide an indication of the amount of wind generation that could be interconnected to the system to support provincial energy

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[1] “Wind Power Integration Study,” Hatch Ltd., October 24, 2022, <https://www.oasis.oati.com/woa/docs/NLSO/NLSOdocs/H-369130_Wind_Power_Integration_Study_Report_Final.pdf>.

requirements in various forecast scenarios. This enhances Hydro’s understanding of the technical viability of wind expansion from a planning perspective.

Project Report

October 24, 2022

Newfoundland & Labrador Hydro

Wind Power Integration Study

2022-10-24	0	For Approval	Semiu Lawal	Tryggvi Olason	M. Carreau	
Date	**Rev.**	**Status**	**Prepared By**	**Checked By**	**Approved By**	**Approved By**
						Client

Table of Contents

List of Tables

List of Figures

1. Executive Summary

Hatch has completed a study to assess the amount of additional, non-dispatchable wind generation that can be added, economically and technically, to the Newfoundland and Labrador power system. Both the ability of the hydroelectric system to operate efficiently with additional wind generation, and issues of system stability and voltage regulation were considered.

The study examined additional installed wind capacity up to 1000 MW, in 100 MW increments, 3 load forecasts for the period to 2040, and the 61 years of available historic inflows. Results indicate that the ability of the system to absorb additional wind generation is strongly related to load growth. The amount of additional wind capacity that can be efficiently utilized, is summarized in Figure 1-1, where efficiently usable wind capacity (95% utilized) is plotted against total annual load.

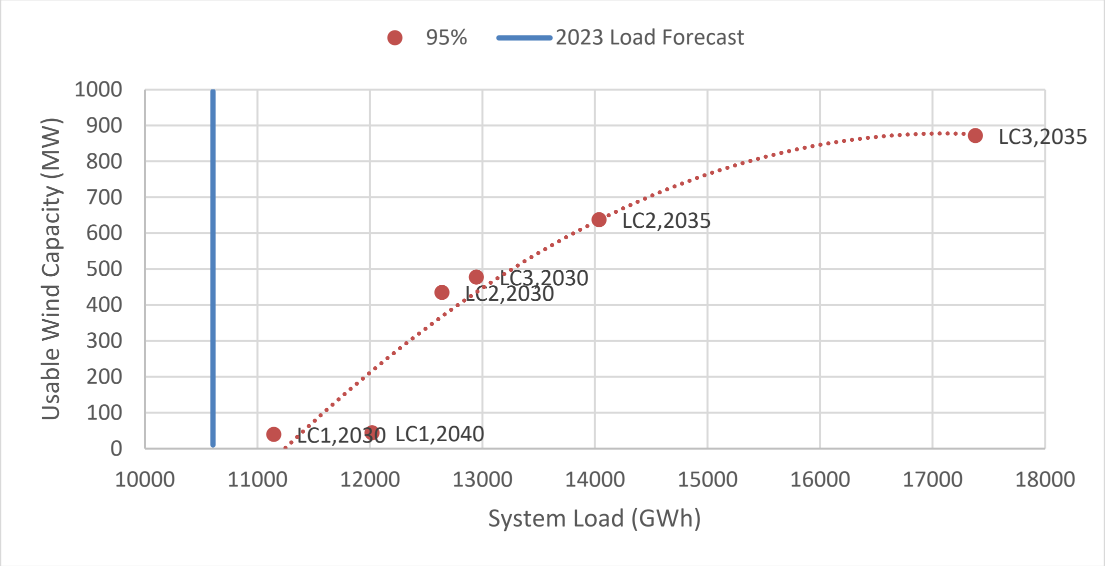

Figure 1-1: Usable Wind Generation and System Load

Data labels indicate the load case and load forecast year. The usable wind energy is plotted against total system load in Figure 1-2.

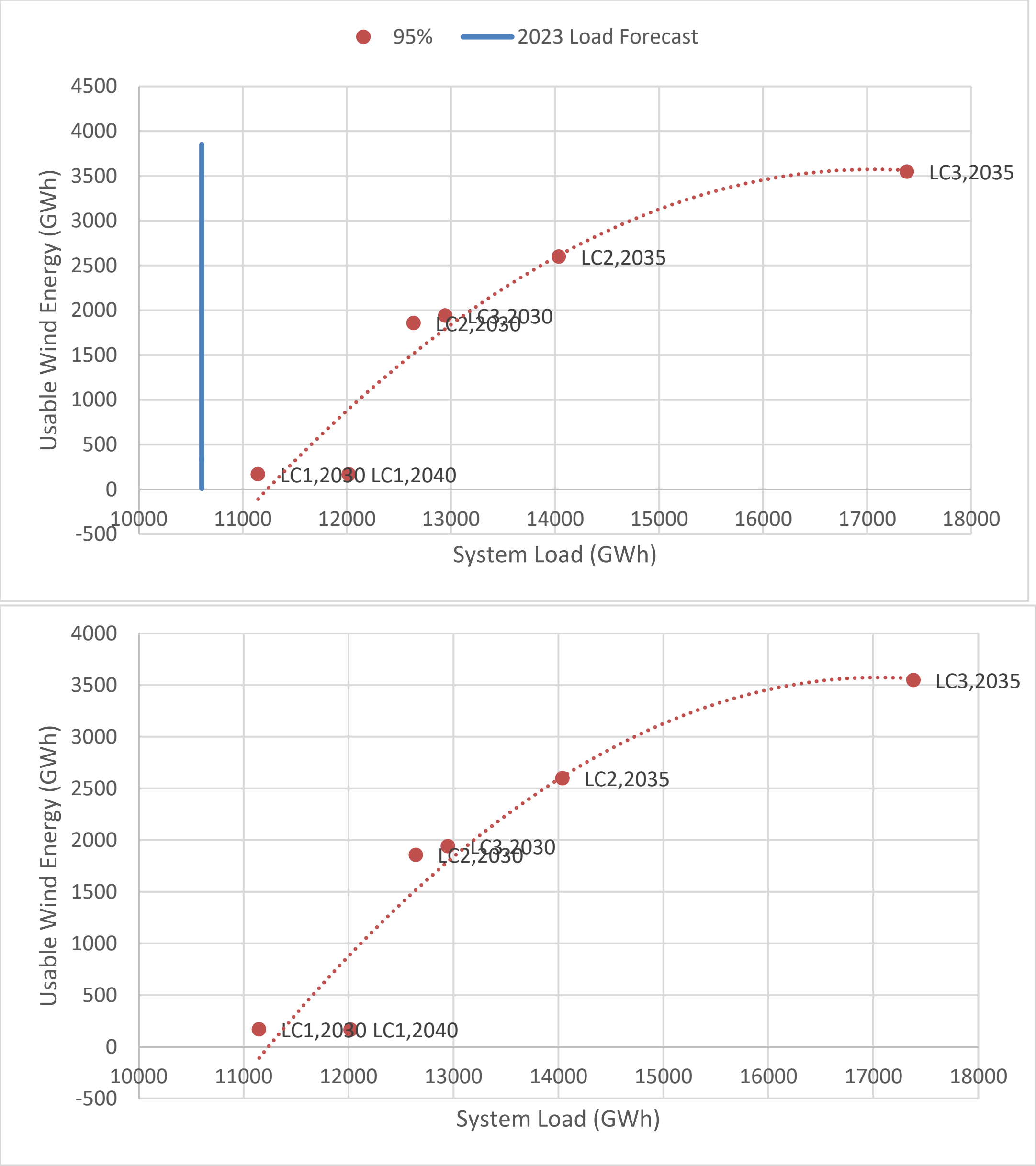

Figure 1-2 Fully Usable Wind Energy and System Load

Additional wind generation, beyond Hydro domestic load requirement, can be built by self-supply customers. Strictly, on a basis of technical interconnection requirements, several large self-supply industrial customers could connect to the NL transmission system. Technical interconnections requirements and recommendation for potential self-supply customers are included in Section 6.4.

Self-supply customers might have excess wind power production, behind the meter, that could be curtailed or potentially exported to NLH. Self-supply customers might require grid support to meet the base load requirement of their facility in the absence of wind power. This topic is discussed in Section 6.6.

2. Introduction

Newfoundland and Labrador Hydro (NLH) requested that Hatch carry out an evaluation of how much additional wind generation can be added to the NLH system, from an economic and technical point of view.

All of the existing hydraulic generation resources on the Island and in Labrador were considered in this study. The hydro plants on Bay D'Espoir, Cat Arm, Hinds Lake, Paradise, Exploits rivers as well as Deer Lake Power were represented in detail, while the Newfoundland Power hydro plants were modelled in a simplified manner. In Labrador, the Muskrat Falls and Churchill Falls were modelled in detail.

The Vista set-up also included detailed representation of major components of the transmission network, including the Labrador Island and Maritime links. Firm export to Emera and the CFLCO power purchase agreement with Hydro Quebec were also modelled along with export markets.

The current Isolated Island Scenario generation expansion plan under consideration has an additional unit 8 at Bay d 'Espoir, 154 MW and the option of continued operation of the Holyrood Generating Station.

The study determines if it is economically and technically feasible to include additional wind generation plants in the NLH system. The study was undertaken by assessing a number of 100-MW increments of wind generation for each of the study years, in succession.

Vista Decision Support System (DSS^{TM}) was deployed for studying the impact of additional wind generation. *Vista* has been implemented and tested for the existing Island system and used in a number of studies for various additional generation resources, both hydroelectric and wind. For the study herein, the focus was to capture hydrologic variability by modeling 67 years of hydrology, for four specific years in the planning horizon – 2025, 2030, 2035, and 2040.

3. System Representation

3.1 Existing System

Capacity

The Interconnected NLH system, including wind generation, has a net generating capacity of 2733 MW. Of this, Newfoundland and Labrador Hydro's own generation consists of :

- 2329 MW of hydroelectric, including generation on the Exploits River.
- 466 MW of thermal plus.

The existing wind generation capacity is 54 MW, consisting of two non-utility generation (NUGs) at St. Lawrence (27 MW with 104 GWh annual average energy) and Fermeuse (27 MW with 84 GWh annual average energy).

The balance of 244.5 MW is primarily hydroelectric from customer generation.

All generation resources on the Island and in Labrador were represented in this study. These include :

- Bay D'Espoir - Granite Canal (41.5 MW, 1 unit), Upper Salmon (84.0 MW, 1 unit), Long Pond (max 604 MW, 7 units).
- Hinds Lake (81.7 MW, 1 unit), and customer owned generation at Deer Lake (125 MW, 1 unit).
- Cat Arm (137.4 MW, 2 units).
- Paradise River (8 MW).
- Exploits River – Grand Falls (76 MW), Bishops Falls (25 MW), as well as Star Lake (18.1 MW), and Sandy Brook (5.6 MW).
- Newfoundland Power numerous small plants were represented in a simplified manner.
- Muskrat Falls, (824 MW, 4 units).
- Churchill Falls, (the 5575 MW, 11 units). Owned by CFLCo and the generation is supplied to Hydro Quebec in accordance with a power purchase agreement. This PPA also stipulates that 525 MW generation is provided to NLH, referred to as Twinco and Recall load.

Energy

- The interconnect NLH system is mainly served by hydro energy capacity by the facilities listed above. In 2021 the interconnected NLH system was serve by hydro (85%), thermal (11%) and purchases (4%) including wind energy (3%). The overall amount of wind energy in the NL interconnected system is low compared other Atlantic jurisdictions. Wind generation in Nova Scotia generated 17% of their electricity in 2021, while New Brunswick wind energy generated 6% of their required energy in 2019/2020.
- With the in-service of the Labrador Island Link the energy sales from hydro generation will increase as it offsets thermal generation from Holyrood. The NL system also has excess green energy and is forecasting to export over 3.0 TWh energy to our export markets including Nova Scotia, New England and New York.
- To increase the amount of wind in the NL system today, new generation in the NL interconnected system would displace existing generation including hydro or increase

exports. As load and energy sales grow in the NL interconnected system, the new load could be serve by new wind generation as well as exports instead of displacing existing hydro generation.

- Considering the current amount of hydro generation in the NL system to efficiently model wind integration a focus has been on limiting hydraulic spill and/or curtailed wind.

3.2 Generation Expansion

New generation over the planning period included the addition of unit 8 at the Bay d'Espoir generating station. For the purposes of this study, unit 8 was assumed to be identical to unit 7.

3.3 Load Forecasts

The analysis include 3 load scenarios for the study period, that is, expected (LC2), high (LC3) and low (LC1) load growth. The load forecasts are comprised of island and Labrador loads. The annual load forecasts (GWh) are illustrated in Figure 3-1.

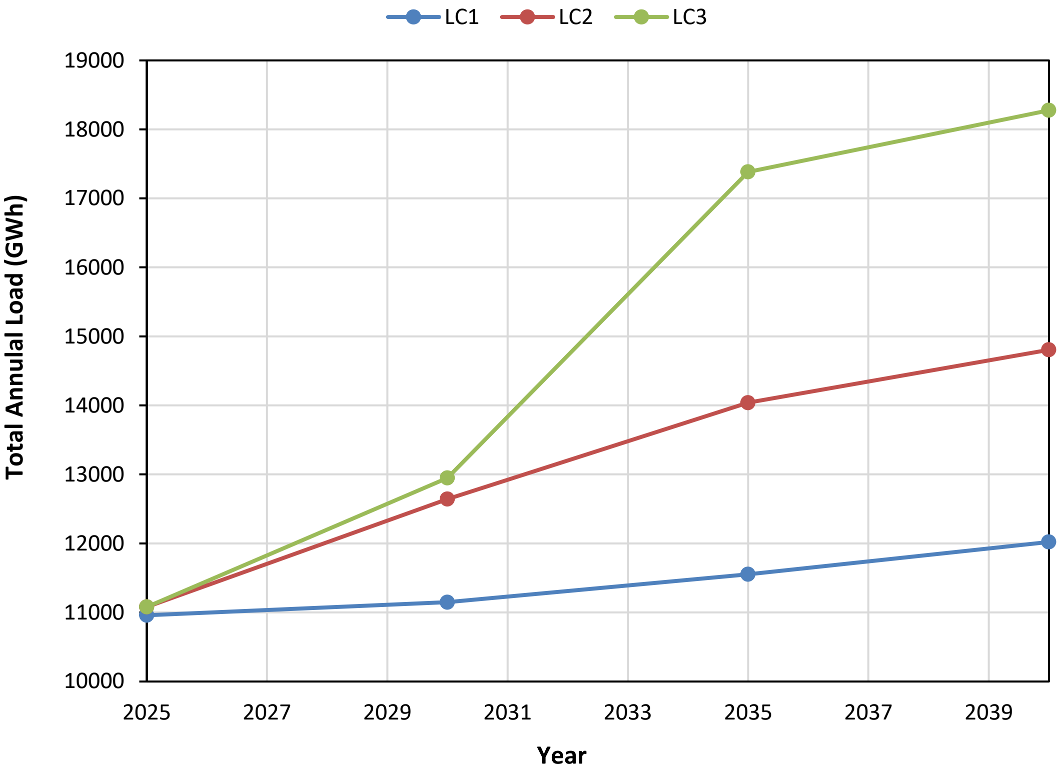

Figure 3-1: Annual Load Forecast (GWh)

3.4 Physical and Operational Constraints

Both physical and operational constraints are used to define allowable operations within the *Vista* DSS^{TM} model. Physical constraints are more stringent and are not to be violated by the model. Operational constraints must lie within the physical constraints; penalties are applied to these constraints to give the model guidance on when the constraints can be violated. The hydraulic constraints include the minimum and maximum water levels for the reservoirs and environmental flow releases. For the transmission network, in addition to physical limits and line losses, there are a few transmission stability constraints that needed to be represented.

The physical and operational hydraulic and transmission constraints are summarized in Appendix A.

3.5 Inflows

The 61-year inflow sequence provided by NLH has been adopted for the current study. This daily inflow sequence spans the years 1958 to 2019.

3.6 Reserve and Minimum Dispatchable Generation Requirements

Spinning and operating reserve requirements were explicitly modelled as well as additional regulating reserve for additional wind generation, as follows:

- Minimum dispatchable generation.
- Operating reserve.
- Spinning Reserve.
- Additional regulating reserve for wind, set as 20% of installed wind capacity.

3.7 Maintenance Schedules

A generic annual outage schedule provided by NLH was used for each study year.

4. Study Methodology

The *Vista* DSS™ has been implemented and tested for the existing Integrated NLH system. The model is used operationally and for a number of studies for various additional generation resources, both hydroelectric and wind. *Vista* uses detailed mathematical equations describing hydro generation unit characteristics (power and efficiency as functions of flow and head), spill, tailwater level and reservoir operations to determine unit generation requirement in any time step. *Vista* can also represent thermal and wind generation, as well as load and market opportunities. The objective of the model is to meet the system load demand in the most economic manner, i.e., operate the entire system in a manner that maximizes system generation to meet system load demand, minimize spill and avoid violation of operational license or constraints. For this wind integration study it was important to capture the hydrologic variability and for that purpose all the available 61 historic inflows were used. The methodology is discussed in more detail below.

The annual load for the selected years was illustrated in section 3.3 Load Forecasts, and is summarized in Table 4-1, below.

x

Table 4-1: System Load Forecasts

Year	Total Annual Load (GWh)		
	LC1	LC2	LC3
2025	10958	11079	11079
2030	**11148**	**12642**	**12948**
2035	11552	**14039**	**17383**
2040	**12021**	14805	18276

In this analyses, the hydraulic and thermal generation resources do not change over the study horizon, only the load and the level of wind generation. Therefore, the analyses were performed using load forecasts for selected years that cover the range of expected load growth. These are as follows :

- 2030 Load Case 1 (11148 GWh)
- 2040 Load Case 1 (12021 GWh)
- 2030 Load Case 2 (12642 GWh)
- 2030 Load Case 3 (12948 GWh)
- 2035 Load Case 2 (14039 GWh)
- 2035 Load Case 23 (17383 GWh)

For each load case, the analyses was performed using 61 years of hydrology and the following wind generation scenarios:

- Base Case (existing system + BDE unit 8)
- Base case + 100 MW of new wind generation
- Base case + 200 MW of new wind generation
- Base case + 300 MW of new wind generation
- Base case + 400 MW of new wind generation
- Base case + 600 MW of new wind generation
- Base case + 800 MW of new wind generation
- Base case + 1000 MW of new wind generation

Each LT *Vista* analysis employed a 5 day time step, with appropriate sub-periods to define weekday, as well as weekend peaks and off-peaks. The 5 day time step was used rather than a week, to facilitate a continuous simulation of each of the focus years using the 61 years of hydrology.

More specifically for each of the wind cases, the methodology was as follows:

- LT *Vista* analysis started on January 1st, using the first (1958) of the 61 years of hydrology and optimized generation until December 31st, in 5 day time steps.
- No end condition was specified for reservoir, but a value of water in storage was used instead. The value of water in storage was based on Holyrood generation costs and reservoir specific water to MW conversion factors.
- The December 31st water levels were then used as start levels for the second analysis, which used 1951 hydrology, then 1952, etc.

The above analysis captures the impact of wind on operations for the range of hydrologic conditions that have occurred in the period 1950 to 2010. Of particular interest are the thermal and hydro generation and spill statistics, in relation to the base case.

4.1 Spill Energy Equivalent

The mechanism used to measure the "Spill Energy Equivalent" associated with increasing wind supply was to monitor the actual spill occurring in the different analysis and converting the spill to an energy equivalent using the energy/water conversion factors. The conversions used to approximate value of spill in terms of MWh is summarized below.

Table 4-2: Energy Conversion Factors

Plant	Conversion Factor (MWh/KCM)
Granite	0.0936
Island Pond	0.0553
Upper Salmon	0.1304
Round Pond	0.0268
Bay D'Espoir	0.4340
Cat Arm	0.9013
Hinds Lake	0.5398
Deer Lake	0.1727
Paradise River	0.0910
Star Lake	0.2980
Buchans	0.0332
Sandy Brook	0.0737
Grand Falls	0.0698
Muskrat Falls	0.0906

5. Results and Conclusions

5.1 Effectiveness of Additional Wind Generation

Each Vista analyses was performed for the 61 years of hydrology. Results were compiled and averaged. Of key importance are :

- Wind energy, available and unused.
- Hydro energy and spill.
- Energy imports, thermal and from market.
- Energy exports.

The base case (existing system + unit 8) includes some additional energy requirements, even with low load forecast and very significant with the high load forecasts. The additional energy required would come from thermal generation, new generation sources and/or imports from mainland.

As more wind generation is injected into system, this wind will displace the additional energy and then be used for energy exports as much as possible with the limited transmission available. Once export opportunity have reach their limits, excess energy has to be spilled or shed for wind generators. The model was configured to shed excess wind generation. However, adding wind generation to the system requires additional regulating reserve (20% of installed wind capacity), and this has to be carried by hydro and will cause additional spill.

Detailed results for each of the load cases are presented in Appendix B, and summarized below.

The total energy exports, wind and hydro along with available and usable wind are illustrated in Figure 5-1 to Figure 5-6 below. There is a clear trend in the ability to absorb (use) the available wind generation increases as the load increases. For small additional wind capacity, the system is able to absorb all the wind, but at some point, there is too much wind and some of it has to be shed. This happens when the available and usable wind lines diverge and it is a function of system load, and this trend is illustrated in Figure 5-7.

For load case 1, significant wind shedding starts around 100 MW of new wind, for load case 2, at 300 MW and for load case 4 at 400 MW. This is also reflected in the exports.

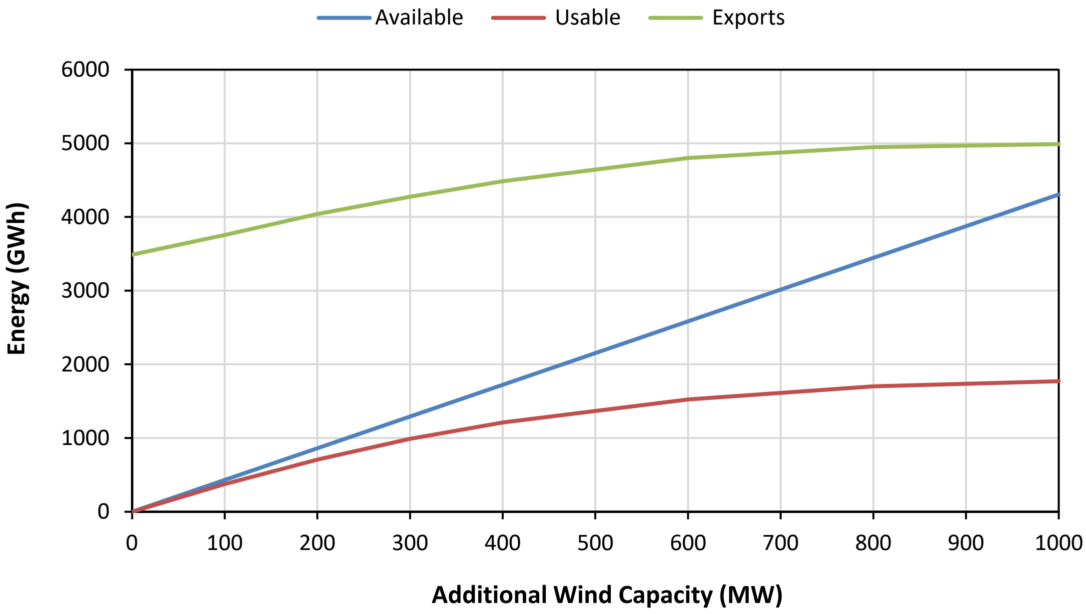

Figure 5-1: Wind Generation and Exports, Load 11148 GWH (2030 L1)

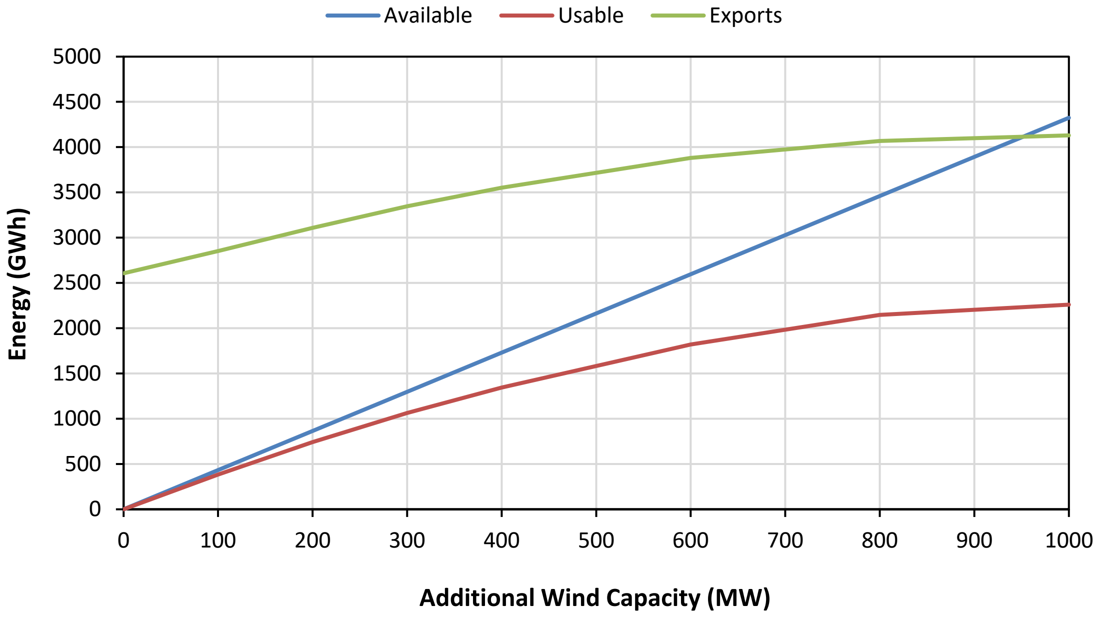

Figure 5-2: Wind Generation and Exports, 12021 GWh (2040 L1)

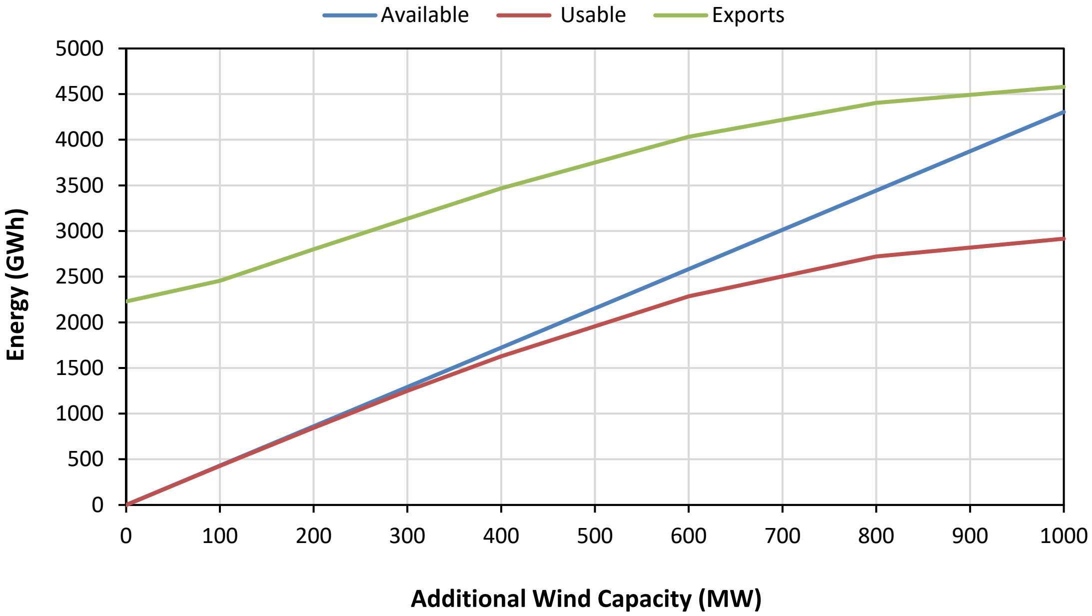

Figure 5-3: Wind Generation and Exports, Load 12948 GWh (2030 L2)

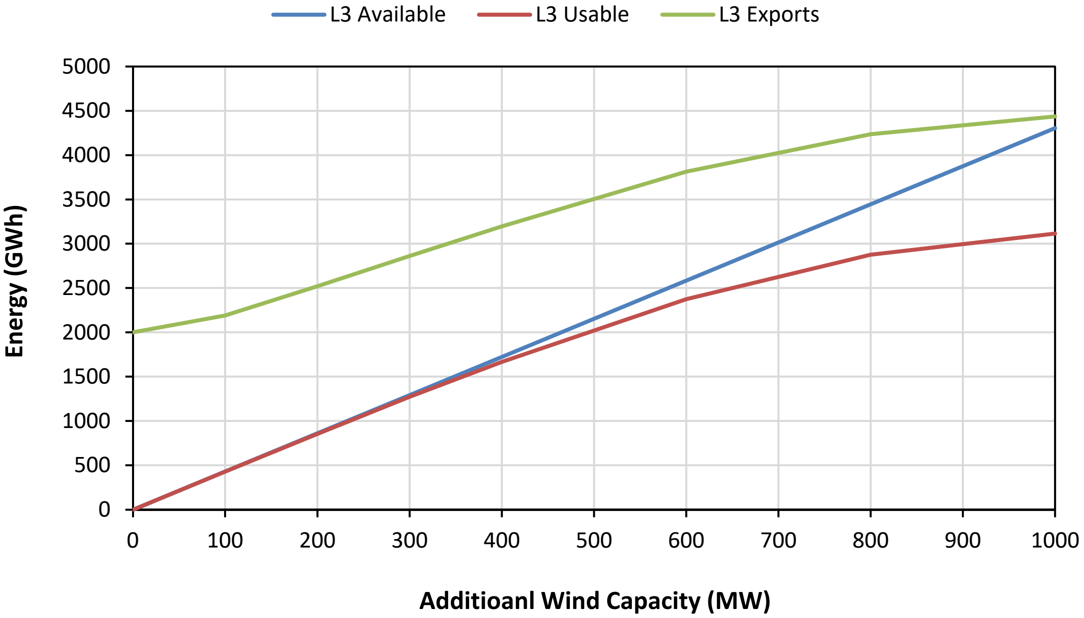

Figure 5-4: Wind Generation and Exports, Load 12948 GWh (2030 L3)

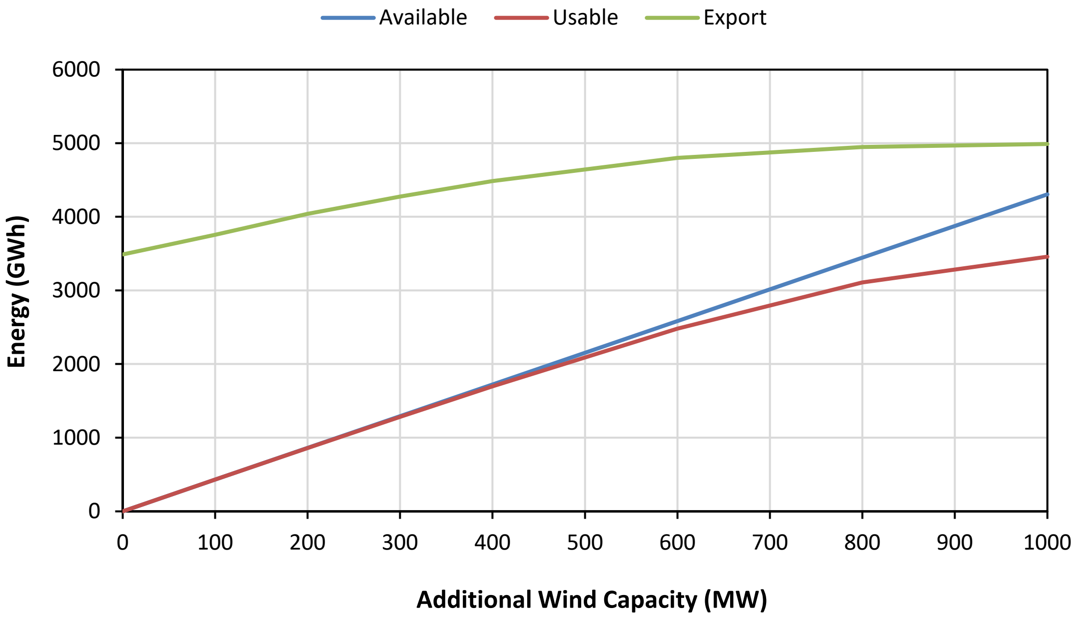

Figure 5-5: Wind Generation and Exports, Load 14039 GWh (2035 L2)

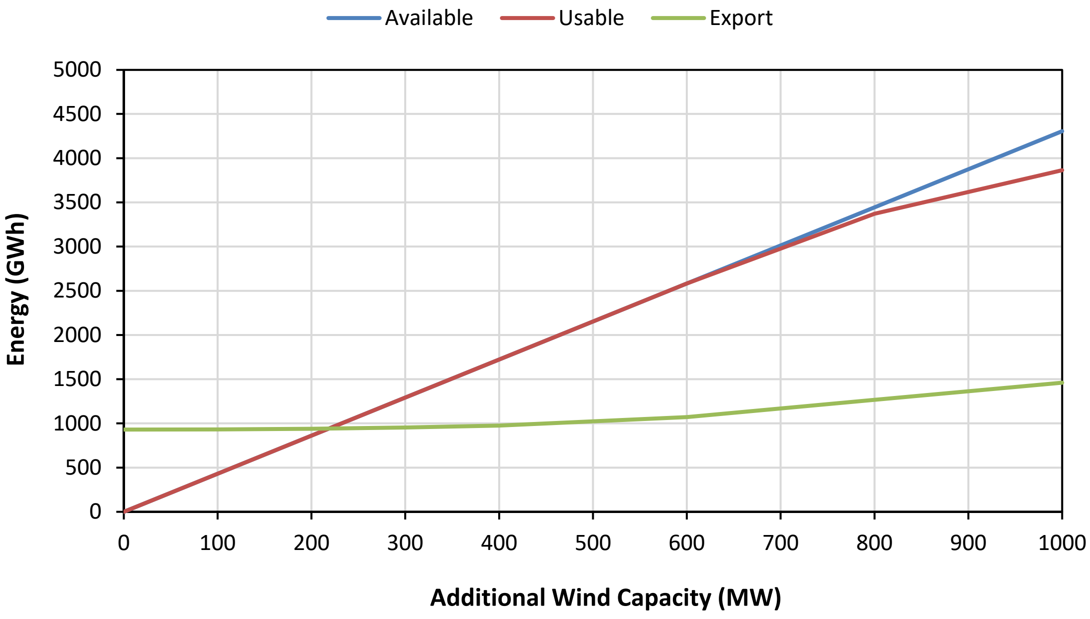

Figure 5-6: Wind Generation and Exports, Load 17383 GWh (2035 L3)

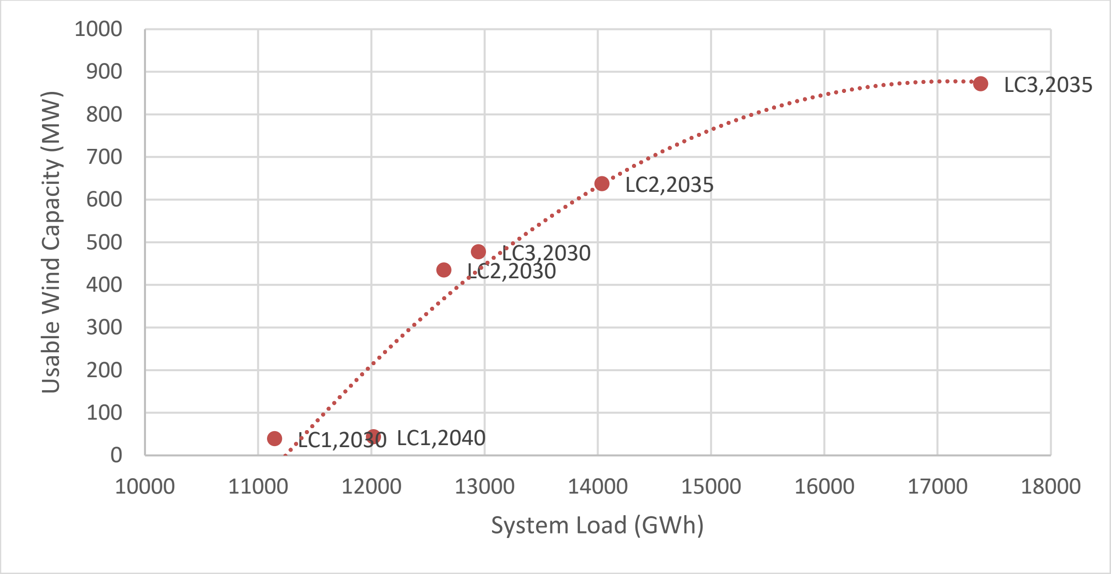

Figure 5-7: Efficiently usable wind capacity versus System Load

The efficiently useable wind in Figure 5-7, refers to additional wind beyond the existing wind capacity and the criteria used is that it represent an installed wind capacity, where 95% of the energy can be absorbed. The useable wind energy versus system load is illustrated in Figure 5-8.

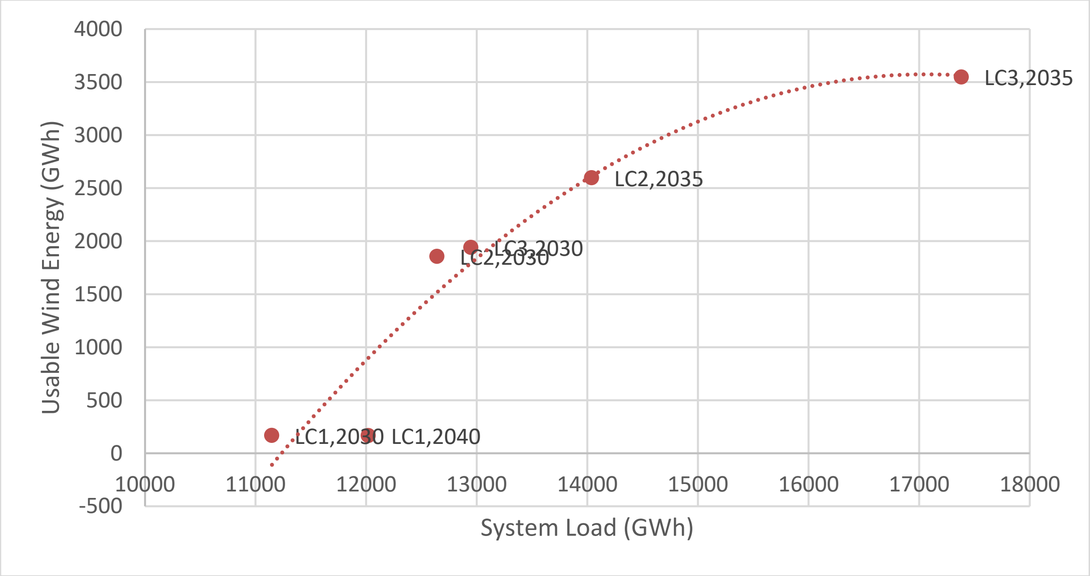

Figure 5-8 Efficiently usable Wind Energy and System Load

Note that the system load of 12021 GWh (LC1,2040) is for load case 1 in 2040. The load forecast for 2040 included some significant reduction in Labrador load due to considerations associated with potential mine closures. This may explain why this point is an outlier in the figure above.

6. Wind Power Production & Technology

6.1 Technology and Characteristics

The selection of turbine type for a site is based primarily on the site's climatic conditions (including wind profile, temperature, wind density, etc.), turbine performance (which depends on its power curve), and wind turbine class.

The wind project site considered in this report is shown in Figure 6-1. Avalon Peninsula is an excellent region for wind projects in Newfoundland. Hatch selected a wind farm site close to the power station (Soldiers Pond, around 5 km). The site is situated 25 km away from the city of St. John's, is accessible through the main roads, and has good wind potential. The main site characteristics are outlined in Table 6-1 below.

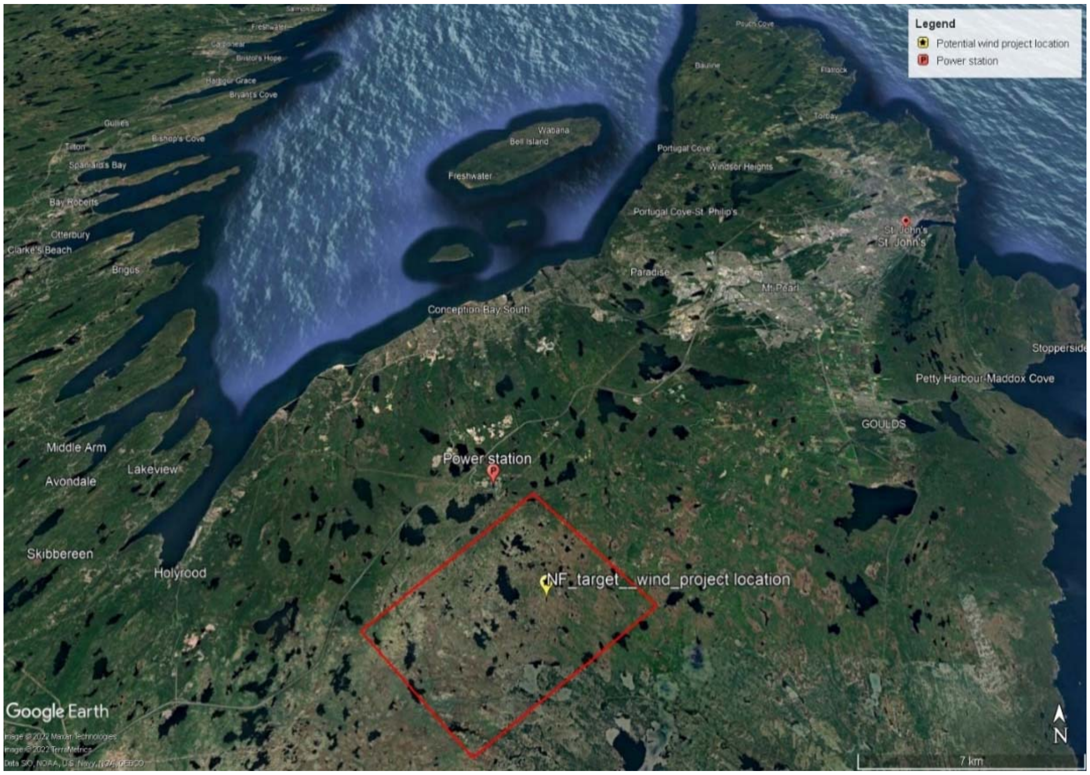

Figure 6-1: Potential wind project location

Table 6-1: Characteristics of potential wind farm site

Latitude	Longitude	Average Site Elevation (m)	Annual Average Wind Speed at 87 m* (m/s)	Annual Minimum Temperature* (°C)	Annual Maximum Temperature* (°C)
47.374°	-52.953°	215	9.86	-18.1	25.6

*Based on Environment and Climate Change Canada (ECCC) 10-min climate data available for this site.

The wind turbine class is a key parameter to determine the optimal type of wind turbine for this site. The International Electrotechnical Commission defines four classes of wind turbines (IEC 61400-1 standard), as shown in Table 6-2. Wind turbine classes are categorized by annual average wind speed (at hub height), 50-year extreme wind speed over 10 minutes, and 50-year extreme gust over 3 seconds.

Wind turbine Class I and Class II correspond to high annual average wind speeds at turbine hub height (8.5 to 10 m/s and 7.5 to 8.5 m/s, respectively). Wind turbine Class III and Class S (IV) correspond to medium and low annual average wind speeds (6 to 7.5 m/s and below 6 m/s, respectively).

Categories A, B, and C designate, respectively, high, medium, and low turbulence intensity characteristics. Turbulence intensity represents the intensity of wind velocity fluctuation. It is defined as the ratio of standard deviation of fluctuating wind velocity to the mean wind speed.

Table 6-2: IEC 61400-1 wind turbine classes

Wind turbine class		I	II	III	S
Annual average wind speed (m/s)		10	8.5	7.5	6
50-year extreme wind speed over 10 minutes (m/s)		50	42.5	37.5	30
50-year extreme gust over 3 seconds (m/s)		70	59.5	52.5	42
Turbulence intensity	A	0.16			
	B	0.14			
	C	0.12			

As mentioned in Table 6-1, the selected site has an average annual wind speed of 9.86 m/s at an 87-m hub height. This denotes that the suitable wind turbine class for this site must be Class I. However, on a case by case basis and in validation with the vendors, a Class IIA turbine could qualify as a Class IB or IC. A Class II wind turbine is generally cheaper, with longer blades and greater yield.

There are few manufacturers who offer Class I onshore turbines (powerful turbines which are designed to survive at very high wind speeds).

Hatch carried out a review of wind turbines best suited to the site selected. Table 6-3 shows a summary of Class I turbines that can be installed at this site.

Gearless (direct drive) wind turbine technology employs a low-speed generator, with variable speed, that eliminates the need for a gearbox in the turbine’s drive train. This type of technology is less complex (compact nacelle design) than gearbox technology, leading to easier operation and lower maintenance costs.

As shown in Table 6-3, the manufacturers Enercon and Lagerwey supply a gearless wind turbine technology. Moreover, Enercon wind turbines have a large range of wind speed for energy production, with a cut-in speed of 2.5 m/s and cut-out speed of 34 m/s (see power curve of E-115-4.2 model illustrated in Figure 6-2). Therefore, these turbines can produce energy even for wind speeds greater than 25 m/s, which is the maximum cut-out wind speed of other turbine models.

Based on these points, the Enercon E-115-4.2 wind turbine model has been selected for this report, in order to provide specific information.

Table 6-3: Class I wind turbine models

Turbine Model	Manufacturer	Rated Power (MW)	Class	Gearbox	Cut-In (Cut-Out) Wind Speed (m/s)	De-Icing	Hub Height (m)	Low Temperature (-30 °C)
V105-3.45	Vestas Wind Systems A/S	3.45	IEC IA	Yes	3(25)	Yes	72.5	Yes
V112–3.45	Vestas Wind Systems A/S	3.45	IEC IA	Yes	3(25)	Yes	69/94	Yes
E-70-2.3	Enercon GmbH	2.3	IEC IA	No	2.5(34)	Yes	57/64/75	Yes
E-82-2.35/3	Enercon GmbH	2.35/3	IEC IA	No	2.5(34)	Yes	78/84	Yes
E-115-4.2	Enercon GmbH	4.2	IEC IA	No	2.5(34)	Yes	87	Yes
L136-4.5	Lagerwey Wind	4.5	IEC IA	No	2.5(25)	Yes	120/132	Yes
SG 5.0-132	Siemens Gamesa	5	IEC IA	Yes	N/A	Yes	84	Yes
GE 4.2-117	GE Renewable Energy	4.2	IEC IA	Yes	N/A	N/A	135 to 169	N/A
GE 1.5-77	GE Renewable Energy	1.5	IEC IB	Yes	N/A	N/A	65/80	N/A
N80-2.5	Nordex SE	2.5	IEC IA	Yes	3(25)	Yes	60/70/80	Yes
C89-2.5	Clipper Windpower	2.5	IEC IA	Yes	3.5(25)	N/A	80	N/A

*N/A: Information is not available

The wind turbines to be installed in Newfoundland require a de-icing system, to detect and remove ice formed on turbine blades during winter, and allow the turbines to operate at full power. They should also be able to operate at low temperatures (at least -18.1 °C, which is the annual minimum temperature in the selected site). Other technical requirements are discussed in Section 6.4.

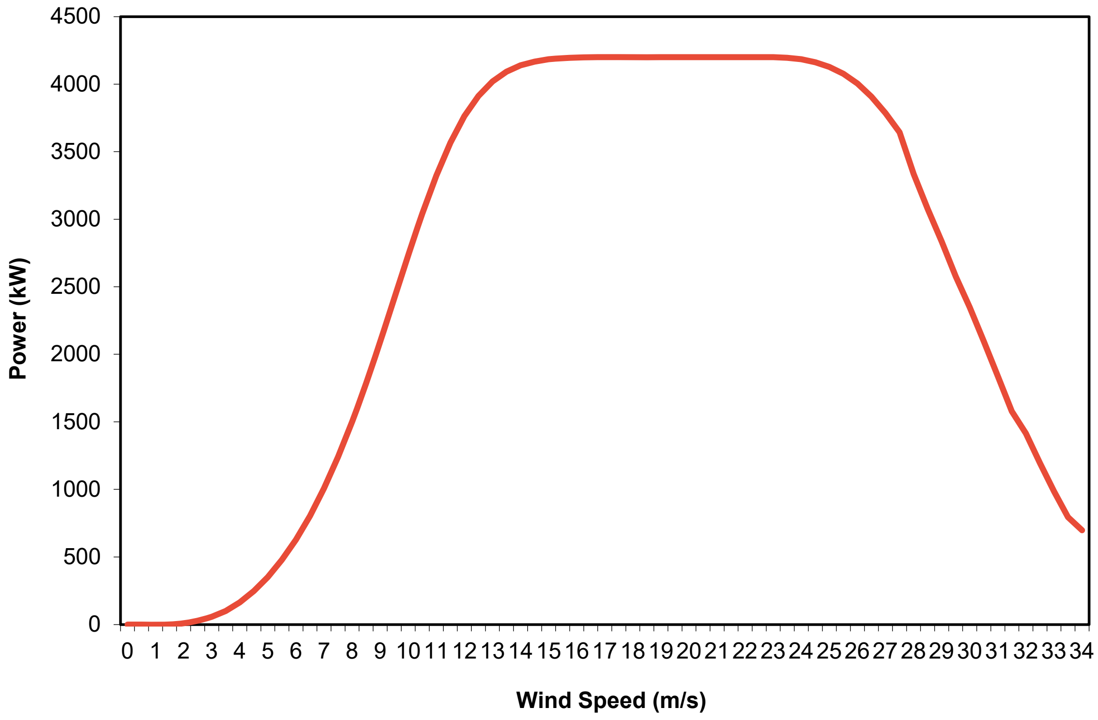

Figure 6-2: E115-4.2 MW turbine model power curve

6.2 Energy Production

The energy production for the Enercon E-115 4.2 MW wind turbine is provided in this section, based on the turbine key characteristics shown in Table 6-4.

Table 6-4: Key parameters considered for energy production calculation

Parameter	Value
WTG Model	Enercon E-115-4.2
WTG Rated Power	4.2 MW
WTG Rotor Diameter	115 m
WTG Hub Height	87 m
WTG Power Curve	See Figure 6-2
Number of Wind turbines	24
Wind Farm Capacity	100.8 MW

The typical types of wind farm production losses are listed in Table 6-5.

Table 6-5: Assumed typical losses for energy production calculation

Losses type	Value
Collection network	3.0%
Auxiliary power	1.5%
Availability	3.0%
Hysteresis	0.0%
Collection network outages	0.5%
Grid outages	0.2%
Icing	2.0%
Soiling	1.5%
Low temperature	0.0%
Wake losses	3.0%
Total losses	**13.8%**

The monthly average wind speed and wind direction at the Avalon site are shown in Figure 6-3 and Figure 6-4 below.

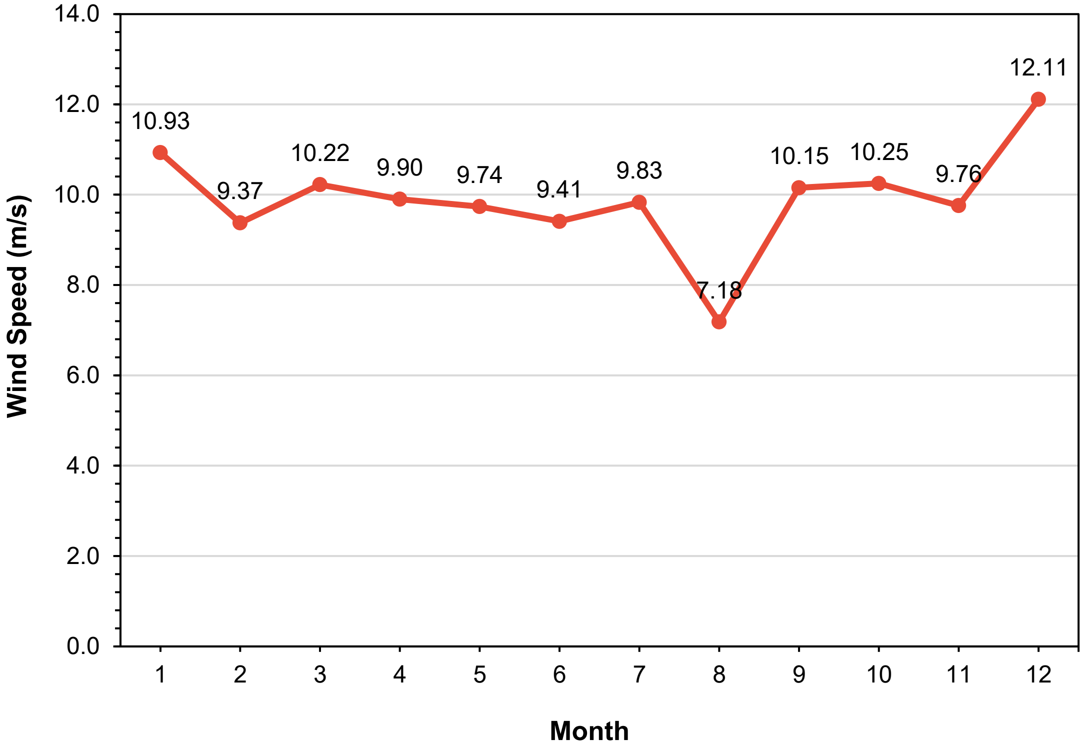

Figure 6-3: Monthly average wind speed (m/s) (at 87 m)

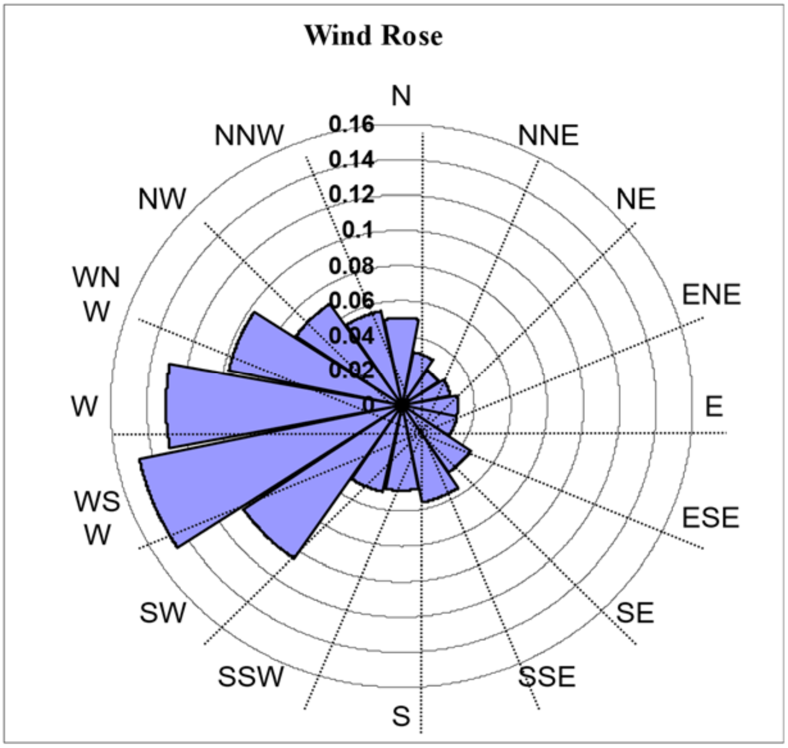

Figure 6-4: Wind rose of the selected site

The resulting typical monthly energy production for a wind farm of 100.8 MW is shown in Figure 6-5 and Table 6-6 below.

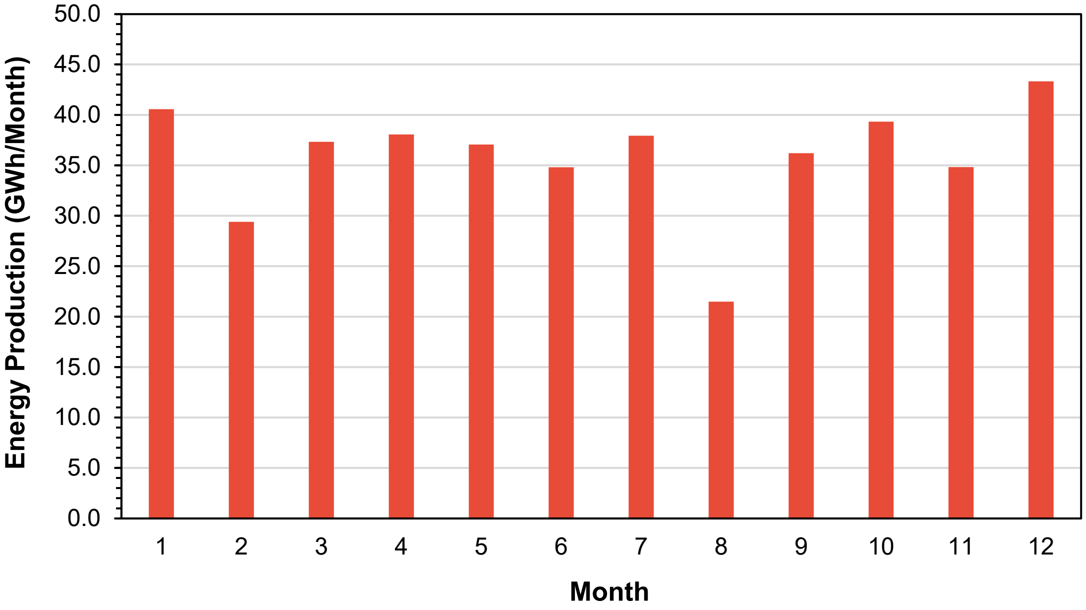

Figure 6-5: Monthly net energy production (GWh/month)

Table 6-6: Summary of wind energy production

Month	Average Monthly Wind Speed (m/s) (at 87 m)	Maximum Monthly Wind Speed (m/s) (at 87 m)	Minimum Monthly Temperature (°C)	Maximum Monthly Temperature (°C)	Monthly Net Energy (GWh)	Monthly Capacity factor
Jan	10.69	20.29	-18.1	10.8	40.566	54.1%
Feb	9.18	23.01	-15.8	9.6	29.397	43.4%
Mar	10.04	20.49	-13.4	10.6	37.325	49.8%
Apr	9.77	19.03	-8.7	13.6	38.051	52.4%
May	9.62	19.90	-1.6	19.2	37.053	49.4%
Jun	9.36	20.49	1.7	25.6	34.809	48.0%
Jul	9.85	18.06	6.0	24.8	37.928	50.6%
Aug	7.19	15.15	8.4	25.0	21.491	28.7%
Sep	10.13	30.68	2.4	24.7	36.209	49.9%
Oct	10.17	22.04	-5.0	19.6	39.325	52.4%
Nov	9.62	21.17	-6.3	14.4	34.822	48.0%
Dec	11.95	29.61	-17.1	13.5	43.321	57.8%
Annual	**9.86**	**30.68**	**-18.1**	**25.6**	**430.299**	**48.7%**

6.3 Wind Farm Cost Estimate

Hatch has completed an indicative cost estimate for a 100 MW wind facility, including both capital and operating expenditures. The estimates have been done using previously acquired vendor quotations, Hatch expertise, and in-house tools. The results are summarized in Table 6-7 below, with more detailed assumptions provided in the following sections. These are high-level estimates which will be refined as the project is further developed.

Table 6-7: Summary of cost estimates for 100 MW wind farm

Estimate	Value
Capital Expenditure (CAPEX)	$194,949,000 ($1,950 per kW)
Operating Expenditure (OPEX)	$5,948,000 per year ($59.5 per kW per year)
Levelized Cost of Electricity (LCOE)	4.67 ¢/kWh based on a 6% discount rate

6.3.1 CAPEX

The capital expenditure estimate consists of construction costs, indirect costs, and contingency. The estimate was prepared assuming the use of Enercon E115, 4.26 MW turbines; a total of 24 turbines would be employed to achieve a 100 MW capacity. However, this is a preliminary assumption and may change over the course of the project.

Typically, CAPEX for similar wind farms would range from $1500-3000/kW. Assuming this is a relatively flat sight without major obstructions and suitable geotechnical conditions for a gravity-based foundation, it is safe to assume approximately $2000/kW as a CAPEX for this project. In addition, it is assumed that the turbine manufacturer would provide a discount (up to 30%) when ordering a large quantity of turbines. The CAPEX estimate is summarized in Table 6-8.

Table 6-8: Summary of CAPEX estimate for 100 MW wind farm

Item	Description	Total, CA$	Comments
	CONSTRUCTION COSTS		
1	**Turbine Generators**		
1.1	Turbine supply, inc. transport from port to site	65,000,000	For 24 turbines
1.2	Turbine transport from Germany to Canada	6,441,492	For 24 turbines
1.3	Turbine assembly, crane cost and tower erection	5,473,500	For 24 turbines
1.4	Turbine assembly, in-tower mechanical/electrical	3,204,000	For 24 turbines
	Total - Turbine Generators	**80,118,992**	**3,338,000 $ / turbine**
2	**Construction Indirect & General Items, Civil and Electrical**		
2.1	General Costs / Supervision & Site Cost	854,400	
2.2	Surveying	569,600	
2.3	QA/QC Subcontract	0	Included in rates below
	Total Construction Indirect & General Items	**1,424,000**	**59,000$ / turbine**
3	**Civil Works**		
3.1	New Access Roads	4,981,553	332,000 $ / km (assuming 15 km of access road)
3.2	Crane Pads and Erection Areas	1,420,013	59,000 $ / turbine
3.3	Foundation for Wind Turbines	38,407,992	1,600,000 $ / turbine
	Total Civil Works	**44,809,557**	**1,867,000 $ / turbine**
4	**Electrical Works**		
4.1	Transmission line 138 kV	6,500,000	5 km
4.2	Collector network 34.5 kV	22,500,000	15 km total collector system
4.3	Transformer including breaker 138 kV	3,500,000	
4.4	E-House c/w switchgear 34.5 kV	2,000,000	
	Total Electrical Works	**34,500,000**	
	TOTAL CONSTRUCTION COSTS	**160,852,550**	**1,609 $ / kW**
	INDIRECT COSTS		
5	**Engineering & Project Management & Site Supervision**	5,464,600	
6	**Owner Capital Investment in Operations Support**	2,358,500	

7	**Accommodation / Mess & Travel Costs**	623,000	
8	**Temporary Construction Facilities**	222,500	
	TOTAL INDIRECT COSTS	**8,668,600**	**87 $ / kW**
	CONTINGENCY		
9	**Owners Contingency**		
	Owners Contingency (Intended to be P50)	25,428,172	Contingency of 15%
	Total Contingency	**25,428,172**	
	TOTAL	**194,949,322**	**1,949 $ / kW**

6.3.2 OPEX

The operating expenditure estimate consists of fixed and variable operating costs and was done for a 30-year lifespan. The Table 6-9 below summarizes the OPEX estimates.

Table 6-9: Summary of OPEX estimate for 100 MW wind farm

Parameter	**Annual Cost**
Fixed Operating Costs	
Administrative expenses (finance, lawyers, miscellaneous)	$200,000
Expenses (utilities, snow removal, access road maintenance, internet)	$400,000
Insurances	$700,000
Payroll (5 people)	$600,000
Turbine service agreement	$1,680,000
Remote 24/7 monitoring services	$150,000
Community local technician support	$100,000
External engineering consultant	$200,000 (Year 1) $130,000 (Year 2) $100,00 (Year 3-30)
Total Fixed Operating Cost	**$4,030,000 (Year 1)** **$3,960,000 (Year 2)** **$3,930,000 (Year 3-30)**
Variable Operating Cost	
Repairs/spare parts inventory	$2,524,594
Major maintenance (change all blades and gearboxes at Year 15)	$19,060,000 (Year 15) $9,700,000 (Year 16)

Total Variable Operating Cost	**$2,524,594 (Years 1-14, 17-30)** **$21,584,594 (Year 15)** **$12,224,594 (Year 16)**
TOTAL	
Total Operating Cost (Fixed + Variable)	**$5,948,000**
Annualized Average	**$59,5/kW**

6.3.3 *Levelized Cost of Electricity (LCOE)*

The levelized cost of electricity represents the average net present cost of the energy generated over the lifetime of the asset. It was calculated using the parameters and assumptions outlined in Table 6-10 below.

Table 6-10: Summary of LCOE calculation parameters for 100 MW wind farm

Parameter	Value
Period (years)	30
Discount rate (%)	6%
Energy produced in one year (GWh)	430, see **Table 6-6**
CAPEX (M$)	194.9
OPEX for one year (M$)	6.0
Results	
LCOE (¢/kWh) with discount rate	**4.67**

6.4 Wind Power Integration Technical Requirements

The integration of a wind farm to the grid has a large impact on grid stability and system reliability. The increase in penetration of wind energy into the power system leads to significant concerns about its influence on transient/dynamic stability, harmonics, voltage and short circuit levels.

In order to maintain reliable grid performance, it is necessary for the Newfoundland and Labrador System Operator (NLSO) to specify wind power integration technical requirements. The following sections provide the most important requirements for wind power integration into the NLH grid.

6.4.1 *Voltage Regulation and Reactive Power Control*

The equipment of the utility and other consumers are designed to operate at specific voltage levels. Therefore, the grid voltage levels should be maintained within a very narrow range, so as not to damage the equipment.

Under normal conditions, the transmission system must operate such that the voltage is maintained between 95% and 105% of nominal voltage. During grid contingency (“N-1 Event”), the transmission system voltage is permitted to vary between 90% and 110% of nominal voltage. Wind farms should have the capability to regulate voltage and stay within these acceptable ranges.

Wind farms must also have reactive power control capabilities to support the Point of Common Coupling voltage (PCC) during voltage fluctuations. They must also be able to assist the correction of reactive power demand on the grid (power factor correction) by dynamically controlling the amount of reactive power (D-VAR) injected into the transmission system. The voltage at the PCC can be increased by injecting reactive power to the grid, and can be decreased by absorbing it. The wind farms should have reactive power capabilities to meet a power factor requirement of at least 0.9, lead or lag.

6.4.2 Frequency Stability

The balance between power generation and load consumption gives an indication about power system frequency stability. For example, in the case of a sudden decrease in the load (or unexpected loss of wind turbine generation), the frequency of the produced voltage increases, and is restored back to the nominal value when power production is decreased by primary control. Thus, any deviation from the planned consumption and/or production moves the system frequency away from its nominal range.

Wind farms must be capable of operating continuously within the frequency variation range encountered in normal operating conditions. In addition, wind turbines should have the ability to remain connected for a minimum time specified (frequency ride-through, FRT, as mentioned in Figure 6-6), usually at a lower power output. In this case, the wind farm can support the utility power system during events and allow for a fast system frequency restoration. For this reason, wind turbine manufacturers must appropriately design their generators as abnormal frequencies can overheat generator windings or damage power electronic devices.

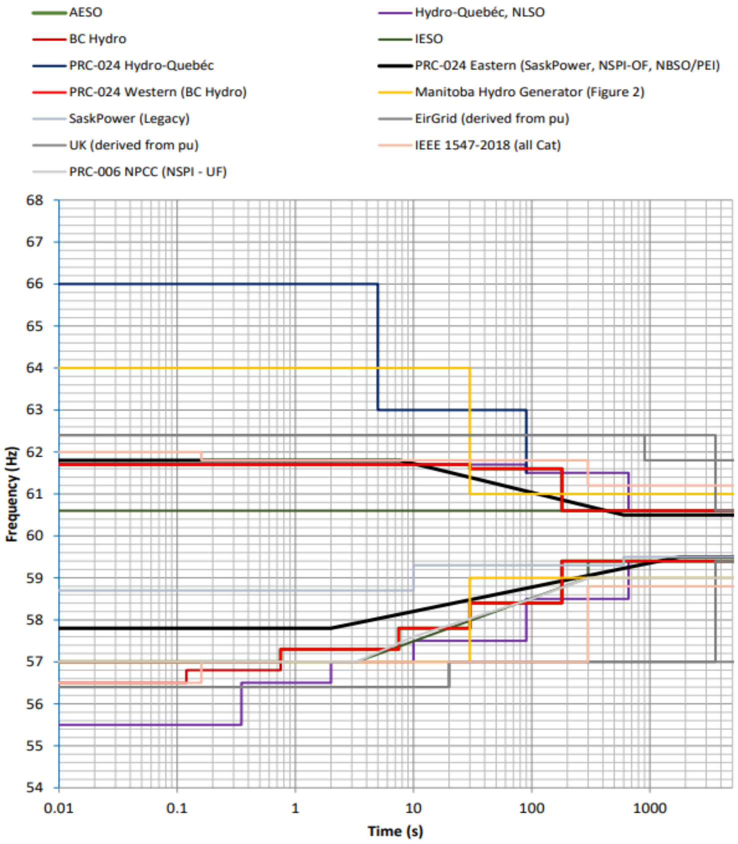

Figure 6-6: Frequency ride-through requirements in Canada[1]

6.4.3 Short Circuit Ratio Requirements

The Short Circuit Ratio (SCR) indicates the amount of power that can be accepted by the power system without affecting the power quality and is defined as follows:

$$SCR = \frac{S_{SCMVA}}{P_{RMW}}$$

S_{SCMVA} - the short-circuit MVA capacity at the bus in the existing network before the connection of the new generation source.

P_{RMW} - the rated megawatt value of the new connected source.

The Short Circuit Ratio should be greater than 3, which is the limit for a weak grid.

6.4.4 Active Power Control

To prevent overloading of transmission lines, ensure a stable frequency on the system, and minimize the effect of the dynamic operation of wind turbines on the grid, the transmission system operators generally request active power curtailment. In this case, the wind farm should have an active power control to avoid an impact to the transmission system.

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[1] GE Energy Consulting. (2021) Canadian Provincial Grid Code Study. Schenectady, New York, USA

The wind farm should have the ability to regulate their active power output to a defined level (maximum power output) and at a defined ramp rate (maximum ramp rate control), by controlling the pitch angle of the blades to limit the power output from the wind turbines, or by disconnecting some wind turbines. The wind farm should also have the ability to vary its active power ramp rate in the range of 10% to 100% of rated power per minute.

An interesting feature added recently in wind turbines is the inertia emulation. This emulator uses the accumulated kinetic energy in the wind turbine shaft to provide a temporary increase of the active power injected to the grid. This helps to support the grid in case of frequency deviation, by injecting active power proportional to the system frequency drop rate. The corresponding active power increase depends on wind conditions; in case of unfavorable wind speeds, it is possible that the active power increase might not be sufficient.

The inertia emulation control (required) can contribute to reliability and stability of power grid by enabling short-term active power (e.g. increase of 10% of nominal power). This feature is very helpful in primary control due to the quick available reserve power in the event of frequency deviations.

6.4.5 Low Voltage Ride Through (LVRT) Capability

Low-Voltage Ride-Through (LVRT) capability is the ability of wind generators to remain connected to the grid during a voltage dip caused by a fault. The wind farms should have the capability to follow the requirement of LVRT as illustrated in Figure 6-7. This helps to support the grid during and after a fault. This is one of the most important requirements regarding wind farm operation that has been recently introduced in grid codes. As in the past, when wind farms were allowed to disconnect unconditionally from the grid in the case of disturbances events, this simultaneous disconnection of wind turbines could cause larger voltage depression and worsen the situation. Therefore, this capability is important for reliable and stable operation of grid power supply, especially in cases with high penetration of wind power production.

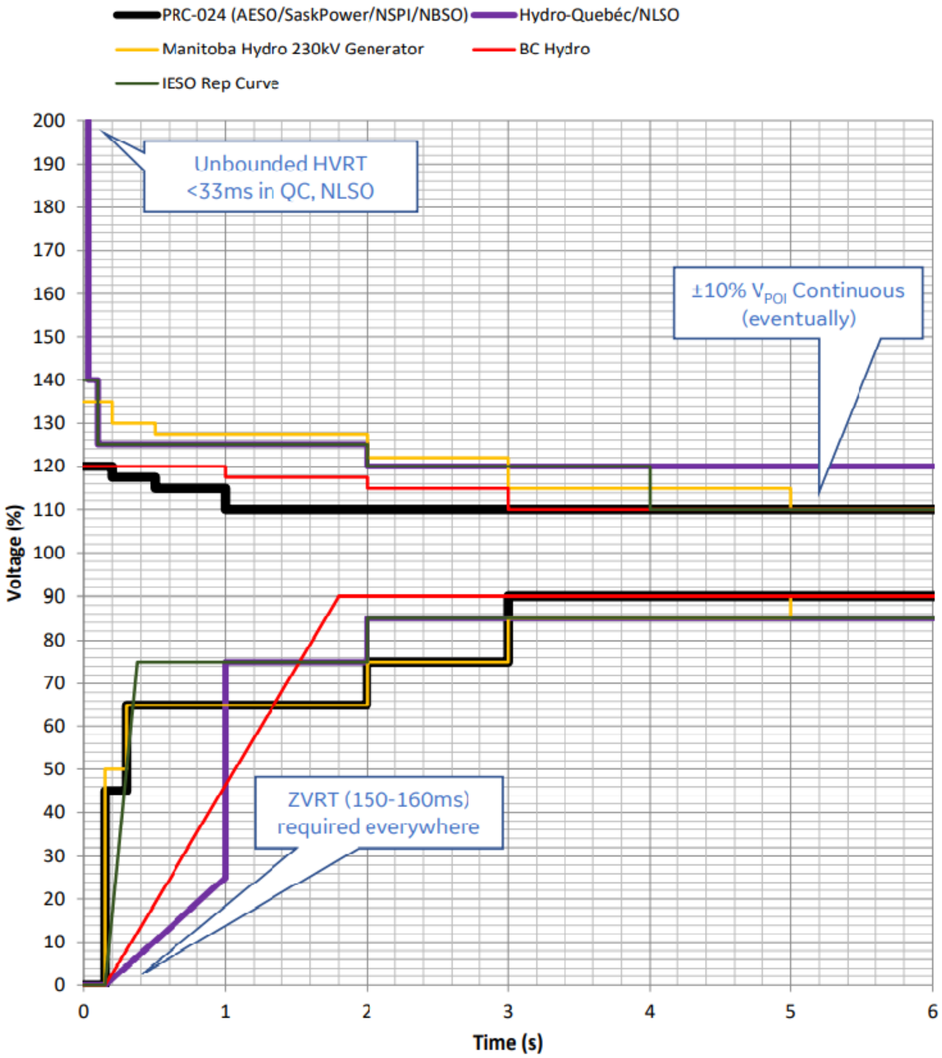

Figure 6-7: Low Voltage Ride Through (LVRT) requirements in Canada

6.4.6 *Island Mode Operation Capability*

Island mode operation capability is the ability of the wind farm to operate in idle mode without being connected to the grid (e.g., blackout, periods of grid maintenance, etc.). Idle mode means the capability of the wind farm to produce enough electricity for its auxiliary systems only (oils pumps, light loads, motors, communications devices, etc.) without the existence of the grid. This state lasts until the islanded wind turbine can be reconnected to the grid. An islanded wind farm can only reconnect to the grid when permission is given by the NLSO.

6.4.7 Wind Power Curtailment and Cut-In and Cut-Out Speed

Wind Turbine technology produces power which is a function of the wind speed. Typically, below a threshold value called the Cut-In speed (typically 3 m/s) and above a threshold value called the Cut-Out speed (typically 25 m/s), wind power production stops.

To minimize the impact of wind power variation on NLH grid, the following is favored:

- Cut-Out speed as high as possible (at least 25 m/s and above).
- Wind turbines should be automatically derated progressively as the wind speed approaches the Cut-Out speed. For example: Between 25 to 34 m/s. This would prevent a major wind farm power drop if a high wind speed front hits the wind farm causing all wind turbines to stop suddenly.

6.5 Wind Power High-Speed-Low Speed and Non-Availability Incidences

Shown in Figure 6-8 and Figure 6-9 are the number of times (on a 10-min basis) that the wind speed is above (or below) the cut-out (or cut-in) speed of the wind turbine.

Cut-out events are significant at and above 25 m/s. If a wind front of wind speed of 25 m/s hits the wind farm, one can see progressively over 10 to 20 minutes the entire wind farm stopping, which was previously operating at full capacity. So, for a 100 MW wind farm, you could lose up to 100 MW in 10 to 20 minutes, up to 74 times during the year.

The higher the cut-out speed of the turbine, the smaller the frequency of occurrence. For instance, the Enercon turbine, equipped with a storm control system and a cut-off speed of 34 m/s, would not experience cut-out speed events, but would see a continuous wind power decrease as the wind speed increases (as shown in Figure 6-2).

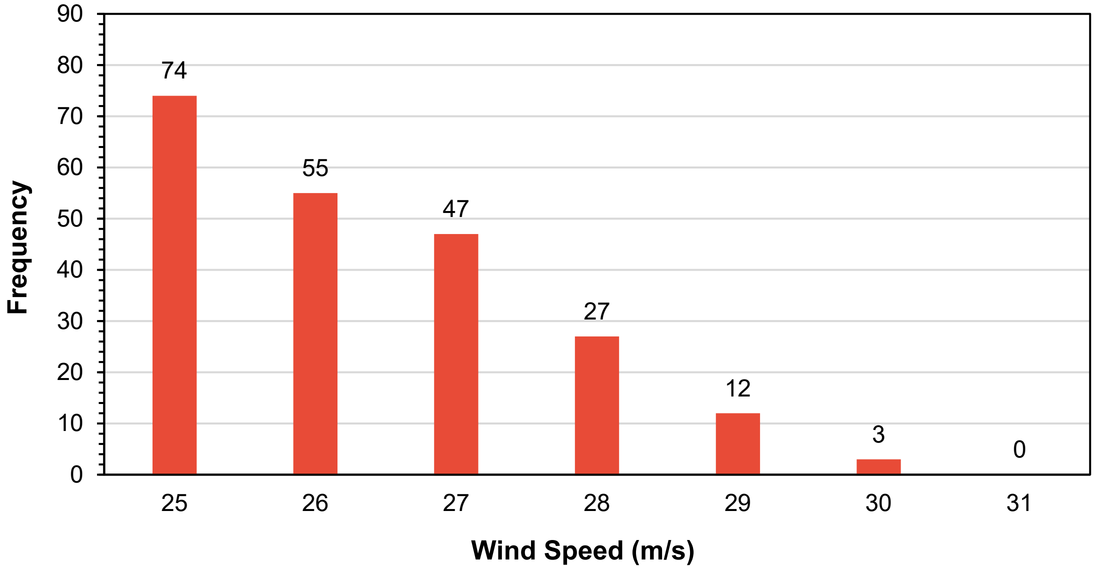

Figure 6-8: Cut-out speed event

The cut-in speeds are significantly more frequent. At the cut-in speed, a 100 MW wind farm would be producing about 1 MW of power. Thus, if the wind speed decreases below the cut-in speed, the power losses are quite small and progressive in time (it is not instantaneous).

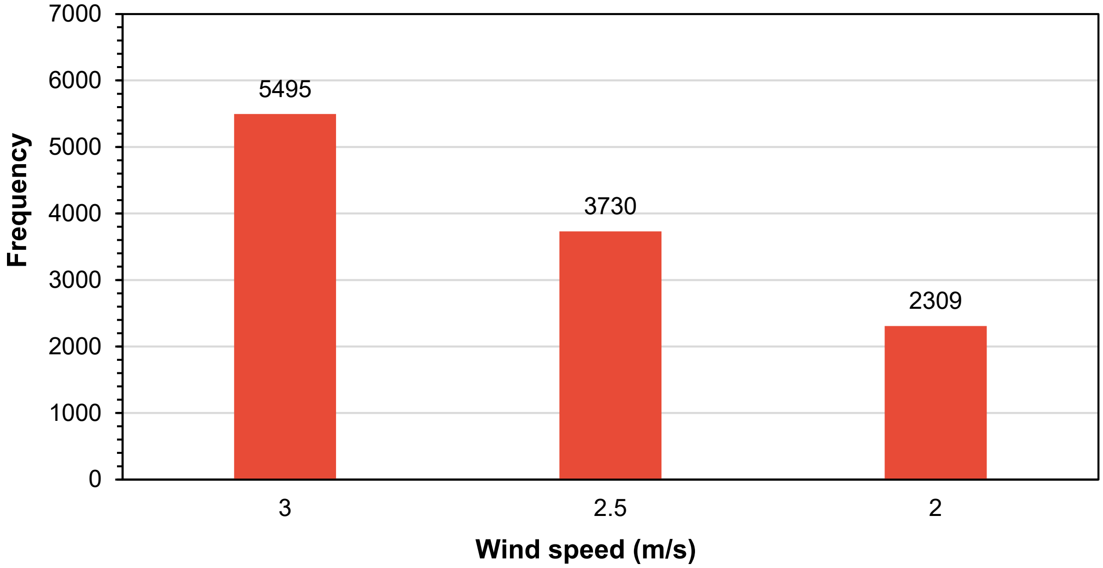

Figure 6-9: Cut-in speed event

6.6 Self-Power Supplier

This section focuses on customers that have a production facility that is self-supplied, behind the meter with renewable power such as wind power.

These customers might still desire to have an interconnection to the Newfoundland and Labrador Transmission System as a secondary supply.

The following key points to be considered:

- The production facility has an electrical load.
- The load can be self-supplied by renewable power.
- Whenever the renewable power is above the load, the customer might have to self-curtail its renewable power production as NLH might not be able to absorb this excess power.
- Whenever the renewable power is below the load, the customer might have to reduce the production as NLH might not be to provide the plant power requirements. Even at the plant minimal production capacity, if there is not sufficient renewable power, the customer may require back-up generation if NLH does not have capacity available or their load will be curtailed.

6.7 Annual load profile for a self-supply customer

This section describes an example of a self supply customer developing a hydrogen/ammonia plant with power input from wind generation.

The following case is evaluated as an example.

- 500 MW electrolyser.
- 1,293 MTPD (Metric Tonne per day) of ammonia production.
- Total plant power requirement at 100% capacity factor is approximatively equal to 550 MW (500 MW electrolyser + 35 MW ammonia plant + 15 MW auxiliaries and balance of plant).
- Total plant requirement when operating at minimum capacity:
  - Typically an electrolyser is operated at 10% capacity factor minimum.
  - The ammonia plant is operated at 30% capacitor factor minimum.
  - At the minimum operation 80 MW (10% of 500 MW, 55% of 35 MW + auxiliaries) of power is required. The 55% is estimated based on a reduction of electricity needed by the Harbor process and the Air Separation Units (ASU) producing the nitrogen. The ASU generating the nitrogen can not ramp down below 75%.
- 950 MW Wind Farm.

A typical operation strategy is to let the electrolyser production follow that wind power:

- When the wind power is above 550 MW, the electrolyser and ammonia plant are producing at 100% capacity factor. At maximum wind power of 950 MW, there is 400 MW of excess wind to be curtailed or potentially be exported to the grid.
- When the wind power is below 550 MW, the electrolyser and ammonia production is reduced or additional power is potentially supplied by the grid on a non-firm basis
- The electrolyser can reduce its production down to 10%, and the ammonia plant down to 30%. At that turn down ratio, the power requirement of the plant is approximatively equal to 80 MW (as above). If the wind farm produces less than 80 MW, than the deficit to keep the plant running becomes a grid load: thus in the worst case scenario, the hydrogen/ammonia plant can ask up to 80 MW (firm) from the grid.

Figure 6-10 shows, on an hourly basis over 12 months that the hydrogen/ammonia load follows the wind power (blue line). The wind power production profile has been developed with simulated wind speed data based on weather station data for a wind farm i located within the Avalon Peninsula region.

When the wind power is above 550 MW, the line in grey shows the wind power excess goes up to about 400 MW and to a max of 950 MW if the hydrogen/ammonia plant is shutdown. The amount of excess wind power to the grid will be established as part of the system impact study.

When the wind power is below 80 MW, the yellow line shows the grid support request which varies from 0 MW to 80 MW. Depending on time of year NLH may be able to supply more than 80 MW.

Figure 6-11 shows the same data for a 3 day period instead of a full year. In this case, we see that during February 12 to 13, the wind power was very low, causing the ammonia plant to shutdown for 24 hours (on February 14, Figure 3-4 shows excess wind because the hydrogen and ammonia plant are stopped).

Key points:

- For a project with a 550 MW maximum power demand, only 80 MW is requested from the grid on a firm basis. Thus the project developer might prefer to only invest in a 80 MW interconnection as opposed to 550 MW since the NLH might not be capable of supplying that demand at certain periods of the year. As part of the system impact study performed by NLH, it can be determined how much power is available (firm and non-firm) during different periods of the year to determine the appropriate capacity of the interconnection with the grid.
- Similarly, with excess wind power up to 400 MW, the grid cannot purchase all this surplus of power, since it may not be economical to develop a transmission line that can support 400 MW., and the wind power is simply curtailed. The amount of excess wind to the grid will be established as part of the system impact study and would be location specific.
- The hydrogen/ammonia plant load requirement from the grid for this example is as follows (the plant is following the wind power):
    - Grid Load requirement > 0 MW for 1278 hours (14.5%); this implies that 85.5% of the time, the proponent does not require power from the grid.
    - Grid Load requirement >10 MW for 748 hours (8.5%); this implies that 81.5% of the time, the load requested is smaller than 10 MW, etc.
    - Grid Load requirement >20 MW for 660 hours (7.5%).
    - Grid Load requirement >40 MW for 556 hours (6.3%).
    - Grid Load requirement >75 MW for 143 hours (1.6%); the load requirement by design, in this example, is always smaller or equal to 80 MW.
- An hydrogen/ammonia plant interconnected to the grid with limited capacity of 80 MW (or other small value), with a wind farm of 950 MW connected behind the meter, will have limited impact on the grid if it trips or if the wind power production drops significantly rapidly. In any case, the wind farm should be designed such it cannot lose more than 155 MW instantaneously.
- The new proponent might consider energy storage for better operation of its plant with self-supply of wind power behind the meter.

- The renewable power curtailment might be able to be reduced when wind power can be integrated or as the result of the System Impact Study.

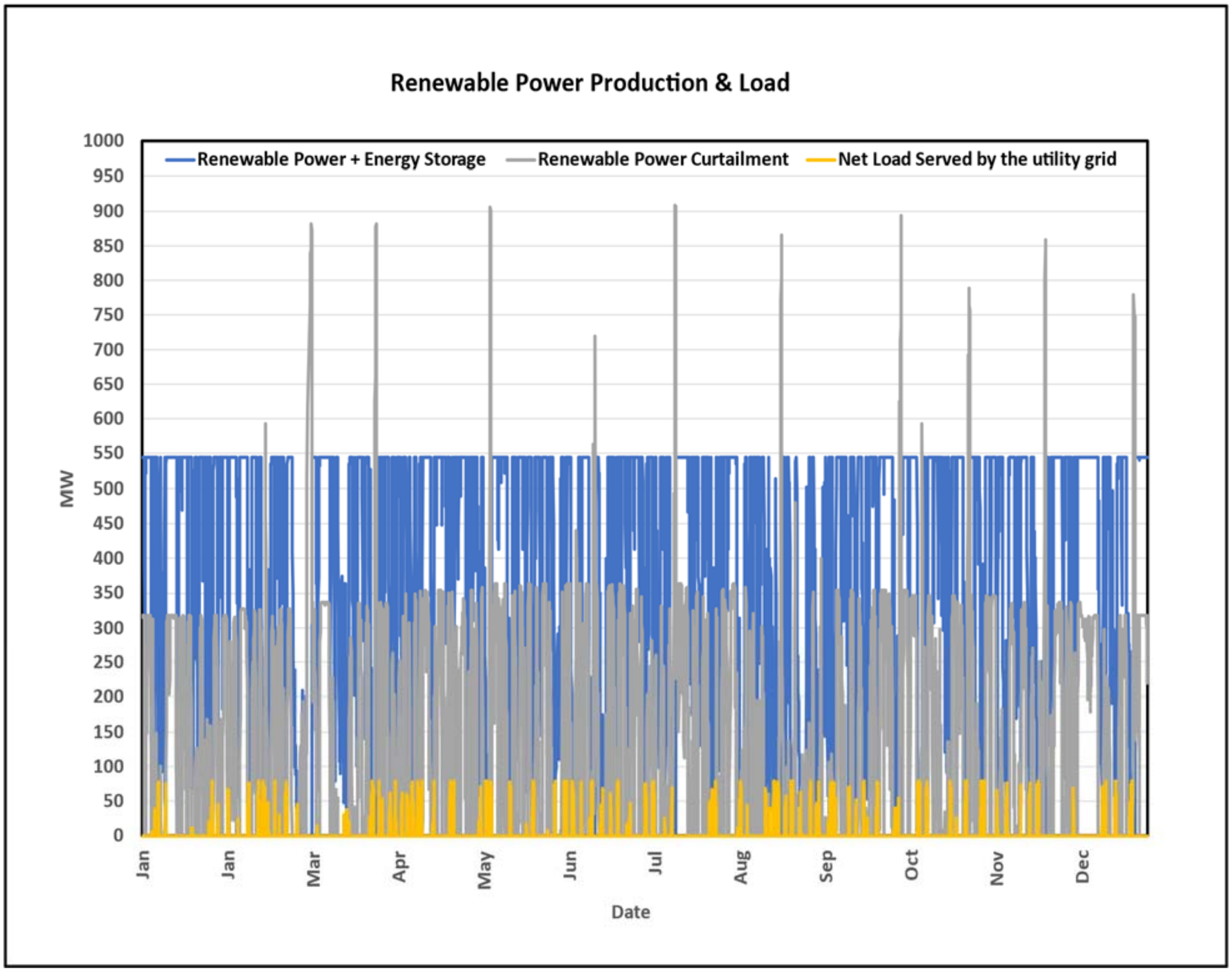

Figure 6-10: Self-Generation Ammonia Plant Load with Wind Power and Grid Support

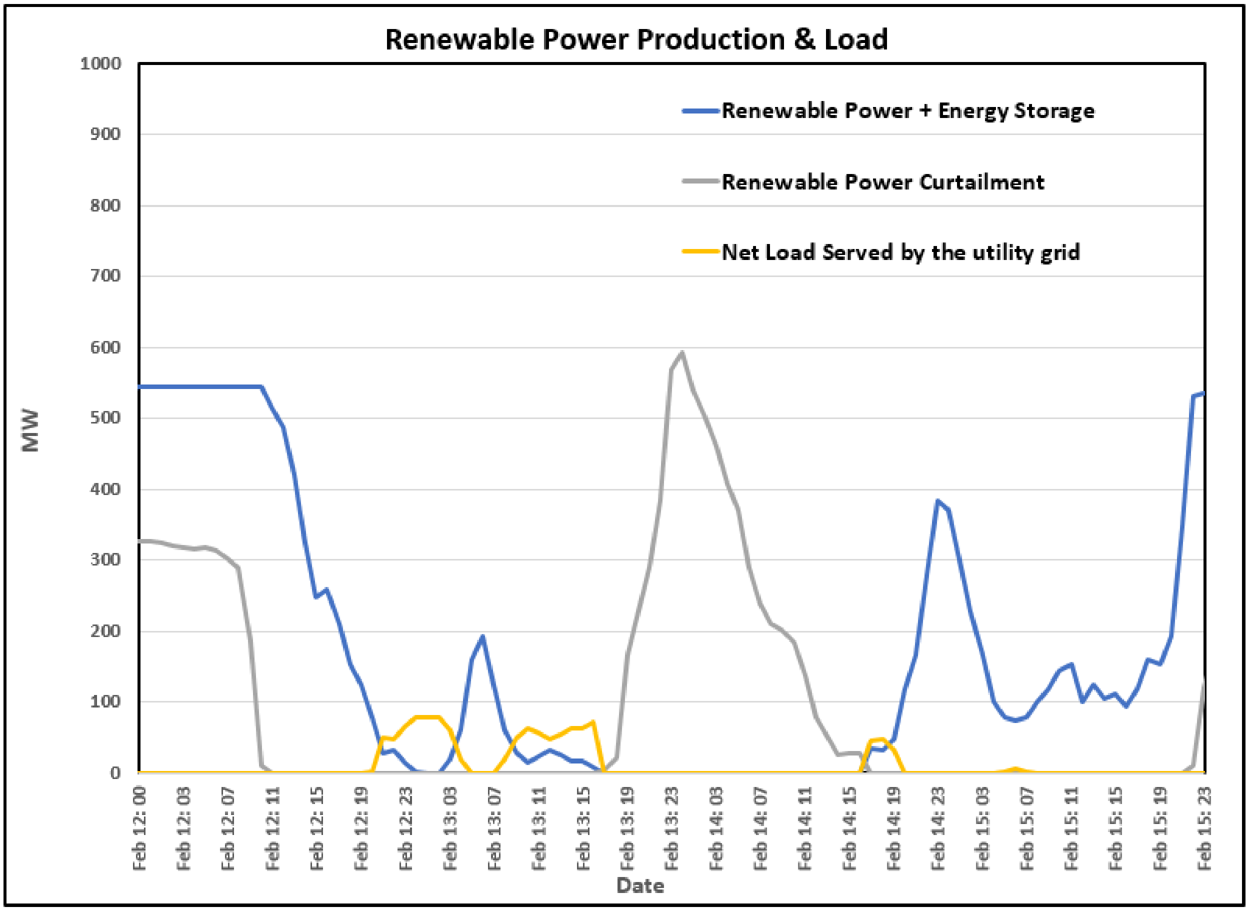

Figure 6-11: Self-Generation Ammonia Plant Load with Wind Power and Grid Support (for a 3 days period)

6.8 Technical Considerations for System Impact Studies

A system impact study (SIS) will be required for any wind proponent requesting interconnection to the NL Transmission System and will be conducted by NLH. As part of the application process, the proponent will have to provide the relevant information necessary for NLH to conduct the power system analysis.

The following is a non-exhaustive list that provides some of the technical considerations that NLH should assess as part of a SIS:

1. **Load Flow Analysis**: Load flow analysis must be performed to assess the customer's impact on system equipment loading and system voltage levels. The proponents load requirements and ability to supply excess wind generation will be significantly dependent on the point of interconnection to the NL System. NLH will provide solutions to address equipment overloads or abnormal voltage levels.
2. **Short Circuit Analysis**: An increase in wind penetration on the Island Interconnected System will likely offset synchronous generation. This will inherently reduce short circuit levels (SCLs) throughout the grid, resulting in a weaker system that could adversely affect the operation of the

HVdc links. NLH will determine the SCLs on the 230kV buses at the converter stations to confirm they meet the minimum requirements for reliability operation of the HVdc links. NLH will provide solutions to mitigate low SCLs.

3. **Transient Stability Analysis**: An increase in wind penetration on the Island Interconnected System will likely offset synchronous generation. This will inherently reduce the amount of total online system inertia, which will negatively impact system frequency response following a contingency event. NLH will perform transient stability analysis to quantify the reduced system frequency response, and propose solutions if unacceptable.

6.9 Recommendations

- New proponents, with the ability to self supply, should be treated as non-firm operators above their minimum load requirement[2]. These proponents that require grid connection should have the capacity to have a variable load as opposed to the traditional proponents with a relatively constant load to facilitate being non-firm operators. The NLH could be expected to serve the minimum load requirement on a firm basis.

- New proponent's hydrogen storage capacity should be based on maximum windows of time without sufficient wind energy production.

- Self-supplied proponents should provide NLH with an expected annual load profile of the timing and quantity of excess wind supply and demand requests from the grid. NLH should use the load profile to determine when the customers load and wind will be curtailed.

- NLH should be able to limit the amount of power imported from the new proponents at any time: this could be done by sending a maximum power setpoint at the point of interconnection. The new proponent will be responsible to manage the plant power requirement and wind farm production to respect the setpoint.

- New proponents should have enough hydrogen storage to allow for process ramp down and operation at minimal load for a period no less than the estimated maximum window that wind power generation is not expect to be available. Based on initial reviews this is expected to be a 4 hour window.

- Self-supplied proponents should consider other forms of renewable power behind the meter to reduce dependency on grid, which could reduce production downtime if the grid does not have the capacity to serve the minimum plant power requirement.

- No single contingency event should result in Under-frequency load shedding (UFLS) on the Island System. For the NLH system that number is 155 MW. This limit is to be confirmed by NLH through transient stability analysis, as the HVdc Frequency Controllers may allow a larger loss of supply.

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[2] Estimated to be 10% of total electrolyser load + 55% of ammonia plant load + 100% of auxiliary load

- The new proponent will provide day, hourly and 10 minutes ahead forecast of its minimum load requirement and project wind supply to the grid.

- The Wind Power Integration Technical Requirement, provided in Section 6.4, should be implemented by NLH and all new proponents wanting to interconnect to the NLH grid to ensure power system reliability.

- NLH should prepare a formal document to outline the scope of SISs for all new proponents looking for an interconnection to exchange power with the utility.

6.10 Key Barriers to Wind Integration and Mitigation

6.10.1 Key Barriers to Wind Integration

Wind power production is variable in time. In the course of a few hours (even less in specific cases) one can see its production changing from 100% of its capacity factor to 0%, and vice and versa.

For a given load, as the wind power varies, other production assets are required to be available to compensate for wind power variability at the same rate that the wind power changes. Failure of generation assets to compensate timely with wind power variability can cause frequency excursion, voltage variation, and load shedding.

Moreover, on very windy days, it might not be possible to fully integrate the wind power production and, therefore, some of the wind power production would be curtailed. Curtailment occurrences increase with the amount of renewable generation installed, thus become a natural limit to the amount of renewable generation that can be viably integrated into the grid.

6.10.2 Mitigation

Modern wind turbines can be dynamically curtailed automatically, thus limiting direct impact to the grid stability.

Wind power excess, instead of being curtailed, could potentially be exported to other markets.

Wind power variations could also be compensated by timely energy import and export, easing the requirement on local generation assets (which might require some time to restart). Moreover, energy storage such as batteries (typically 4-hour batteries) could play an important role in smoothing out these variations.

Finally, having a variable load on the grid, that can ramp up and down with the renewable power, is a cost effective solution to support more renewable integration into the grid (such as a electrolyser plant that can rapidly ramp up and down with renewables).

Appendix A - Physical and Operational Constraints

A.1 Hydraulic Constraints

Vista has a large library of operational constraints that are used to capture license, environmental and operational limitations. The Vista setup includes:

- Limits on reservoir minimum and maximum levels.
- Environmental flow releases for fish, bypass and compensation flows.
- Seasonal reservoir rule curves
- Elevation and flow constraints for stable ice cover.

The constraints were defined to conform with the Major Reservoir Operations Manual (Hydro 2015) and other relevant operating guides. Table A1 presents list of the defined constraints.

Table A-1: Summary of defined Hydraulic Constraints

Location	Type	Value	Notes
Victoria Reservoir	Min Target	318.15	
Victoria Reservoir	Max Target	328	
Victoria Reservoir	Upper Rule Curve	325.7918	
Burnt Pond Reservoir	Min Target	312.49	
Burnt Pond Reservoir	Max Target	315.06	
Burnt Canal	Minimum	42.5	Min Flow to provide a stable Ice cover on the canal
Burnt Fish Comp	Maximum	4.25	Jun1-Sept30 4.25 cms fish comp requirement
Burnt Fish Comp	Maximum	0	Oct1-May31- No fishery Compensation Required
Granite Lake Reservoir	Min Target	311.37	
Granite Lake Reservoir	Max Target	312.5	
Granite Lake	Upper Rule Curve	311.92	
Granite Lake	Lower Rule Curve	311.37	
Granite Canal Headpond	Min Target	311.37	

Granite Canal Plant	Minimum	62	62 at specified hours of the day, 0 other hours
Granite Canal Bypass	Requested	2	
Meelpaeg Reservoir	Min Target	266.98	
Meelpaeg Reservoir	Max Target	273.71	
Meelpaeg Reservoir	Upper Rule Curve	272.2216	
Grey River Fish Comp	Maximum	11.3	June to Oct: Maximun Fish Comp flow for Grey River
Grey River Fish Comp	Maximum	0	Nov to May:, No Fish Comp Flow required For Grey River
Great Burnt Lake Reservoir	Min Target	247.11	
Great Burnt Lake Reservoir	Max Target	247.31	
Cold Spring Pond Reservoir	Min Target	246.11	
Cold Spring Pond Reservoir	Max Target	247.3	
U Salmon Fish Comp	Minimum	1.3	
U Salmon Fish Comp	Minimum	2.6	
Long Pond Reservoir	Min Target	178.31	
Long Pond Reservoir	Max Target	182.7	
Long Pond Reservoir	Upper Rule Curve	182.3634	
BDE Plant Units 1 and 2	Min Target	100	minimum of 100 MW to keep one u
Long Pd Spillway	Maximum	0	
BDE Tail JCT to Sink	Minimum	64	Minimum flow to keep 2 units on
Grey River to Sink	Minimum	15	Grey River Minimun Fish Comp Flow
Whitebear River	Minimum	9	Minimum Fish Flow for White Bear River
Cat Arm Reservoir	Min Target	385.95	
Cat Arm Reservoir	Max Target	393.2	

Cat Arm Plant	Free Flow Maximum Rule	33.0229	
Hinds Lake Reservoir	Min Target	306	
Hinds Lake Reservoir	Max Target	311.3	
Hinds Lake Reservoir	Upper Rule Curve	310.9868	
Hinds Lake Fish Spill	Minimum	0.71	
Hinds Lake Fish Spill	Minimum	0.71	
Hinds Lake Canal	Min Target	305.5	
Hinds Lake Canal	Max Target	306.25	
Grand Lake Reservoir	Min Target	84.3	
Grand Lake Reservoir	Max Target	87.9	
Grand Lake Reservoir	Upper Rule Curve	86.9751	
Grand Lake Reservoir	Lower Rule Curve	85.2	
NP-A Reservoir	Min Target	4.3	
NP-A Reservoir	Max Target	4.3	
Paradise River Reservoir	Min Target	35	
Paradise River Reservoir	Max Target	38	
Star Lake Forebay	Min Target	284	
Star Lake Forebay	Max Target	292	
Buchans Forebay	Min Target	261	
Buchans Forebay	Max Target	263.3	
Red Indian Lake	Min Target	146	
Red Indian Lake	Max Target	153.3	
Red Indian Lake	Upper Rule Curve	152.8003	
Red Indian Lake	Lower Rule Curve	148.0171	
Millertown Controlled Spill	Minimum	82.2	
Millertown Controlled Spill	Minimum	49.3	

Millertown Controlled Spill	Maximum	700	
North Twin Lake	Min Target	99.8	
North Twin Lake	Max Target	102.55	
South Twin Lake	Min Target	99.8	
South Twin Lake	Max Target	102.55	
Sandy Brook Spillway	Min Target	212	
Sandy Brook Spillway	Max Target	217	
Sandy Brook Forebay	Min Target	125	
Sandy Brook Forebay	Max Target	126.5	
Grand Falls Forebay	Min Target	88	
Grand Falls Forebay	Max Target	89	
Grand Falls GS	Min Target	23	
Grand Falls Spillway	Minimum	7.1	
Grand Bishops Falls River R	Minimum	212	
Grand Bishops Falls River R	Maximum	226	Min and Max to limit discharge
Grand Bishops Falls River R	Maximum	1000	max for recreation
Grand Bishops Falls River R	Maximum	300	max for recreation
Bishops Falls Forebay	Min Target	10	
Bishops Falls Forebay	Max Target	13.46	
Bishops Falls GS	Minimum	185	
Bishops Falls GS	Min Target	9	
Bishops Falls Spillway	Minimum	7.1	
NP-N Reservoir	Min Target	4.3	
NP-N Reservoir	Max Target	4.3	

A.2 Transmission System and Dispatch Constraints

The Vista setup includes operational limitations and assumptions of the interconnected systems as contained in the TP-TN-176 document issued on July 12, 2022. The constraints include the followings and the details are as outlined in the aforementioned document.

- Labrador Island-Link limits.
- Maritime Link limits.
- 10 minutes Reserves requirements.
- Minimum generation requirement.
- IIS spinning reserve requirement.
- Muskrat Falls dispatch requirements.

Appendix B - Study Results

B.1 2030 Load Case 1, Annual load of 11148 GWh

Table B-6-11: 2030 Load Case 1, Annual load of 11148 GWh

New Wind			Existing Wind	Hydro Energy				Potential Additional Energy Requirements		Energy Export		Unused Wind	
Wind Farm	Wind Energy (GWh)		(GWh)	(GWh)				(GWh)		(GWh)		(GWh)	
Installed Capacity (MW)	Available Energy	Usable Energy	Energy	Gen	Δ wrt base	Spill	Δ wrt base	Gen	Δ wrt base	Gen	Δ wrt base	(GWh)	(%)
Base			170	16238		603		38.7		3491			
100	430.6	375.5	170	16103	-135	773	170	30.6	-8.1	3756	265	55	12.8
200	861.0	706.2	170	16091	-147	781	178	18.7	-20.0	4040	549	155	18.0
300	1291.6	989.7	170	16067	-171	808	205	10.0	-28.7	4275	784	302	23.4
400	1722.1	1210.1	170	16085	-153	791	188	4.8	-33.9	4485	994	512	29.7
600	2583.1	1523.2	170	16082	-156	796	193	1.3	-37.4	4799	1309	1060	41.0
800	3444.3	1700.7	170	16093	-145	786	183	0.4	-38.3	4947	1456	1744	50.6
1000	4305.3	1771.0	170	16094	-144	783	180	0.2	-38.5	4991	1501	2534	58.9

B.2 2030 Load Case 2, Annual Load 12642 GWh

Table B-6-12: Load Case 2, Annual Load 12642 GWh

New Wind			Existing Wind	Hydro Energy				Potential Additional Energy Requirements		Energy Export		Unused Wind	
Wind Farm	Wind Energy (GWh)		(GWh)	(GWh)				(GWh)		(GWh)		(GWh)	
Installed Capacity (MW)	Available Energy	Usable Energy	Energy	Gen	Δ wrt base	Spill	Δ wrt base	Gen	Δ wrt base	Gen	Δ wrt base	(GWh)	(%)
Base			170	16252		587		244.6		2229			
100	430.6	426.8	170	16121	-130	752	165	163.9	-80.7	2455	226	4	0.9

200	861.0	844.3	170	16121	-131	754	167	109.4	-135.2	2799	571	17	1.9
300	1291.6	1249.8	170	16112	-139	763	176	68.9	-175.6	3134	905	42	3.2
400	1722.1	1627.8	170	16119	-133	757	170	44.2	-200.4	3468	1239	94	5.5
600	2583.1	2284.5	170	16104	-148	774	188	1.3	-243.3	4799	2570	299	11.6
800	3444.3	2721.9	170	16093	-159	787	200	0.4	-244.1	4947	2718	722	21.0
1000	4305.3	2916.8	170	16101	-151	780	193	3.7	-240.9	4580	2351	1388	32.3

B.3 2030 Load Case 3, Annual Load of 12948 GWh

Table B-6-13: 2030 Load Case 3, Annual Load of 12948 GWh

New Wind			Existing Wind	Hydro Energy				Potential Additional Energy Requirements		Energy Export		Unused Wind	
Wind Farm	Wind Energy (GWh)		(GWh)	(GWh)				(GWh)		(GWh)		(GWh)	
Installed Capacity (MW)	Available Energy	Usable Energy	Energy	Gen	Δ wrt base	Spill	Δ wrt base	Gen	Δ wrt base	Gen	Δ wrt base	(GWh)	(%)
Base			170	16252		586		351.9		2001			
100	430.6	428.8	170	16117	-135	753	167	240.3	-111.6	2191	190	2	0.4
200	861.0	854.9	170	16122	-129	749	163	155.3	-196.6	2521	521	6	0.7
300	1291.6	1273.8	170	16115	-136	759	173	104.5	-247.4	2862	862	18	1.4
400	1722.1	1666.9	170	16119	-133	755	169	65.3	-286.5	3196	1196	55	3.2
600	2583.1	2374.1	170	16116	-135	763	177	1.3	-350.6	4799	2799	209	8.1
800	3444.3	2875.6	170	16102	-150	776	189	0.4	-351.5	4947	2946	569	16.5
1000	4305.3	3115.6	170	16096	-155	782	196	6.8	-345.1	4437	2437	1190	27.6

B.4 2040 Load Case 1 – Annual Load 12021 GWh

Table B-6-14: 2040 Load Case 1 – Annual Load 12021 GWh

New Wind			Existing Wind	Hydro Energy				Potential Additional Energy Requirements		Energy Export		Unused Wind	
Wind Farm	Wind Energy (GWh)		(GWh)	(GWh)				(GWh)		(GWh)		(GWh)	
Installed Capacity	Available	Usable Energy	Energy	Gen	Δ	Spill	Δ	Gen	Δ	Gen	Δ	(GWh)	(%)

(MW)	Energy				wrt base		wrt base		wrt base		wrt base		
0	0	0	170	16238		625		124.9		2606			
100	432.5	383.0	170	16085	-153	803	179	99.5	-25.4	2853	246	50	11.5
200	865.0	741.6	170	16052	-187	833	208	67.0	-57.9	3108	502	123	14.3
300	1297.6	1064.3	170	16045	-194	835	211	40.5	-84.4	3346	740	233	18.0
400	1730.1	1344.7	170	16030	-208	845	221	26.1	-98.8	3552	946	385	22.3
600	2595.1	1820.1	170	15988	-250	883	258	7.8	-117.1	3880	1274	775	29.9
800	3460.1	2146.0	170	15945	-294	919	294	3.5	-121.4	4068	1462	1314	38.0
1000	4325.2	2261.1	170	15931	-307	932	307	1.8	-123.2	4131	1525	2064	47.7

B.5 2035 Load Case 2, Annual Load 14039 GWh

Table B-6-15: 2035 Load Case 2, Annual Load 14039 GWh

New Wind			Existing Wind (GWh)	Hydro Energy (GWh)				Potential Additional Energy Requirements (GWh)		Energy Export (GWh)		Unused Wind (GWh)	
Wind Farm	Wind Energy (GWh)												
Installed Capacity (MW)	Available Energy	Usable Energy	Energy	Gen	Δ wrt base	Spill	Δ wrt base	Gen	Δ wrt base	Gen	Δ wrt base	(GWh)	(%)
Base			170	16256		578		891.2		1428			
100	430.6	430.4	170	16124	-132	741	163	678.3	-212.9	1520	92	0	0.0
200	861.0	857.9	170	16114	-142	748	169	499.3	-391.8	1747	319	3	0.4
300	1291.6	1282.2	170	16103	-153	759	180	356.5	-534.6	2003	575	9	0.7
400	1722.1	1697.3	170	16103	-153	758	179	243.9	-647.3	2287	859	25	1.4
600	2583.1	2481.6	170	16099	-157	767	188	107.0	-784.1	2885	1457	102	3.9
800	3444.3	3107.7	170	16096	-160	765	187	54.0	-837.2	3406	1978	337	9.8
1000	4305.3	3458.9	170	16092	-164	768	189	34.4	-856.7	3701	2273	846	19.7

B.6 2035 Load Case 3, Annual Load 17383 GWh

Table B-6-16: 2035 Load Case 3, Annual Load 17383 GWh

New Wind			Existing Wind (GWh)	Hydro Energy (GWh)				Potential Additional Energy Requirements (GWh)		Energy Export (GWh)		Unused Wind (GWh)	
Wind Farm	Wind Energy (GWh)												
Installed Capacity (MW)	Available Energy	Usable Energy	Energy	Gen	Δ wrt base	Spill	Δ wrt base	Gen	Δ wrt base	Gen	Δ wrt base	(GWh)	(%)
Base			170	16295		560		4147.2		931			
100	430.6	430.6	170	16211	-84	658	98	3767.4	-379.7	931	0	0	0.0
200	861.0	861.0	170	16219	-76	649	89	3315.3	-831.8	939	8	0	0.0
300	1291.6	1291.6	170	16210	-84	654	94	2894.0	-1253.1	953	22	0	0.0
400	1722.1	1722.1	170	16216	-78	657	97	2472.4	-1674.7	976	45	0	0.0
600	2583.1	2583.1	170	16195	-100	677	117	1728.3	-2418.9	1071	140	0	0.0
800	3444.3	3370.8	170	16166	-128	701	142	1184.2	-2963.0	1267	336	73	2.1
1000	4305.3	3865.3	170	16135	-160	725	165	933.3	-3213.9	1462	531	440	10.2

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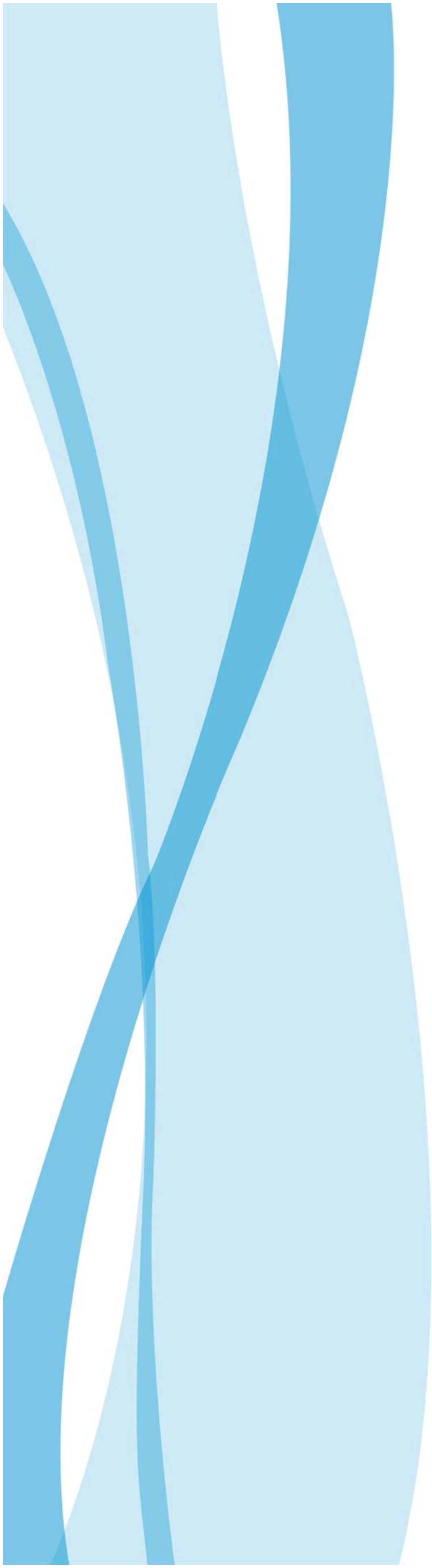

Summary of Wind Integration Study

October 2022

Agenda

- Wind Integration Study
- Self-Supply Customer Considerations
- Wind Generation Limits
- Summary

WIND INTEGRATION STUDY

Wind Integration Study - Principles

- Hydro engaged third-party consulting support to perform a wind integration study for the NL system. The third party has extensive national experience and is an expert in the wind industry.
- This study sets general guidelines for integration. Detailed system impact studies are required to confirm specific project interconnection requirements and business case viability.
- For any jurisdiction, there are technical limits to wind integration:
  - Any jurisdiction is not directly comparable to another regarding the role of wind or other intermittent sources of electricity. Typically, wind generation is constructed to provide primarily “energy” to a system. Jurisdictions with significant capacity can procure wind, or jurisdictions looking to lower costly fuel based energy sources will procure wind. Each jurisdiction is different.
  - Technical limits are set to ensure reliable and stable system operation
  - This study includes general technical considerations to inform conceptual designs for any wind project proponent
- There are limits to how much wind energy can be absorbed by the power system:
  - Too much wind energy would result in water spill from Hydro’s reservoirs, likely resulting in increased costs for all customers
  - Analysis was performed to determine the amount of wind energy that could be absorbed in a series of load forecast scenarios with load growing over time

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Technical Findings

- There are some guiding technical parameters that limit wind plant interconnection size on any system and such guidelines will now be provided to project proponents to incorporate into their engineering plans:
  - For stability, the wind generation at any point on the system cannot exceed 1/3 of the “system strength” (short circuit level) at the point of interconnection
  - For example, the maximum wind interconnection in Stephenville cannot exceed 344 MVA without adding system upgrades (new lines, sync condensers, etc).
  - Further, Hydro cannot allow for a single system contingency (a trip of an element or loss of supply) to exceed 155 MW due to risk of underfrequency load shedding (large blocks of customers suddenly losing power).
  - The above are guiding conclusions. Specifics on what investments would be required on the bulk system to address the issues noted above will be determined in detailed system impact studies completed with those proponents that advance through the process (exactly how many and who is to be determined with GNL)
  - If system reinforcements/investments are required for reliable interconnection, proponents are responsible for costs

Energy Considerations

- Hydro currently has ~ 3 TWh of excess energy
- Incremental wind energy would result in spill from Hydro’s reservoirs due to finite storage capacity in reservoirs and limited transmission for exports.
- Excess spill is deemed to be unacceptable due to customer cost implications. If industrial customers were to self-supply, wind generation over and above industrial customer needs that is generated at industrial customer wind farms would need to be curtailed and is not expected to be able to be “stored” in Hydro’s reservoirs without risk of costly spill.
- Load growth presents opportunity for incremental wind to be used for native supply.
  - Given ongoing residential and industrial electrification initiatives, load growth is likely and Hydro does expect to need new energy resources, for which wind is expected to be a likely alternative to be examined
  - Hydro will have more details in the next 12-24 months
- Analysis was performed to determine the amount of viable wind energy in various load forecast scenarios for the NL system.

Capacity Considerations

- There is significant uncertainty in terms of available <u>firm</u> capacity for large new industrial customers supplied from Hydro as has been communicated publicly in various regulatory filings for several years
- Projects that require firm supply will likely be subject to additional regulatory process (absent GNL direction) to resolve incremental and long term generation requirements/cost allocation (similar to process ongoing in Labrador for multiple customers interested in capacity)
- Projects that are fully interruptible would have a more streamlined process as non-firm rate proposals are already being considered before the regulator
- Proponents may be able to accelerate the interconnection process by minimizing grid interchange through the following measures:
  - Loads (electrolyzers, ammonia plants, auxiliary systems, etc.) should be adjustable to match available renewable supply
  - Consideration should be given to having on-site firm generation to meet minimum load requirements

General Considerations

- Strictly on the basis of technical interconnection requirements, several large self-supplying industrial customers could interconnect to the NL transmission system – this is an important conclusion
- The technical parameters presented above could limit the size of operation at each site
- It is expected that wind farms will have to be dispersed to minimize risk of reliability issues including loss of a large local wind supply
- The total capacity and energy interchange these facilities have with the power system will ultimately limit the number of connections
- Hydro expects that any new power purchase agreement with a proponent would require PUB approval, unless GNL chooses to order action to enter into agreements with any proponent

SELF-SUPPLY CUSTOMERS

Example: Self Supply Scenario

- Sample project parameters:
  - Wind farm capacity of 950 MW
  - Total 550 MW power requirement:
    - 500 MW electrolyser,
    - 35 MW ammonia plant,
    - 15 MW auxiliaries and balance of plant.
    - All loads at 100% capacity factor
    - Customer minimum capacity requirement of 80 MW
  - Recommend customer-owned generation to ensure firm supply
    - Hydro may not have this amount of firm supply readily available
    - Other regulatory files will inform availability

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Results: Self Supply Results

- Potential Energy Interchange:
  - Excess wind energy available from theoretical customer wind installation:
    - 41–137 GWh per month with annual total of ~1.2 TWh
  - Interchange capacity would be restricted to 155 MW due to technical limits
    - Therefore, wind energy interchange would be reduced to 27-72 GWh per month with an annual total of ~0.65 TWh
    - This reflects a curtailment of ~0.55 TWh (1.2 – 0.65 = 0.55)
  - Until load growth materializes, the majority of the ~0.65 TWh would also have to be curtailed to prevent spill from reservoirs
  - Opportunities for the export of energy cannot be assumed:
    - Hydro currently has 3 TWh of surplus energy, resulting in congestion of transmission export paths

*Proponent wind profiles, load profiles and storage capabilities could impact the figures above newfoundland labrador hydro

WIND GENERATION LIMITS

High Level View of Current NL System

- Capacity
  - Primarily hydraulic
    - Hydraulic capacity ~2350 MW
    - 54 MW of existing wind
  - Surplus capacity is limited
  - 2022 load forecast
    - 2023 NLIS Peak Demand - ~2100 MW
    - 2030 NLIS Peak Demand - ~2220 MW

- Energy
  - 2022 load forecast
    - 2023 NLIS load - 10.6 TWh
    - 2030 NLIS load - 11.1 TWh
  - Surplus energy available
    - Exports in 2030 ~ 2.5 TWh after losses

- This forecast includes the current electrification plan but no major new customers loads or significant electrification expansion.

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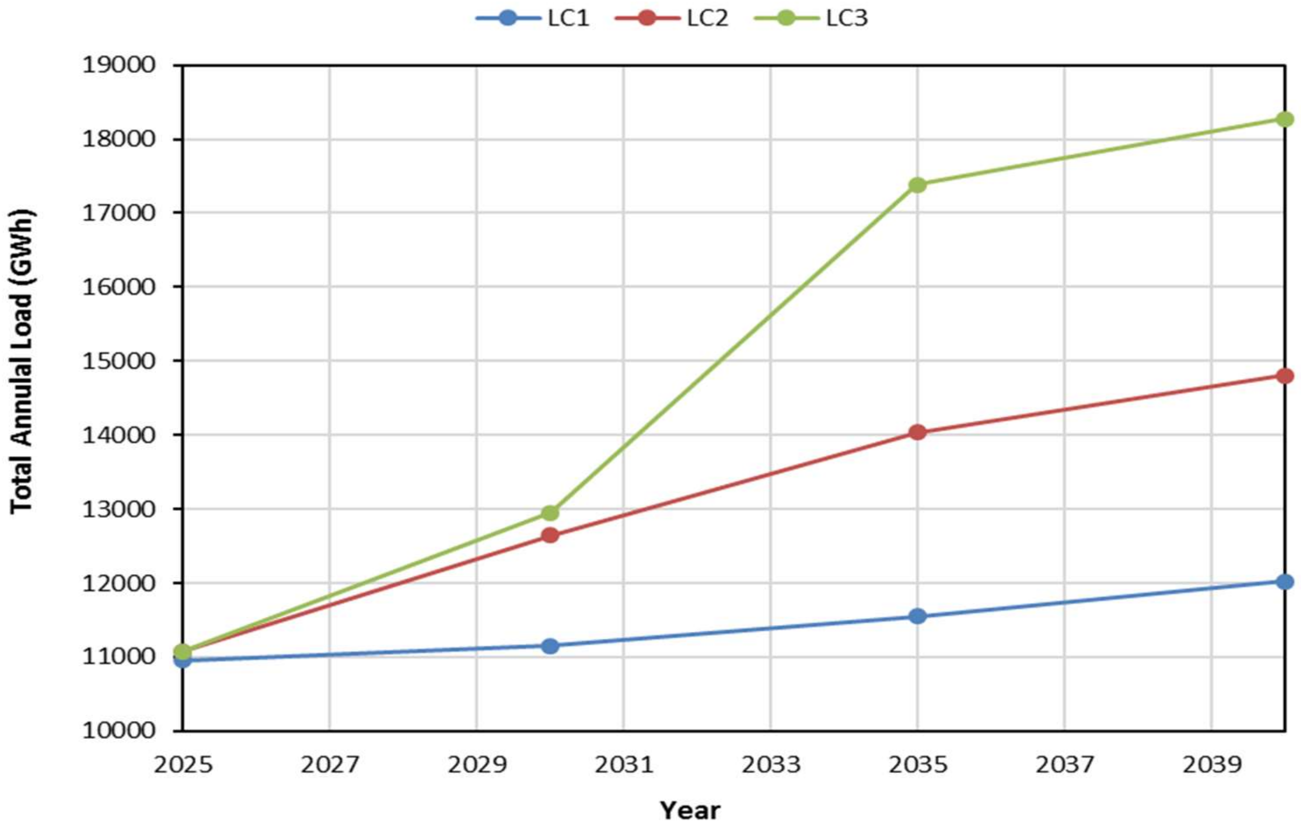
Wind Study - Details

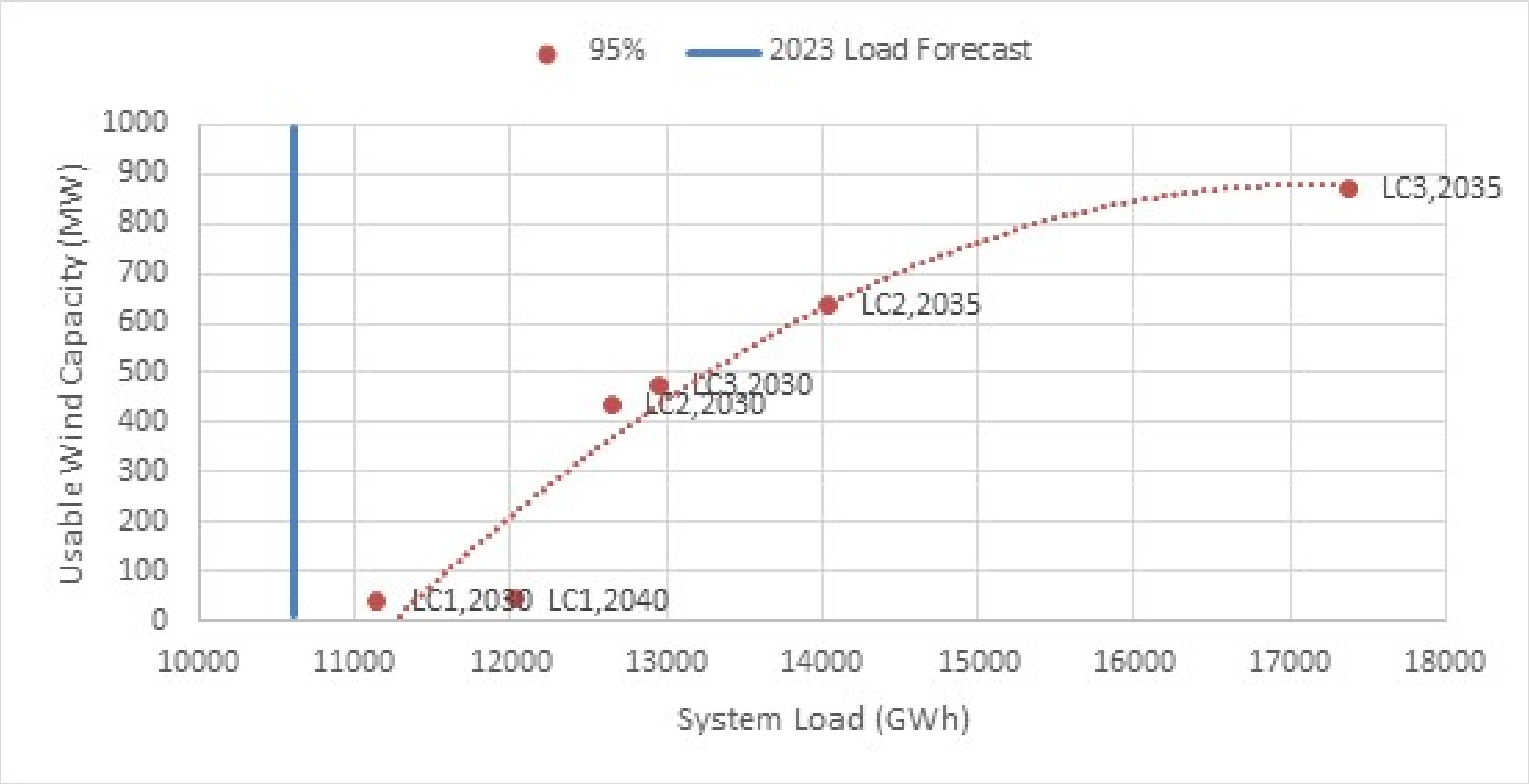
- Consultant has completed analysis to assess the amount of additional, non-dispatchable wind generation that can be added to the NL system.
- The analysis included the expansion of the hydroelectric system and it’s ability to operate efficiently and incorporated transmission system requirements
- The installation of 100 MW to 1,000 MW of wind capacity was assessed under three load forecast scenarios.

Wind Study - Results



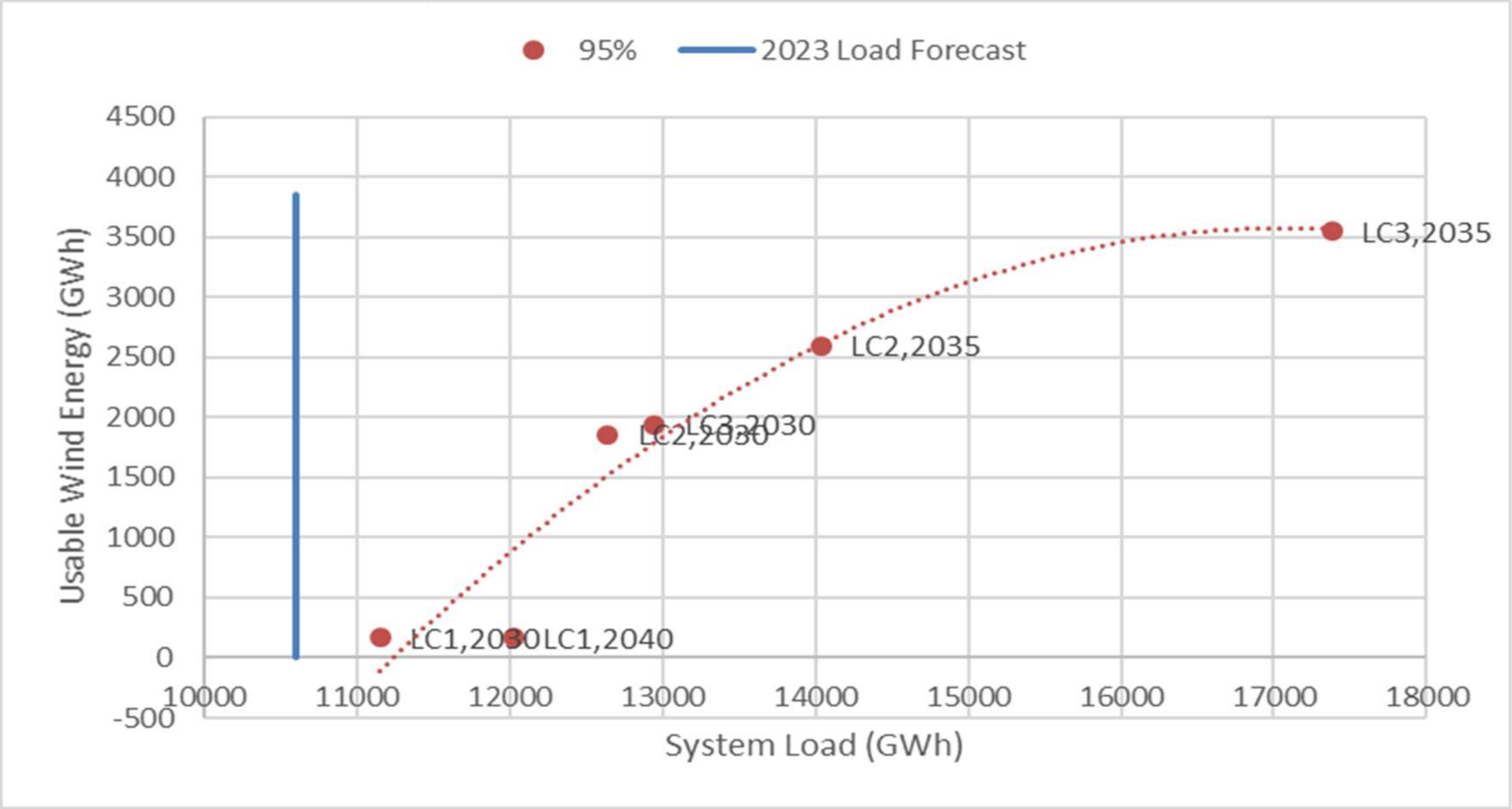
- The figure above illustrates Hydro’s load growth scenarios.

Wind Study - Results



- The figure above illustrates how much wind generation capacity can be integrated by Hydro to the NL System as demand increases.
- The 95% represent how much wind energy at the applicable wind capacity value that can be integrated into the NL system without contributing to significant hydraulic spill

Wind Study - Results



- The figure above illustrates how much wind generation <u>energy</u> can be integrated by Hydro to the NL System as demand increases.
- The 95% represent how much wind energy at the applicable wind capacity value that can be integrated into the NL system without contributing to significant hydraulic spill

SUMMARY

Summary of Findings and Next Steps

- Technical limits are required to ensure reliable system operation
- The ability for Hydro to absorb wind energy will increase as new load materializes
- Industrial customers who wish to self-supply should seek to minimize interchange with the grid
  - Fully interruptible loads can be more readily integrated
  - Excess wind energy would need to be largely curtailed in the near term
  - Appreciable wind energy could be absorbed by Hydro in the future to meet future load growth.
- Hydro will work with GNL on how the results of the wind integration study will inform the pending land auction.

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