NOVA SCOTIA POWER INC

Challenges of Large Scale Wind Integration in Nova Scotia

Whitepaper

1/21/2013

Integration of large amounts of intermittent generation creates challenges in planning and operating the electric power system in a reliable manner. In this whitepaper, we provide an overview of such challenges to the Nova Scotia system with 40% renewable penetration. For each identified challenge, we also provide potential recommendations and examples from other markets.

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I. Executive Summary

Nova Scotia Power Inc. (NSPI) has made significant progress to date adding wind generation resources to the power system and will have upwards of 500MW on line in 2015. As NSPI contemplates various options to achieve the renewable energy goals for 2020 set forth in the Renewable Electricity Standards of Nova Scotia and compliance with provincial air emission hard caps, operational challenges emerge should it be necessary to meet these objectives with additional wind generation alone. This report contains an overview of these major challenges that NSPI has identified based on its experience of operating renewable generation sources, predominantly wind, and through reviewing a number of studies that have been conducted to facilitate large scale renewable energy integration in various jurisdictions. The bibliography contains a consolidated list of wind integration and related studies that were referenced.

Integrating large levels of variable renewable generation presents a considerable challenge to power system operators and planners and can adversely impact reliability of the power system without the required supporting capital investments and changes in power system operating procedures. Examples of supporting capital investments that would be required to support large-scale integration of wind generation in Nova Scotia include:

- Investment in new conventional generating capacity to maintain planning reserves and address needs for two shifting or fast acting generation
- Investment in transmission upgrades within NSPI and developing stronger links with neighboring utilities to comply with system stability and reliability standards and reduce thermal generator cycling
- Deployment of energy storage and load shifting programs to complement conventional generation for managing wind variability and wind ramps

The level of capital investment required to support the large-scale integration of wind is dependent on the amount of new wind generating capacity installed over the next seven years as the province moves towards renewable electricity requirements for 2020. While this analysis is not exhaustive at this stage, it would be reasonable to expect that capital expenditures for such significant wind penetration levels as discussed herein would be within the ranges presented in Figure 1.1.

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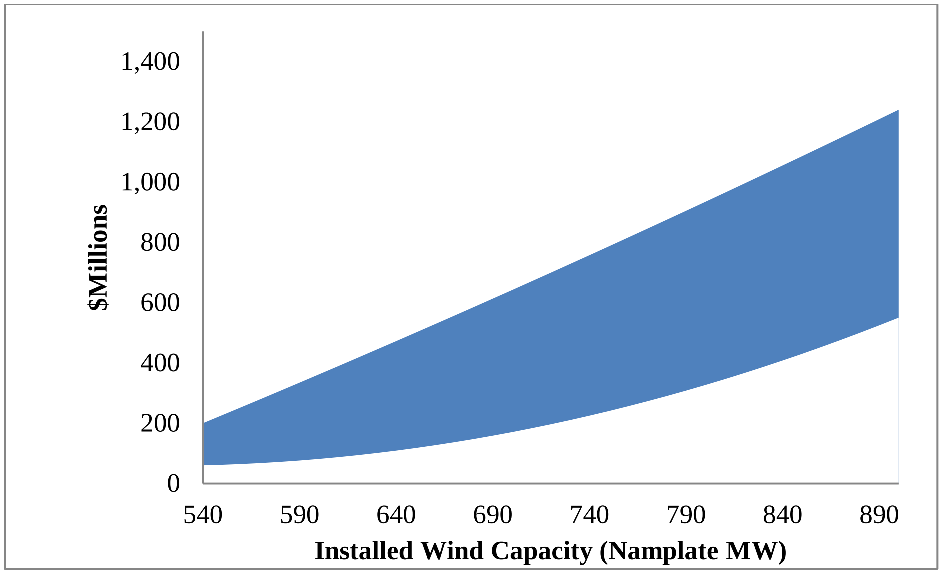
Figure 1.1 Estimated Range of Capital Investments to Support Large Scale Wind Integration



Source: NSPI

These cost estimates are for capital expenditures only and do not reflect operating costs related to wind integration such as thermal unit cycling costs, heat rate penalties, wind curtailment, and other related costs. It should also be noted that any costs associated with new or enhanced natural gas infrastructure to support a wind/gas option are not contemplated in these capital costs and would be incremental to the estimates in Figure 1.1.

The inherent variability of wind generation combined with the uncertainty in wind forecasts adds to the complexity of balancing supply with demand for grid operators in real-time conditions. If not well-planned and managed, these challenges can result in significant additional costs for ratepayers and new system stability risks. In the Nova Scotia context, these challenges are exacerbated by limited interties with the rest of the regional transmission grid system and insufficient generation resources to provide the fast-start capability required to balance increasing levels of nondispatchable variable wind generation.

Table 1.1 below highlights key challenges along with mitigating options. Following an introduction to the generation and operations environment and requirements of NSPI, the balance of this white paper examines each challenge and, in turn, the potential solutions. Mitigating options proposed for a particular challenge can also help in addressing other related issues as shown in Table 1.2.

Table 1.1: Nova Scotia Wind Integration Challenges and Recommendations - Summary

Section	Challenge	Potential Solution(s)
III A	Reduced Planning Reserve Margins	• Adding additional reserves through new gas fired generation • Construction of the Maritime Link
III B.1	System Stability/Reliability	• Stronger interconnection with New Brunswick through a 345 kV line between Salisbury, NB to Onslow, NS • General transmission upgrades
III B.2	System Ramping Requirements	• Improved wind forecasting • Voluntary load shedding or load control • Increasing online generation to maintain tie-line flows with NB
III B.3	Thermal Cycling	• Energy storage • Stronger transmission links with neighboring areas • Additional investments in steam units
III B.4	Minimum Unit Commitment	• Shifting/fast-start units • Load shifting (e.g. Power Shift Atlantic)

Table 1.2: Cross-Functional Nature of Recommendations

Challenge	Adding Gas-Fired Generation	Construction of Maritime Link	Transmission Upgrades and 345 kV connection with New Brunswick	Improved Wind Forecasting	Energy Storage, Load Shedding, Shifting
Reduced Planning Reserve Margins	√	√	X	X	√
System Stability	√	√	√	X	√
System Ramping Requirements	√	√	X	√	√
Thermal Cycling	√	√	√	√	√
Minimum Unit Commitment	√	√	X	X	√

Note: √ indicates that the recommended solution can be used for the challenge while an X indicates that the solution may not be applicable for the challenge

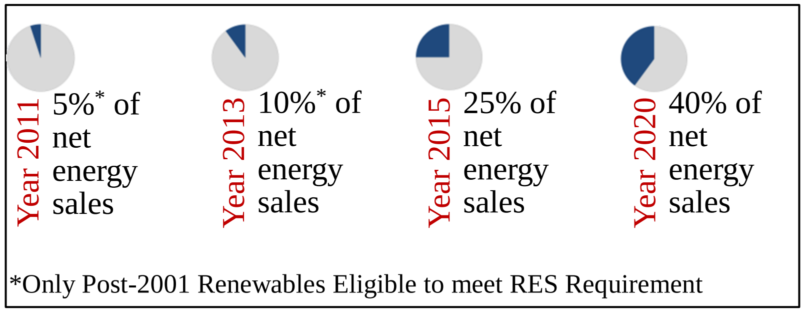
These challenges are not unique to Nova Scotia. Other markets and jurisdictions around the world have grappled with the same or similar issues as they integrate higher levels of wind generation into their systems. In order to demonstrate that these challenges are global, experiences of power system operators in Europe and the United States with large renewable energy penetration goals are discussed in this whitepaper. The bibliography contains a consolidated list of wind integration and related studies. Wherever possible, the estimated total or per unit cost of implementing the recommended solutions has been provided.

Through this whitepaper and various studies in progress, NSPI is reaffirming its commitment to maintain a sustainable, reliable, efficient and cost-effective electric grid in Nova Scotia.

II. Introduction

A. Background on Renewable Energy Requirements

In April 2010, the Nova Scotia Department of Energy (DOE) released its Renewable Electricity Plan, which establishes out the provincial government's commitment to a renewable electric energy supply. The plan included a legislated renewable energy requirement of 25% of net energy sales by 2015, and a target of 40% of net energy sales by 2020. The legislation committing to a 40% target in 2020 received Royal Assent in May 2011[1] and was subsequently amended in October 2012 to be a requirement for Nova Scotia Power.



The Electricity Act of Nova Scotia lists a number of renewable generation sources that can be used to accomplish the Renewable Electricity Standard (hereafter referred to as RES)[2]. These are:

- Solar energy,
- Wind energy,
- Run-of-the-river hydroelectric energy,
- Ocean-powered energy,
- Tidal energy,
- Wave energy,
- Biomass that has been harvested in a sustainable manner,
- Landfill gas,
- Any resource that, in the opinion of the minister and consistent with Canadian standards, is able to be replenished through natural processes or through sustainable management practices so that the resource is not depleted at current levels of consumption;

[1] (An Act to Amend Chapter 25 of the Acts of 2004, the Electricity Act 2011)
[2] (Renewable Electricity Regulations made under Section 5 of the Electricity Act 2010)

In May 2011, the Electricity Act was amended[3] to include hydroelectric energy as a qualifying form of renewable generation, whether produced inside or outside the province.

B. Existing and Committed Renewable Electricity Generation procured by NSPI

NSPI is working towards meeting its RES compliance requirements. NSPI has already added the renewable energy sources listed in Table 2.1 to the generation fleet for achieving compliance with the 2011 and 2013 RES requirements. The table contains both NSPI owned wind and Independent Power Producer (IPP) owned post-2001 generation.

[3] (An Act to Amend Chapter 25 of the Acts of 2004, the Electricity Act 2011)

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Table 2.1: Inventory of Post-2001 Renewable Generation in Nova Scotia

Renewable Generation Project	In Service Year	Annual GWh	Installed Capacity (MW)
NSPI Owned Wind			
Grand Etang & Little Brook	2002	3.3	1.3
Nuttby Mountain	2010	140.3	50.6
Digby Neck	2010	110.1	30.0
Total NSPI Owned Wind		**253.8**	**81.9**
Post-2001 Renewable Independent Power Producer (IPP)			
Pubnico	2004 - 2005	88.7	30.6
Lingan	2006 - 2007	41.9	14.0
Glace Bay	2005	2.5	0.8
Donkin	2005	2.5	0.8
Tiverton	2006	1.5	0.9
Springhill	2005 - 2006	5.2	2.1
Higgins Mountain	2007	7.0	3.6
Goodwood	2005	1.0	0.6
Brookfield	2005	0.8	0.6
Fitzpatrick Mountain	2006	4.0	1.6
Point Tupper 1	2006	2.0	0.8
Digby (RESL)	2006	2.0	0.8
Tatamagouche (Marshville/River John)	2006	1.5	0.8
Amherst (Sprott)	2012	86.7	30.0
Dalhousie Mountain	2009	168.0	51.0
Glen Dhu North	2011	165.0	60.0
Maryvale	2010	14.5	6.0
Point Tupper 3	2010	66.2	22.0
Watts Section	2011	4.3	1.5
Distribution Connected Wind	2013	52.6	9.5
Halifax Landfill	2006	9.0	2.0
Total Post-2001 Renewable IPPs		**726.9**	**240.0**
Total - All Renewable Sources		**980.6**	**321.9**

Source: NSPI

In addition to the renewable generation in Table 2.1, in 2012 the Renewable Electricity Administrator awarded contracts for 116 MW of renewable capacity accounting for 355 GWh of Independent Power Producer (IPP) wind generation to be completed for 2015 RES compliance. These projects include the South Canoe Wind Project - Oxford (78 MW) and South Canoe Wind Project - Minas (24 MW) both located between Chester and Windsor; and the Sable Wind Project led by the Municipality of the District of Guysborough located near Canso (13.8 MW)[4].

The Renewable Energy Plan also includes provisions for a Community-Based Feed-in-Tariff (COMFIT)[5] for approximately 100 MW of community-owned projects connected to the distribution system, and further provides for enhanced net-metering for renewable projects up to 1 MW in capacity. These development processes will help NSPI meet its RES requirements. While NSPI has not attempted to forecast renewable electricity produced under enhanced net metering, it has been provided with an estimate by government for 100 MW of COMFIT generation. NSPI foresees COMFIT projects coming online between 2014 and 2018, which will aid in achieving the 2015 and 2020 RES requirements. Additionally, tidal generation could contribute to the renewables mix in the coming decades.

C. Additional Renewable Generation Required to Achieve 2020 RES Compliance

As discussed above, Nova Scotia RES requires that 40% of net energy sales in the province are to be from renewable sources by 2020. NSPI has analyzed the amount of additional renewable energy it would need to meet the RES requirement for low and base load scenarios to account for the uncertainty associated with long-term load forecasts. In addition, these studies analyzed the impact of the Maritime Link[6] (ML) in satisfying the additional renewable energy needs of Nova Scotia. The results of this analysis are summarized in Table 2.2.

[4] (Nova Scotia Department of Energy 2012)

[5] Under the COMFIT program community based small scale renewable energy projects are encouraged to connect to the distribution grid and supply renewable energy. Developers of such projects are guaranteed a fixed rate per kilowatt hour for a certain period. The projects developed as part of this program must be lower in capacity than the minimum load expected on the respective distribution substation. (Nova Scotia Department of Energy n.d.) (Canadian Renewable Energy Alliance n.d.)

[6] The Maritime Link is a proposed 500 MW, ±200 to 250 kV high voltage direct current (HVDC) transmission system which is expected to bring to Nova Scotia the excess hydro power generated by the planned Lower Churchill Hydroelectric Generation Project in Newfoundland and Labrador (Emera Newfoundland & Labrador 2011)

Table 2.2: Renewable Energy Needs on NSPI System, 2020-2040

Scenario	No ML Low Load[2] RES 2020	No ML Base Load RES 2020	ML Base Load RES 2020	No ML Base Load RES 2040	ML Base Load RES 2040
Net System Requirement less DSM	9,605	10,950	10,950	12,174	12,174
Total Sales (Assume 7% Losses)	8,977	10,233	10,233	11,378	11,378
RES Target %	40%	40%	40%	40%	40%
RES Requirement (GWh)	**3591**	**4093**	**4093**	**4551**	**4551**
Eligible NSPI Wind & IPP Renewables	1609	1548	1548	1548	1548
Eligible NSPI Legacy Hydro	985	985	985	985	985
REA Procurement	353	353	353	353	353
Maritime Link Contracted Energy	0	0	1118	0	895
Total Renewable Energy (GWh)	**2947**	**2886**	**4004**	**2886**	**3781**
Existing Renewable Energy Surplus or Deficit (GWh)	**-644**	**-1207**	**-89**	**-1665**	**-770**
Additional Wind Energy Required [1]	657	1303	0	1724	0
Additional Economic Renewable Energy Purchases	0	0	89	0	770
Proposed Renewable Energy Surplus or Deficit (GWh)	**13**	**96**	**0**	**59**	**0**

[1] Wind energy has been adjusted in each case to account for varying capacity factors due to estimated curtailment
[2] In the low Load Case (no ML) the RES deficit reduces to 365 MW by the year 2040 due to the declining load trend.
Source: NSPI

Table 2.3: Installed Wind Capacity (MW) on NSPI System, 2020-2040

Scenario	No ML Low Load RES 2020	No ML Base Load RES 2020	ML Base Load RES 2020	No ML Base Load RES 2040	ML Base Load RES 2040
Existing NSPI & IPP Wind	319	319	319	319	319
REA Procurement	116	116	116	116	116
COMFIT	100	100	100	100	100
Additional Wind Capacity Required	250	425	0	575	0
Total Nameplate Wind Capacity (MW)	**785**	**960**	**535**	**1110**	**535**

Source: NSPI

Table 2.2 shows the anticipated deficit levels of renewable generation in years 2020 and 2040 for varying load conditions. It shows that needs for incremental renewable energy can be largely met by the development of the Maritime Link. For base load conditions in 2020, with the Maritime

Link in place, the need for additional renewable energy generation within the province drops to 89 GWh, a reduction of 93% over the original need (without the Maritime Link) of 1,207 GWh. With the Maritime Link in place, the renewable energy deficit in both 2020 and 2040 would potentially be addressed through economy energy purchases from outside the province. If the Maritime Link is not developed, significant additional wind generation and related integration costs will be required to achieve compliance with RES requirements for 2020 and maintain compliance through 2040. Table 2.3 shows the installed wind capacity (MW) that would be needed to meet the 2020 RES without a qualifying import or any other source of indigenous renewable energy.

Due to the inability to control “fuel” supply for wind generation resources and the nature of electric generators used to convert wind energy into electricity, operation of electric grids with a large penetration of wind energy sources poses unique operating challenges that require additional investments besides the cost of constructing a wind farm and transmission lines to connect the wind farm to the electric grid.

This whitepaper presents the challenges associated with the large-scale integration of wind to meet the 2020 RES requirements, and provides an overview of the additional investments required to maintain power system reliability under such a scenario. Wherever possible, examples of similar challenges from other jurisdictions across the United States and Europe are provided.

III. Challenges with Large Scale Wind Integration

In this section, we describe each of five major challenges presented to utility system operations as a result of integrating large amounts of renewable energy on power systems originally designed an operated with fossil fuel generation. The challenge is described first, lessons from other jurisdictions are presented, and finally potential solutions are presented. The following challenges are addressed:

- Sustaining Planning Reserve Margins
- Maintaining System Security (Stability, Operating Limits, System Control);
- Managing System Ramping Requirements;
- Accommodating Thermal Cycling
- Minimum Unit Commitment

A. Sustaining Planning Reserve Margins

Challenge

Retiring base load capacity and addition of variable renewable resources provide for reduced net dependable peak capacity in the system. Consequently, the reserve margins could go down further if not appropriately augmented through strategic capacity additions to compensate for the intermittency of wind generation.

The Nova Scotia Environment Act[7] and The Canadian Environmental Protection Act[8] have imposed increasingly stringent emission restrictions that limit the emission of carbon dioxide, sulphur dioxide, nitrogen oxides and mercury from power plants. These restrictions limit the dispatch of coal fired units and reducing unit capacity factors to below 10% in comparison with historical operating capacity factor of 80% to 90% for these units.

Even as some of NSPI's base load generation reduces to such low capacity factors, planning reserve margins must be maintained to restrict the Loss of Load Expectation (LOLE)[9] value to less than one day in ten years as required by Northeast Power Coordinating Council standards[10].

[7] (Air Quality Regulations, made under Section 112 of the Environment Act Section C 2010)
[8] (Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations, Canadian Environmental Protection Act 1999)
[9] LOLE is defined as the expected number of days in the year when the daily peak demand exceeds the available generating capacity
[10] (Northeast Power Coordinating Council 2009)

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To achieve this LOLE, NSPI maintains a Planning Reserve Margin of 20% over firm peak load. In the context of NSPI, system peak is defined as the duration of the day during the year where electricity consumption is at the maximum level, usually the darkest and coldest day of the year. In 2013, the system peak for NSPI is forecasted as approximately 2100 MW[11]. With retiring coal-fired thermal generation there is an increasing need to add dependable capacity to supply loads during system peak conditions. However, since much of the generation added in recent years has been wind, it has not contributed much to the firm capacity even with hundreds of MW's of nameplate wind capacity added to NSPI's system. This is due to two main reasons:

1. Because of the variable nature of wind, only a fraction of the actual nameplate capacity can be counted as firm for capacity planning purposes. Within NSPI, the average capacity contribution from wind during peak load conditions is in the range of 20% of nameplate. In other jurisdictions, this capacity factor varies, in some as little as 8.7%[12]. Further, due to the intermittency and volatility associated with wind speeds, contribution of wind generation during peak load conditions could vary across years. Unlike conventional generation, wind speeds determine the power output and consequently significant volatility exists on the supply side due to uncertainty in future climatic conditions.
2. Since wind is variable and not firm, most wind generation developers have opted for NSPI's non-firm generator interconnection service (Energy Resource Interconnection Service or ERIS). They do this to avoid having to pay the full cost of network upgrades to accommodate the new generation. When the system is congested because of load, a generator with ERIS can be curtailed to allow the transmission system to operate within acceptable transfer limits and hence provides little in terms of capacity contribution to the system's reserve requirements. The interconnection firm service, Network Resource Interconnection Service (NRIS), would provide more secure access but at a higher cost to the generator.

[11] (Nova Scotia Power Inc. 2012)
[12] (ERCOT 2011)

Examples from other Jurisdictions

From a reserve planning perspective, generally speaking, larger shares of wind in the generation portfolio translate to reduced capability for responding to system contingencies. As wind generation continues to make up a larger share of total generation, the need for back-up generators and/or electricity storage will increase to cover peaking periods when wind may not be available. More fossil-fueled generation will be utilized to serve ancillary service needs. In New York, a wind integration study found when wind resources increase from 4,250 MW to 8,000 MW (approximately about 20% of the total generation capacity in the State), that the reserve margin requirement would need to increase from 18% to 30%[13]. The same study also determined that the average regulation requirement increases approximately 9% for every 1,000 MW increase between the 4,250 MW and 8,000 MW wind penetration level.

The Electric Reliability Council of Texas (ERCOT) manages the wholesale power transactions for about 85% of the state of Texas. ERCOT is a leader in wind integration in the United States, having over 9,000 MW installed at the end of 2011. In that year, wind generation accounted for about 9% of total electricity consumed in ERCOT[14]. A study by the ERCOT market operator showed that penetration of 5,000 MW of wind generation in their system would necessitate the introduction of a new category of operating reserve - a 10-minute non-spinning reserve[15]. These results from markets like New York and Texas indicate that in order to successfully integrate large levels of wind generation into the system, there would likely be additional costs associated with procuring fast-start generation and ancillary services to offset the variability associated with wind speeds.

Recommendations

1. Add Additional Reserves: New gas fired power generation should be built to provide firm capacity while maintaining compliance with the emission regulations. Natural gas-fired generation is highly favorable in this context since it tends to have fast start capability with the ability to change output quickly based on variations in the system. As a result, these plants will

[13] (New York Independent System Operator 2010)
[14] (Potomac Economics, Ltd. 2012)
[15] (GE Energy 2008)

assist in meeting the ramping requirements which are discussed in the next section. It has been estimated that the cost of providing additional reserves because of wind generation is around $8-$16 per MWh of wind generation[16].

2. Maritime Link: Construction of the Maritime Link can help improve the planning reserve margin thereby facilitating the integration of wind generation. Tables 3.1 and 3.2 show the planning reserve calculations for NSPI power system with and without the Maritime Link. As shown in Table 3.1, one coal unit retirement is possible in 2015 (153MW retirement plus the return to service of Burnside 4 at 33MW, net change -120MW) while a second unit could retire in 2017/2018 provided there is new capacity introduced to compensate for the Planning Reserve deficit. Table 3.2, reflecting the addition of the Maritime Link firm capacity of 153MW, shows that one unit could retire in 2015 and another in 2017/2018 while still maintaining adequate planning reserve margins. In summary, construction of the Maritime Link would provide significant system flexibility to operate and retire power plants while still retaining the capacity to maintain system reliability with growing levels of wind penetration. The absence of the Maritime Link would add to constraints to the ability of system operators to retire power plants within the province and would require additional new firm capacity to accomplish the second unit retirement.

[16] (Committee on Climate Change 2011)

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Table 3.1: Estimated Planning Reserve Margins on NSPI System without Maritime Link

	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020
Firm Peak Forecast (Base Load)	1,891	1,890	1,892	1,888	1,890	1,889
Planning Reserve Required (20% Firm Peak)	378	378	378	378	378	378
Required Capacity (Firm Peak + Reserve)	2,270	2,268	2,270	2,266	2,268	2,267
Existing Resources	2,340	2,340	2,340	2,340	2,340	2,340
Resource Additions:						
Thermal		-120		-153		
Contracted Wind (Firm capacity)	23					
Biomass		55				
Community Feed-in Tariff (Firm capacity)	3	3	5	5		
Maritime Link Import						
Total Annual Additions	27	-62	5	-148	0	0
Total Cumulative Additions	27	-35	-30	-178	-178	-178
Total Firm Supply Resources	2,367	2,305	2,310	2,162	2,162	2,162
Surplus/ - Deficit	97	36	40	-104	-106	-105
Reserve Margin %	25%	22%	22%	14%	14%	14%

(All Values in MW except as noted)
Source: NSPI

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Table 3.2: Estimated Planning Reserve Margins with Maritime Link

	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020
Firm Peak Forecast (Base Load)	1,891	1,890	1,892	1,888	1,890	1,889
Planning Reserve Required (20% Firm Peak)	378	378	378	378	378	378
Required Capacity (Firm Peak + Reserve)	2,270	2,268	2,270	2,266	2,268	2,267
Existing Resources	2,340	2,340	2,340	2,340	2,340	2,340
Resource Additions:						
Thermal		-120		-153		
Contracted Wind (Firm capacity)	23					
Biomass		55				
Community Feed-in Tariff (Firm capacity)	3	3	5	5		
Maritime Link Import				153		
Total Annual Additions	27	-62	5	5	0	0
Total Cumulative Additions	27	-35	-30	-25	-25	-25
Total Firm Supply Resources	2,367	2,305	2,310	2,315	2,315	2,315
Surplus/ - Deficit	97	36	40	49	47	48
Reserve Margin %	25%	22%	22%	23%	22%	23%

(All Values in MW except as noted)
Source: NSPI

B. Operational Challenges with Wind

Several operational challenges are expected in the NSPI system as the amount of wind generation increases. These challenges relate to:

1. Maintaining System Stability
2. Managing System Ramping Requirements
3. Accommodating Thermal Cycling
4. Minimum Unit Commitment

A number of studies in multiple jurisdictions across the world have shown that integrating large amounts of wind energy, such as that potentially needed in Nova Scotia, is possible, but only with significant investments in power plants and equipment required for load following and firm capacity to meet system reliability requirements. Energy storage could be considered as an option to firm-up variable wind capacity, but the relative cost of storage devices has to be weighed carefully against the benefits to system operations and reliability. Careful consideration must also be given to changes required in the operation of the power systems including changes in dispatch and contracts for wind energy. These and other operational challenges are discussed next in more detail.

B.1 Maintaining System Stability

Challenge

NERC defines power system stability as "*The ability of an electric system to maintain a state of equilibrium during normal and abnormal conditions or disturbances*"[17]. A power system can lose its ability to maintain equilibrium between generation and load under high demand, low generation or sudden large change in load and generation. In such a state, a power system is said to be unstable which can even lead to localized or even widespread loss of power.

A number of factors can impact the ability of a power system to maintain stable operation. Due to certain characteristics of wind generators (as discussed below), they tend to have a negative impact on the stability of the electric grid. Some of the important factors that affect system reliability and the impact of wind generators are listed below.

[17] (North American Electric Reliability Corporation 2013)

- **Inertia of Rotating Equipment** (primarily generators): Higher system inertia enhances system stability by providing for enhanced capability to control the frequency of the electric grid. Wind generators typically have little to no natural inertia, although it can be synthesized through appropriate control mechanisms of wind generators in the system. Conventional synchronous generators offer high inertia to the system because of their physical and operational characteristics.

- **Reactive Power and High Speed Voltage Control**: Wind generators do not have the reactive power output range of a typical synchronous generator. Speed of control response is also significantly slower, since individual wind turbines are controlled via a local Supervisory Control And Data Acquisition (SCADA) system and that wind speeds cannot be increased at will.

- **System Strength**: Wind generation is often located in remote, weakly interconnected parts of the electric grid. Large power flows over a weak transmission system can result in voltage flicker, low substation voltages and overall negatively impact power system stability. Since conventional synchronous generators are not constrained by fuel location, these are often strongly interconnected with the grid and can be closer to load centers.

- **System Frequency**: System frequency is the result of a balance between generation and load. Conventional generators are equipped with speed/load governors which maintain frequency within acceptable limits by adjusting the mechanical power input from a turbine to the connected generator. While it is theoretically possible to add some level of frequency control to wind turbines, it generally only works well in one direction when frequency needs to be reduced. Since the flow of wind cannot be increased, controls for increasing system frequency can only be useful if wind generators are normally operated at less than their full potential, so that they can pick up a portion of power in the short term. This operating pattern, while feasible, is mismatched with an RES compliance environment which looks to maximize the production from renewable sources.

Stability implications of adding large quantities of wind generation must be determined at both the regional level and for Nova Scotia alone. NSPI has conducted preliminary stability simulations with high levels of wind generation in the Maritimes - New Brunswick, Prince

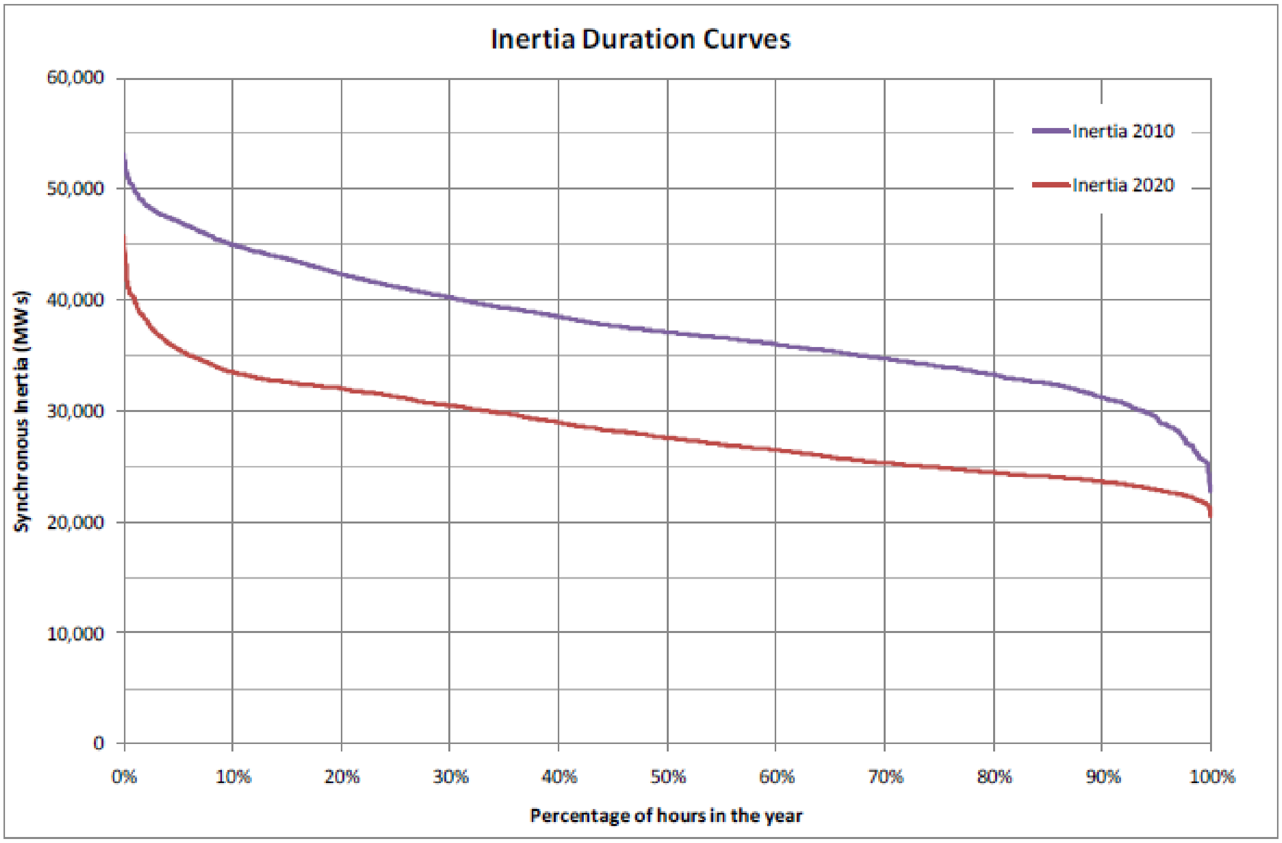
Edward Island (PEI) and Nova Scotia areas. Results from these studies indicate that a reasonable mix of conventional (minimum unit commitment) and wind generation would be required during light load conditions to maintain system stability. These requirements could translate into higher operating costs since conventional generation facilities would likely be required to address inertia-related concerns on the system.

Examples from other Jurisdiction

Ireland: The Irish system is similar in nature to NSPI's system due to the limited level of interconnection with neighboring control areas. Recent studies conducted in Ireland indicate that as wind generation increases from 1,700 MW in 2010 to 6,100 MW in 2020 (over 37% of total generation), system inertia will significantly decrease. In comparison, the NSPI system currently has 319 MW of wind capacity and would have to grow to about 960 MW by year 2020 with an indigenous RES compliance plan. Negative correlation between wind penetration and system inertia is also expected to increase to 0.7 in 2020 from 0.25 in 2010. This implies that system inertia on the Irish electric power system is expected to reduce at an increasing rate as the amount of wind generation increases. Such a reduction in system inertia negatively impacts reliability by limiting the ability of the system to respond to changes in demand conditions. Figure 3.1 shows the estimated reduction in system inertia in 2020 compared to the observed system inertia in 2010[18].

[18] (EirGrid and System Operator for Northern Ireland 2011)

Figure 3.1 System Inertia EIRGrid in 2010 (Actual) and 2020 (Estimated)



Source: EirGrid

<u>Recommendations</u>

1. Build a new 345kV Circuit between Salisbury, NB and Onslow, NS: The greatest risk to stability with high levels of wind generation is expected if Nova Scotia separates from the interconnected system when wind generation is high. If Nova Scotia is importing at the time of this contingency, firm load may be lost due to system stability concerns. This phenomenon can also occur with conventional generation, albeit to a lesser degree because of governor response characteristics. By building another high voltage path to import power from NB, the stability of the system can be maintained through the first contingency. Further studies are required to determine the level of wind penetration at which the second 345kV line would become necessary, however, it is anticipated that this is above 500MW installed.

The second 354kV transmission tie-line would also play an important role in maintaining system stability if Nova Scotia is exporting at the time of the separation. Presently, during system export conditions there is a limitation on the operation of Lingan[19] units for reliability considerations. Construction of a new transmission line between Salisbury, NB and Onslow, NS would eliminate such operational constraints of the Lingan units during export periods.

2. General Transmission Upgrades: The exact location of all new wind generation in Nova Scotia that would contribute to meeting the RES requirements cannot be predicted. In addition, existing methods of maintaining stability rely on the Lingan units which may be displaced by new wind or other generation in future years. As a result, it is likely that transmission upgrades will be needed to incorporate high levels of wind penetration. These upgrades may include reinforcement of the backbone 345 kV transmission system to eliminate the need for Special Protection Schemes[20] associated with the Lingan units. NSPI has identified transmission upgrades that may be needed to address the addition of new generation in the system and has included a review of these in its "10 Year System Outlook"[21]. These transmission expansion scenarios represent high-level investment estimates of the transmission reinforcements required to interconnect blocks of generation at various locations on the transmission system. In addition to these transmission investments, large reactive power sources may also be needed at strategic locations such as Port Hastings, Onslow and Brushy Hill.

3. Investments in Transmission Upgrades: As discussed earlier, most wind generation projects to date have applied for Energy Resource Interconnection Service, which allows for access to the transmission system on an "as available" basis and typically requires minimal transmission upgrades. Consequently, transmission upgrades to accommodate wind generation have been minimal. Appropriate policy measures to incentivize the reinforcement of the transmission system could enable development of appropriate infrastructure to reliably integrate future wind generation. There are examples in other jurisdictions where public policy has accelerated investments in the transmission grid. For example, in California the development of a Location Constrained Resource Interconnection Tariff (LCRI) helped utilities pay for certain sections of the Tehachapi Renewable Transmission Project (TRTP) by rate payers sharing the cost burden of

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[19] Lingan is a 617 MW coal-fired generation facility located in Nova Scotia

[20] NERC defines SPS as "*An automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability*" (North American Electric Reliability Corporation 2013)

[21] (Nova Scotia Power Inc. 2012)

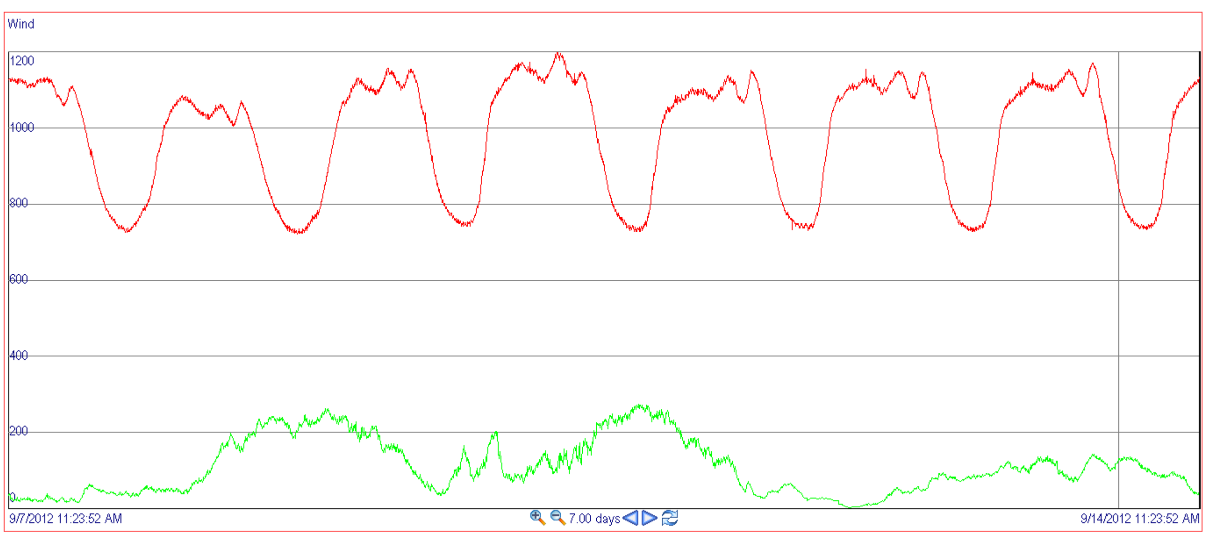
transmission investments upfront and potentially new wind generators paying for transmission service as they come online in future years. Similar mechanisms have also been used in the ERCOT market through the Competitive Renewable Energy Zone (CREZ) projects.

B.2 System Ramping Requirements

Challenge

In electric utility parlance, "ramp" refers to the increase or decrease in demand or generation over a specified time interval and is typically measured in MW per minute. Since utilities do not control consumer demand, electric load can change independent of the generation in the system. Over the years, however, utilities have developed accurate load forecasting techniques by taking advantage of the cyclical nature of load variations. As a result, generating unit commitment and dispatch can be planned day-head and optimized within the operating hour. Similarly, the timing and magnitude of load ramps can also be predicted quite accurately. The red curve in Figure 3.2 shows cyclical load variations in NSPI's system over a period of seven days and the green curve shows the wind generation profile during the same time period.

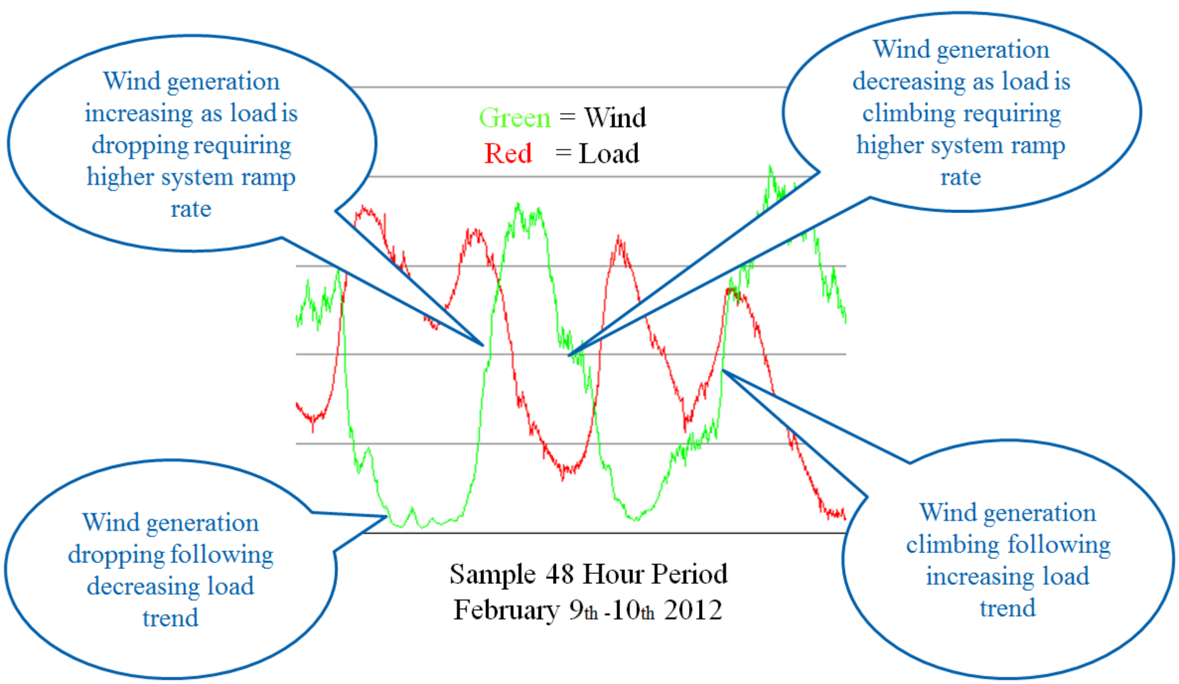
Figure 3.2: Typical System Load Profile and Wind Generation – Seven Day Period



Note: Red line in exhibit indicates system load, Green line indicates wind generation over a seven-day period
Source: NSPI

Similar to variations in load, wind generation also varies with time. However, the existing wind generation forecasting techniques are not as accurate as those used for load forecasting. Moreover, wind generation from IPPs, which accounts for 74% of wind generation in Nova Scotia (as shown in Table 2.1) is predominantly contracted on a take or pay basis. As a result wind generation essentially becomes non-dispatchable (except in emergency curtailment conditions) and is typically netted with load to determine the actual amount of conventional generation needed to maintain the balance between electricity demand and supply. As illustrated in Figure 3.3, netting of load and wind generation can either reduce the ramps or increase them because wind is not generally correlated with diurnal electricity demand patterns. Similar relationships are seen in other jurisdictions[22].

Figure 3.3: Interaction of Wind Generation and System Load



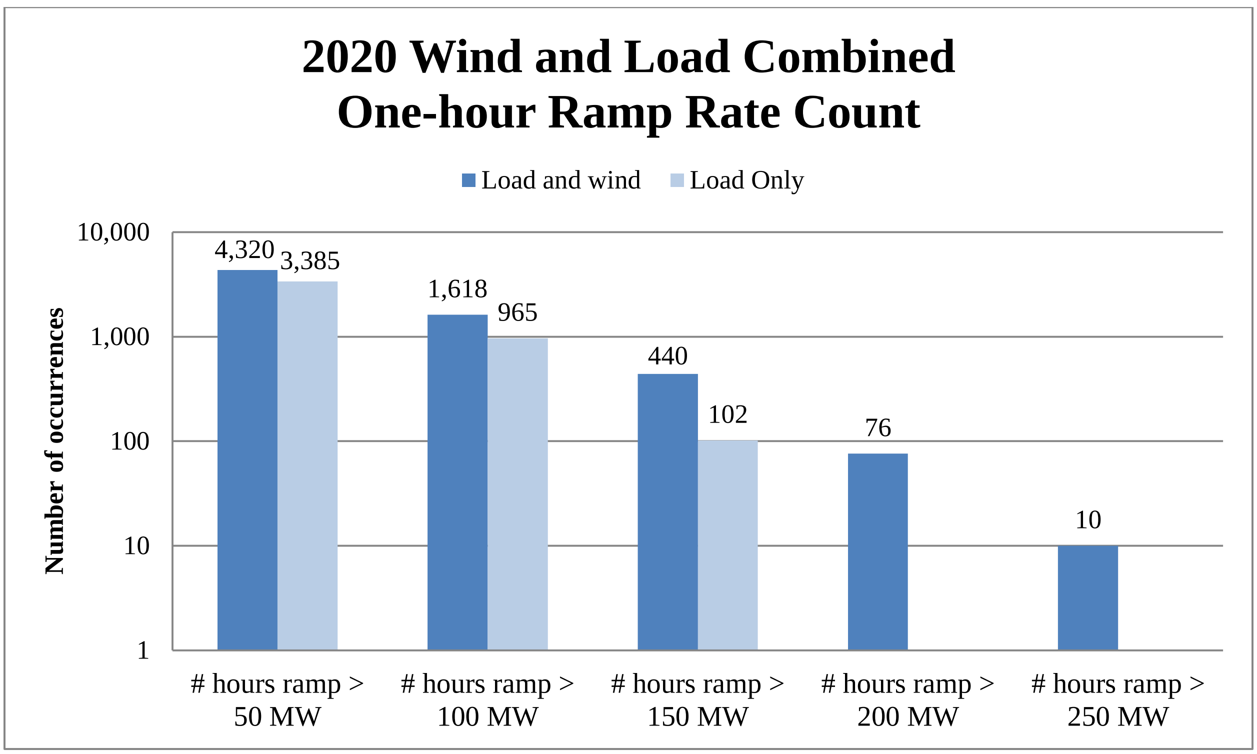
Source: NSPI

Increased ramp rates and the uncertainty associated with wind generation forecasts can make the task of balancing demand and supply very challenging. NSPI conducted an analysis to better understand the possible system ramp rates that could be encountered under high levels of wind penetration, and found that the load net of wind ramping requirements are consistently higher

[22] (North American Electric Reliability Corporation 2009)

than the load before modification by wind. These forecasts were conducted on the Low Load case which requires approximately 785MW of wind to meet RES requirements (Table 2.2). As shown in Figures 3.4 and 3.5, hourly ramp rates of over 200 MW could be expected to occur close to 100 times in a year due to the integration of 785 MW of wind in the system. The frequency of 3 hour ramps of over 450 MW is also forecasted to increase to 135 events per year for wind generation modified load compared with only 2 events for unmodified load[23]. The significance of this to the system is that NSPI must plan to have over 450 MW of ramping capability available in three hours without activating ten and thirty minute reserves. 6 hour ramp events of over 700 MW will challenge NSPI operators to have sufficient capacity available to meet these requirements after decommiting steam generators, which have historically provided much of this load following capacity, to make way for wind generation within the environmentally constrained system dispatch.

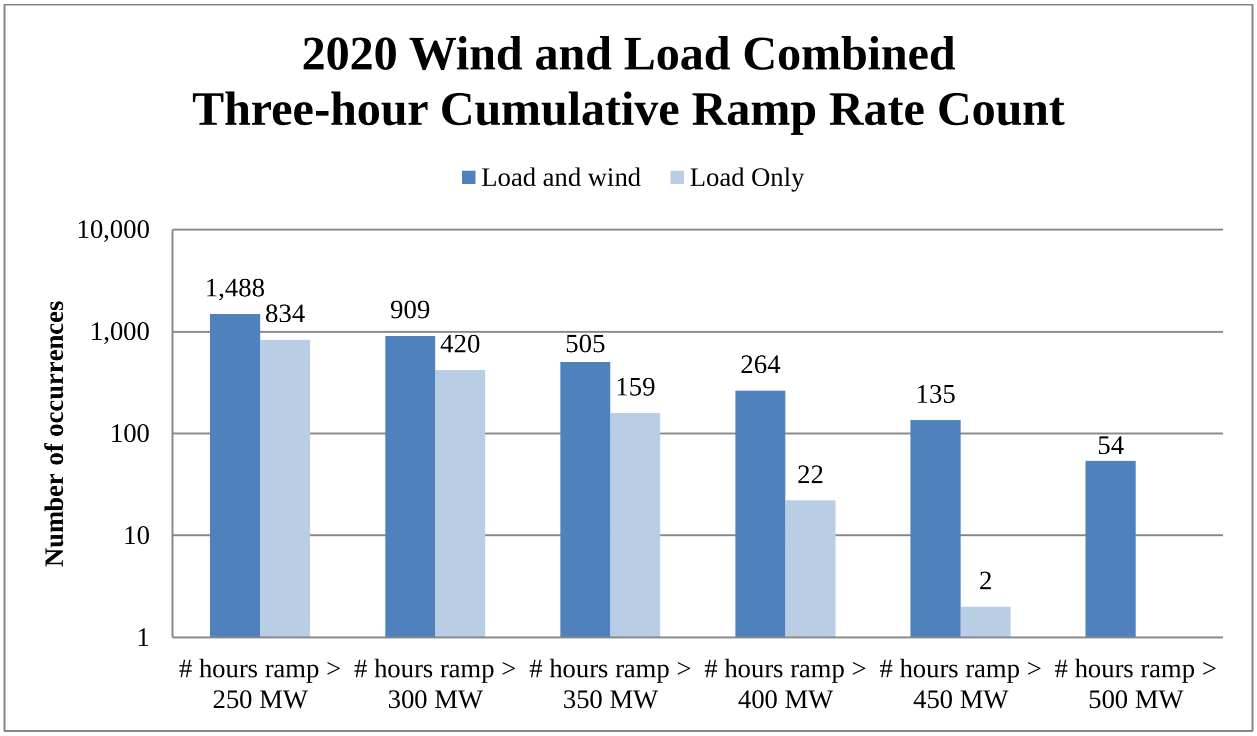
Figure 3.4: One Hour Ramps Rates with 785 MW of Nameplate Wind Generation Installed

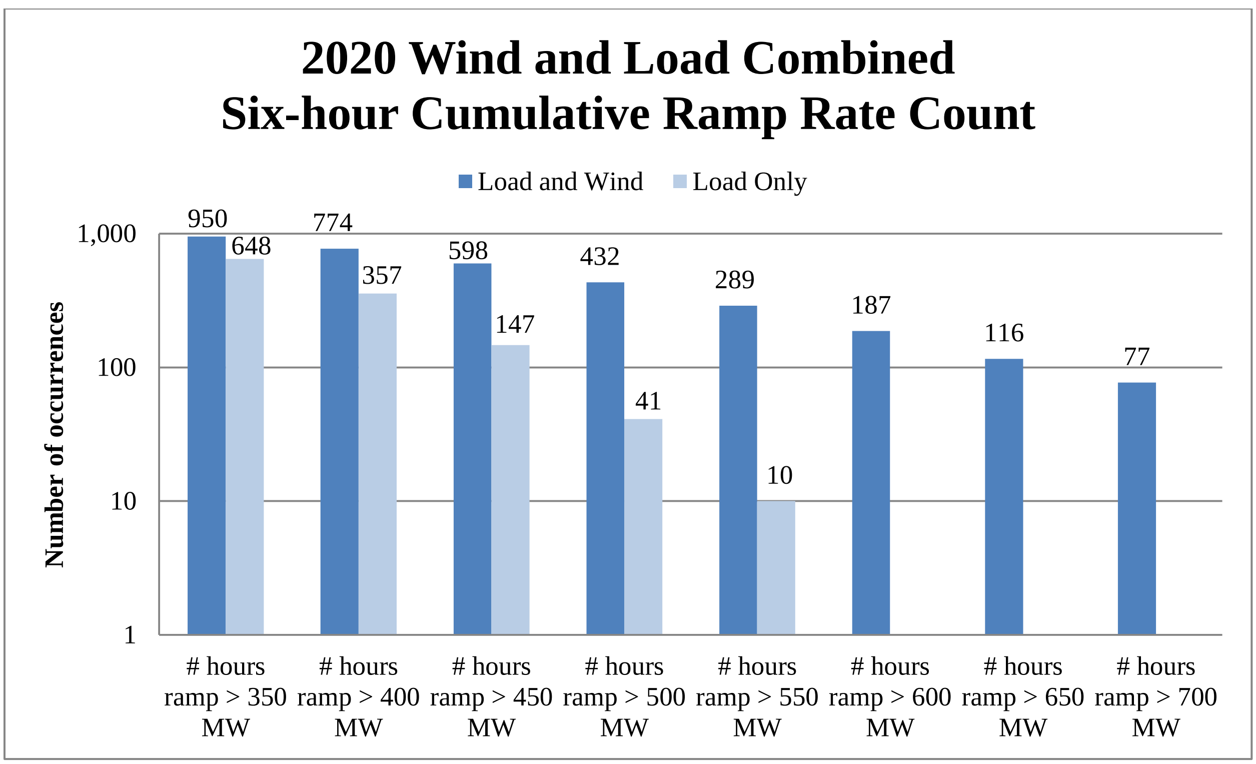


Source: NSPI

[23] Unmodified load implies actual electricity demand without any reduction by wind generation.

Figure 3.5: Multi-Hour Ramps Rates with 785 MW of Nameplate Wind Generation Installed





Source: NSPI

These ramp requirements would be expected to be more severe for the higher wind penetration levels which would be necessary at Base Load conditions.

Traditionally, NSPI's power system has derived its ramping capability from its steam units, and its hydro generating fleet. Each of these options has certain limitations on their ability to provide ramping support, the need for which is expected to increase as wind penetration increases in Nova Scotia.

The problem of increased ramps is compounded by environmental regulations that tighten air quality standards and restrict greenhouse gas emissions. As discussed earlier, these emission regulations will marginalize generation from coal fired power plants which provide much of the dispatch flexibility needed to counter load ramps.

The fleet of hydro power plants (381 MW as of 2012[24]) in Nova Scotia, which play an important role in serving the ramping needs and providing operating reserve, may not be sufficient to fill the ramping deficit created by marginalization of the coal fleet. Almost all of the hydro power facilities are run-of-river systems with limited storage, and none have sufficient storage (with the possible exception of the Mersey) to guarantee year round operation. In years where runoff from precipitation is below average, many of the hydro systems will be shut down as operators protect remaining storage in headponds for emergency use (reserve). Moreover, operational flexibility is limited on some hydro systems by stringent operating licenses which impose restrictions on dispatch for periods up to six months. In addition, hydro power plants will also need to be used for providing energy towards meeting the RES requirements. Due to all of these factors, the ability of hydro power plants to provide ramping support will be significantly limited.

Beyond the present day transfer limits imposed on the existing tie line, New Brunswick Power is another source that could be called upon to meet future ramping needs. New Brunswick Power faces many of the same challenges as NSPI. The New Brunswick Balancing Area includes Northern Maine and Prince Edward Island and, accordingly, NB Power must plan to manage the wind integration aspirations of the three political jurisdictions. While both Northern Maine and PEI are relatively small system loads when compared with NS or NB, their wind integration ambitions contribute to the large system balancing challenge for NB Power. Therefore, because

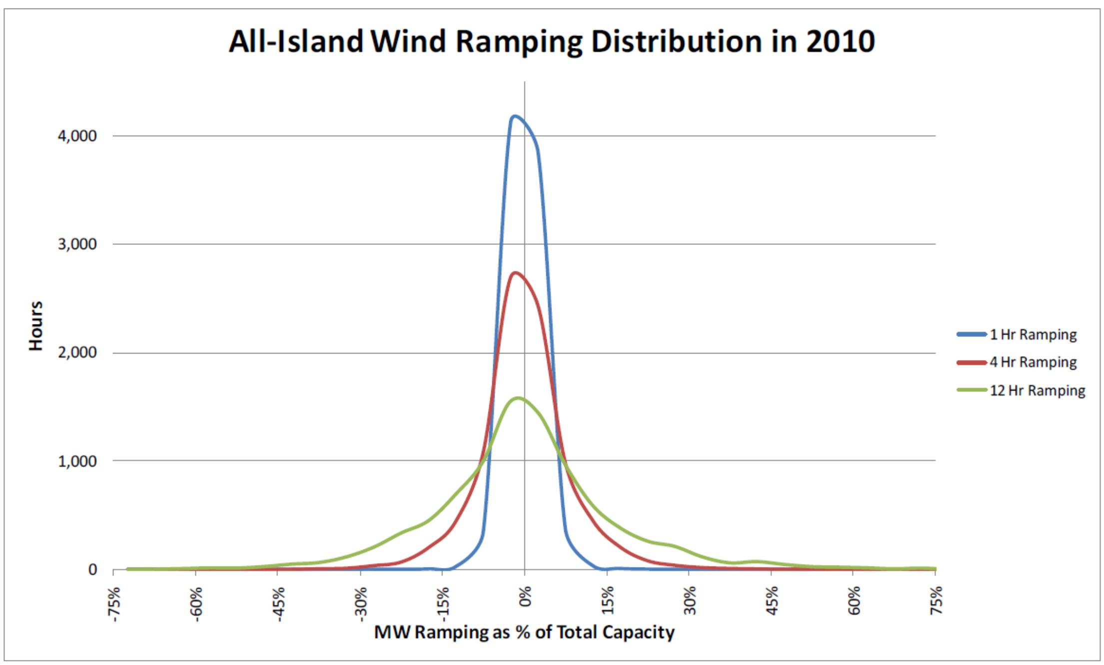
[24] (Nova Scotia Power Inc. 2012)

of these challenges within its own Balancing Area, New Brunswick Power will likely be limited in its ability to provide ramping support to NSPI.

Examples from other Jurisdictions

1. Ireland: The Irish electric power system managed by the system operator (EirGrid) has a peak demand of 7,500 MW and is required to achieve a renewable energy penetration target of 40% by 2020. At present, EirGrid has about 1,700 MW of wind generation and significant wind generation ramps have already been experienced. As shown in Figure 3.6, in 2010 some wind generation ramps were as high as 45% (of available wind capacity) in a 12 hour period, i.e., if wind generation were 1,000 MW in an hour, it could increase or decrease by 450 MW within next 12 hours[25]. In such cases, generation resources to provide for the supply shortfall need to be committed and ready for dispatch within the 12-hour timeframe.

Figure 3.6: Wind ramps in EirGrid (Ireland)



Source: EirGrid

[25] (EirGrid and System Operator for Northern Ireland 2011)

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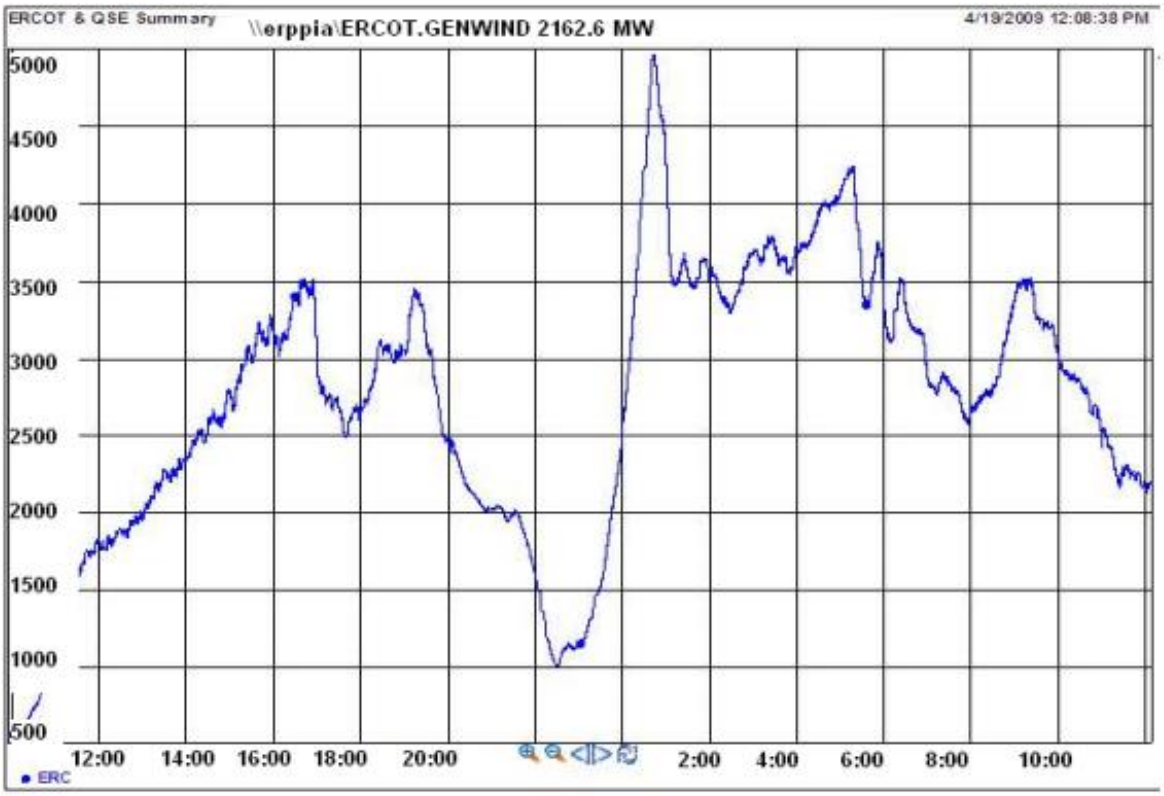
2. ERCOT: The ERCOT market has experienced significant wind generation ramps, sometimes in excess of 3,000 MW/hour. One such ramp occurred in April 2009 and is shown in Figure 3.7[26].

Figure 3.7: Wind ramp in ERCOT in 2009

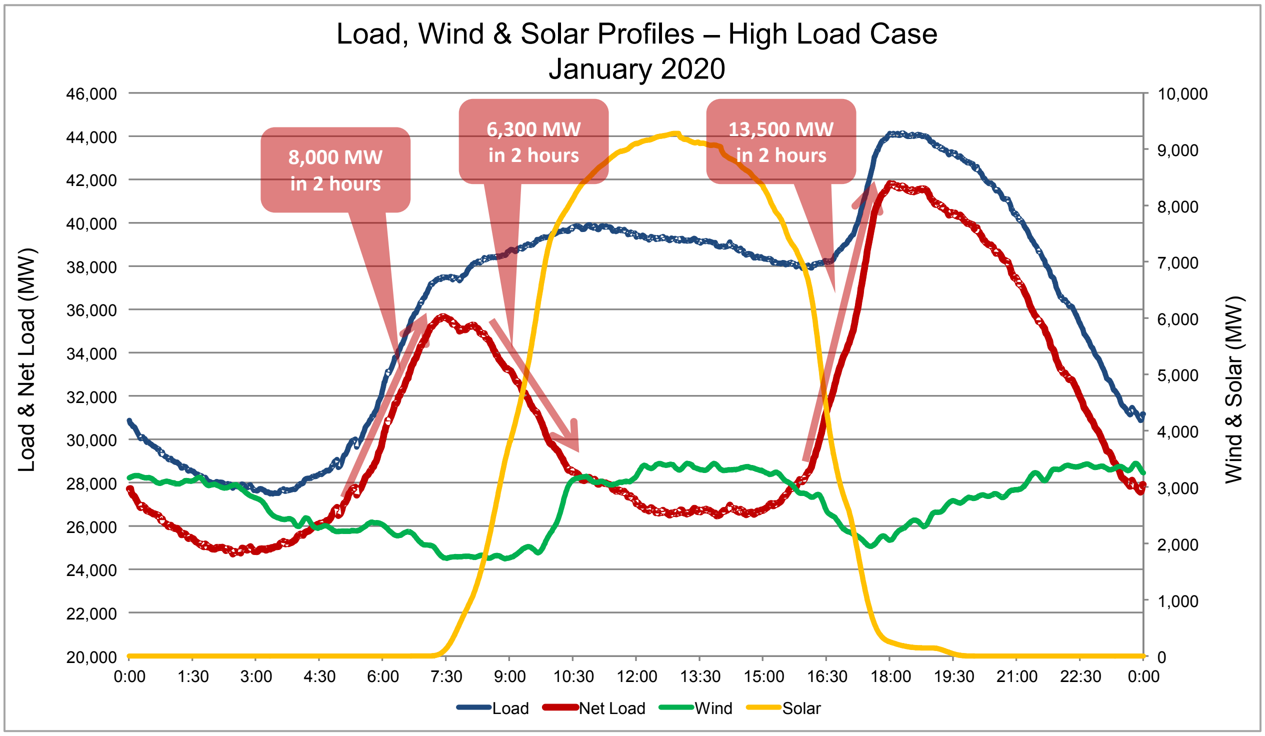


Source: NERC

3. California ISO: The state of California has a renewable portfolio standard of 33% by year 2020. The results of recent studies performed by the California Independent System Operator (CAISO) indicate that the system could experience a ramp of 8,000 MW in a 2-hour time frame with the 33% renewable penetration level necessitating flexible capacity to be available for supply shortfalls[27]. Figure 3.8 below shows the ramp requirements along with net load.

[26] (North American Electric Reliability Corporation 2010)
[27] (California Independent System Operator 2012)

Figure 3.8: Projected generation ramps in California for 2020



Source: CAISO

Similar to NSPI, the California system also has stringent environmental standards on the operation of conventional steam units creating significant concern on the amount of flexible capacity available to grid operators during such ramp-up or ramp-down conditions. The State and the operators are considering available options including a proposal to solicit flexible capacity additions to enable the 33% renewable standard by year 2020.

Recommendations

1. Wind generation forecasting methodology must be improved. NSPI is diligently working towards improving its wind forecasting methodology. This will enable NSPI to better manage the timing and level of ramps by efficiently dispatching its own generating units as well as by better scheduling of imports and exports from New Brunswick.

2. Since the tie-line with New Brunswick has a finite power carrying capacity, sudden large wind generation changes can lead to violations of the tie-line limit. In order to prevent such violations, the amount of generation kept online to maintain tie-line flows within limits must be increased.

3. NSPI is engaged in the PowerShift Atlantic project to test new opportunities to control customer load through a virtual power plant approach to respond to wind variability or other operational upsets. Additionally, voluntary load shedding programs such as the program used in the Alberta market called the Load Shed Service for Imports (LSSi)[28] can be instituted to help the system operator in maintaining demand and supply balance if sufficient conventional generation resources are not available.

B.3 Cycling of Thermal Generators

Challenge

As the amount of wind generating capacity on the power system increases, the variable nature of wind generation will result in increased cycling of thermal generating units. In high wind penetration cases, it is expected that that the number of starts and stops on the thermal generators will increase dramatically. This increase in coal generator cycling will result in higher variable maintenance costs as well as additional capital investments to refurbish plant equipment[29].

As recently as the end of the last decade, coal fired units at Lingan were valued for their capacity and high reliability. At present, however, Lingan units are operating across ranges that would not have been considered 5 to 10 years ago. This is primarily due to their displacement within the dispatch order by renewable energy sources and also by some reduction in system load since 2010[30]. While the units have proven that they can respond to these system needs, it is uncertain whether they should. Concerns for increased variable operating costs and potential long term damage from thermal cycling are under investigation by NSPI.

[28] (ENERNOC 2011)
[29] (APTECH Engineering Services n.d.)
[30] (Nova Scotia Power Inc. 2012)

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Recommendations

1. **Energy Storage**[31,32]: Energy storage systems can help in reducing thermal generator cycling by absorbing (charging) energy during excess wind generation and supplying (discharging) energy when wind generation is low. Pumped hydro energy storage, battery storage and Compressed Air Energy Storage (CAES) systems are some examples of systems that have the potential to store large amounts of energy. These technologies however, have certain limitations. Pumped hydro and CAES systems are location constrained while large scale battery storage can be extremely expensive.

2. **Transmission Links with Neighboring Areas**: Increased transmission capability to import power when wind generation is low and export power when it is in excess can also help in reducing thermal generator cycling. However, this option is predicated on the other jurisdictions having more flexibility in their generation sources to absorb excess wind generation. As discussed earlier, New Brunswick has limited generation flexibility and other neighboring regions, Prince Edward Islands and Northern Maine, also intend to develop large amounts of wind. These factors may limit the benefits that enhanced import/export capabilities may provide in managing thermal generator cycling.

B.4 Minimum Unit Commitment

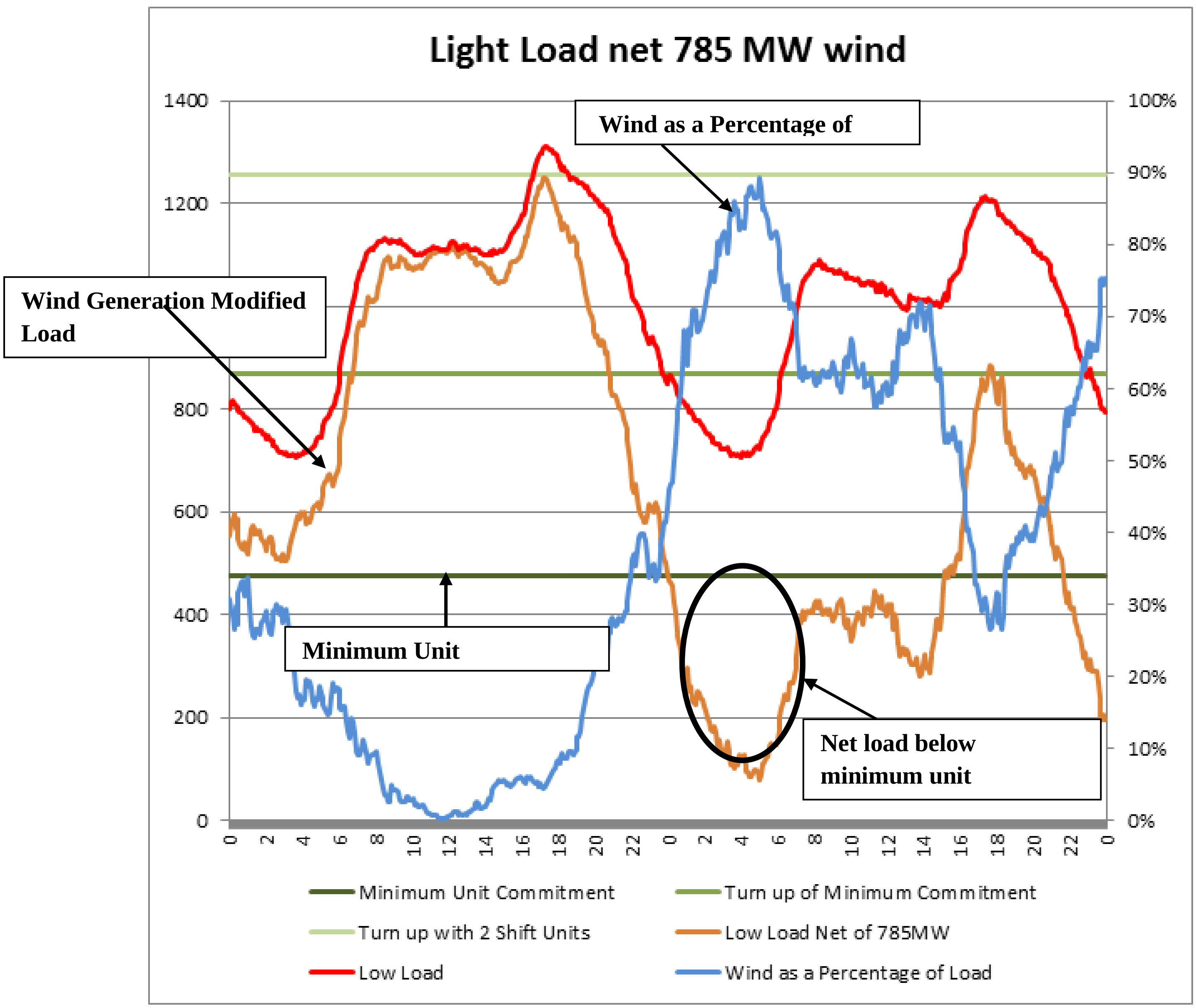
Challenge

As system load reduces in the off peak overnight hours, generation must be turned down to follow load. With wind generation added to the system, conventional generation must be turned down even further or *de-committed* to limit curtailment of wind generation in order to meet the RES requirements. With approximately 300 MW of wind generation installed, NSPI is already encountering the challenges of minimum unit turndown and commitment. However, the amount of conventional generation that can be de-committed is limited by the high morning load. This problem of minimum unit commitment is further complicated by possible unit contingencies and uncertainties introduced by errors in wind forecasts. To demonstrate the magnitude of the issue, Figure 3.9 presents an excerpt of actual system load data and actual wind generation data scaled

[31] (Goransson and Johnsson 2010)
[32] (Niamh, Eleanor and O'Malley 2009)

up to emulate the output of 785MW of installed wind capacity (the installed wind capacity that would be required to meet the 2020RES under low load conditions). The black circled portion on Figure 3.9 shows that for the five hour period between midnight and early morning, high wind generation (blue line) causes the modified load (actual load less wind generation, shown by the orange line) to become significantly lower than the minimum generation that is online. Such an event would necessitate wind curtailment due to low load conditions and the potential inability to de-commit conventional generation on short notice.

Figure 3.9: Example of Net Load Falling below Minimum Unit Commitment Level



Source: NSPI

Normally, NSPI plans for a minimum of five synchronized steam units to be on line at all times (generally a consideration during light load off peak periods). This minimum commitment provides up and down regulation, reactive support and frequency response in the event of a contingency. The selected of minimum committed units, along with the dispatchable hydro units (when available), and two-shifted gas units provides the necessary capacity to meet the increase in morning load.

Table 3.3 below examines the swing in capacity requirements in the daily load cycle with 785 MW of wind installed and the resource availability to meet these needs. In this example, installed wind is considered as a system variable from zero to full range. System load can swing close to 600 MW between overnight minimums and daytime peaks. Other capacity, both synchronized and dispatchable must be available above peak system load to serve regulation and operating reserve requirements. All of this adds up to a maximum possible daily swing in capacity of just over 1,600MW.

NSPI must be certain that it can deploy the generation capacity necessary to serve this swing. Table 3.3 shows a range of possible minimum unit commitment scenarios and derives the remaining capacity that must be met by hydro, wind, or imports. Since, none of these resources can be counted to be online under all circumstances it leaves the outstanding capacity requirement to be potentially un-served. While larger minimum unit commitment overnight reduces the outstanding capacity requirement, it will result in greater wind generation curtailment and reductions in renewable energy production for RES compliance. Conversely, the fewer the number of steam units which are kept online in overnight hours to maximize the opportunity for wind generation, less capacity will be available online to serve the capacity requirements for the next day. The challenge in this context is in the tradeoff between minimizing wind curtailment and retaining sufficient online capacity to meet the next day's load and reserve requirements.

Table 3.3: Daily Capacity Swing and Deployable Resources

(all values in MW)	5 Units Committed	6 Units Committed	7 Units Committed	8 Units Committed
Wind Range (Installed Capacity)	785	785	785	785
System Typical Daily Min/Max Range	580	580	580	580
Regulating Reserve	25	25	25	25
Operating Reserves	224	224	224	224
Total Capacity Range	**1614**	**1614**	**1614**	**1614**
Minimum Capacity of Committed Units	460	520	580	640
Turn-up of Minimum Commitment	409	499	590	680
Two Shifting Unit Capacity[1]	388	388	388	388
Reserve - Combustion Turbines	210	210	210	210
Total Turn-up & Combustion Turbines	**1007**	**1097**	**1188**	**1278**
Remaining Capacity Requirement (Hydro, Wind, Imports, Interruptions)	**607**	**517**	**426**	**336**

[1] Two Shifting Units are TC2, TC3, TC4,5,6
Source: NSPI

Examples from other Jurisdiction

Curtailment of wind generation is a potential issue in the EirGrid system as well. Studies[33,34] by the operator in this region indicate that with 40% of wind penetration, the minimum generation from conventional plants may be in excess of the net load (actual load less wind generation) during certain off-peak grid conditions. Under such instances, it is likely that generation would have to be curtailed while carefully considering the operational characteristics of conventional generation units (up time and down time restrictions).

Recommendations

1. Additional Two Shifting or Fast Start Units: In order to meet the aforementioned range of capacity swings while accommodating wind generation in system dispatch, NSPI would require additional two shifting or fast start generation units. Modern combined cycle generating units can be started and loaded on relatively short notice and can also provide energy at economic heat

[33] (EirGrid and System Operator for Northern Ireland 2011)
[34] (EirGrid and System Operator for Northern Ireland 2011)

rates. Simple cycle combustion turbines in comparison offer lower capital cost, excellent dispatchability, but have higher unit heat rates than combined cycle facilities.

2. Load Shifting: If some loads can be shifted to low load periods to shave the peak load and fill in the low load valleys, the problem of minimum unit commitment can be addressed to some extent. NSPI is already participating in such an initiative called as “PowerShift Atlantic”. This pilot project is focusing on controlling electric thermal loads such as space and water heating to shift load. NSPI would have the ability to control the thermal loads of participating customers remotely, and is targeting a load shifting capacity of 8 MW by summer 2013.

IV. Summary and Capital Integration Costs

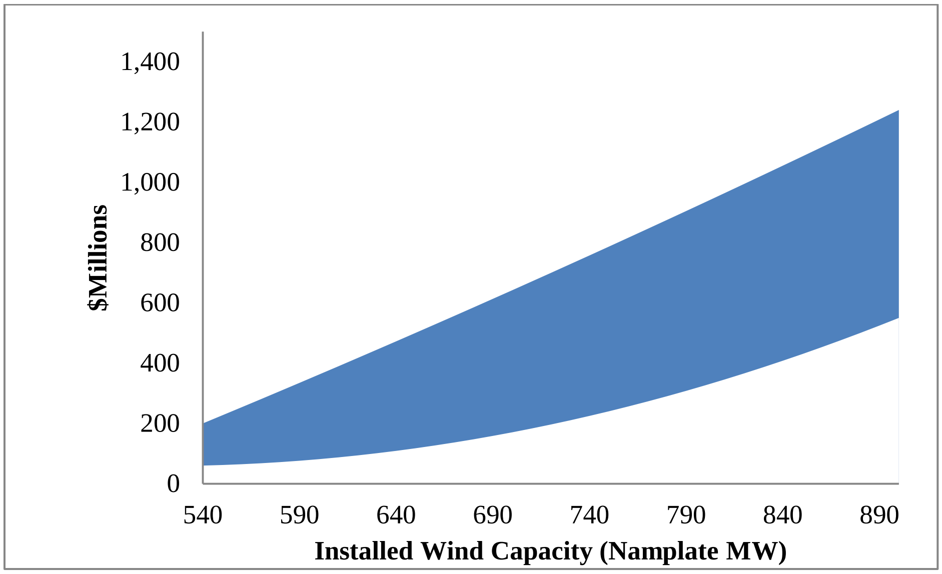
As discussed, large scale wind integration presents new challenges to system planners and operators. NSPI has endeavoured in this paper to articulate some of these challenges – from an experience and best practices perspective within the industry, as well as from a forward-looking perspective in anticipation of potential impacts on the operation of the NSPI system.

Should it be necessary for NSPI to meet the 2020 RES requirements predominantly with wind, significant integration costs will be incurred over and above the costs associated with building wind generation and associated interconnection facilities. While NSPI is continuing to detail these costs the following system requirements have been identified to date which would require some level of capital investment depending on the penetration levels of variable wind generation:

- Investment in new conventional generating capacity to maintain planning reserves and address needs for two shifting or fast acting generation. Simple-cycle combustion turbines in various multiples of 50MW ($60M) and 100MW ($100M) were assumed to address this requirement across the range of wind options.
- Investment in transmission upgrades within NSPI and developing stronger links with neighboring utilities to enhance system stability and reduce thermal generator cycling. Transmission investments with a mid-range of $250M were assumed to represent these costs.
- Deploying energy storage and load shifting programs to complement conventional generation for managing wind variability and wind ramps. In cases where energy storage/load shifting was assumed necessary, costs were forecasted at $200 to $400M.

While this analysis is not exhaustive at this stage, it would be reasonable to expect that capital expenditures for significant wind penetration levels as discussed herein would be within the ranges presented in Figure 4.1:

Figure 4.1 Estimated Range of Capital Investments to Support Large Scale Wind Integration



Source: NSPI

As noted, these cost estimates are for capital expenditures only and do not reflect operating costs related to wind integration such as thermal unit cycling costs, heat rate penalties, wind curtailment, and other related costs. It should also be noted that any costs associated with new or enhanced natural gas infrastructure or fuel inventories for dual-fuel options to support a wind/gas alternative are not contemplated in these capital costs and would be incremental to the estimates in Figure 4.1.

V. Conclusion

Wind generation has been the primary source of new renewable electricity in Nova Scotia. As recent amendments to the RES have established new legislative requirements for 2020, NSPI is planning now to ensure compliance within the context of building, operating and maintaining a sustainable, reliable, efficient and cost-effective electric power system in Nova Scotia.

As discussed in the previous sections, there are several operational and planning related challenges associated with the integration of the large levels of variable renewable generation that would be necessary to achieve compliance in 2020. Most of these challenges can be addressed and mitigated, but require appropriate (and sometimes substantial) investments in the power system as well as significant shifts in operating practices. Further, the level of wind penetration necessary to achieve RES compliance is under consideration by a relatively small number of jurisdictions. In fact, NSPI is already working to integrate what typical industry standards would characterize as significant levels of wind generation. Recent commitments for new wind projects through the Renewable Electricity Administrator will bring total wind on the NSPI system close to 500 MW before COMFIT projects are counted. This will be a reality on a power system where the minimum nighttime load can be as low as 700 MW.

The variable nature of wind, together with other dispatch challenges, make the high wind option dependent on natural gas and energy imports. Investments in fast acting generation, stronger interties, load shifting, and load management will be necessary to allow the system to be operated reliably. NSPI is in the process of completing its renewable energy integration study to allow a more complete understanding of the operational impacts of integrating substantial amounts of wind generation into the power system.

NSPI is committed to achieving the compliance requirements of Nova Scotia's Renewable Electricity Standard. NSPI will continue to review, quantify and optimize the most appropriate mix of renewable generation, transmission expansion, and other system enhancements to enable achievement of RES requirements, reliable operation of the electric power system and lowest cost to customers.

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