Nova Scotia POWER
An Emera Company

MAY 1, 2014

Variable Generation Integration Costs

Executive Summary

The addition of variable generation (wind and solar) to the electrical system introduces additional costs associated with unit dispatch and commitment, system reserves and capital investments. These additional costs the utility incurred due to addition of variable energy sources are called: Variable Energy Integration costs.

Modelling of NSPI's 2020 system (current system plus committed wind plus Maritime Link, but excluding other new infrastructure) indicates that operational dispatch costs associated with integration of variable energy on the NSPI system would increase sharply after 550-600 MW of wind generation reflecting dispatch challenges, absent new capital infrastructure.

Experience with the characteristics of wind generation on the system and wind forecasting suggests that the existing and committed 550-600 MW of wind generation, and any further increases, will increase operational reserve requirements. The extent of such increases will depend on many factors, including wind forecast error. The system must have adequate reserves to ensure reliable operation, and the planning exercise must include an estimate of such reserve requirements.

In order to maintain system reliability, new capital investments will be necessary to integrate more variable generation on the system past 600 MW. The capital investments will address needed requirements for fast acting firm capacity, system inertia, reactive power support, primary and secondary frequency response and other system reliability requirements. In addition, they mitigate some of the operating cost increases.

Executive Summary

Quantifying Variable Generation Integration Costs

Integration costs vary depending on the level of variable generation penetration and system characteristics, and thus it is not possible to provide a single integration cost figure to cover all scenarios.

Variable generation integration costs will be included in the analysis of resource plan costs by considering the following:

1. Operational Dispatch Costs
2. Capital Investment Costs
3. Additional Reserve Requirement Costs

Operational dispatch costs reflect costs associated with generating unit operation at lower heat rates, unit starts and stops, and unit commitment optimization. Estimates for these costs absent incremental infrastructure have been derived using simulation software.

Capital investments for system upgrades are necessary to support reliable system operation for additional variable generation above the existing and committed 600 MW. A profile for the capital investments required for incremental variable generation will be derived to complete the template table that follows.

The cost of additional, non-contingency reserves will not be directly factored into this analysis, but is reflected to some extent in the capital investments discussed above.

These cost elements have interrelationships that should be considered. For example system upgrades required to integrate additional renewable generation could be expected to lower the operating portion of integration costs. To account for this NS Power proposes to redevelop operational dispatch cost estimates based on the capital investments that are assumed for incremental additions of variable generation.

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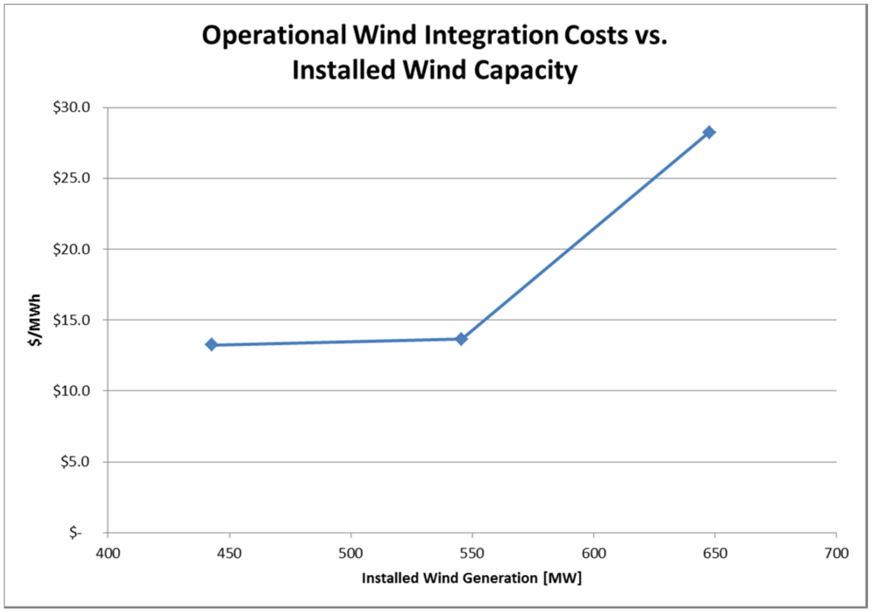
Executive Summary

Operational Dispatch Costs



The sharp increase in the operating portions of variable generation integration costs indicates stress on the current power system. Graph shows costs in 2020 dollars per MWh.

Simulations conducted in this study, supported by conclusions in the GE Energy Renewable Energy Integration Study, suggest that the maximum quantity of wind generation that can be reliably integrated on the presently forecasted 2020 system configuration is 550-600 MW.

The operating portion of wind integration cost presented here does not include the effects of capital investments made for system reliability, which are expected to lower this cost and will be calculated on a case by case basis.

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Executive Summary

Capital Investments to Support Variable Generation Integration

600 MW + Required Technology - roughly in order of lower to higher cost	50 MW (650 MW)	100 MW (700 MW)	150 MW (750 MW)	200 MW (800 MW)	250 MW (850 MW)	300 MW (900 MW)	Estimated Cost Range / Notes
Minimum requirements for wind turbine characteristics							TBD?
Reactive power support (SVC, Synch Cond, Cap Bank)							\$15 - \$35 million
NS Transmission other than Link reinforcements							TBD?
Incremental existing hydro storage/capability (eg Wreck Cove, Mersey system)	Some of the costs associated with this incremental investment may be included in all resource plans.						TBD?
Firm fast acting capacity – CTs or CCs							\$50 million per 45MW, 45-135 MW need
Additional Reliability Tie to NB							\$170 million
Other Energy Storage							\$135 million per 50 MW, 50-100 MW need

The table above is a template of capital projects which will enable integration of further variable intermittent generation. The table will inform candidate resource plan development as the necessary system upgrades will be included in the model representation for each plan involving variable generation additions to the system. Additionally, these same capital investments will be used to redevelop the operational dispatch costs on a plan by plan basis. In this manner, NS Power expects to properly reflect the costs and the benefits of any system upgrades on variable generation integration costs.

Additional Study Information

Study Methodology

Variable energy integration costs consist of:

1. Operational Dispatch Costs
2. Capital Investment Costs
3. Additional Reserve Requirement Costs

All three aspects of the variable energy integration cost will be addressed individually.

Once candidate resource plans which contain incremental additions of variable generation are developed with respect to resource location and timing, the scenario specific operating portion of integration costs can be calculated by including the capital investments to support variable generation integration in the simulation.

Study Methodology –

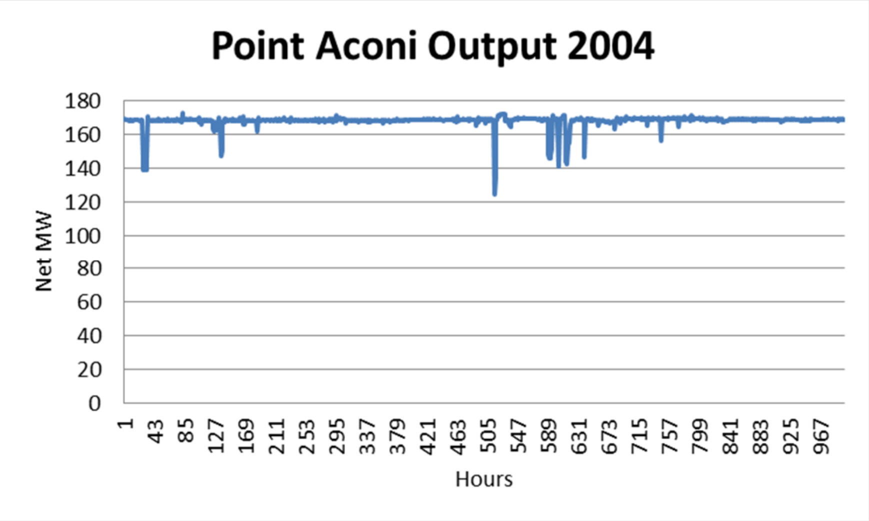
Operational Dispatch Costs

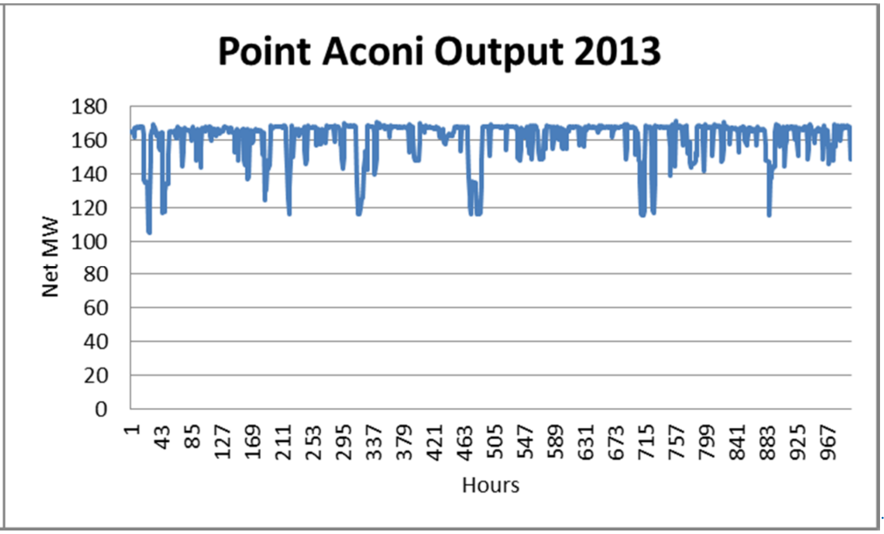
- In order to profile operational integration costs of variable generation increases a series of comparison simulations was conducted (for 2020, assuming the existing system plus Maritime Link) in which variable non-dispatchable generation was replaced with equivalent dispatchable generation (i.e. generation of the same capacity but whose limited monthly energy could be dispatched most cost effectively). This simulates how variable, non-dispatchable generation affects the overall system operating costs associated with unit operation at lower heat rates, unit starts and stops, and unit commitment optimization.

- These operating cost simulations did not consider:
  - additional non-contingency reserve requirements
  - additional reliability mitigating resources additions
  - additional maintenance costs associated with unit ramping and 2-shifts

Introduction –
Examples of Variable Generation Impact on System

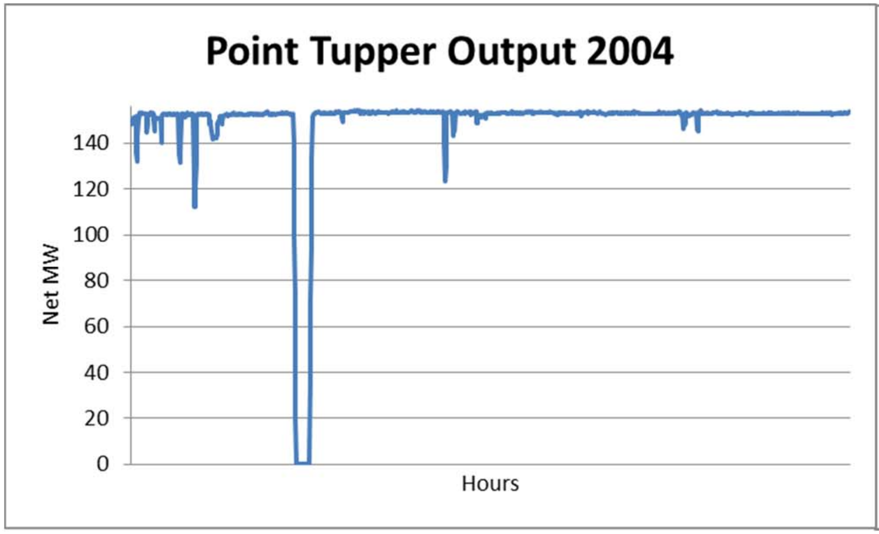
- The example below shows Point Aconi hourly generation for the first 1000 hours in two different years; 2004, with little wind generation on the system, and 2013 with approximately 300 MW of wind generation.
- In the 2013 Point Aconi is frequently seen to be operating in sub-optimal regions largely to accommodate the variability generation.
- Operating in sub-optimal regions will incur costs in the form of higher realized heat rate and resulting higher fuel consumption as well as wear and tear of the unit components.
- Similar pattern has been observed on other generating units, but Point Aconi was picked as an example of a unit which by design (related to sulphur capture technology) is not well suited to such mode of operation.

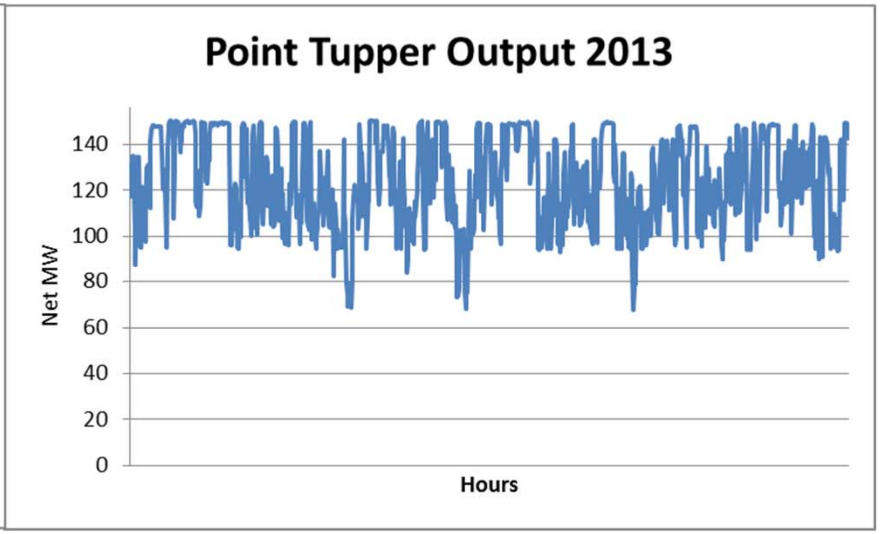




Introduction –
Examples of Variable Generation Impact on System

- A more pronounced contrast in the way steam units on the NSPI system are being dispatched to follow variable generation can be seen at Point Tupper. As in the previous example, we see that the unit seldom operates steadily at full output, which has an effect on average realized heat rate as well as wear and tear of the unit components.

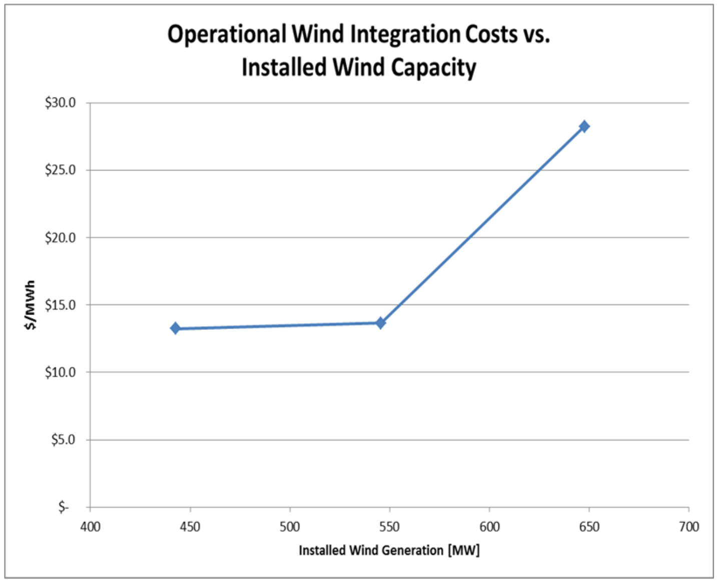




Operational Dispatch

System Costs

Wind Penetration Level [MW]	Incremental Operating Integration Cost [$/ MWh]
650	28.2
550	13.7
450	13.2



Operational costs of integration wind energy on the system result from steam generating unit heat rate degradation - as described on the previous slides, increased number of starts and stops, wind and hydro energy curtailment, etc.

The modeling work shows that the cost of integrating wind generation up to 550 MW is in the range of $10-$15/MWh, which is consistent with the assumptions used in the studies leading up the integration of 550 MW of wind generation .

The cost of wind generation integration past 550 MW increases, with the simulation showing dispatch challenges associated with integrating this quantity of wind, indicating that additional system reliability mitigating measures will be required as we integrate more than 550 MW of wind generation.

NOTE: The integration cost figure for 650 MW of wind generation is only an indication of sharply increasing integration costs at present system configuration plus Maritime Link. The simulation producing this figures did not include any system reliability mitigating measures, such as additional ties or firm capacity. Integration costs used in simulations will be re-calculated for specific candidate resource plans reflecting the operational benefits of any capital investments made to support further variable generation additions.

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Operating Reserve Requirement

- Additional operating reserve requirements were not considered in the modeling of operational dispatch integration costs.

- GE Renewable Energy Integration Study shows that additional 10-minute reserve will be required to integrate large quantities of wind generation: *"The wind variability adds to the short-term variability of net load (load minus wind), which requires following with synchronized reserve. This additional synchronous reserve requirement is above and beyond the synchronized contingency reserves or Regulation Up and Regulation Down since most variations should not impinge on the contingency reserves. The grid operator needs guidance, in advance, to set and hold these incremental reserves."*

  (Page 64 GE Renewable Energy Integration Study)

- The discrete cost of 10-minute reserve additions is difficult to estimate since it may result in the requirement to add additional capacity. GE Energy estimates that NSPI will have to carry additional 32 MW of non synchronous 10-minute reserve in order to integrate ~600 MW of wind generation, and additional reserve for further variable generation. A estimate for this cost was not prepared for this integration assumption set.

Capital Investments to Support Variable Generation Integration

- Since much of the flexibility in the existing power system plus Maritime Link has been consumed by the variable generation existing and committed, some combination of resources indicated on slide 5 – including possibly new fast acting generation - will be needed in order to integrate additional wind generation past the already committed 550-600 MW. Additional flexibility obtained with the addition of the Maritime Link will be included in resource scenario modeling.

- The new capacity is needed to address challenges in:

    - additional replacement reserve
    - wind forecast error reserve
    - wind following capability
    - system stability

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Capital Investments to Support Variable Generation Integration

- It is difficult to estimate the exact level of wind penetration at which the system starts to experience instabilities. System modelling indicates that operating cost rises past 550-600 MW of wind generation. This coupled with violations of system constraints within the Plexos modeling conducted to date suggests that the system is experiencing difficulty integrating larger quantities of variable generation with the existing balancing resources.

- Furthermore, system dispatch simulations show system constraints violations with incremental 200 MW past 550 MW of installed wind generation, which indicates that there is a problem with system stability at this level of wind penetration, even with hourly simulation granularity which assumes average hourly wind generation and system demand, without considering sub hourly fluctuations.

- For the purpose of this study, we may assume (based on Plexos analysis to be performed) that additional fast acting firm capacity will be required to reliably integrate wind generation past the presently committed 600 MW. We will first analyze the system with anticipated incremental flexibility available from the Maritime Link, possible incremental hydro improvements, demand response resources, and internal transmission improvements.

Capital Investments to Support Variable Generation Integration

At a wind penetration level somewhere above 600MW, an additional 345kV line to New Brunswick may be required to ensure NS system stability, depending on the extent of infrastructure investment (e.g. (but not limited to) increased amounts of fast-start generation). The threshold wind penetration level will be difficult to determine with certainty, but the modeling exercise will aim to create increased wind penetration scenarios up to, and then above this level, including the costs of a 2nd tie for the highest level of wind penetration to be studied.

If the single tie to NB trips, and NS is separated from NB with a high percentage of wind generation, reliability standards require the re-dispatch of the system to survive the next contingency within 30 minutes. System studies have shown the NS system would collapse under such conditions. A properly configured second tie would minimize the probability of this configuration. It should be noted, however, that transmission configuration inside NB may require further upgrades to meet this goal.

At a certain (currently unknown) level of higher wind penetration, it is possible that additional energy storage will also be needed to effectively use the energy from incremental wind additions. Whether or not this is required will depend on the overall level of system "flexibility" which is based in part on the set of resources in place in the modeled resource scenario. We will determine whether or not a storage resource (incremental to other infrastructure improvements) will be required as part of the modeling of higher wind penetration scenarios.

Internal Transmission Reinforcements

Displacement of conventional generation with wind generation will require augmentation of the characteristics of the displaced generation to maintain system reliability. Wind generation is, in theory, capable of providing some of these features, but they are not "off the shelf" and are not available from all wind generation suppliers.

Unit inertial response, high speed reactive power control, system frequency control, synchronized operating reserve, system black-start capability, under-frequency load shedding programs, and short-circuit ratio are all considerations that will raise the cost of future generations of wind turbine technologies. These necessary "ancillary services" currently provided by conventional generation can be augmented by external devices such as Static VAr Compensators, Statcom, synchronous condensers, and other Flexible AC Transmission Systems (FACTS) devices.

It may not be possible or feasible to retro-fit existing wind farms with such controls. Depending on which additional infrastructure investments are considered in place in different resource scenarios, future wind farms may need to be specified with some combination of these types of auxiliary equipment to permit higher wind generation penetration levels.

It is anticipated that SVC and/or synchronous condensers will be needed at Tupper, Onslow, and in HRM. The proposed reactive power support solutions are chosen for being more cost effective than building new generation and /or transmission while still enabling higher energy transfer.