Overview of the Sheffield-Highgate Export Interface (SHEI)

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Introduction

As early as 2012, the electric transmission system in Northern Vermont reached its capacity to integrate new generators without financial impact on existing generators. Several factors contribute to this situation. Public policies and customer desires continue to fuel utility-scale renewable generation projects and smaller, customer-owned net metered projects. The transmission system operator altered its dispatch rules in 2016. VELCO periodically must take elements out of service for necessary grid maintenance. In 2013, ISO New England (ISO-NE)[1] demarcated the Sheffield-Highgate Export Interface (SHEI) and established generator operation limits to ensure that the transmission system's capacity to function reliably remains intact. When the limit is reached, renewable capacity is restricted or becomes uneconomic to run, contrary to the interests of the state's renewable energy policy goals and generator and customer interests.

The intent of this paper is to share VELCO's knowledge regarding the SHEI area in as transparent a manner as possible, while following Federal Energy Regulatory Commission's (FERC) Standards of Conduct and other information protection rules[2]. Accordingly, this paper does not include any non-public transmission function information or Critical Energy Infrastructure Information (CEII), but does provide a complete enough picture to enable affected and interested entities to conduct an open and informed discussion of solutions to reduce renewable energy curtailment in Northern Vermont.

This overview: (1) describes the minimum standard a utility scale generator is required to meet to interconnect into the grid; (2) outlines generation growth in Northern Vermont; (3) explains how electrical load and generation behave in the SHEI area; (4) discusses export limits that help system operators maintain system reliability in real-time; and (5) offers some solution ideas in the areas of system operation, equipment utilization and system reinforcements.

Transmission reinforcements are driven by reliability, not economics

Transmission system reliability is a core goal for both ISO-NE and VELCO, Vermont's transmission company. Thus, from time to time, following federal rules, ISO-NE and VELCO identify Vermont transmission system projects that are necessary to ensure overall grid reliability both here and in New England (so called "reliability projects"). Before VELCO pursues reliability-driven transmission projects it examines whether viable non-transmission alternatives, such as load reduction or generation augmentation, can adequately address the reliability deficiency. When a Vermont reliability project is ultimately determined to be necessary to maintain New England grid reliability, VELCO constructs the project, and project costs are spread across all of New England's electric customers.

Grid reliability also undergirds ISO-NE's determination whether a new generator can interconnect with the transmission system. In order for a new generation project to interconnect into the grid, ISO-NE analyzes whether and how the project can comply with NPCC standards and ISO-NE standards

[1] ISO-NE is the "independent, not-for-profit corporation responsible for keeping electricity flowing across the six New England states and ensuring that the region has reliable, competitively priced wholesale electricity today and into the future." ISO-NE has functional control of the high voltage electric grid in New England and operates it to ensure its reliability. Source: ISO-NE website.

[2] See appendix for details regarding FERC Standards of Conduct for Transmission Providers and Critical Energy Infrastructure Information.

consistent with the FERC-sanctioned minimum planning standards [the so-called "Network Capability Interconnection Standard" or Minimum Interconnection Standard (MIS)]. The MIS ensures that a project will not have any significant adverse effect on the reliability, stability, and operability of the New England transmission system. Through the MIS study, ISO-NE determines what specific transmission system measures are necessary for reliability and, therefore, must funded by the developer. But developers are *not required* to reinforce the system to ensure they or other generators can run at their capacity, i.e., to ensure against adversely impact existing generators' financial performance. The system is designed this way in light of an express prohibition in federal law on the imposition of undue restrictions on a generator's right to compete for open access to the transmission grid.

Generation growth in Northern Vermont

Three utility-scale generation projects—Swanton Gas (40 MW), Sheffield Wind (40 MW) and Kingdom Community Wind (KCW) (64.5 MW)—have interconnected in the northern portion of the Vermont transmission system, all based on the MIS, which requires generators to undertake system upgrades only if their operation reduces system capacity. The wholesale generation market is highly competitive, consistent with FERC regulations, and generation developers, including those in Northern Vermont, prefer lower cost interconnections.

As VELCO stated in our 2012 Vermont Long-Range Transmission Plan filed with the Public Service Board, shared at the VELCO Operating Committee and Vermont System Planning Committee, and discussed with regulators, legislators, interest groups and the media, the transmission system in Vermont's northern tier has reached its capacity to accept additional generation. Additional generation in this area will either increase competition for transmission capacity during heavy generation periods or require mitigating measures to increase transmission capacity that could accommodate heavy coincident generation, such as operational or design improvements, energy storage, energy transformation initiatives, or transmission grid reinforcements of some kind. That does not mean that additional generators cannot interconnect, but it does mean that the developers of generation projects will likely be required to fund mitigating measures in order to interconnect.

Its interconnection study indicated that KCW's operation would reduce system capacity. Its owners largely mitigated this concern by installing a synchronous condenser[3], which restored system capacity to pre-KCW levels, but not to a level that would allow KCW to run at full capacity under all conditions. ISO-NE created the SHEI in 2013 to monitor system flows and adjust local generation resources, including the Highgate converter, to ensure that system capacity would not be exceeded under certain conditions. System capacity is a power flow threshold that should not be exceeded by actual export flows. It is calculated by adding flows on the Sheffield-to-Lyndonville transmission line and the Highgate-to-St. Albans transmission line section, with due regard to the effects of local generation. The SHEI boundary is illustrated in the following ISO-NE diagram.

[3] A synchronous condenser is a device identical to a synchronous motor, whose shaft is not connected to anything but spins freely. Its purpose is not to convert mechanical power to electric power, but to adjust voltage on the electric grid. Voltage is a force that makes electricity move through a wire. Low voltage is a serious concern.

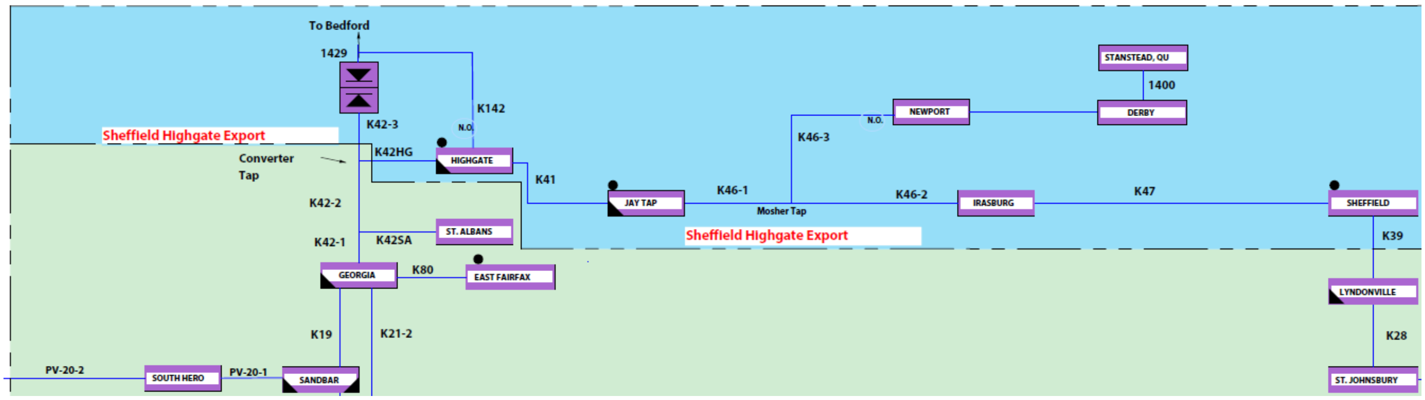

Figure 1: SHEI transmission boundaries

All substation loads and generation plants located in the blue-shaded area above the Sheffield-Highgate Export dashed line affect power flows across the dashed line directly. Below is a description of these loads and generation plants based on data from June 2015 to May 2017. The period is too short to discuss trends, but it is useful to observe load and generation behavior.

Load behavior in the SHEI area

Total load was calculated by adding loads that are served by the Irasburg 46 kV substation, the Jay 46 kV substation and the Highgate 46 kV substation. Load served from the Newport 46 kV substation is not included in this calculation because it is not normally served from the Vermont system; however, this load can skew the maximum load at a particular time when it is moved from the Canadian system to the Vermont system. For example, we suspect this happened during June 2015 and August 2016.

The data show that load within the SHEI area is variable, but only to a small degree. In the following diagram, the green curve represents the maximum load during each month; the blue curve represents the average load during each month; and the orange curve represents the minimum load during each month.

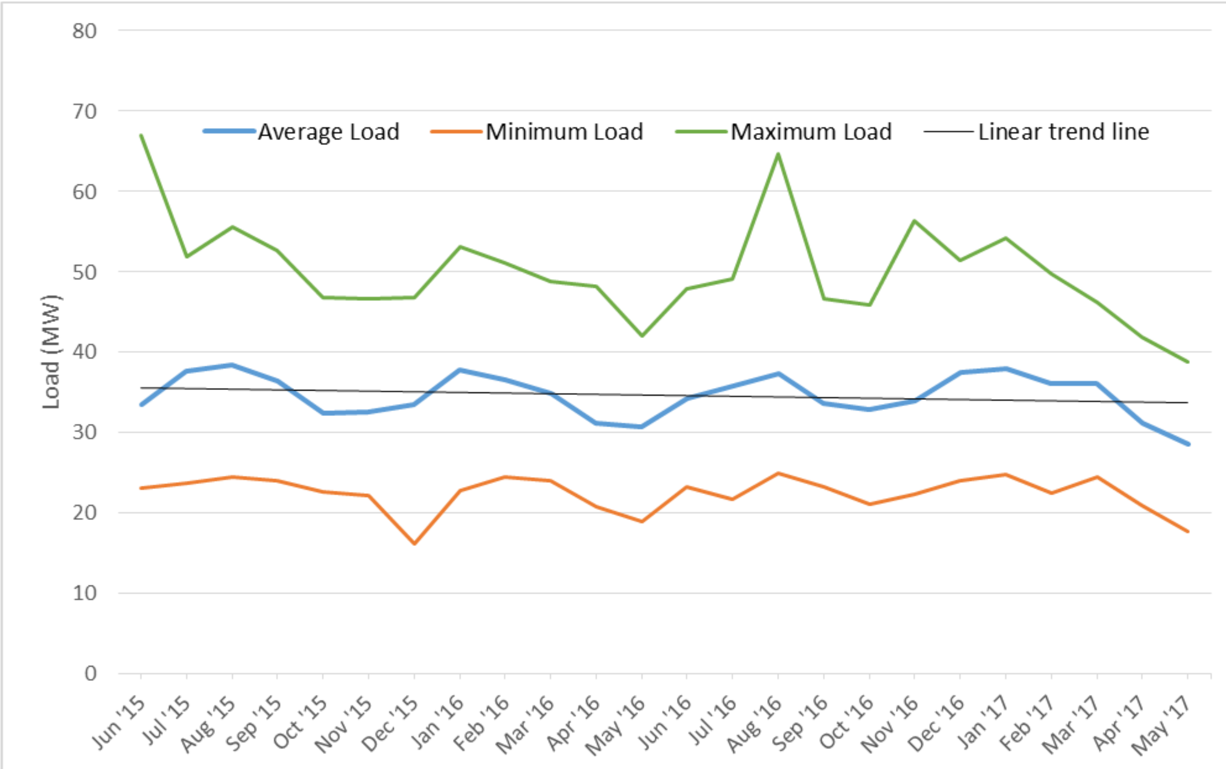

Figure 2: Seasonality of SHEI load

The average load is about 35 MW, with about a 5 MW variability depending on the season. As can be expected, the average load is higher during summer and winter, and lower during fall and particularly spring. A trend line dropped onto the average curve indicates a slightly declining slope over time. Although the two-year time period is short, this declining trend is consistent with our understanding that behind-the-meter generation is progressively reducing system load as seen from the transmission system.

The maximum load is about 50 MW, and it appears to be more variable than the average load, but we believe this variability is caused by the occasional relocation of the Newport load from Canada to Vermont. The maximum amount of the Newport load is approximately 15 MW.

The minimum load is about 22 MW with an almost imperceptible seasonal variability. Note that the minimum load does not occur frequently, as can be seen on the following load duration curves, which also show that the total load is typically 35 MW within a tight band of +/- 5 MW for about 5000 hours.

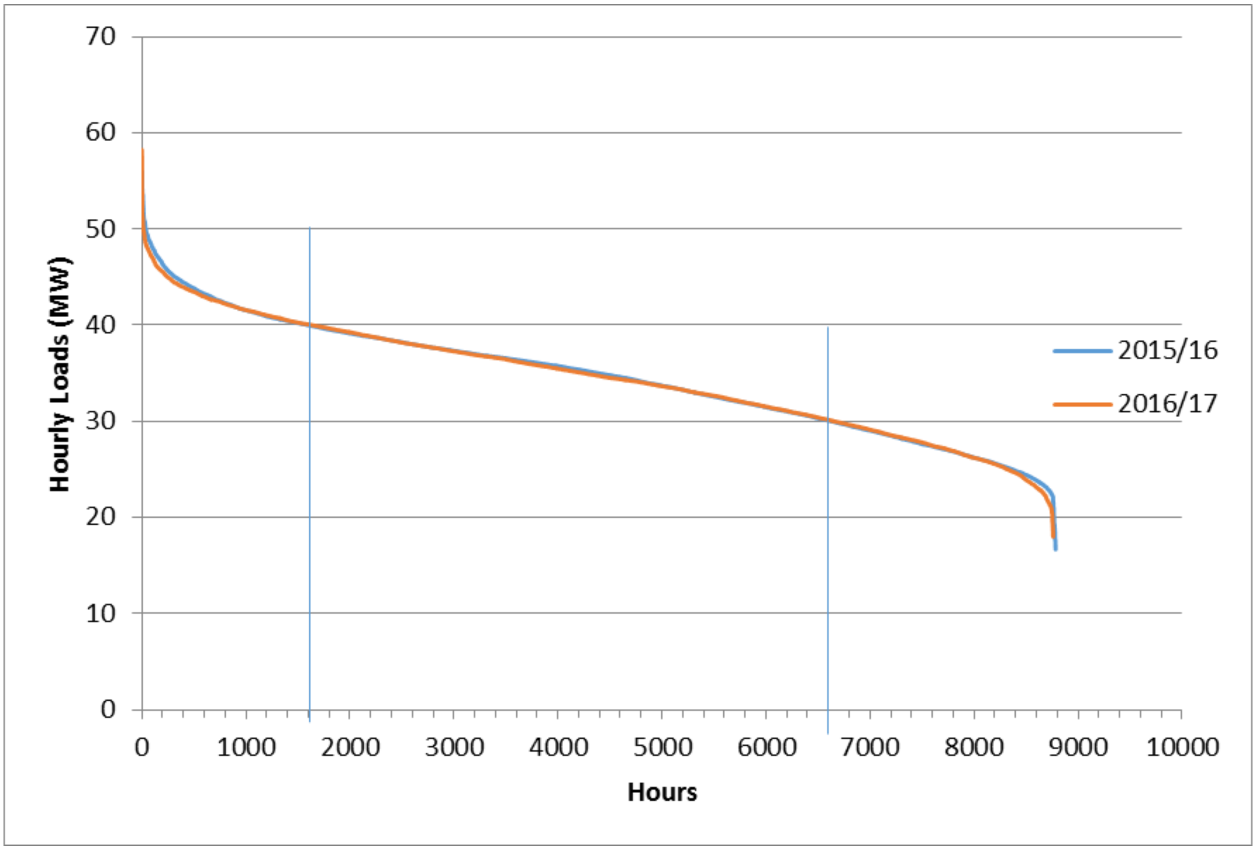

Figure 3: SHEI annual load curves (June to May)

Generation behavior in the SHEI area

While load levels vary within a tight band, generation can vary significantly because of the intermittency of wind and hydro generation resources. The other resources, including the Highgate HVDC converter[4], are relatively constant.

In figure 4, the blue curve represents the total monthly average generation, which includes Highgate imports. The seasonal variability of SHEI generation is caused primarily by the seasonality of hydro and wind resources with higher generation from October to April, but mostly in April that is the highest generation period for hydro and wind generation. This coincidence tends to concentrate system concerns during the spring season. The export limit was reduced for some time this last spring during an equipment outage and, consequently, wind curtailments were particularly acute. With a lower export limit in place, wind generation appears to be reduced to allow hydro generation to run. The trend line on the average curve has an upward slope indicating that more generation has been able to run in recent months, although less so this spring. The green curve shows that the maximum monthly amount of generation has been consistently above 320 MW and has reached 345 MW on occasion.

[4] An HVDC Converter is a device that utilizes power electronics to convert Alternating Current (AC) into High Voltage Direct Current (HVDC) and vice versa to transmit electrical energy. This device is utilized in cases where it offers significant benefits over AC connections, one of which is the precise control of energy from one region to another.

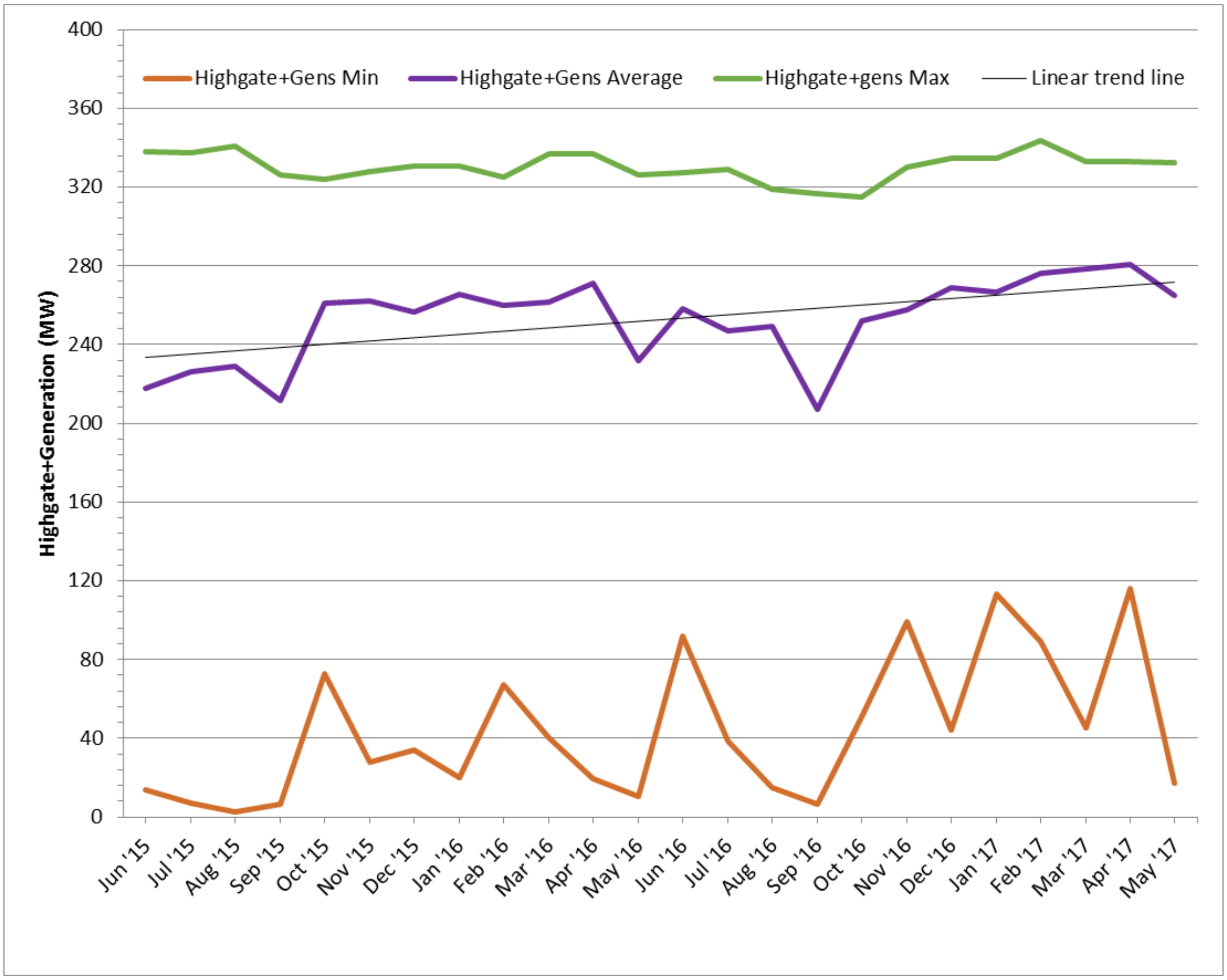

Figure 4: Seasonality of SHEI generation

As described later in this paper, system capacity under all-lines-in conditions is generally sufficient to allow SHEI generation to run with little to no curtailment. The total nameplate capacity of all resources in the SHEI area is approximately 415 MW. Accounting for the minimum amount of load, the electric system could, in theory, carry approximately 395 MW. With the Swanton Gas Turbine units ignored, the maximum amount of generation could be as high as 370 MW, which would yield a total flow on the order of 350 MW, accounting for the minimum SHEI load. In reality, the maximum amount of generation has not exceeded 345 MW at any time, and this would yield a total flow on the order of 325 MW, accounting for the minimum SHEI load. Any one of three export values—395 MW, 350 MW and 325 MW—can be considered as a suitable target for system capacity with a critical facility out of service. The 325 MW target may yield more frequent curtailments because the observed maximum 345 MW generation may have been caused by the current export limits.

Description of the SHEI limit

As illustrated in Figure 1, the export interface monitors flows on the Sheffield-to-Lyndonville transmission line and the Highgate-to-St Albans transmission line section with due regard to the effects of local generation. System operators and planners create interfaces as a means to measure the system's ability to transfer power from one region to another. Some interfaces have a simple structure, and others are more complex. Where an interface is designed to predict voltage or stability performance, the interface structure has to be designed to predict system behavior closely under a wide variety of system conditions so system operators can act quickly. The SHEI is a complex interface where a simple arithmetic calculation based on the measured load and generation is insufficient, and predetermined limits and operating procedures are necessary to maintain system reliability at all times. The SHEI limit allows operators to pre-position the system to anticipate a potential system outage and prevent unacceptable performance.

The SHEI limit has been established to guard against a voltage collapse following a transmission line outage. The limit varies based on system conditions, such as load level, generation dispatch and equipment status. Any event that reduces system strength will reduce the limit to an extent commensurate with the event's severity or the amount of grid support that the disconnected equipment provides. Historical data (Figure 5) show that actual export levels are comfortably below the limit the vast majority of the time. The duration diagram in Figure 5 depicts the difference between the limit and the actual export level by the number of hours of operation above a certain export margin level. The green curve shows the export margin was greater than 50 MW for about 6400 hours during this past year, or about 73% of the year.

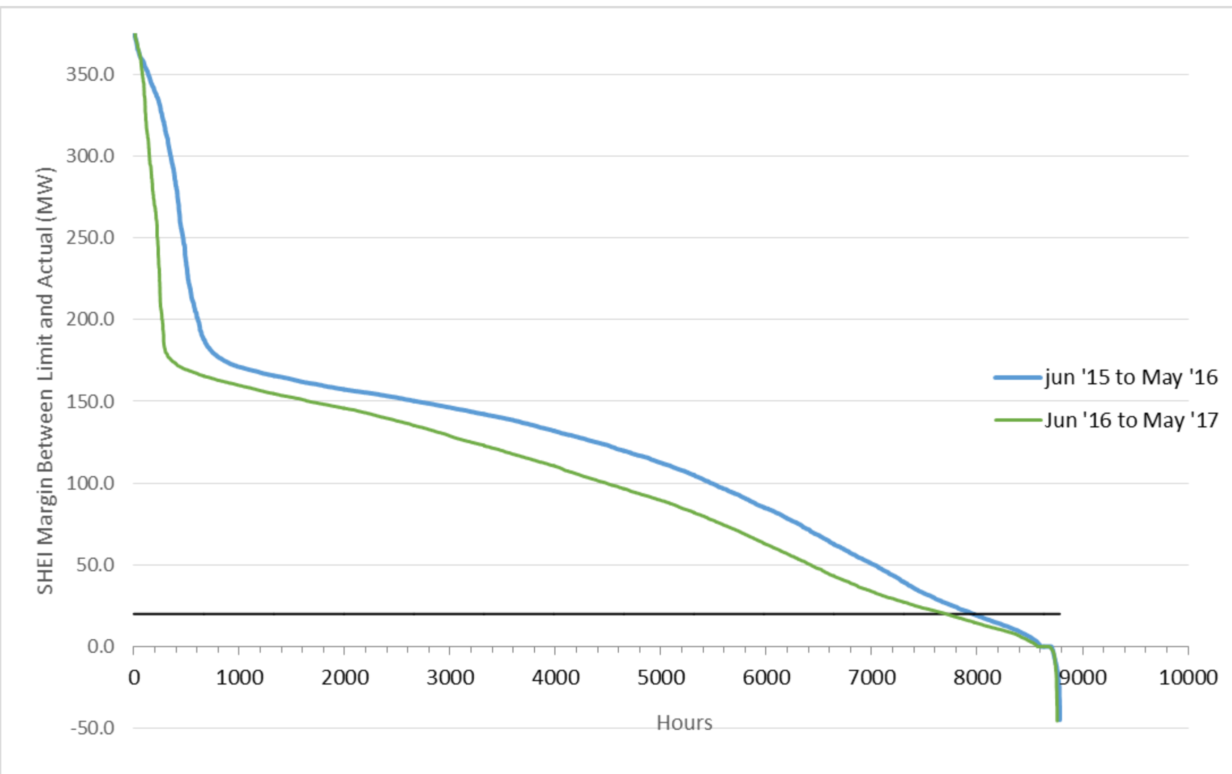

Figure 5: SHEI export margin duration curve

We do not have sufficient data to determine when and the extent to which resources have been curtailed within the SHEI area; however, we can assume that a large export margin indicates sufficient capacity to avoid curtailment. If we also assume that operator action will take place as export levels approach the limit, and that the threshold is generally within 20 MW of the limit, the above curves suggest that generation has been curtailed for approximately 1000 hours each year. We also observe negative export margins (sections below the 0 MW line) for about 100 hours. A negative export margin means that actual exports have exceeded the export limit. This analysis is by no means conclusive in terms of the financial impact of curtailment on SHEI resources, because we do not have complete visibility of curtailments. We do not know how frequently resources have been curtailed, how deep the curtailments have been, and the amount of energy that was lost during these events. Anecdotally, we have been informed that curtailments to one generating plant have reduced revenues on the order of millions of dollars over recent months.

Potential system reinforcements

With large revenues losses, interest has increased in mitigating the system concerns that have led to the export limits. As stated previously, the primary concern is to maintain adequate voltage. With all facilities in service, the system limit is sufficient to allow most of the generation to run unencumbered. Curtailments tend to occur during high generation periods, which are seasonal, and/or during planned system maintenance outages, which are also seasonal, traditionally coinciding with the periods of lowest demand to prevent negative impacts to load. Unfortunately, these periods also happen to be periods of higher wind and hydro generation. The seasonality of load, generation and system outages presents us with a significant challenge, but also a means to manage these concerns as discussed below.

Better outage coordination

Generation and transmission outages are coordinated by ISO-NE, which ensures system reliability from the perspective of serving electric load, but also to minimize impacts to generation to the extent possible. On occasion, there may not be a perfect time for scheduling a system outage, or a piece of equipment must be removed from service immediately. Outside of these circumstances, there may be opportunities to improve outage coordination to minimize impacts to both load and generation. For example, it may be possible to schedule a generator outage during the spring period instead of the fall period.

Better utilization of equipment

Several resources in the SHEI area provide no voltage support. These resources may already have the technical capability to provide voltage support, or this capability may be achieved at a relatively small expense. Green Mountain Power (GMP) is currently exploring this possibility, as well as the capability of the Jay synchronous condenser to take advantage of its continuous service factor, which is not yet recognized in real-time operation because the synchronous condenser has not yet completed an ISO-NE audit demonstrating that it can maintain its output for an hour at the service factor level. The service factor is a continuous capacity that is 15% greater than the nameplate capacity of the synchronous condenser. The export limit is expected to be increased somewhat when the condenser’s service factor is modeled.

Operational flexibility if voltage concerns are mitigated

Assuming system reinforcements sufficient to address voltage concerns under all-lines-in conditions and most outage conditions, the export limit will likely be based on a thermal (equipment overload) concern, which would present some advantages during real-time operation. The software used to predict system operating state in real time is capable of identifying impending thermal concerns to allow operators to secure the system in anticipation of a potential future concern. In this case, a possible operating procedure may be to trigger an alarm when export levels approach the thermal limit, and the operator can decide whether to adjust generation at that time. Historical data show that generation tends to be at or near maximum during the cooler seasons of the year. This is also the period when equipment thermal ratings are the highest. In the case of thermally based export limits, these limits can be increased during cooler months to account for the higher equipment ratings, which may then revert the limits to voltage-based limits, which should be higher than today's limits.

The best strategy for selecting a solution may be to proceed in stages, where the first stage is to address the voltage concerns described above. This step relies upon GMP implementing its B20 project, which consists of reconductoring the Lowell-to-Johnson 34.5 kV line and replacing the Lowell 46/34.5 kV transformer. This upgrade will increase the line capacity, but the most important benefit is the voltage support that it provides. The B20 upgrade, in combination with the equipment utilization improvements, will make the system more robust, which is critical not only during all-lines-in conditions, but more importantly during system outage conditions, where curtailments are more severe.

Beyond the B20 upgrade, a VELCO project to replace degraded structures on the K42 line from Highgate to Georgia would provide additional benefits. VELCO will investigate whether it makes sense to reconductor this line in the context of the current Structure Condition Improvement Project.

None of the reinforcements, whether alone or in combination with other reinforcements, will allow all generators to run at full output under all conditions. Such an objective is not practical on the transmission network. Seeking to prevent generation curtailment at all times would lead to disproportionately costly projects compared to the marginal benefit that can be achieved.

Appendix: Information Policies

Critical Energy Infrastructure Information (CEII)

FERC regulation prohibits VELCO from publicly sharing "specific engineering, vulnerability, or detailed design information about proposed or existing critical infrastructure." Information is deemed to be CEII based on a four-part test of whether it: (1) provides details about the production, generation, transportation, transmission, or distribution of energy; (2) could be useful to a person in planning an attack on critical infrastructure; (3) is exempt from mandatory disclosure under the Freedom of Information Act; and (4) does not simply give the general location of the critical infrastructure.

FERC Standards of Conduct for Transmission Providers

FERC Standards of Conduct for Transmission Providers prohibit VELCO from sharing non-public transmission system information, including: information related to day-to- day transmission operations and planning; denials or grants of transmission service requests; available transmission capacity ; network configuration; transmission outages; reliability conditions and operations information.

Transmission information shared in this presentation by VELCO is being shared simultaneously with a broad range of energy marketing and non-marketing stakeholders and has been posted on VELCO's OASIS website so that it is available publicly. Accordingly, the information, to the extent it can be deemed transmission system function information, is public and falls outside of the SOC restrictions.