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Integration of High Levels of Renewables on the Vermont Electric System

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SUMMARY

This paper describes the situation in the US state of Vermont in terms of the integration of high levels of renewable energy resources (RES) onto the distribution and transmission system. With wind and photovoltaic generation levels at 50% of the state's peak load, there are new sets of technical and planning issues which need to be addressed. The state has significant renewable goals and the state's utilities are working to meet these new challenges.

KEYWORDS
Renewable Energy, Renewable Energy Impacts, High level of Renewables

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1. Introduction

The interconnection of renewable energy to the bulk transmission system and to distribution systems in the United States has, over the span of a few short years, grown from serving only niche applications into a mainstream trend. While renewable energy makes up only a small part of the country's electric supply [1], the growth of renewable energy resources is expected to continue. Support for this growth is in no small part due to increasing warnings of the impacts of climate change from organizations such as the Intergovernmental Panel on Climate Change if greenhouse gas emissions are not drastically reduced worldwide [2].

Since the upsurge in growth of renewables began around ten years ago, utility executives and engineers have theorized about what effects might occur on the transmission and distribution systems under moderate and high levels of penetration of distributed renewables. Some of the identified breakpoints for grid reliability have come and gone without adverse impact, the system buoyed by the baseload power production of coal, nuclear, and natural gas. However, no region of the U.S. has reached distributed renewables penetrations on the order of the 80 to 100% targets discussed in policy circles. It remains to be seen what this level of penetration implies for grid operation and utilization, though it is possible to anticipate some of the impacts by examining those areas with high levels of penetration relative to the capability of the local infrastructure. The state of Vermont is one such location.

2. Vermont Electric System Overview

The Vermont electric system forms the northwestern corner of the New England electric system. In comparison to the New England system, as well as to the New York and Quebec systems with which it also shares borders, it is small, with a peak load of roughly 1000 MW. Particularly after the loss of large baseload generation facilities in the region, the Vermont transmission system can be subjected to large swings in power across its tie lines. Vermont Electric Power Company (VELCO), which is responsible for Vermont's transmission system, regulates flow on its tie lines by the use of phase shifting transformers. Voltage issues also result from regional or local operating conditions; these are addressed by the use of several dynamic reactive power control devices, including several synchronous condensers, a FACTS device, and a newly installed Static VAr Compensator. VELCO also employs traditional voltage control devices: capacitor banks, which are widely dispersed through the transmission system; and reactors, to keep voltages down when the 345 kV backbone of the system is lightly loaded.

Since the retirement of the 640 MW Vermont Yankee nuclear plant in 2014, Vermont's in-state generation resources have consisted mainly of renewables. There are also 138 MW of infrequently run fossil fuel fast-start units connected in the state. Many small hydropower facilities sum to about 120 MW, and a handful of small to moderately sized wind plants sum to 150 MW. Although not actually a generator, the back-to-back HVDC converter station at Highgate connecting Vermont to the Hydro Quebec system provides baseload power of 225 MW during most hours. PV generating facilities in Vermont, mostly behind the meter, have reached nearly 350 MW. For several years, PV growth along with targeted energy efficiency programs and declining commercial loads resulted in flat to declining peak loads. However, the growing amounts of PV also shifted the hour of peak demand to later in the day, when output is diminished. While winter peak loads traditionally occur after dark in Vermont, summer peaks now occur after dark as well, meaning PV generation is not aligned with peak demand.

Due to the seasonal dependence and intermittency of renewables, Vermont imports power during all hours of the year, and in some hours, imports most of its power. However, on days with clear skies and moderate ambient temperature, particularly in the spring, Vermont's net load curve dips down sharply in the middle of the day, evocative of the famous California "Duck Curve." In Figure 1 below, net load curves from selected sunny April days from the past five years are contrasted with the net load curve of an overcast day. In 2017 for the first time, Vermont experienced a lower net load during the day than at night, an event that now occurs with increasing regularity.

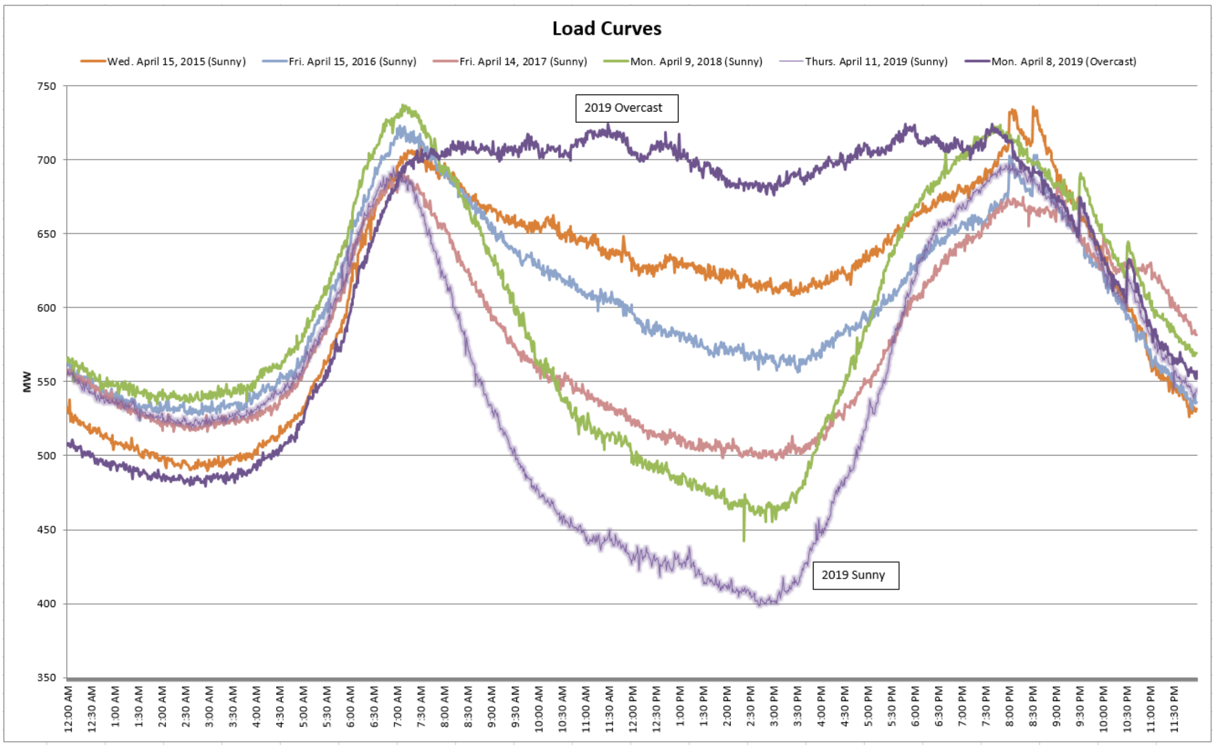

Figure 1: Vermont Net Load Curves

3. Vermont Energy Goals

3.1 Portfolios and Policy

VELCO is owned by the 17 distribution utilities of Vermont according to their share of state load; of those utilities, Green Mountain Power (GMP) is the largest, serving over 75% of the state. [3] GMP and the Vermont Electric Cooperative own, operate, and maintain their own subtransmission systems. In April 2019, GMP announced a goal of producing or purchasing 100% carbon-free energy by 2025, and 100% renewable energy by 2030 [3]. Other utilities, such as Burlington Electric Department and Washington Electric Cooperative, have 100% renewable power supply portfolios [4], [5]. These voluntary commitments result in a higher amount of renewable generation connected to the grid but do not compel the utilities to procure the generation locally within Vermont.

To encourage development of in-state renewable resources, the Vermont legislature implemented Tier II of the Renewable Energy Standard (RES). The Vermont RES, signed into law in 2016, consists of three sections, setting minimum requirements for purchase, production, and use of renewable energy [6]. Tier II requires the utility portfolio consist of 1% in-state distributed renewable energy in 2017, increasing to 10% in 2032. The RES fits into Vermont's greater energy policy picture, guided by the vision of the 2016 Comprehensive Energy Plan [7]. The Plan sets targets for meeting Vermont's energy needs with renewable sources at 25% by 2025, 40% by 2035, and 90% by 2050. Additionally, it targets a reduction in total energy consumption per capita of 15% by 2025, and of 33% by 2050.

3.2 Long-Range Transmission Plan

As a result of stakeholder feedback from the 2006 build-out of the Vermont transmission system, the Vermont Department of Public Service formed a group called the Vermont System Planning Committee. The objective of the committee is to identify reliability issues that may require mitigation within the next 20 years, and where possible to avoid or defer transmission upgrades associated with those reliability issues by the use of a Non-Transmission Alternative (NTA). To identify reliability issues, VELCO transmission planners study the Vermont transmission and subtransmission system in a process known as the Long-Range Transmission Plan, or Long Range Plan.

In the 2018 Long Range Plan, VELCO undertook supplementary analysis to examine the power system implications of a high PV penetration scenario [8]. This scenario was informed by the Vermont Solar Pathways Report, published by Vermont Energy Investment Corporation (VEIC) in 2016 [9]. The report described work done to determine the feasibility of using in state PV, and the amount needed, to meet 20% of the Vermont's electricity needs in 2025. VEIC determined 1000 MW was needed, that it was possible to install this much solar capacity without adversely impacting the transmission or distribution systems, and it would create $8 billion in net savings for the state of Vermont over 30 years. VELCO set out to test the assertion the transmission system could accommodate 1000 MW of PV.

Though the Vermont Solar Pathways study acknowledged the need for careful siting of PV in order to avoid grid reliability issues, it did not specify how this might be achieved. Initially, it was decided to spread the 1000 MW of PV across the state in proportion to the existing PV distribution. If an electrical zone comprised 15% of existing PV at the present, then it would be set to comprise 150 MW in the high penetration scenario. This distribution was referred to as the "2018 Distribution." Since much of the existing PV in Vermont is installed either in the urban Burlington area or in the more rural area to its south, analysis found severe violations of system criteria. The cost to rectify these violations with traditional transmission infrastructure was estimated at $300 million, and to do so with transmission- and sub-transmission connected batteries was estimated at $1 billion.

After receiving feedback from external stakeholders, two new methodologies for distributing PV were examined in an attempt to reduce stress on the system, and to utilize what might be a more realistic distribution. In the first, PV was matched proportionally with load on the basis of demand, bus by bus; in the second, it was matched proportionally by annual energy consumption, again bus by bus. Because the areas of Vermont with the highest concentrations of load generally overlapped with areas of high installed solar capacity, the results of these two new scenarios were similar to that of the 2018 distribution. Additional testing was performed with several permutations of the "MW distribution," with higher loads and lower generation levels. By reducing in-state dispatchable generators by 145 MW, transmission upgrade costs were found to fall to $246 million, and by increasing load by 125 MW, costs fell to $247 million. Combining the two brought costs down to $86 million.

Given the localized nature of the most critical violations of criteria observed, and the relatively low utilization of other parts of the transmission system, it was determined to allocate PV by electrical zone in an "optimized distribution." Additionally, several assumptions were modified to be less restrictive, primarily around tie flows and inverter voltage control. Where the previous scenarios had assumed tie flows similar to typical present-day values, the phase-shifting transformers were set to import no power from New York or New Hampshire. Additionally, the previous scenarios had assumed that the inverters for new PV installations would not have voltage control capability, while this new scenario assumed the new inverters would contribute reactive power according to a fixed power factor.

Starting with the southernmost zone, PV was added incrementally using a MW distribution for that individual zone. At each increment, contingency analysis was performed. This continued until a violation was observed, at which point the limiting element was recorded, and the zone was considered to have reached its limit for new PV. Repeating this process for each zone yielded the zonal results shown in Figure 2, below. It was found that, including roughly 300 MW of PV installed in 2018, a total of 1,058 MW of PV could be accommodated in the state without upgrades to the transmission system. Though the study did not address potential distribution system limitations, they are planned to be accounted for in the 2021 Long Range Plan.

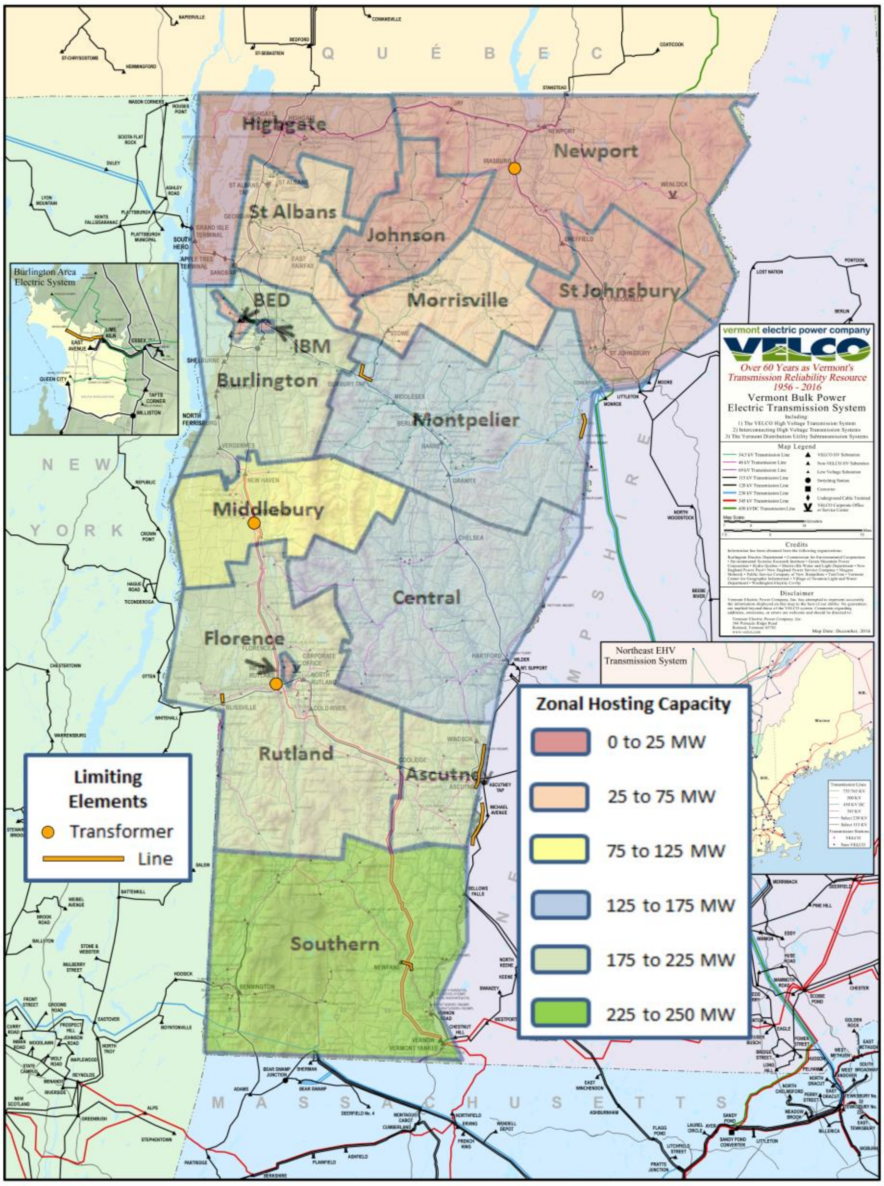

Figure 2: Optimized Distribution

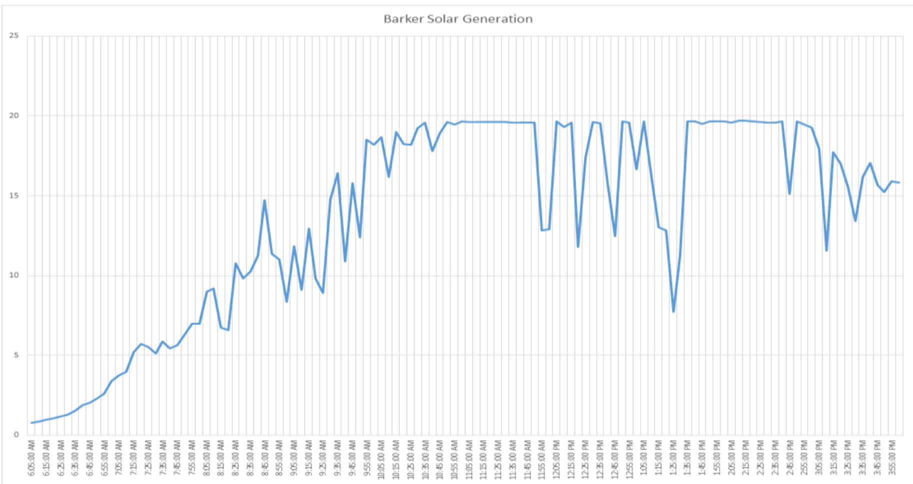

Figure 3: Barker Solar Generation Output (MW)

Recognizing that Distributed Energy Resources located on the distribution system are an important part of the Vermont generation picture, it is difficult to supply all the energy needed on many distribution circuits due to land constraints and the cost of utility-scale storage. Given that approximately five acres of PV are required to generate a single megawatt of electricity, the amount of land needed to site sizable photovoltaic plants pose an issue. Land tends to cost less and be more readily available in rural areas, but unfortunately, the transmission systems in these areas have not typically been designed to export the large amounts of power being generated far from load centers. This will likely require transmission systems to be upgraded in these areas.

4. Challenges

4.1 Weather Dependency

PV generation in Vermont has a capacity factor of approximately 15%. This means a significant amount of other generation resources are needed to meet demand. VELCO will have several challenges to maintaining the reliable transmission system in Vermont as we continue to transition from large traditional power plants to smaller distributed and renewable energy sources.

Renewable energy sources such as wind and solar are weather dependent. In areas like Vermont, we receive significant amounts of snow in the winter. This is great for our ski resorts and winter recreation, but after a snowstorm and until the snow melts off the photovoltaic panels, there is minimal generation from this source. Since there is nearly 350 MW of solar in the state (which corresponds to 35% of the peak load), the impact of its availability can be significant. Similar to snow cover, passing clouds also create challenges in managing dynamic PV generation on the grid. In the mountainous areas of the state, it is common to have fair weather clouds. When a cloud passes over a PV plant, the output can change very quickly. Figure 3 shows the output of a 20 MW PV plant during a partially sunny day. The output fluctuates between 20 MW to 12 or 10 MW very quickly. This change in generation must be balanced from other sources almost instantly to maintain grid integrity, otherwise there will be a decrease in system frequency and the potential for a significant power system disturbance. Another challenge of PV generation is in colder northern climates, like Vermont, electric peaks are after dark making solar infeasible at peak load, unless it has been previously stored in an energy storage device.

Wind generation has a better capacity factor than PV, at around 25-30%, but there are times in the year (typically in the summer) when there is little wind available. In the winter, harsh weather can cause icing inhibiting the ability of the wind turbines to spin and generate power. Of the 150 MW of wind power installed in Vermont, about 100 MW is connected to the northern part of the system. As northern Vermont is very rural and lightly populated, there is a correspondingly low amount of load, ranging from 20 to 60 MW. Given the proximity of the wind plants to the 225 MW Highgate converter station in this pocket of low load, it became necessary for reliability to implement an export interface to limit generation in real-time. ISO-NE, as the system operator for New England, is responsible for this voltage-limited interface, and dispatches generators in the pocket to stay below pre-determined limits based on current system conditions.

Hydro plants are classified as renewable in Vermont and valued as an important generation resource. This type of generation is also weather dependent on rain and the snow melt in the spring. In August, one of the driest months, the output of hydro generation can be less than 5% of the amount available in the spring.

These challenges are a reality of integrating renewable energy sources into our power mix that engineers must find solutions for. Energy storage will play a significant role in stabilizing the system for short generation variations, and the use of other energy sources will be needed. In the short term, natural gas power plants have met this demand gap. At many times in New England, 60-70% of generation consists of natural gas plants, with about 24% consisting of nuclear plants.

4.2 Technical Challenges

Other technical challenges for engineers to solve involve how the grid's evolution to include an increasing number of intermittent renewable generators will impact operating the power system. Due to siting of solar plants, many distribution circuits in Vermont routinely supply surplus PV energy to the transmission system, creating a voltage control challenge. The voltage profile on a distribution circuit with a large amount of PV is different at night than when PV along the circuit is generating during full sun. New IEEE standards now enable PV inverters to control voltage and new, faster acting voltage controlling devices will be required to compensate for generation fluctuations.

Generation from solid state inverters, which are used in almost all renewable generation applications, do not supply fault current. What this means is that when an energized power line is grounded or a short circuit is created (think of storms, lightning, tree contacts, equipment failure, or animal issues) the circuit on a traditional power system will supply a high current from the system (rotating generator) sometimes an order of magnitude higher than the normal operating current level. Protection systems are designed to detect this current increase and interrupt the circuit until the problem can be determined, or when it passes. With a large number of these inverters satisfying significant power demands, there will be less fault current available to trigger protection schemes which protect equipment and people's safety. There will have to be a significant modification to these protection systems to ensure they operate properly when required.

5. Emerging Innovations

Energy storage has been a part of the power system for many years. Pumped hydro storage was installed in New England in the 1970's to store surplus nuclear power during low load periods (at night) and use the stored water to generate power during the high load periods in the daytime.

Today, new storage technologies continue to emerge. As the cost of battery energy storage continues to drop, batteries will increase in prevalence on the grid. With the intermittency issues associated with weather dependent renewable energy, the ability to quickly supply electricity to make up for deficiencies is critical to the reliability of the power system.

In Vermont, GMP has installed nearly 2000 Tesla Powerwalls. These are generally leased to customers and located behind the utility meter, each with a rating of 5 kW/13.5 kWh. The Powerwalls are used as a backup power supply for customers in the event of a power outage, and are also used to lower the company's peak loads, which lowers costs to all customers. In addition, there are two utility scale storage facilities currently installed, rated at 4MW/3.4 MWh (Stafford Hill) and 1 MW/4 MWh (Panton), with more planned. These utility scale batteries lower peak demand, improve local reliability, and supply frequency regulating services. In this evolving generation situation with emphasis on renewable intermittent sources, storage will play an important role in keeping the system reliable.

6. Conclusions

The power system continues to evolve at a very fast pace. Vermont, like many states, has aggressive renewable energy goals. Renewable energy technologies like wind and solar generation are proliferating at a rapid rate. Although the installed capacity of these renewable generators is high in Vermont, the capacity factors are low and the weather dependency of the output creates new challenges for the power system. With most of this new generation being connected to the distribution system, lack of visibility to the transmission operator adds new complexities. Planning for this new generation in Vermont has been and will continue to be a collaborative effort between the government, regulators and utilities. This is certainly an interesting and exciting time to be a power system engineer.

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