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Green Mountain Power (GMP): Significant Revenues from Energy Storage

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Abstract

Green Mountain Power's Stafford Hill microgrid, a 4MW/3.4 MWh battery energy system integrated with solar generation in western Vermont, exemplifies the multiple uses and significant revenue potential of advanced energy storage combined with solar PV in a microgrid configuration, behind a utility meter. This project, funded in part by the US Department of Energy Office of Electricity, was commissioned in 2015. It provides power resiliency for critical infrastructure while earning revenues for the operator. Savings from peak shaving have been demonstrated.

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1.   EXECUTIVE SUMMARY

With the development of the Stafford Hill microgrid, composed of solar PV and battery energy storage, Green Mountain Power is addressing several issues related to the modern electric grid, including increasing penetration of renewable power generators, the increasing costs of capacity and transmission services within the balancing area of the New England Independent System Operator (ISO-NE), and the need for back-up power for critical facilities. For example, this is the first such project that has demonstrated how utilities in ISO-NE can use batteries to significantly cut their cost obligations to the ISO. In August 2016, combined output from Stafford Hill reduced the GMP load during the 1-hour period of the annual ISO-NE peak by nearly 2MW, thus saving the utility approximately $200,000/year in capacity charges. Other routine benefits of system operation accrue from cutting monthly transmission peaks, general peak shaving and frequency regulation. When adding together the savings from shaving monthly and annual peaks, along with the revenue for providing frequency regulation services, the payback period on the battery energy storage system capital cost is estimated at approximately 8-10 years.

The project is highlighted in the Vermont State Energy Plan as a model project that should be replicated. Indeed, GMP has impressive plans to build Stafford Hill-like systems at substations through the state. GMP has also launched a program that will aggregate smaller, distributed energy storage systems located behind customer meters, for the purpose of further reducing capacity and transmission costs.

The GMP project has been observed closely by other utilities in New England, and several are developing battery storage systems using the same economic case. For example, the Sterling, Massachusetts municipal light department commissioned a battery storage project in December 2016 that replicates GMP's use case. The Sterling project was one of several recipients of resiliency grants in Massachusetts, which has recently taken a number of steps to advance the deployment of energy storage. In 2016, legislation was approved by the Massachusetts legislature requiring the state Department of Energy Resources to determine whether to establish utility procurement targets for energy storage, and allowing utilities to own energy storage equipment. The state has also announced several other grant and incentive programs for energy storage, and in 2016 released a landmark study of energy storage opportunities in the state. Both the GMP and the Sterling projects illustrate one of the major findings of that report, which is that storage is needed to reduce peaks, integrate renewables and reduce the need for overbuilding of peaked capacity.

2.   INTRODUCTION/BACKGROUND

Green Mountain Power (GMP) is the largest electricity utility in the state of Vermont. It positions itself as a progressive, customer-focused utility – for example, it was the first utility in the country to be certified as a B Corporation**i** – and it has invested in a number of innovative clean energy projects. With the development of the Stafford Hill microgrid, the utility has attempted to address several related issues, including increasing penetration of renewable power generators (solar and wind) on its grid, the increasing costs of capacity and transmission services within the balancing area of the New England Independent System Operator (ISO-NE), and the need for back-up power for critical facilities in the seemingly more frequent event of severe storms that disrupt the electric grid.

One attractive solution to these issues is the use of energy storage, which can mitigate against power outages while lowering costs for electricity and serving as a buffer for intermittent renewable generators.

The Stafford Hill Project came about through an opportunity offered in 2013 by the Vermont Department of Public Service (DPS), in partnership with the US Department of Energy –Office of Electricity DOE-OE, for an Electrical Energy Storage Demonstration Program, with funding through its Clean Energy Development Fund (CEDF) and the DOE-OE Stationary Energy Storage Program, with technical support from Sandia National Laboratories and Clean Energy States Alliance. The Energy Storage program, managed by Sandia National Laboratories, supports the DOE-OE's overall infrastructure improvement plan, which in turn has built a significant portfolio of energy storage projects over the past decade and can be legitimately credited with advancing the state of stationary energy storage in the United States.

GMP won the energy storage grant with a microgrid proposal that would serve a number of objectives, including providing resilient power to a public shelter, integrating the large amount of solar PV the utility had developed in Rutland, providing grid services, and demonstrating cost-effective operation of energy storage. The project was timely in that it fit well with GMP's plan for revitalization of Rutland, which included installing enough solar PV to make the city the "solar capital of New England," and enough advanced energy systems to make Rutland a model for the "Energy City of the Future." Furthermore, as the city was hit hard by Hurricane Irene in 2011, it was eager to have in place emergency backup power for a local emergency shelter.

Currently, GMP has over 355 MW of solar installed throughout its service territory, mostly on rooftops, with another 26 MW pending or under consideration. The 2.5 MW Stafford Hill PV project is the largest in the Rutland area, which currently has a total of over 3800 kW installed.

3.   GMP MICROGRID / ENERGY STORAGE PROJECT DESCRIPTION

The project is located at a former landfill site (Stafford Hills) outside of the town of Rutland, Vermont, in the vicinity of the Green Mountains National Forest in central Vermont. Green Mountain Power is the electric utility company that serves this portion of Vermont.
The system consists of 4 MW/3.4 MWh of lead-acid and Li-ion batteries, integrated with 2.5 MW of solar photovoltaic (PV) panels. The microgrid is designed for islanding, that is, it can operate independent of the utility electric grid using the installed PV and batteries. When connected to the grid, it generates and stores power for GMP, furthering renewable integration and providing peak shaving. The system diagram is shown in **Error! Reference source not found.**

Installation Details

Year Commissioned: 2015

Services Provided: Ancillary services, Backup power, Demand management, Renewables integration

Supported Infrastructure: Emergency shelter at Rutland High School

Solar: 2.5MW (GroSolar)

Storage: 4MW/3.4MWh – Combination of 2 MW lithium-ion and 2 MW lead-acid batteries

Project Partners: City of Rutland, Green Mountain Power, VT Department of Public Service, U.S. Department of Energy Office of Electricity, Sandia National Laboratories, Clean Energy States Alliance

One feature of the system is a multi-port inverter system customized and provided by Dynapower Corporation for this project. The four inverters are triple port-500kW Dynapower systems. They have 3 DC inputs - one each for the PV, the lead-acid batteries, and the lithium ion batteries. Each DC input can be discretely controlled or the inverter can be controlled as a complete unit, and additionally the site can be controlled as a master site (all 4 units together). Dynapower was a collaborator on the original proposal and system installation. They continue as contractor to operate and maintain the data and data communication system.

A number of dispatch modes can be selected from, to provide the best output at a given time. One dispatch mode allows GMP to set the entire site output, and it will automatically adjust the batteries to provide maximum output depending on the output of the PV. There are also voltage correction modes, and individual battery dispatch modes as well, which allows control of an individual battery bank.

Figure 1. Illustration of Multiport Solar Energy System as proposed.

There are 4 of these modules. The installed PV system has a nameplate capacity of 2.5 MW DC. A particular benefit of a multiport inverter is that it can harvest any clipped solar power on the DC side. (Large solar installations often undersize the inverter relative to the name plate capacity of the generator to allow for some degradation of the solar arrays over time, and to save money on the inverter.) In GMP's case the PV is sized at 2.5MW DC and only 2 MW AC output. That means the solar could be generating 2.5MW DC but the inverters will only deliver 2MW to the external grid. In this case, the batteries can capture and store the additional 0.5MW "clipped" from the PV output. This is not possible with separate inverters, which are dedicated to either the PV or the batteries. The disadvantage of this configuration is that total output is limited by the capacity of the inverters, so if the PV is delivering 2MW, no additional output is possible from battery storage. This constrains the total output and can prevent the system from serving a peak load with all the energy available.

Data collection, which is important for understanding, documenting and optimizing system performance, is enabled by an advanced domain controller that aggregates PV generation and battery data and continuously uploads it to a cloud-based remote monitoring and analysis tool. The local domain controller responds to the Network Operations Center (NOC) dispatch signal, as described above, to maximize the energy storage system value.
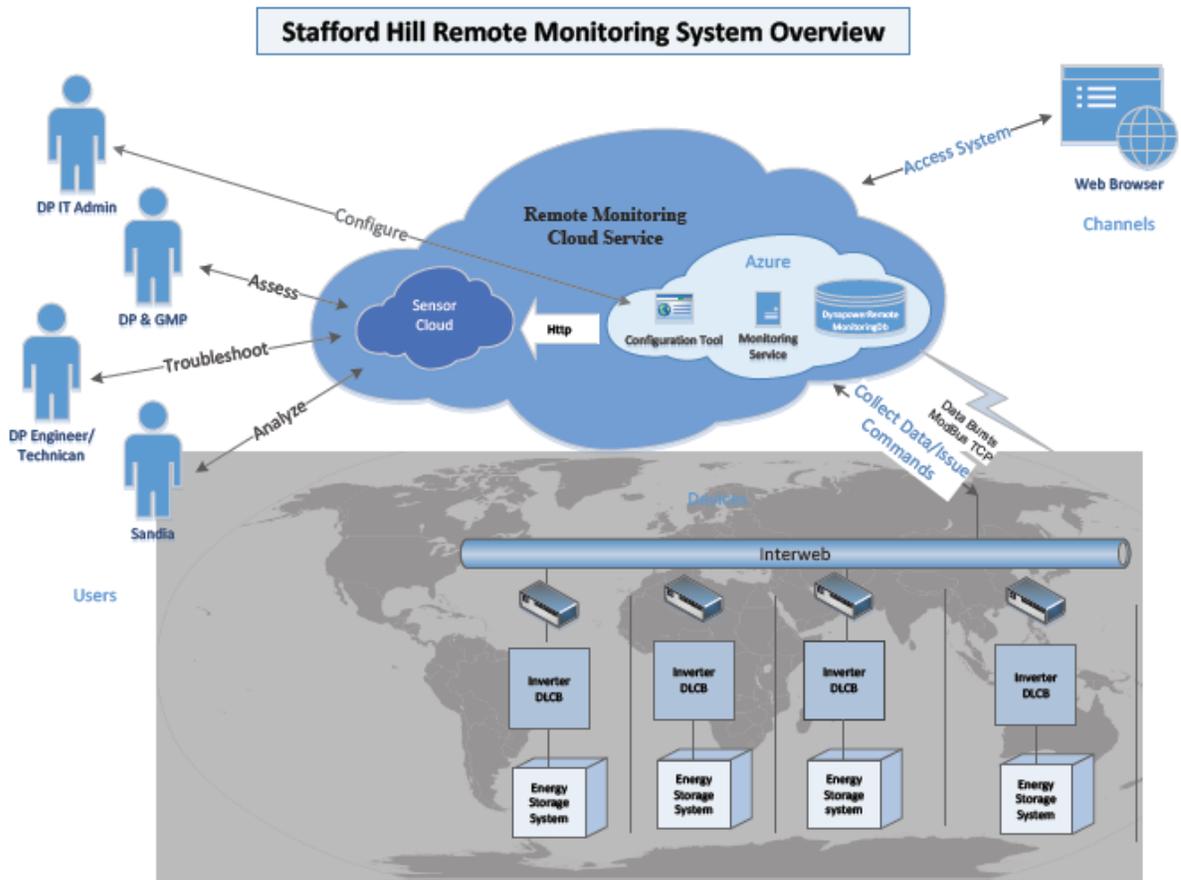
Figure 2. Cloud-based remote monitoring configuration.

Finally, as per the proposal for the Stafford Hill project, a display, including real-time data of energy being produced, stored and dispatched, will be developed and installed at the Rutland High School and the Energy Innovation Center in downtown Rutland. The display will also contain information on the environmental and societal impacts of the project including future uses such as electric vehicles and benefits to the grid and the functions and benefits and challenges of developing a micro-grid. Displays about micro-grids, renewables and grid storage technology and economics will be included. Surrounding schools will be invited to visit the site and the center.

4. VALUE OF ENERGY STORAGE OPERATION ON THE GMP SYSTEM

One objective of the project is to assess the financial value of energy storage operating on the microgrid within the overall GMP system. A number of the services provided by the system are important, but not easy to monetize, such as the ability to provide resilient back-up power for a public shelter. Many of the services, however, can be monetized, i.e., it is possible to earn revenue (or save expenses) from these operations. The most Subparagraph Heading

- Peak shaving: Monthly transmission peak Regional Network Services (RNS) charge reduction, Annual capacity peak Forward Capacity Market (FCM) charge reduction
- Grid services: frequency regulation, demand management
- Arbitrage
- Transmission investment deferral

4.1. Peak Shaving

The monthly **transmission charge** GMP pays for Regional Network Services (RNS) is calculated based on GMP's demand during the statewide peak transmission hour in each month. This charge is levied by ISO-NE based on the load carried by the Vermont transmission company, VELCO. Significant savings could result from discharging the batteries during that statewide transmission peak to reduce GMP's portion of the statewide monthly transmission obligation.

Even more important is the annual **capacity charge** GMP pays to ISO-NE, which is determined by GMP's demand during the regional peak demand hour for the year. Pricing is set by ISO-NE's three-year Forward Capacity market (FCM). Capacity prices have risen over recent years and are expected to remain high, relative to historic prices, for the foreseeable future.

The RNS and FCM projections for future years, as provided by GMP from discussion with ISO-NE, are listed in Table 1. Values for 2014, 2015, and 2016 are historical values. For FCM, 2017, 2018, 2019 and 2020 are firm/known values. For 2021 and beyond, the values are projected. For RNS, the values for 2017 and beyond are projected, but are considered to be fairly firm, as GMP's future budgets are based on them. Note that both values generally increase over time, especially the FCM charge. By 2019, the per kilowatt-month FCM charge will be three times that in 2016, meaning that savings from offsetting this charge could also triple. The 2020 value then dips a bit, but more increases are projected for the future years after that. GMP is anticipating that reductions in RNS and FCM costs will more than justify the cost of the battery system. All data used and adapted in this analysis can be found on the ISO-NE website.[ii]

Some examples of the potential savings are estimated in the box below the table. Note that the FCM charge is for GMP's portion of the ISO-NE peak. Since GMP load is a small portion of the whole ISO-NE load, the savings from shaving the GMP peak is approximately linear with charge times the load reduction. If all the utilities in ISO-NE adopted this strategy, the annual peak would decrease and GMP's fraction may or may not be affected.

For shaving the monthly transmission peak, the savings is directly proportional to the fee times the load reduction. Since GMP makes up a significant fraction of the transmission load in Vermont, any reduction in their fee may shift to other utilities. It is unknown at this time whether that could cause a modification to the RNS fee values.

Table 1. Historical, firm and projected values for the Regional Network Services and Forward Capacity Market fees (provided by GMP)

Green Mountain Power		
	RNS	FCM
Year	$/kW-yr	$/kW-Month
	Historical values	Historical values
2014	89.49	3.10
2015	89.88	3.34
2016	94.23	3.27
	Projected values	Firm values
2017	102.31	5.41
2018	106.98	8.50
2019	111.56	9.00
2020	116.11	7.03
		Projected values
2021	120.27	10.19
2022	124.22	11.20
2023	128.29	11.81
2024	132.50	12.11
2025	136.85	12.41
2026	141.33	12.72
2027	145.17	13.04
2028	148.04	13.36
2029	150.96	13.70
2030	153.95	14.04
2031	156.99	14.32
2032	160.09	14.61
2033	163.26	14.90
2034	166.49	15.20
2035	169.78	15.20

Some examples of the potential savings from peak shaving are estimated below.

If GMP could discharge the battery energy storage to capture 1MW during a monthly 1-hr peak in 2016 it would look as follows:

2016 RNS Forecast = $94.23/kW-yr / 12 = $7.85/kW-Mo

Assume GMP could capture 1,000kW one month: 1,000*7.85 = $7,850 for that single month. Every month that the peak is captured, this savings value is accrued. So, if the savings were accrued every month, the total would be $94,230 for the year.

It's a little different for the FCM since this is a 1 time per year peak that GMP is shooting for. If GMP can capture 1MW by operating during the FCM peak hour in 2018, for example, it will save GMP customers the following in 2019: 2018 FCM Price = $8.50/kW-Month

1,000kW x $8.50 x 12 = $102,000.
This value is further multiplied by the reserve margin of 1.2, yielding $122,400 for 1MW.

A more detailed study by Sandia has shown that in general the greater the MWh capacity of the storage system, up to about 3 or 4 hours discharge duration, the greater the likelihood of hitting the monthly and annual 1-hour energy consumption peaks. This is because the discharge can take place over longer time, increasing the probability of capturing the peak. The GMP combination of batteries, if fully charged could discharge for 1.7 hours at the maximum 2 MW inverter throughput, or 3.4 hours at 1 MW. Depending on the ease or difficulty of anticipating the peaks, the system could be scheduled for discharge over a shorter or longer period to maximize the savings from peak shaving.

To ensure that the batteries are fully charged for addressing the peak hour, one approach is to use the "clipped" PV power earlier in the day. A typical such operation is illustrated in the sketch below (Figure 3). Another approach is to charge the batteries at night when prices are low, or even negative.
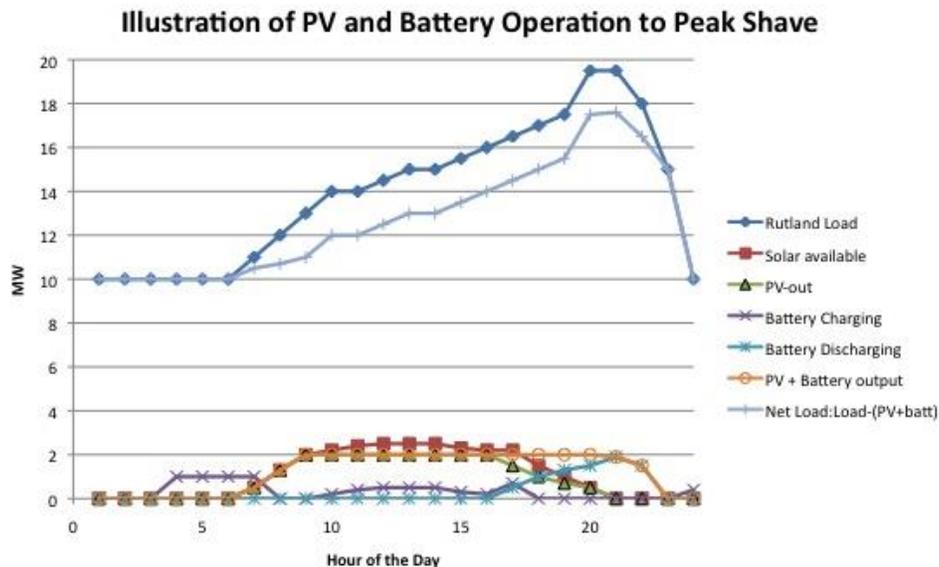
Figure 3. Author's illustration of nominal operation of PV/energy storage system to prepare battery for peak shaving.

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4.1.1. GMP RNS and FCM Peak Shaving Probabilities

Knowing the likely hour of the monthly peak helps forecast and plan the operation of the batteries. From analysis of historical data, the distribution of the RNS peak is shown in Figure 4 and Figure 5. Figure 4 shows that the Vermont peak is consistent during the winter and spring months. Figure 5 shows that the Vermont peak is very inconsistent during the summer and fall month. For this reason, GMP relies on sophisticated forecasting tools to schedule discharge of the batteries during the peak.
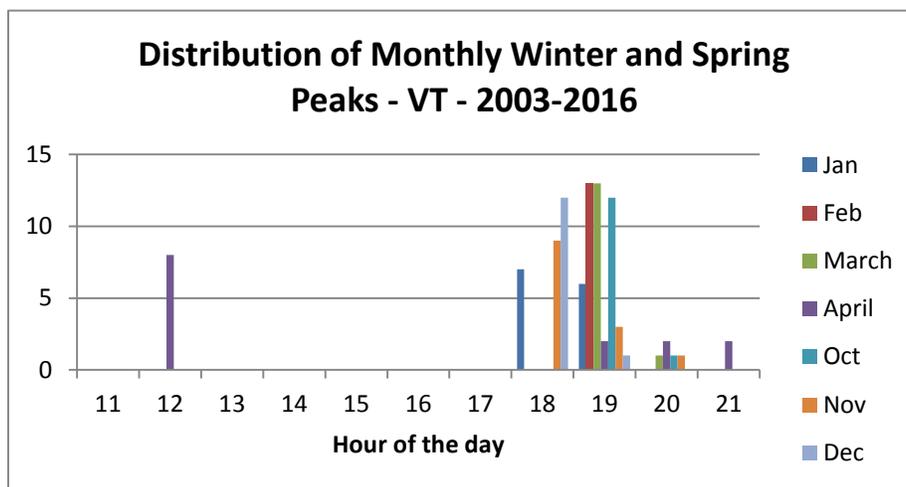
Figure 4. Distribution of Vermont Monthly Peak Hours – Winter and Spring hours
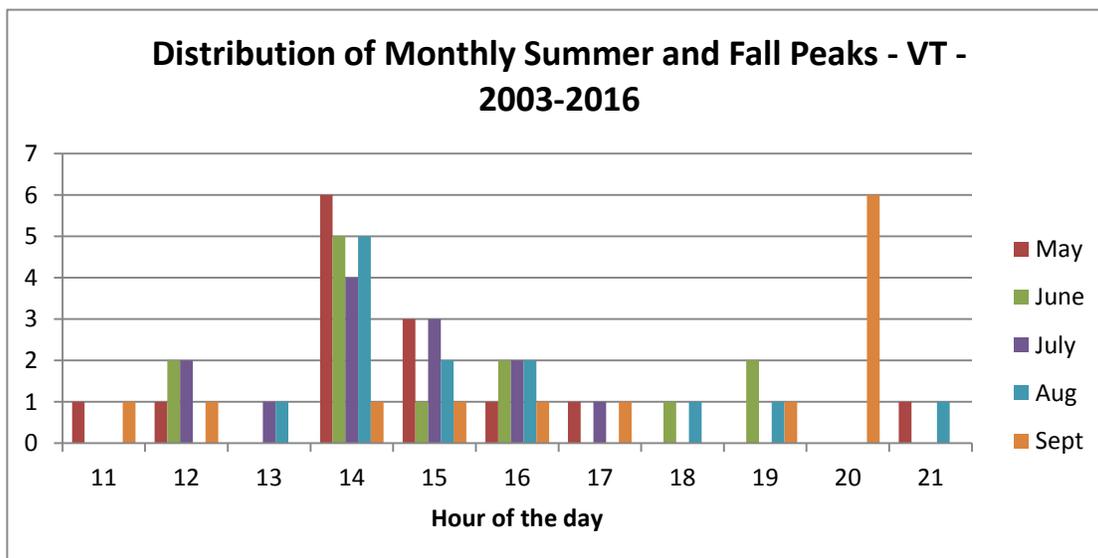
Figure 5. Distribution of Vermont Monthly Peak Hours – Winter and Spring hours

Knowing the likely hour of the annual peak helps forecast and plan the operation of the batteries. From ISO-NE data, the distribution of annual peaks is shown in Figure 6. Figure 7 shows the month of the annual peak.
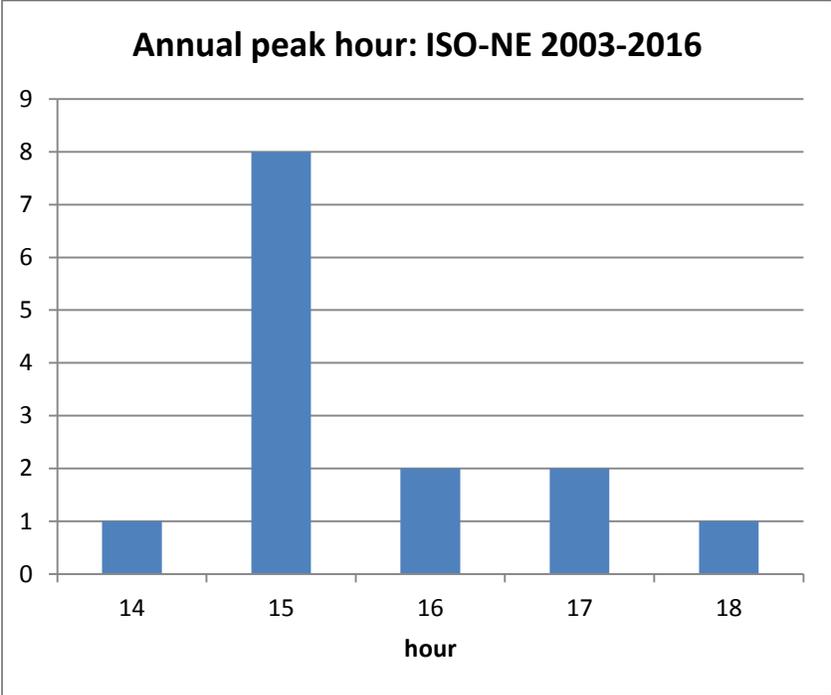
Figure 6. Distribution of ISO-NE Annual Peak Hours
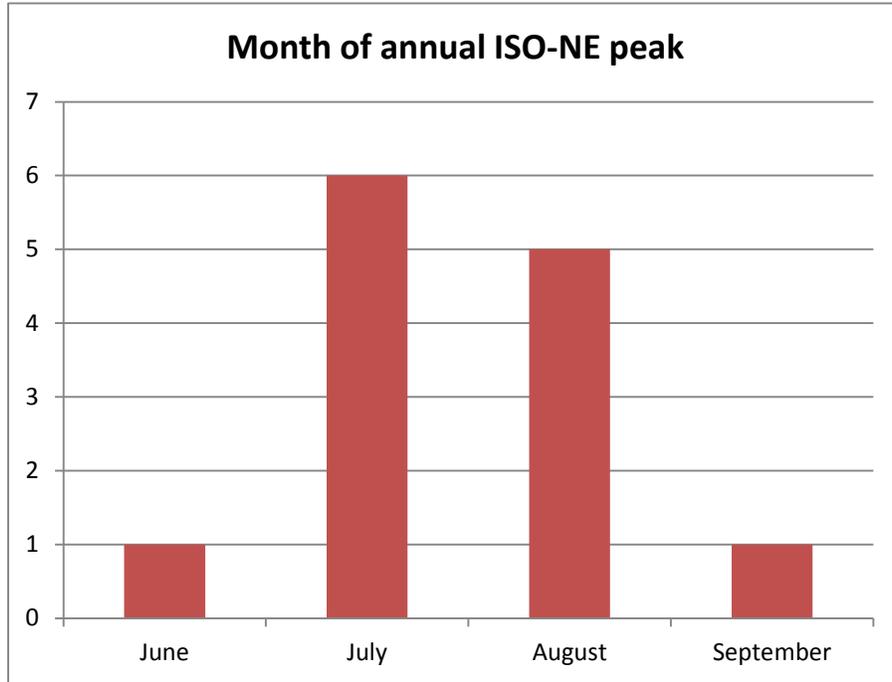
Figure 7. Distribution of ISO-NE Annual Peak Hours by Month

Given the high probability of an afternoon peak, it should be possible for GMP to schedule battery discharge operations to capture and reduce the system load. The annual peak appears to fall during a time when the PV system will likely be operating. Since both the PV and the batteries cannot operate at full power at the same time due to shared inverter restrictions, GMP may decide to continue to operate PV during the peak. Especially if battery cycle life is a concern, they may choose to operate the PV rather than discharge the batteries. The most likely scenario would be a combination of PV generation and battery discharge, with the battery making up the difference if PV output should fall below 2 MW.

4.2. Grid services

Grid services potentially provided by the energy storage system include **frequency regulation** and **demand response**.

4.2.1. Frequency Regulation

Deriving revenues from frequency regulation requires GMP to bid into the ISO-NE system using the appropriate tariffs. Bidding into the ISO-NE system is currently facilitated by a third party scheduler (Customized Energy Solutions) to optimize profits to GMP.

The installed batteries are capable of providing both regulation down and regulation up from a medium state of charge. Estimated values for frequency regulation in ISO-NE are in the range

$35 - $40/ MWh. An early exercise to test the batteries for Frequency Regulation is shown in Figure 8.
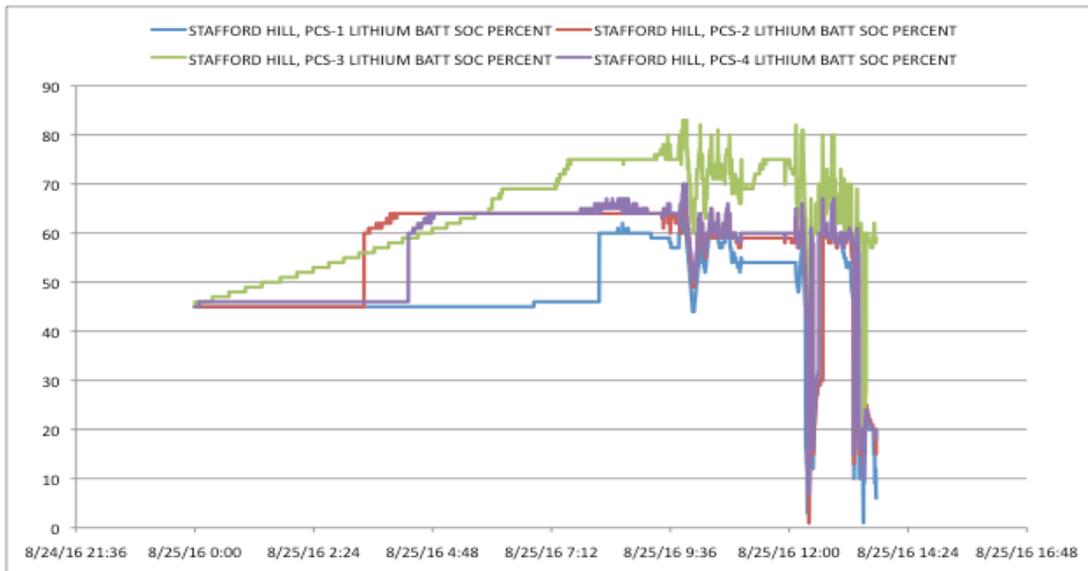
Figure 8. Lithium batteries operating in Frequency Regulation mode

4.2.2. Demand Response

A demand response product is currently offered by ISO-NE, in which turn-down of load (e.g., battery charging) can be bid into the market. GMP is not yet participating in this market, although they could, as they are still refining their participation in the frequency regulation market.

4.3. Energy Arbitrage

Energy arbitrage involves procuring or generating and storing energy when prices are low, and then selling or consuming the stored energy when prices are high.

Energy prices are typically low in off peak hours, especially in the early morning hours. Prices tend to increase in late afternoon or early evening. Another source for low cost energy is renewable generation like wind or solar that is owned or directly procured by the utility.

Energy prices often spike in response to a shortage of generation. An example would be an unplanned generator outage. Energy storage is ideal for energy arbitrage, although to be profitable, the difference between the selling and buying prices must be high enough to overcome the inefficiency of energy conversion in the system. Fortunately, round trip energy

efficiency for batteries, especially lithium ion batteries, is relatively high, so profit may be possible.

Using historical data for GMP, Sandia[iii] used an optimization algorithm to estimate the maximum potential revenue available from energy arbitrage for energy storage systems of different sizes. Figure 9 indicates the potential revenue from arbitrage for GMP at the North Rutland node. The optimization assumes perfect foresight, e.g., knowledge of all past and future data. Therefore, this estimate serves as an upper bound. The current system is 2 MW with 3.4 MWh output.
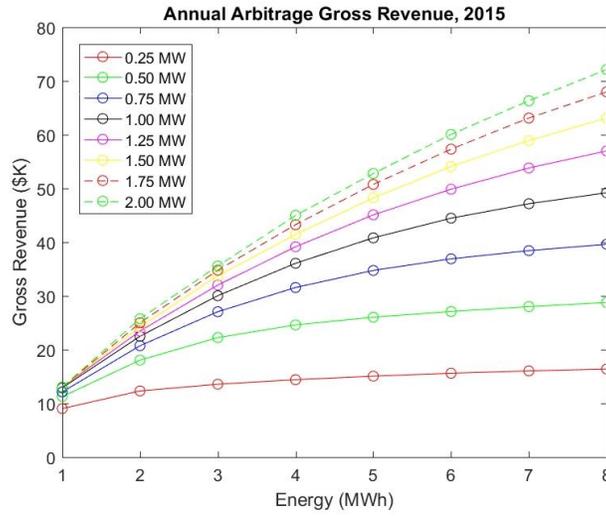
Figure 9. Potential Annual Revenue from Arbitrage for GMP

4.3.1.   Regulation plus Arbitrage

Using historical data for GMP, Sandia also calculated the sum of frequency regulation plus energy arbitrage for systems of various sizes. These results are shown in Figure 10. Note that frequency regulation opportunities are significantly more valuable than energy arbitrage. Also note that for a 2 MW system, the revenues continue to increase for systems up to 4 MWh in storage capacity, i.e., 2 hours duration. The optimized savings are presented in Table 2.
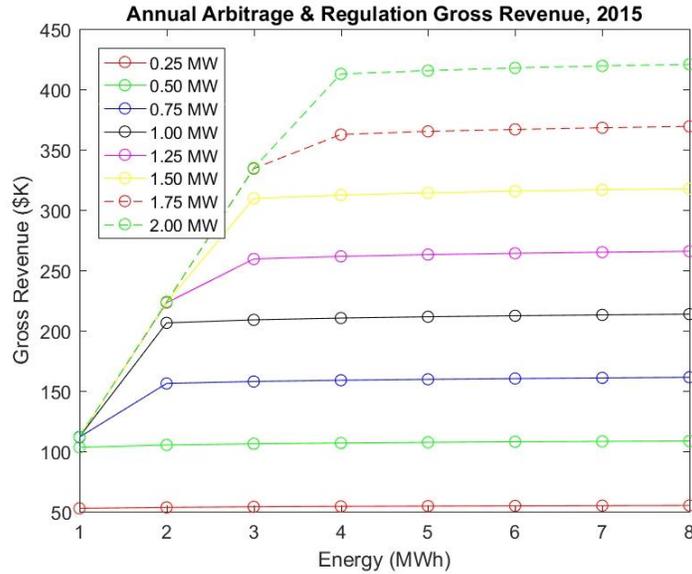
Figure 10. Potential Annual Revenue from Frequency Regulation plus Arbitrage for GMP

Table 2. Maximum potential arbitrage and frequency + arbitrage annual revenue opportunities for a 1 MW plant using GMP 2015 data at the North Rutland node.

	1 MWh	2 MWh	3 MWh	4 MWh
Arbitrage only	$12,872	$22,486	$30,038	$36,072
Arbitrage + Frequency Regulation	$111,932	$206,410	$208,916	$210,405

4.4 Renewables Integration

Vermont has seen a significant installation of solar power with over 165 MW currently connected to the GMP grid[iv] and more in development. The peak Vermont load is over 700 MW. As transmission is already congested in some areas, anticipated increases in solar generation capacity are likely to create integration and stability problems in areas with high concentrations of solar PV. Currently there is no tariff to incentivize flexible load to assist with integration or prevent curtailment of renewable power. There are also times of excess renewable generation within the ISO-NE region when energy prices are negative. GMP can get paid for charging during periods when the price goes negative. However, because the current LMP is on a 1-hr basis, this benefit can be hard to capture. Next year, the LMP will be priced on a 5-minute basis and then there should be more opportunities to capture this benefit. A sophisticated control capability is needed to operate the batteries in this charging fashion. The lithium-ion batteries

have fast enough response for this, while the lead-acid batteries do not. (In California, a flexible load can also get paid as a service for using this excess energy at negative prices.)

Energy storage combined with renewables also provides the benefit of smoothing any fluctuations in the output of the renewable source, solar or wind. This can be a significant benefit in maintaining power quality, especially when a solar project is located a long way out on a distribution line, where power quality is more difficult to maintain. The fluctuations can cause disturbances if not properly mitigated – storage can help counter these fluctuations, maintaining high power quality for all customers. While the batteries at Stafford Hill certainly smooth the solar output, the distribution system at that location is fairly robust so that fluctuations have not been known to cause noticeable issues.

In general, it is up to the developer / installer of a solar system to make sure they resolve any issues that are determined during pre-installation studies. Examples of traditional solutions to avoid power quality problems are circuit re-conductoring, adding regulators, or changing equipment settings. Adding energy storage to distributed generation instead can avoid those costs and provide other benefits as well. The Stafford Hill project provides power quality assurance in this way, but the quantitative value of these trade-offs has not been assessed.

4.5. T&D Upgrade Deferral

As noted above, transmission is congested in some areas of Vermont (hence the RNS charge for network services). The installation of energy storage to provide local power not only reduces the required transmission of energy, but can also defer transmission and distribution upgrades. The value of transmission deferral has been estimated by Sandia[v] as a significant benefit, in a range from 500 to 1000$/kW in the first year for general cases. Distribution deferral is estimated at 50-500 $/kW each time applied, again for general cases. This benefit can also accrue to GMP, who operates the distribution on their system. Other estimates of the value can be found in the Massachusetts "State of Charge" report[vi]. GMP believers these values to be optimistically high. Nonetheless, GMP expects to save $3 million over 5 years by installing storage at a number of other substations. The quantitative value of T&D upgrade deferral resulting from the Stafford Hill installation has not be assessed.

4.6.   Back-up Power

Back-up power is an important application for energy storage. GMP has installed the microgrid to provide reliable back-up power for the adjacent Rutland High School, which is the community's designated Red Cross emergency backup shelter. The photo in Figure 11 shows the location of the system.

The typical critical load at the school is estimated at 100 kW, climbing to as high as 250 kW in winter. The critical loads are heating, lights and building infrastructure. The islanding system has not yet been tested because that requires a complete disconnect from the grid. GMP is planning to test the system at a time that will not be disruptive, once the school year has ended in summer 2017.

Figure 11. Photo showing Stafford Hill microgrid, adjacent high school and Stafford Technical Center. Batteries are in the four containers at the top of the solar field. There are two containers to the left and two containers to the right.

Although the back-up power benefit to the community has not been quantified and is not monetizable by GMP, this benefit is valuable. An estimate of its value can be made by examining resilient power grants made to comparable systems in Massachusetts under the Community Clean Energy Resiliency Initiative (CCERI)[vii]. The school resiliency projects most similar to Stafford Hills (PV+storage) received grants ranging from $300,000 to $1.5 million. An estimate can also be made from literature values of the Value of Lost Load (VoLL)[viii], although they were derived for business losses and may not apply directly to community security. Based on references [6] and Sandia study [2], the value for energy capacity is $40,819 per 1MWh at 1MW output.

5.   GMP EXPERIENCE TO DATE

Typically the lithium-ion batteries are operated for frequency regulation and solar smoothing. This is to take advantage of the higher efficiency and cycle life of these batteries. For peak shaving, both the lithium-ion and lead-acid batteries are used, with the lead-acid batteries more suitable for longer discharge.

5.1.   Typical operation

GMP has conducted some cost/benefit analysis to determine the benefits of daily cycling for peak shaving or frequency regulation compared to the costs in terms of battery life. GMP has worked with both the inverter supplier Dynapower and the battery suppliers to determine total life cycle value, which included the costs and degradation over time. As this was GMP's first large-scale battery, it is an estimate based on the vendors' experience.

Because of the configuration with the multi-port inverters, priority is for the solar PV output during daylight hours. Participation in the frequency regulation market occurs only during dark hours. Hence, the high frequency cycling of the batteries is somewhat limited. Every battery system has a performance curve – basically the guaranteed amount of energy capacity over time and after so many cycles. In addition to simple time and cycle count there are other factors that are important to extend battery life, including state of charge (SOC) and temperature. For the Lithium-ion batteries, those considerations are as follows:

- Keep the average state of charge at 30-40% as much as possible. Even holding at 80-90% is much better than charging to 100%.
- Keep the batteries as cool as possible
- Partial discharging is best. In many cases you don't have the option, but 10 charge/discharge cycles of 10% SOC is much less damaging than 1 charge/discharge cycle of 100% SOC.

GMP expects to still have approximately 70% of the original energy value at year 10 based on our profile.

For the lead batteries, typical operation is to keep them topped off – up at 100% state of charge – and they can be drained completely. The batteries are maintained at approximately 77 degrees Fahrenheit, for which the battery shelter HVAC has been designed.

5.1.1.   August 12, 2016 Operation

The Stafford Hills project has been in operation since late 2015, providing both solar power and battery power to the GMP system. In response to forecast ISO-NE load peaks on August 11 and August 12, 2016, the batteries were prepared for peak shaving operation to reduce the GMP portion of the annual peak. The forecast and actual ISO-NE loads are shown in Figure 12. The actual yearly peak occurred on August 12 during the hour between 1500 and 1600 (3PM to 4PM Eastern Time).

The ISO peak forecast is pretty accurate for a range of 2 hours. For this reason, GMP plans a two-hour period for battery discharge. Both the ISO and GMP forecasts are based on sophisticated meteorological models, which are constantly improving. GMP also operates the IBM Watson model "deep thunder" to forecast their supply and demand 36 hours ahead, with 3-hr updates.
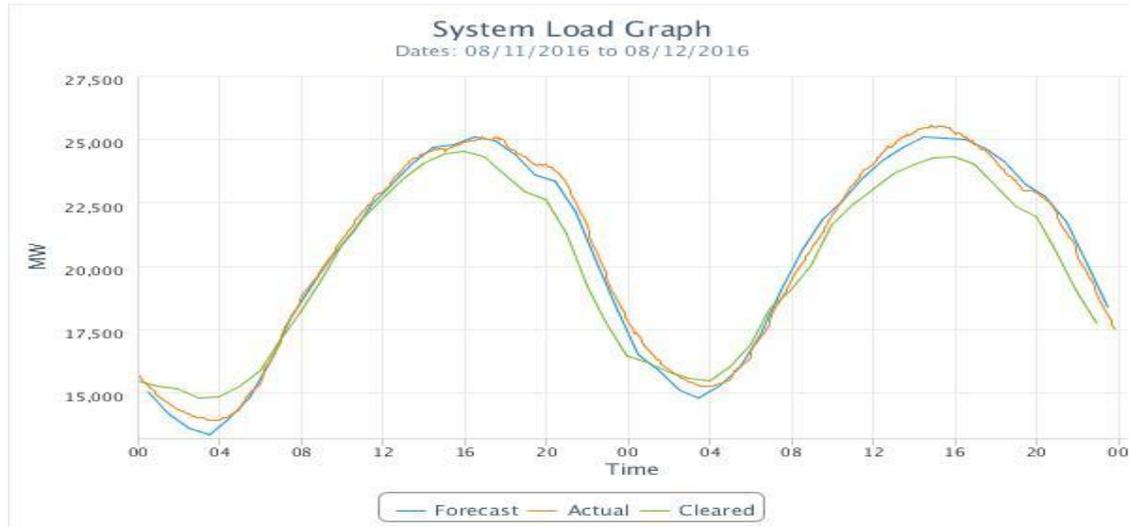
**Figure 12. ISO-NE Forecast and Actual load on August 11 and 12, 2016.**

The Stafford Hills operation is shown in Figure 12, showing output for August 12 of all three generators: PV, lead acid batteries and lithium ion batteries. In Figure 14, the output of the two battery types is shown to meet the system peak. The total output over the peak hour was approximately 1 MWh.
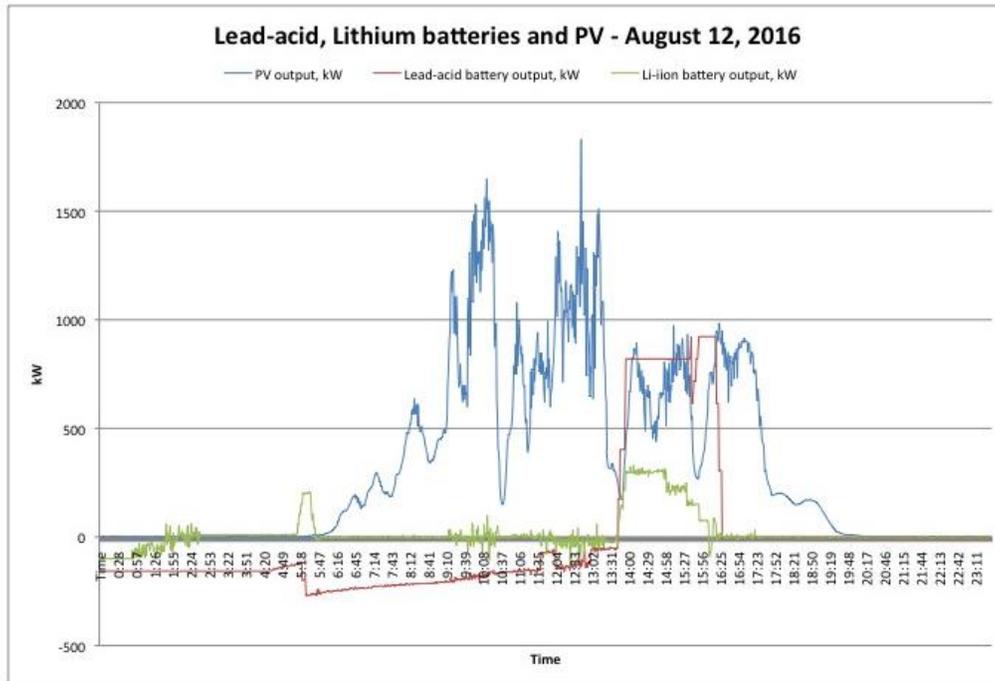
Figure 13. Stafford Hill output, August 12, 2016
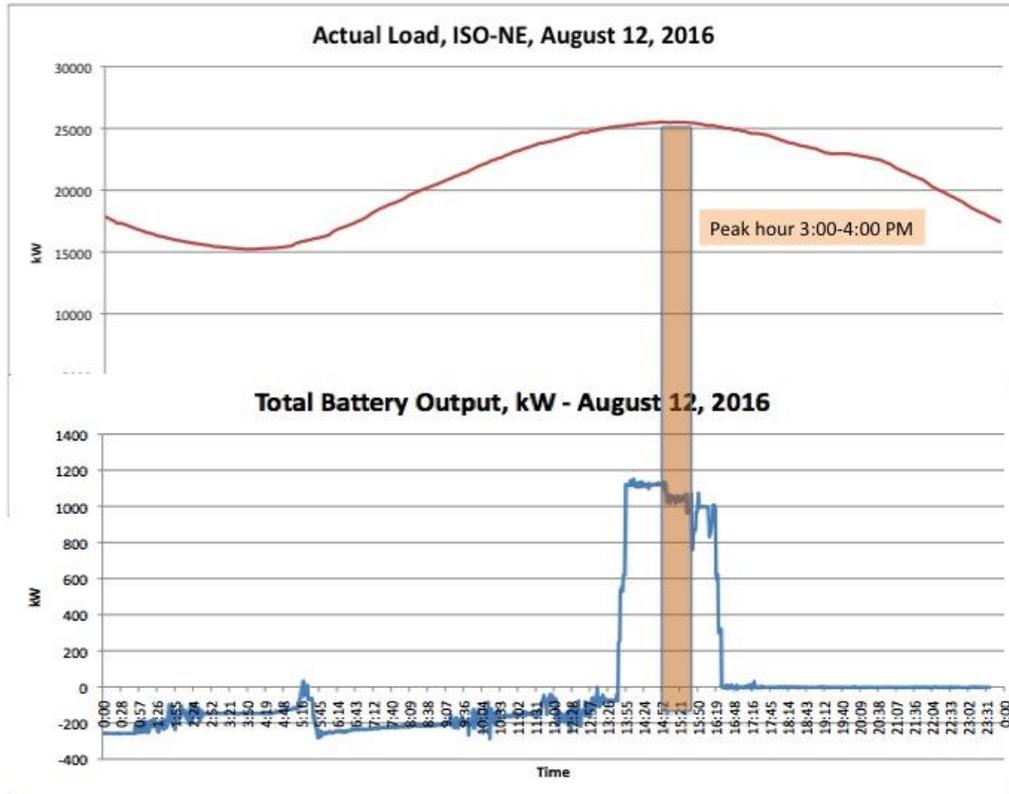
Figure 14. ISO-NE load peak and Stafford Hill total battery output, August 12, 2016

5.1.2. Estimated Savings from August 12 Peak Shaving

On average, the Stafford combined battery output during the hour ending 16:00 (from 3PM to 4PM) on August 12th is about 1,000kW, and according to the Director of Power Supply at GMP, the applicable auction price for June 2017 to May 2018 is **$7.025**/kW-month. Also, the ISO-NE capacity requirement includes a reserve margin of 20%.

Thus, the total calculated potential savings from energy storage is:

1,000 kW * 1.20 (20% reserve margin) * $7.025/kW-month * 12 months = **$101,160.**

Adding the value of the PV output (1MW) during that same period doubles the savings from load reduction. **Thus the total savings is over $200,000.** If the PV had not been operating and the batteries discharged the stored energy of 3.4 MWh fully over 2 hours to cover the peak, the maximum output would have been 1.7 MW. As the market value of the FCM fee increases in the next few years, GMP will be able to save even more by capturing the annual peak with their microgrid system.

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6. DISCUSSION

6.1. Summary of Potential Benefits

Table 3 summarizes the potential benefits from the Stafford Hill project, or one like it, in the GMP system. Note that if the peaks are shaved at the full output power of 2000 kW, the savings are greater.

Table 3. Potential Benefit streams for GMP energy storage system

Benefit	Value
Forward Capacity Market – peak shaving	$102/kW-year in 2018, increasing in most future years, for capturing annual peak at 1000kW
Regional Network Services = peak shaving	$103/kW-year in 2018, increasing in future years, for capturing monthly peaks at 1000kW
Energy Arbitrage	Approximately $13/kWh/year, but GMP is not exercising this benefit.
Frequency Regulation	Up to $150/kWh/year in ISO-NE
Transmission Investment Deferral	$500 - $1000/kW for the first year
Distribution Investment Deferral	$50 - $500/kW each time applied
Renewable Integration	No current market tariff, but negative prices for energy may be captured in future years.
Resiliency	Estimated at $40,000 / event for a 1MWh / 1 MW system

6.2. Payback Period Analysis

The payback period on the capital cost of the energy storage system has been estimated. The annual benefits accrue primarily from three sources:

1) Peak shaving of the annual ISO-NE peak load, which reduces the FCM annual charge. Two-hour discharge over forecast peak yields 3.4MWh / 2hr = 1.7MW.
2) Peak shaving of the monthly transmission peaks, which reduces the monthly RNS charge. Two-hour discharge over the forecast peak yields 3.4MWh/2hr = 1.7MW.
3) Revenue from bidding into the frequency regulation market. Since the PV system uses the inverters during the day, frequency regulation using the batteries is only bid during the nighttime hours.
4) The parameters for these benefits are presented in Table 4.

Table 4. Parameters and basis for benefits calculation

Benefit	Basis	Value
Annual FCM peak shaving	1.7 MW * FCM factor * 1.2 (1.2 multiplier for reserve margin)	FCM factors: See Table 1
Monthly RNS peak shaving	1.7 MW * RNS factor) *0.75 *(75% of monthly peaks assumed captured)*	RNS factors: See Table 1
Frequency regulation	2 MW * 12hr / day (Night-time operation only)	$150/kW, current ISO-NE market price

The capital cost of the energy storage system, which includes both batteries, the associated portion of the power conditioning system (inverters) and the system housing, was $5.5 million, after accounting for the grant funding of $250,000 from the US DOE and $40,000 from the Vermont DPS. To estimate the payback period for the capital investment, the annual benefits are applied against the capital expenditure in each year, as shown in Table 5, using the parameters and assumptions found in Table 4. From Table 5, the shift from negative expense to positive earnings can be seen in year 8. Without the investments from DOE and Vermont DPS, the payback period would be closer to 9 years. This analysis is based on projected values of the benefits. The results could shift either up or down if the various values change from these projections.

Table 5. Payback Period Calculation for Energy Storage Capital Costs

year	year	RNS factor	$ RNS benefit	FCM factor	$ FCM benefit	Freq Reg revenue	Total Annual benefit	Cumulative benefits	Net Cash Flow
0									-5,500,000
1	2016	94.23	141,345	3.27	78,480	300,000	535,521	535,521	-4,964,479
2	2017	102.31	153,465	5.41	129,840	300,000	609,273	1,144,794	-4,355,206
3	2018	106.98	160,470	8.50	204,000	300,000	705,270	1,850,064	-3,649,936
4	2019	111.56	167,340	9.00	216,000	300,000	726,540	2,576,604	-2,923,396
5	2020	116.11	174,165	7.03	168,720	300,000	676,629	3,253,233	-2,246,767
6	2021	120.27	180,405	10.19	244,560	300,000	773,877	4,027,110	-1,472,890
7	2022	124.22	186,330	11.20	268,800	300,000	808,890	4,836,000	-664,000
8	2023	128.29	192,435	11.81	283,440	300,000	832,563	5,668,563	168,563
9	2024	132.50	198,750	12.11	290,640	300,000	847,518	6,516,081	1,016,081
10	2025	136.85	205,275	12.41	297,840	300,000	862,683	7,378,764	1,878,764

GMP has not estimated a quantitative value for T&D deferral, although some deferral might result from having the Stafford Hill facility in place. In terms of calculating payback period, additional benefit for T&D deferral could reduce the payback period to less than 8 years.

6.3.   Lessons learned

During the first year of operation, GMP has been learning lessons from the Stafford Hill project. Some of the most significant:

- Data acquisition, storage and accessibility have not been as user-friendly as they need to be for proper assessment of the system's performance.
- Communication challenges, both digital and personal, have also impeded information flow.
- Whereas the multi-port inverters have some advantages in the transfer of energy from the solar system to the batteries, the disadvantage has been the constraint on total output from the overall system.
- Lithium ion batteries show good response in frequency regulation mode.
- Lead-acid batteries have been successfully deployed for peak shaving.
- The ability to schedule peak-shaving dispatch from the ISO load forecast has been successful.
- Various revenue and savings opportunities are still being evaluated but show promise for a good return on investment for the battery units.
- Going forward GMP will most likely be looking primarily at lithium ion batteries and will not use lead acid as installed at Stafford.
- The modeling that GMP utilizes to forecast peaks has improved over time. However, it is possible that, as more utilities in the ISO-NE region add dispatchable distributed generation (renewables plus energy storage) both in front of and behind-the-meter, the system-wide peaks could flatten and become less valuable, and/or less easy to shave. In the long term (5-10 years out), the forecasting could become more challenging as more non-dispatchable (variable) distributed generation is added within the system.

6.4.   GMP Future plans

GMP is planning additional energy storage deployment at substations all over the state. This is supported by the Vermont Comprehensive Energy Plan,[ix] which cites the Stafford Hill project as a model project that should be replicated. Not all such installations will feature multi-port inverters, as GMP has learned that in some instances it might be better to not constrain the output of the either the batteries or the PV. Additionally, not all future GMP projects will include PV; some may be stand-alone energy storage systems not connected to the grid. GMP would sell these systems outright to serve some customers.

GMP is also putting small behind-the-meter batteries in customer sites to expand their energy storage capacity. This will allow for load management both at the customer location and, when aggregated, for the system as a whole. For example, 25-30 Tesla Powerwall[x] system deployments are planned, because they have a good price point. When the larger, Powerwall 2.0 systems become available, these will also be considered. Customers will be able to install their own batteries and be compensated, or lease batteries from GMP. GMP is working on specs for this application. GMP expects 1MW of energy storage behind customer meters within the next year or two.

Finally, as per the proposal for the Stafford Hill project, GMP is still planning to develop and install a display, including real-time data of energy being produced, stored and dispatched, at the Rutland High School and the Energy Innovation Center in downtown Rutland. The display will also contain information on the environmental and societal impacts of the project including future uses such as electric vehicles and benefits to the grid and the functions and benefits and

challenges of developing a micro-grid. Displays about micro-grids, renewables and grid storage technology and economics will be included. Surrounding schools will be invited to visit the site and the center.

7.   BROADER CONTEXT

During the first full year of microgrid (solar + energy storage) operation at the Stafford Hill facility, GMP has gained considerable experience in operating their system. They have optimized operations to earn revenue from frequency regulation and save costs on FCM and RNS fees. They have moved to install additional similar systems within their service territory, with some changes based on lessons learned. Other utilities in New England have taken note and are similarly moving to install energy storage. They can also take advantage of peak shaving. The calculation of peak shaving benefits for a municipal utility in Massachusetts, for example, would be similar. While Vermont is unique in New England in that RNS services are provided by VELCO, utilities in other states in New England purchase transmission directly from the ISO-NE. Since GMP is a major provider in Vermont, any reduction in their RNS payment could shift costs to other utilities in Vermont. It remains to be seen whether this will affect either the RNS fee value or the rules around this payment.

Other territories beyond New England are also considering capacity markets. Similarly to Massachusetts, the grid in some regions is overbuilt to accommodate intermittent renewables, in that the gas turbine peaker plants sit idle most of the time. Other DOE and CESA activities are promoting the use of energy storage to optimize the use of clean generation on the electric grid in these instances.

[i] B Corporations are for-profit companies certified by the nonprofit B Lab to meet rigorous standards of social and environmental performance, accountability, and transparency.

[ii] ISO-NE website. <http://iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info>

[iii] Byrne, R. et al, "The Value Proposition for Energy Storage at the Sterling Municipal Light Department," accepted for publication in Proceedings of the 2017 IEEE Power Engineering Society (PES) General Meeting, Chicago, IL, July 2017, pp. 1-5..

[iv] Solar Energy Industries Association factsheet <http://www.seia.org/state-solar-policy/vermont>

[v] Eyer, J. and Cory, G. "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment." Sandia report number SAND2010-0815, February 2010.

[vi] "State of Charge: Massachusetts Energy Storage Initiative Study," < http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf.> September 27, 2016.

[vii] Community Clean Energy Resiliency Initiative. Projects found at >http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/resiliency/resiliency-initiative.html< March 24, 2015.

[viii] M. J. Sullivan, M. Mercuriov, and J. Schellenberg, "Estimated value of service reliability for electric utility customers in the United States," Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, Tech. Rep. LBNL-2132E, June 2009

[ix] Vermont Department of Public Service, "2016 Comprehensive Energy Plan" http://publicservice.vermont.gov/publications-resources/publications/energy_plan, January 1, 2016.

[x] https://en.wikipedia.org/wiki/Tesla_Powerwall

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