CADMUS

Utah Wattsmart Batteries Program

Grid Service Benefits Analysis

November 2021

Prepared for:

Rocky Mountain Power, PacifiCorp

Shawn Grant

Prepared by:
Danielle Kolp
Stephen Treat
Ari Kornelis
Josh Fontes

CADMUS

Table of Contents

Tables

Figures

Glossary of Terms

Distributed Battery Grid Management System (DBGMS)
A battery control system which provides automated integrations with a utilities energy management system for advanced real-time grid management.

Distributed Energy Resource (DER)
A DER is a small-scale unit of power generation that operates independently and is connected to a larger power grid.

Load
Load, or electrical load, is a portion of a circuit that consumes electric power such as appliances or lighting.

Solar Production
Electricity produced from solar panels.

Virtual Power Plant (VPP)
A virtual power plant refers to a collection of decentralized distributed energy resources that are aggregated to enhance power generation and dispatch of power on the grid.

Introduction

Rocky Mountain Power (RMP) operates a battery management program, Wattsmart Batteries, which aggregates individual customer batteries into a coordinated system for providing grid services. The program provides incentives for utility customers who integrate their battery into a distributed battery grid management system (DBGMS), which RMP can call upon via software to provide grid services at scale. This distributed system of dispatchable batteries is also sometimes known as a virtual power plant (VPP). While typical demand response programs operate with predetermined dispatch calls, the Wattsmart program goes a step further, using the DBGMS to actively manage power dispatch in real time. To develop the Wattsmart Battery program, RMP partnered with a local housing developer and battery provider to explore the feasibility of the DBGMS and to support regulatory approval, using the pilot project, Soleil Lofts, as a proof of concept (using the sonnen Wattsmart Battery generation 1, or "SWB gen-1"). In addition to the participants from the housing development, additional residential customers have enrolled in the Wattsmart Battery program using the newer sonnen Wattsmart Battery generation 2, or "SWB gen-2," battery systems.

Study Objectives

In this study, Cadmus analyzed data from Wattsmart Battery Program participants to assess the benefits of the DBGMS VPP. While the data is primarily from participants at Soleil Lofts, the goal is to demonstrate the benefits from participating in the Wattsmart Battery program as a whole. We also documented lessons learned about the performance of residential buildings with solar arrays and battery storage, which included an analysis of seasonal variation in facility load and solar production, as well as of the expected performance of the batteries as a backup power resource.

Program Benefits

The Wattsmart Batteries program DBGMS provides four primary grid service benefits:

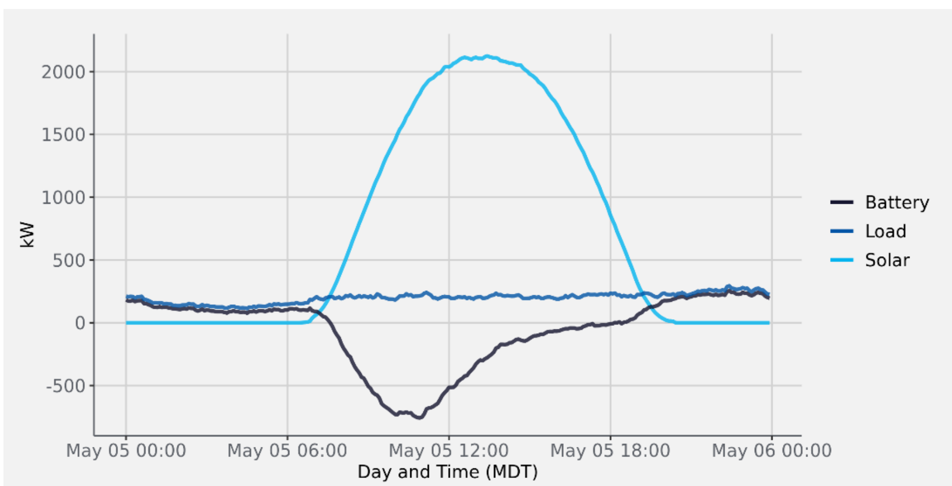
Frequency Regulation Services	Batteries can be dispatched automatically to provide real-time power output, stabilizing the grid in response to unexpected fluctuations in electricity consumption or generation.
Peak Load Management	Batteries can be deployed to offset load during peak hours. Depending on deployment timing, this can ease capacity restraints at the system level.
Circuit Congestion Relief	In aggregate, DBGMS can provide congestion relief at the circuit level.
Backup Power	Battery systems can be designed to deploy automatically during an outage to prevent service interruptions in customers' homes.

Multi-Family Pilot Facility

To demonstrate that the DBGMS concept would be successful, RMP partnered with a local developer Wasatch Development, battery manufacturer sonnen, and Auric Energy to deploy solar PV and battery storage across all units at the newly constructed 600-unit Soleil Lofts apartment complex in Herriman, UT (see Appendix A for further details). While the Soleil Lofts complex features sonnen equipment, the Wattsmart Batteries program is intended to be manufacturer agnostic, so long as the batteries meet the requirements to participate in the DBGMS. The facility pilot provides a rich dataset from which to analyze the various grid benefits as a proof of concept.

To introduce the electric load, solar production, and battery function, Figure 1 depicts aggregate facility operations on a sample day. During early morning hours, residents' energy use, or load, is primarily served by battery output. During midday hours, the solar arrays produce electricity and the batteries recharge using solar production. The energy consumed by the batteries during recharge is represented by negative battery values in the figure. The remaining excess solar production during midday hours is returned to the grid. In the evening, when solar is no longer producing, load is again served by the battery output and grid power, when necessary. This functionality demonstrates a day without a frequency regulation event or a loss of power.

Figure 1. Sample Daily Solar + Battery Facility Performance



Methodology

Cadmus' approach to analysis is primarily data driven, informed by qualitative research and interviews we used to gain useful context into the development and goals of the DBGMS for the Wattsmart Batteries program overall. Cadmus used visual analysis and descriptive statistics to analyze the performance of the DBGMS system and to answer a number of study research questions determined by Cadmus and RMP at the study start. The research questions focused on assessing the impact of distributed solar and storage on the per-unit and aggregate load over time. We also reviewed the impact of seasonality on DBGMS performance. Cadmus collected and prepared a variety of system performance data from the Soleil complex:

- Facility Load: per unit
- Solar Production: per unit, from date of interconnection
- Storage Recharge and Discharge

sonnen provided all other solar production, load, and battery charge data. sonnen provided the system performance data in 5-minute intervals for May 2020 through July 2021, and provided additional samples of 1-second interval data for analysis of frequency regulation events.

We focused on characterizing facility load, solar production, and battery storage operations for Wattsmart Battery Program participants. Cadmus determined the daily, seasonal, and annual peak loads and created supporting visualization. The load analysis revealed distribution outliers and provided an overview of the seasonal variation and coincidence of solar production, as well as details of facility and system peak load events.

Cadmus used the model[1] to analyze battery storage system operations and determine the systems' capability to provide backup power. In addition, we reviewed the average length of time the system was able to provide backup power during an outage, how quickly it provided backup power, and at what point the storage is recharged from the solar (specifically on November 4, 2020). As with our other analysis, we characterized the backup power timing and recharge variation with seasonality, as applicable.

---

[1] Cadmus conducted nearly all the system analysis research provided in the report using R or Excel. We used data visualization techniques and descriptive statistics to investigate relevant research questions, creating all data visualizations using the *ggplot2* and *plotly* packages in R.

Findings

The Soleil Lofts facility, which was the first phase of the Wattsmart Battery Program (using SWB gen-1 batteries), provides an ideal case study to demonstrate the many capabilities of DBGMS. RMP can control the dispatch of each of the 600 batteries, including timing and the amount of power, using the DBGMS. RMP has used the DBGMS to deliver several types of grid benefits: frequency regulation services, peak load management, circuit congestion relief, and backup power. Where possible, Cadmus provides comparisons between different battery generations to show the evolution of the technology.

Frequency Regulation Services

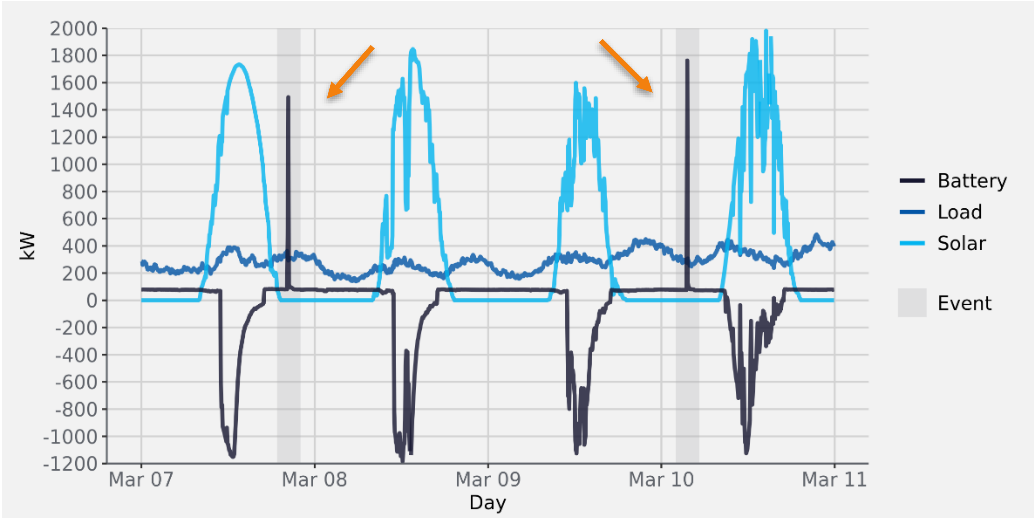
One primary benefit of the Wattsmart Battery program is its ability to provide frequency regulation services to the grid, helping to maintain grid stability by responding to rapid and unexpected electricity fluctuations on the overall grid. The DBGMS is integrated into RMP's Energy Management System (EMS) and provides these grid balancing services 24x7 by automatically controlling the batteries with near-immediate response times. Regulations dictate a response time of 50 seconds with traditional fossil fuel resources or demand response programs.

After conducting a series of tests in 2020 and early 2021, the Wattsmart Battery Program entered production as a frequency regulation resource in February 2021. Over a sample of frequency regulation events between February and May 2021 using the first-generation batteries, the average response time between the delivery of the frequency response signal and dispatch of the batteries to compensate load has been roughly 6.5 seconds for batteries set in discharge mode. The range in response time between the frequency response signal and dispatch of the battery to peak output was between 11 and 12 seconds.

Figure 2 depicts an example of two frequency regulation events, which occurred on the evening of March 7 and morning of March 10. On March 8 and 9 the system operated in a typical manner. Solar production occurred during midday, and the battery systems were in discharge mode during the night and evening hours and in recharge mode using solar production during midday hours.

On March 7 and 10 frequency events occurred. Frequency fluctuations generally occur due to issues with generation sources throughout the western United States. During these events, there are visible spikes in battery output as the batteries automatically responded to a command issued by RMP's EMS through the DBGMS (indicated with orange arrows). In each event, the aggregate battery output quickly ramped from approximately 75 kW to over 1.5 MW. As is typical for frequency regulation services, the events only lasted around five minutes.

Figure 2. March Frequency Regulation Events

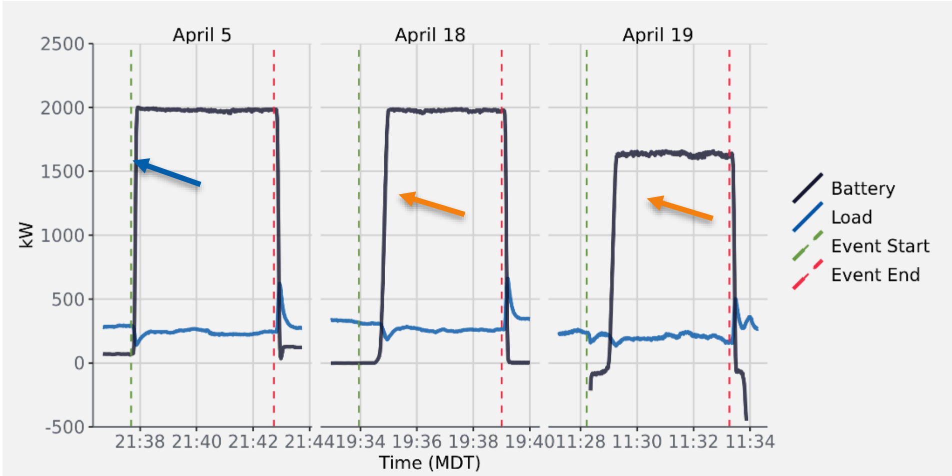


There is a limitation to the frequency regulation services provided by the SWB gen-1 batteries. The speed of the individual batteries' response to the frequency event signal depends on the battery status when the signal is received. If the batteries are in discharge mode, the response time is quite fast, with the batteries beginning to ramp up after 6-7 seconds after signal delivery and then reach target output level after approximately 12 seconds. If the batteries are in standby or recharge mode, there is a 45 second delay before the battery output begins to ramp up and the batteries reach the target output level after approximately 60 seconds. Figure 3 depicts a series of frequency regulation events, showing a dashed line for the DBGMS commands to begin and end each event, in comparison to when the batteries delivered.

- The first panel depicts an April 5 event, when the batteries were already discharging at a low level when the frequency event signal was delivered. This is visible in the *Battery* line, which is already slightly above zero before the event signal. In this event, the batteries responded quickly, with output spiking to 2,000 kW shortly (11 to 12 seconds) after the command was issued (blue arrow).
- The second and third panels depict events on April 18 and 19, when the batteries were in standby and recharge mode, respectively, when the event signal was delivered. In these cases, the response time was noticeably slower (60 to 65 seconds), which is visible in the space between the dashed *Event Start* line and the spike in the *Battery* line (to over 1,500 kW) (orange arrows).

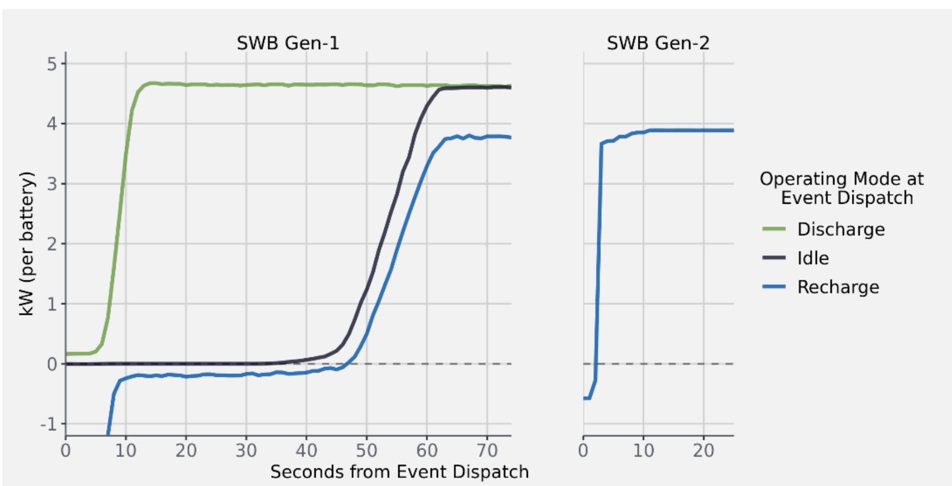
The figure makes it clear that, with this particular type of battery system and configuration, grid administrators should recognize that there is a difference in response times based on the battery charging mode.

Figure 3. April Frequency Events for Three Types of Battery Charging Mode



Based upon the lessons learned during the early stages of implementation, sonnen has implemented design improvements to further increase the response time for frequency events. The major improvement was a redesign of the inverter to increase the ability to respond near-real time. Figure 4 shows a comparison of the response times from the three SWB gen-1 battery frequency events discussed in the previous section and an additional test frequency event conducted with the new SWB gen-2 batteries. With the early generation program batteries, the batteries in discharge mode (green line) shows a quick event response, whereas the idle and recharge lines (black and blue) took nearly a minute. The newer battery model demonstrated a response time of less than 5 seconds when beginning in recharge mode (idle or discharge mode perform as well or better) showing the rapid improvements being made in the battery technologies.

Figure 4. Frequency Event Response Time Comparison



Peak Load Management

RMP has also operated the Wattsmart Battery Program to manage system peak loads. Battery storage capacity can absorb excess solar production during midday hours, then discharge during peak hours in the morning and evening when energy is needed most.

As an example, Figure 5 depicts program operations on December 16, 2020. The batteries operated in load compensation mode, offsetting a large share of consumption during morning and evening hours. The batteries delivered sustained output between 200 kW and 300 kW from 9 a.m. to 11 a.m. and from 5 p.m. to 9 p.m. (highlighted with dark gray vertical bands). During midday hours, the batteries recharged using available excess solar production, shown by the inverted production and charging curves.

Figure 5. Peak Management Operations, December 16, 2020

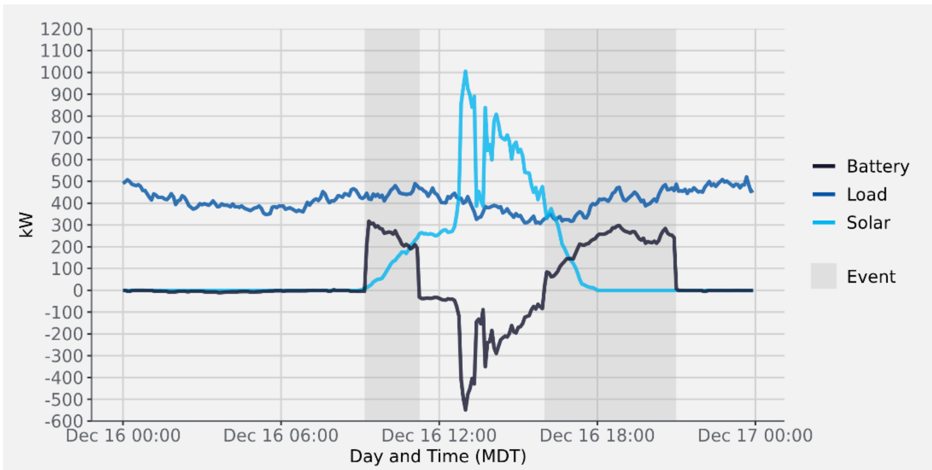
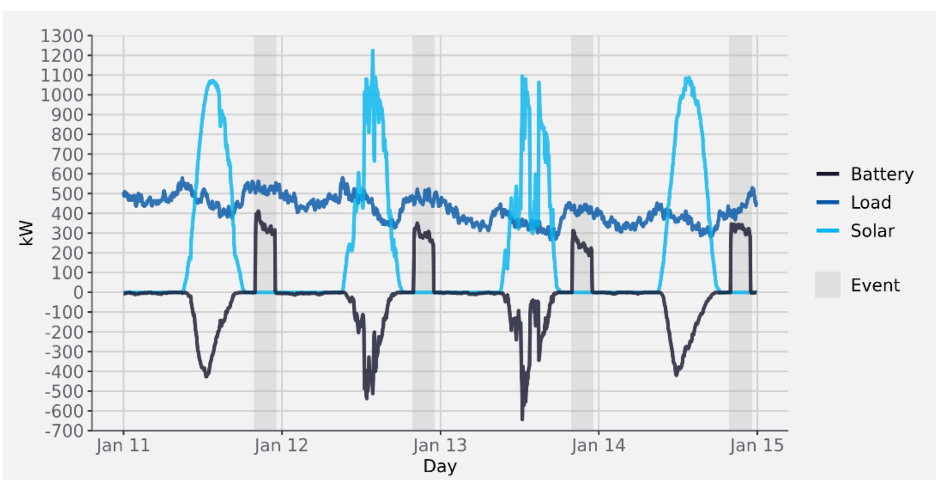


Figure 6 depicts a series of days in January 2021 when the battery systems were used to target evening peak hours between 8 p.m. and 11 p.m. Battery output, depicted by the black lines, ranged from 200 kW to 400 kW during these hours (highlighted with dark gray vertical bands).

Figure 6. Peak Management Operations, January 2021

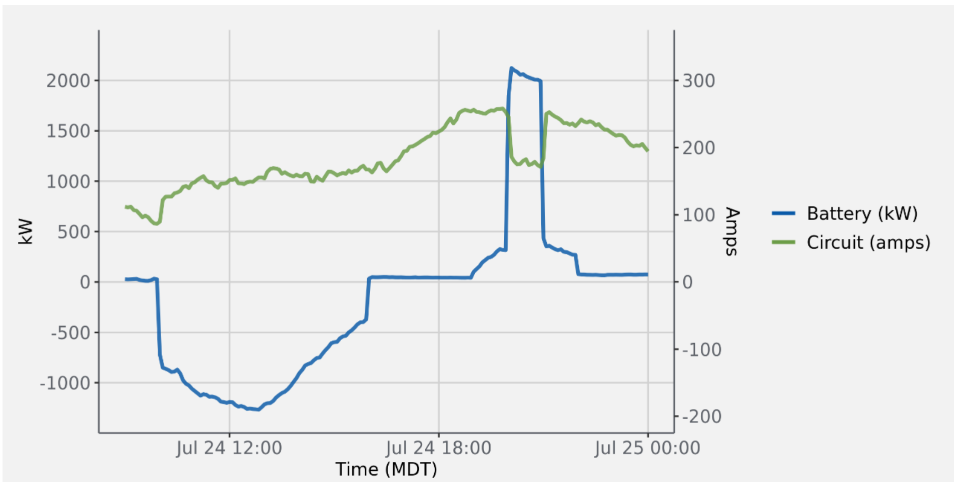


Congestion Relief

The Wattsmart Battery program can help mitigate congestion issues (such as insufficient transmission throughput due to transmission capacity constraints) by delivering power to the specific distribution system areas that are experiencing congestion. Congestion relief from battery storage can help defer costly future local transmission and distribution investments.

Figure 7 depicts operations during a local circuit congestion event on July 24, 2021. The figure includes the output of the program batteries and load on the nearby circuit. Between 8:00 p.m. and 9:00 p.m., the Wattsmart Battery systems were dispatched to reduce load at the circuit and relieve transmission congestion. In aggregate, the batteries delivered approximately 2 MW throughout the event hour. Due to the battery output, load at the circuit was reduced by 30% (from approximately 250 amps to 175 amps).

Figure 7. Distribution Circuit Congestion Event – July 24, 2021



Backup Power

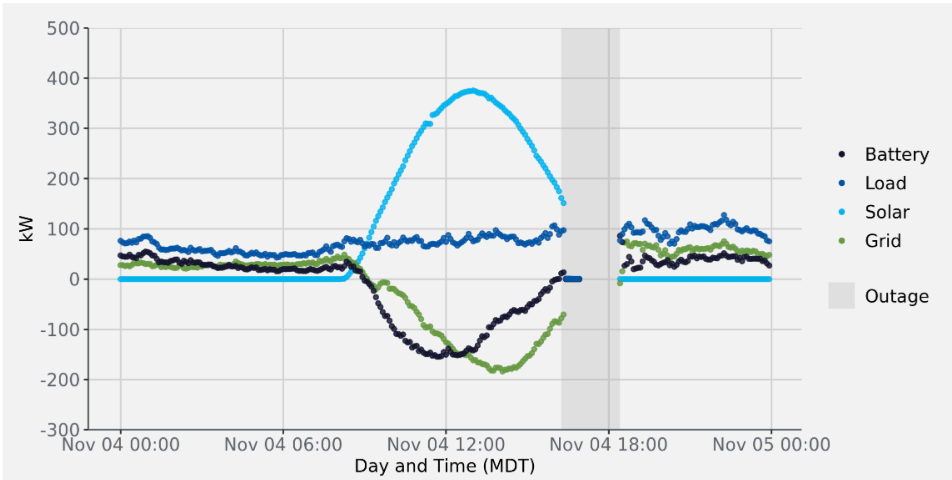
Another major grid benefit of battery systems is the backup power they can provide during power outages. When an outage occurs, battery output ramps up to serve electricity use in the home. If the outage occurs while solar is being produced, the solar output will serve home power needs, preserving energy in the battery for later use.

A power outage is known to have impacted the multi-family complex enrolled in the program (Soleil), on November 4, 2020. Figure 8 depicts aggregate power flows for a sample of units (*n*=267) on that day, where aggregate facility load is the sum of wattage used by that sample of units in 5-minute intervals. Solar production occurred between 8 a.m. and 5 p.m., peaking around 1 p.m. (shown in light blue dots). The green points indicate battery input and output. The positive battery values, which occurred before 8 a.m. and after 6 p.m., indicate output. The negative battery values between 8 a.m. and 5 p.m. indicate battery recharge coinciding with solar production. The grid points depict positive and negative power flows from the grid. Positive grid values indicate grid power consumed at the facility. Negative grid values indicate power exported from the facility to the grid.

Energy use during night, early morning, and evening hours was served by a mix of grid power and battery output. During midday hours, solar production serves all facility load and battery recharge, and exports additional power to the grid.

The outage occurred between approximately 4 p.m. and 6:20 p.m. During the outage, there was an interruption in data collection (the dark gray band in Figure 8). Based on information provided by RMP and sonnen, the solar and battery systems successfully responded to the outage automatically and provided continuous service. Few customers were aware that an outage even occurred.

Figure 8. Aggregate Facility Operations, November 4, 2020



General Backup Power Calculation

The calculation of how long a battery might last during an outage depends on many factors. Below is an example with various assumptions, for illustrative purposes.

Table 1. Backup Power Example Assumptions (Without Solar)

Variable	Assumption
Battery Size	10 kWh
State of Charge	80%
Daily Usage	24 kWh
Time of Outage	10:00 pm

$$Backup\ Coverage\ (no\ solar) = \frac{Battery\ Size\ \times State\ of\ Charge}{Daily\ Usage / 24\ hours}$$

$$Backup\ Coverage\ (no\ solar) = \frac{10\ kWh\ \times 80\%}{24\ kWh / 24\ hours} = 8\ hours$$

As can be seen from the above example (assuming no additional power from solar), a battery with 10 kWh of usable capacity, with an 80% state of charge could cover 8 hours of an average daily usage of 24 kWh. If the state of charge was only 40%, the coverage would be only 4 hours; or conversely, if the daily usage was 48 kWh, the battery would provide 2 hours of coverage, on average.

Next is a simplistic example showing the additional hours of back up power with the supplement of solar production during the day. Note that the solar power will charge the battery to full because the solar production is greater than the average hourly usage, and the battery will only start exporting power once the solar production stops serving the electric load of the home.

Table 2. Backup Power Example Assumptions (With Solar)

Variable	Assumption
Battery Size	10 kWh
State of Charge	80% charges to 100%
Daily Usage	24 kWh
Average daily solar production	30 kWh
Time of Outage	10:00 am
Solar Production Ending	5:00 pm

$$Backup\ Coverage\ (with\ solar) = \frac{Battery\ Size \times State\ of\ Charge}{Daily\ Usage/_{24\ hours}} + (Solar\ Production\ Ends - Time\ of\ Outage)$$

$$Backup\ Coverage\ (with\ solar) = \frac{10\ kWh\ \times 100\%}{24\ kWh/_{24\ hours}} + (5{:}00\ pm - 10{:}00\ am) = 10hr + 7hr$$
$$= 17\ hr$$

It is important to note that the state of charge can vary greatly during different hours of the day (between usage level as well as solar recharging), and average daily usage may vary greatly depending on the season of the year. As shown in the two examples above, the time of day that the power goes out can make a large difference. If the power went out at 9:00 pm, the battery could provide back up for the night but then would be depleted. If the power went out at 9:00 am, the solar PV system would provide ample power to cover the daily load and recharge the battery, so then the battery would be utilized only when solar was no longer available. Thus, the battery back-up coupled with the solar input could provide coverage throughout the day and night (again, caveating that usage patterns differ during the day and night). The variation in day-time and night-time usage complicates a straight average calculation of back-up battery coverage hours, but the subtleties are important to consider. Additional considerations are provided in the next sections.

Backup Power Seasonality

The battery systems are managed by RMP and dispatched to provide various grid services, while maintaining a minimum state-of-charge of 20% in each battery. This reserve capacity ensures that the systems are available to provide power during an outage. With typical unit load, a battery with 20%

remaining capacity would be capable of maintaining service for about 5 hours.[2] Throughout the year, the average battery state-of-charge was 71.3%. At this level, the batteries would be expected to provide service during an outage for 18.5 hours.

Due to differences in consumption patterns, the expected time period that the batteries could deliver backup service varies by season. Table 3 contains a summary of the typical electricity usage and expected length of outage service by season. The winter heating load and lower typical state-of-charge reduces the expected backup service to about half that of the other seasons. The backup service capabilities detailed in Table 3 would be expected to be consistent for multi-unit dwellings with electric heating. The following estimates do *not* include any solar recharging.

Table 3. Backup Power Service Expectations for a Unit with 20 kWh or 10 kWh Battery (With No Solar Recharge)

Battery Storage Capacity Rating	Season	Average Hourly Load (kWh)	Average State-of-Charge		Expected Backup Service at Average State-of-Charge (Hours)
			Percentage	kWh	
20 kWh	Summer	0.7	85%	16.9	24.2
	Winter	1.1	69%	13.9	12.6
	Fall	0.7	76%	15.2	21.7
	Spring	0.6	84%	16.8	28.0
	Average	**0.8**	**71%**	**14.3**	**17.8**
10 kWh	Summer	0.7	85%	8.5	12.1
	Winter	1.1	69%	6.9	6.3
	Fall	0.7	76%	7.6	10.8
	Spring	0.6	84%	8.4	14.0
	Average	**0.8**	**71%**	**7.1**	**8.9**

The expected performance of the batteries during a multi-day power outage differs by season due to the variation in typical hourly load and solar production. Under typical summer conditions, daily solar production was roughly twice as large as daily electricity consumption. After allowing for some loss of energy due to battery round trip efficiency, the battery systems would still be expected to recharge using excess solar production and provide continuous power throughout a multi-day outage of indefinite length. During winter, typical daily solar production was less than half of daily electricity consumption, so there is unlikely to be sufficient solar production to recharge the batteries during a multi-day outage.

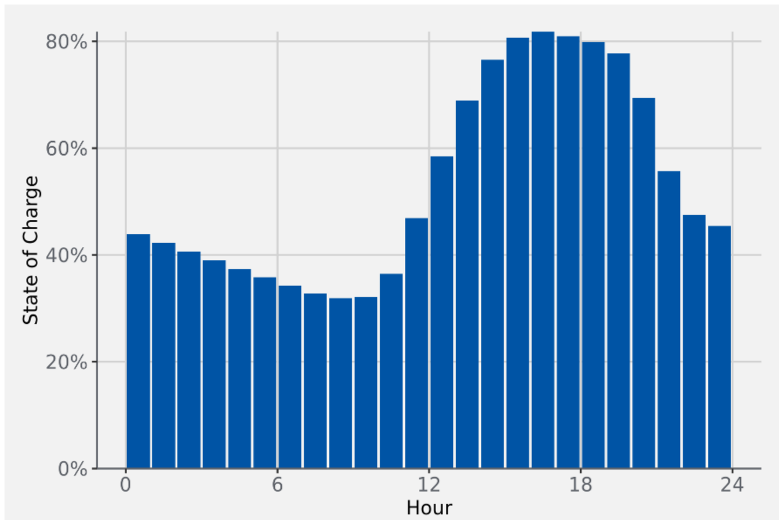
Hourly State of Charge

Available battery state of charge also varies throughout the day, following common profile where available charge peaks later in the day, after the solar PV has been charging the battery throughout the day. The available state of charge available during a power outage will approximately follow the profile

[2] Between May 2020 and May 2021, each unit consumed an average of 0.74 kWh per hour.

shown in Figure 9 below, meaning that more or less power would be available based on Table 2 depending on the time of day.

Figure 9. Daily Variation in Battery State of Charge (July 2021 Average)



Summary of Findings and Recommended Next Steps

The DBGMS employed by RMP provides many facility and grid benefits, which Cadmus quantified using representative data from Wattsmart Battery Program Participants. The Wattsmart Battery Program effectively allows RMP to:

- Manage customer owned batteries for the benefit of the overall grid, allowing the integration of renewable solar energy while avoiding solar energy congestion issues during the middle of the day
- Store excess solar generation on the system during the middle of the day and utilize it during peak time periods in the evening and the morning
- Automatically respond to broader western electric grid emergencies in real-time (frequency response)
- Change the load usage profile of participants based upon highest value for the benefit of all RMP customers by storing abundant low-cost power and utilizing it during more expensive peak times
- Effectively provide battery power to participants during power outages

This study also yielded many findings about solar and battery functions generally:

- Available energy from solar production varies greatly between seasons, with fall about twice as much as winter, and summer about three times as much as winter. This variation impacts battery recharge times throughout the year.
- Electrically heated homes will have shorter back up coverage in winter than homes heated with other fuels. The expected back up during an outage is about half the time during winter than all the other seasons.
- First-generation SWB Gen-1 batteries generally respond more quickly to frequency response signals when already in discharge mode. However, the newer SWB Gen-2 battery models provide frequency event response time in under 5 seconds in all operating modes.

Table 4. Frequency Regulation Response by Battery Vintage

Benefit	SWB Gen-1			SWB Gen-2		
	Discharge	Idle	Recharge	Discharge	Idle	Recharge
Frequency Regulation Services	Yes	No	No	Yes	Yes	Yes

Recommended Next Steps

Cadmus recommends that RMP revisit this analysis one year after the Soleil facility has reached full occupancy, as well as once the Wattsmart Batteries program has secured more participants. This additional data will allow a 3rd party to better distinguish the seasonal factors from solar output, battery performance, and loads that create differences in DBGMS capabilities.

Appendix A. Soleil Lofts Apartment Complex

Facility Specifications

RMP partnered with battery manufacturer sonnen and Auric Energy to deploy solar PV and battery storage across all units at the newly constructed 600-unit Soleil Lofts apartment complex in Herriman, UT. Each Soleil housing unit has a solar photovoltaic array and sonnen battery system. Residents of Soleil Lofts are renters, with the solar and storage simply included in rent. The battery systems have a storage capacity of 20 kWh and the inverters produce continuous output of up to 7.2 kW. The 600 Soleil Loft apartment units are linked through the DBGMS, creating an aggregate battery storage capacity of over 10 MWh with 4.8 MW of output potential. Each unit also includes a 5 - 8 kW solar array, for an aggregate solar capacity up to 5 MW. RMP has access to a DBGMS dashboard that allows them to schedule dispatches based on grid needs, initiate several automated operating scenarios it can assign, and specify how much battery capacity should be held in reserve in the event of a power outage.

Facility Operations

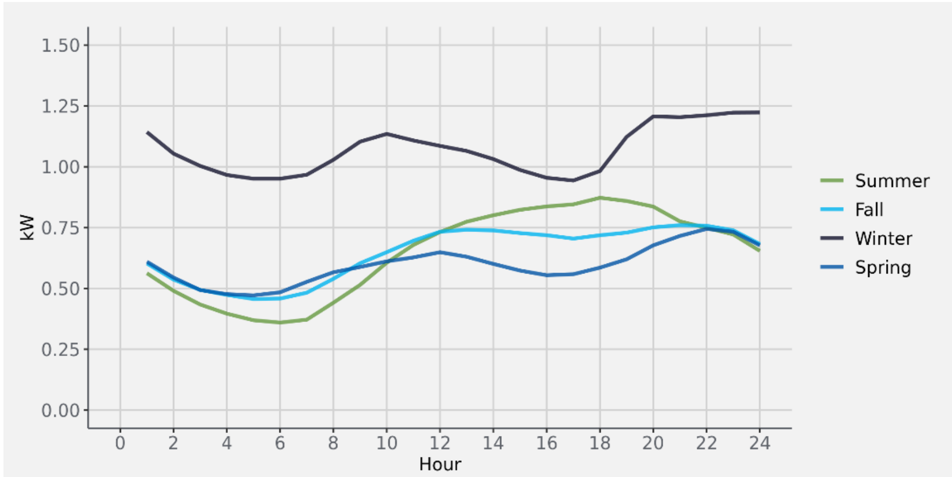
In the future, additional customers who enroll in the Wattsmart Batteries program will come from a mix of single-family homes and multi-unit dwellings. The Soleil Lofts apartment complex is a unique example of a comprehensive electric housing development. Some aspects of the unit operations are likely unique to this type of facility, but some of the lessons learned will be applicable to any residential housing unit with solar and storage. The following sections detail the seasonal variation in facility load and in solar production at the Soleil complex, along with a discussion of whether the load and solar production characteristics are unique to Soleil or can be more generally applied.

Facility Load

The Soleil Complex is a fully electrified facility, meaning that all units are designed for electric cooking, heating, cooling, and other home energy end uses. Figure 10 depicts the average 24-hour loadshape for a Soleil unit by season (note that weekend and weekdays did not show difference in consumption). Overall consumption is somewhat higher in the winter, likely due to greater heating load (which typically contributes to peak during morning [10 a.m.] and evening hours [8 p.m. to midnight] in winter months). There also appears to be a summer peak in consumption due to increased cooling loads during late afternoon and evening hours.

These customer loadshapes are likely somewhat unique to a fully electric multi-unit dwelling. A typical single-family house would likely exhibit greater seasonal and daily variation in consumption.

Figure 10. Per-Unit Average 24-Hour Soleil Loadshape by Season



Solar Production

Each unit in the Soleil Lofts apartment complex has a solar array. The average amount of daily solar production per unit by season is shown in Table 5. The annual average for daily solar production is 24.1 kWh. Daily solar production was greatest in the spring and summer months and the was smallest in the winter months. These seasonal differences in daily solar production can mainly be attributed to seasonal variations in climate. For instance, on average there is a greater proportion of cloud cover during the winter months, which can limit the amount of daily solar production. Furthermore, the duration of daily solar availability is much longer in the summer months than in the winter months, regardless of cloud cover. The variation in solar production and usage by season is shown in Table 5, and is illustrative of the relative level of production for other similar sized systems on other homes, but the actual values should not be assumed given the large range in potential differences in location and home characteristics.

Table 5. Average Daily Solar Production and Electricity Usage by Season

Season	Unit Count	Solar Production (kWh)	Daily Usage (kWh)	Hourly Usage (kWh)
Spring 2020	164	28.6	10	0.4
Summer 2020	253	34.2	16	0.7
Fall 2020	339	20.4	15.6	0.7
Winter 2021	430	10.4	26.1	1.1
Spring 2021	440	27.0	16.8	0.7
Average	-	**24.1***	18.6	0.8

* Annual average value includes summer 2020 to spring 2021.