Emerging Technologies

Pomona Mosaic Battery Control and Optimization: Final Report

DR.19.02

Prepared by:

Emerging Products
Customer Service
Southern California Edison

April 2022

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Acknowledgements

Southern California Edison's Emerging Products (EP) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technologies Program under internal project number 20010942. Nav Pillay conducted this technology evaluation with overall guidance and management from David Rivers and Mark Martinez. For more information on this project, contact navniel.n.pillay@sce.com.

This report was prepared by the Electric Power Research Institute for Southern California Edison (SCE) and funded by California utility customers under the auspices of the California Public Utilities Commission.

EXECUTIVE SUMMARY

Project Goal

This project was designed to conduct research related to the design, interconnection, installation, commissioning, system performance, customer objectives and grid impacts of the installed energy storage system and solar photovoltaic array at Mosaic Gardens at Pomona. The lessons learned and best practices were captured and delivered as knowledge transfer to key constituents within various departments in Southern California Edison. The primary objective of this project was to demonstrate how customer storage can be leveraged and to quantify impacts to both customers and grid stakeholders.

Technology Description

This project was conducted at an apartment complex operated by Linc Housing in Pomona, California. Linc Housing partnered with SCE for technical and funding assistance to take their building from LEED Platinum design to Zero Net Energy. The building is a three-story low-income residential development consisting of forty-six apartment units on an infill lot. The units vary in size from one to three bedrooms. Designed to the LEED Platinum standard, this development includes underground parking, community laundry, management offices, a community lounge with internet terminals, and a courtyard playground area. The targeted tenants are low-income qualified, with half the units designated for those who are identified as displaced or without shelter. The units are projected to reduce energy usage by as much as 1,350 kWh compared to a current unit built to code.

Energy storage was added to the site, with a rooftop photovoltaic solar system. The project pairs four battery energy storage systems totaling 60 kW with two solar arrays providing a total power capacity of 34 kW. Two 11.4 kW smart inverters connect with the batteries and the PV systems, while a third inverter operates in solar-only mode. The solar-plus-storage systems allow operation in a variety of modes to serve both customer and grid needs.

Project Findings

- Time-of-Use rates encouraging energy storage systems to discharge in the evening, combined with solar only charging, may leave energy storage systems without adequate capacity for backup during the evening hours.
- Incorrect placement of current transformers may create significant issues post installation, and can be prevented by standardized best practice material, as described in the project recommendation section, below.
- Installation of data monitoring prior to project installation provides historical data essential to some analyses.
- Full utilization of BESS requires planning at building design in ordering to avoid the need for complicated conduit and network connections that may be difficult to impossible.

- Effectively scaling efforts in multifamily contexts is made difficult by the complication of having a site that is a hybrid of residential and commercial
  - Combination of three-phase and single-phase systems
  - Mix of residential and commercial entities and incentives

Project Recommendations

- In multi-tenant buildings, electrical components and sub-panels are often spread out. Depending on distance and access to conduit, it may be difficult to backup a variety of loads as intended. Additionally, startup currents and 3-phase loads need to be investigated for backup potential.
- Product support is often limited for end users. Utilities may be able to provide helpful resources to their customers, including information on what modes of operation are of greatest benefit and why.
- Standardized requirement and best practice materials will assist the utility in ensuring successful installs and documentation are delivered. Consider providing installers with incentives to encourage success. Recommended materials include:
  - Description of parties responsible for documentation, and specific documentation required should be provided
  - Standardized hardware photos to be taken at installation site
  - On-site post-installation checklist
- Comprehensive and properly configured monitoring systems are critical to achieving optimal operation and reaching the full potential of any battery energy storage system
  - Standardized, automated monitoring techniques can find issues and report back on data and performance quickly
- Utilities may desire to use AMI data from pre- and post-installation to verify correct operation of energy storage units. For instance, analysis of AMI data would help determine when energy storage units are not being used for Time-of-Use Management and bill savings

ABBREVIATIONS AND ACRONYMS

AC	alternating current
BESS	battery energy storage system
BTM	behind the meter
CT	current transformer
DC	direct current
EPRI	Electric Power Research Institute
K&A	Kliewer and Associates
kW	kilowatt
kWh	kilowatt-hour
POC	point of common coupling
PTO	permission to operate
PV	photovoltaic
RTE	round-trip efficiency
SCE	Southern California Edison
SGIP	Self-Generation Investment Program
SLD	single line diagram
SOC	state of charge
TOU	Time-of-Use

CONTENTS

FIGURES

INTRODUCTION

EPRI's battery storage research and SCE's operational engineers and DSM technology demonstration teams have a strong history of collaboration and coordinated effort. This relationship provided a unique opportunity to further the understanding of how SCE can most effectively and efficiently incorporate battery energy storage technologies located behind the meter for grid reliability, new models of distributed energy resources, and additional customer savings benefits.

SCE's Emerging Markets and Technology (EM&T) research program identified the multi-family housing complex at Pomona Mosaic Garden as a key venue to test and validate function, operation, and value of battery energy storage in the context of photovoltaic (PV) solar and customer loads. This project sought to characterize customer values and grid impact qualities associated with behind-the-meter (BTM) customer-sited energy storage. The result of this effort was an analysis of the installation and use of energy storage, yielding a series of useful learnings and ultimately providing forward-looking recommendations. We intend for the learnings and recommendations produced through this collaboration to provide avenues for SCE to capture greater grid value from customer-sited energy storage assets, while also maximizing the customer value that incentivizes customers to install these systems.

BACKGROUND

Customer energy resource adoption trends are forecasted to increase substantially in the Southern California Edison (SCE) service territory in the coming years. Specifically, photovoltaic solar, electric vehicles, and battery energy storage will continue to add intermittent generation, new coincident load, and a potential solution to mitigate those impacts, respectively. Battery energy storage attachment rates to new PV solar deployments are approaching 60% in pockets of the SCE grid, and there is a demonstrated need to further define battery system impacts to customers and the grid. Battery energy storage applications installed at customer sites differ from other distributed energy resource options, such as distributed generation or energy efficiency. On the one hand, they are "limited energy" resources with a narrow band of dispatch and operation, and they are not yet distributed at wide scale. On the other hand, they are able to be dispatched to the benefit of the grid with little to no impact on a customer's lifestyle or business operations.

Under current energy and climate policy changes and reliability challenges, incentives in California and other areas are now paving the way for rapid storage adoption. SCE's research interests in customer-owned storage are emerging and broad, and as customers increase their adoption of solar-plus-storage systems at the multi-family level, SCE seeks to understand how these systems can:

- Create incremental grid value in locations with demonstrated needs, such as areas with reliability-related service interruptions or distribution circuits experiencing high loads.
- Create incremental customer value above the typical use case for PV-paired battery systems. Efforts may help to unlock additional customer value streams, such as increased customer satisfaction or incremental customer revenue streams from grid deferral.
- Provide "stacked value" benefit streams with solar plus storage and how those can impact customer perceptions, customer education, and awareness of the use and benefits of PV-paired battery systems for future models of DR programs.

This particular project incorporates four 15 kWh battery energy storage systems totaling 60 kW with two solar arrays having a total power capacity of 34 kW AC. Three smart inverters, each capable of outputting 11.4 kW AC, are installed at the site. The solar and storage systems are DC-coupled, with two of the three inverters each connected to two of the four battery cabinets. Two monitoring systems provided data collection for the project. See Figure 1 for a high-level view of the installation. One inverter is a solar-only inverter operated consistently in Grid Tie mode. The battery inverters are able to operate in many more modes, including—but not limited to—Priority and Clean Backup, Self-Supply, and Time-of-Use modes.

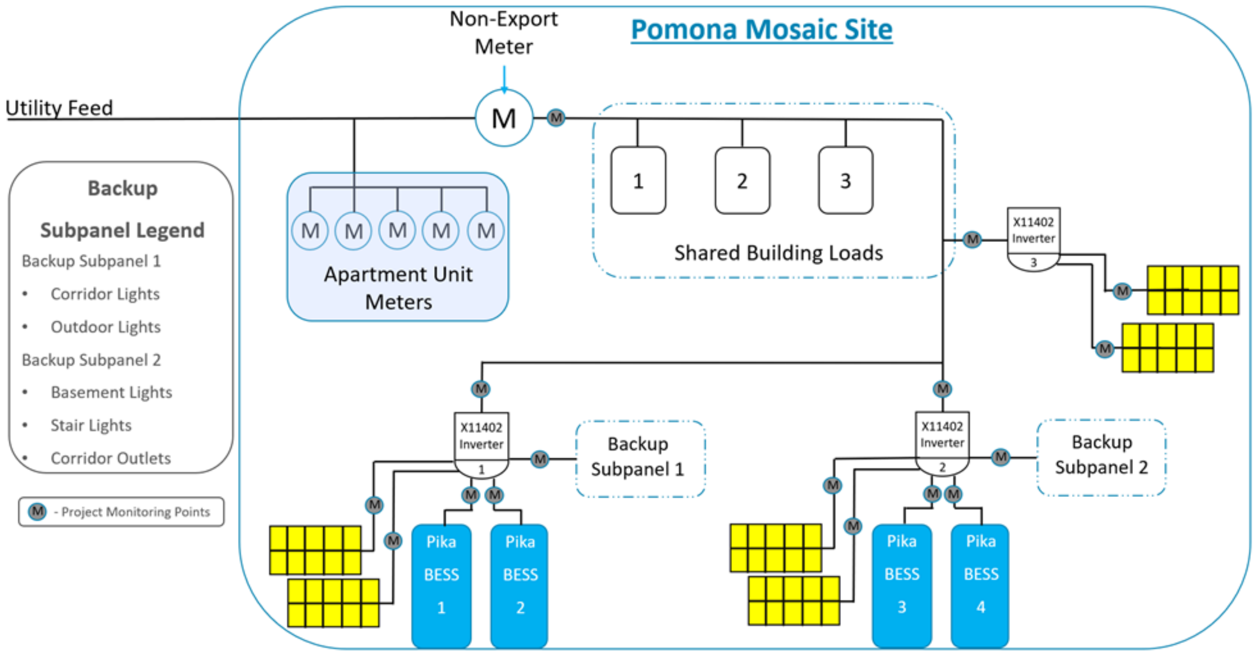


FIGURE 1. HIGH-LEVEL OVERVIEW OF INSTALLATION

Certain operating modes, particularly those for backup power, allow for the powering of essential-loads panels during grid outages. The system topography also allows circuits on the essential-loads panels to be powered from solar PV and/or battery energy storage without needing to have power routed through the building's main AC bus.

ASSESSMENT OBJECTIVES

This project was executed in multiple phases. Phase 1 concluded with the completion of battery and solar interconnection. Phase II concluded with design validation, ensuring interconnection was completed as intended, while reporting and fixing any issues that would result in operational or data collection issues. Finally, Phase III executed test plans, resulting in data used to characterize the Pika energy storage system as well as its impact on the customer and the utility.

The research associated with this project addressed the following topics and concerns:

- Interconnection: providing lessons learned and best practices.
- Design: validation of as-built design.
- Installation & design support related to backup loads.
- Characterization of battery modules under operation.
- Control Strategy: understanding the objectives of the parties involved—grid services needs and customer requirements—and observing how certain control modes may focus on achieving one party's objectives or serve both simultaneously.
- System Performance: evaluation of efficacy of energy storage systems and software with respect to:
    - Control and communication, both local and remote
    - Grid services and tariff compliance
    - Customer uses and applications
- Economic Analysis: characterization of customer economics and grid benefits associated with this system, and similar optimized systems, based on specific control strategies
- Technology/Knowledge Transfer: providing lessons learned, best practices, and economic and technical data to various groups within SCE. The above tasks are expected to assist the general public by contributing to more rapid interconnection of battery energy storage systems (BESS) in the future. This work also provides further information on control strategies and system performance, which may improve renewable integration costs.

TECHNOLOGY/PRODUCT EVALUATION

In this instance, the technology had been pre-selected by SCE for this application.

SYSTEM DESIGN

PRODUCT SOURCING, INSTALLATION, AND SUPPORT

The community solar-plus-storage system was installed by Promise Energy, with interconnection assistance and analysis provided by Kliewer and Associates and EPRI's customer-sited energy storage team. The lithium-ion battery was initially provided by Pika Energy. Since then, Pika Energy has been acquired by Generac; the new parent company helps manage, maintain, and service all previous product installations. Appendix A provides detailed design documentation.

Data collection was performed using two primary monitoring systems: the PWRview dashboard provided by Generac and the eGauge energy monitoring platform provided by naak. Together, these monitoring systems measure and log values such as AC and DC voltage, current, power, temperature, state of charge, production, and system status. This data was critical for the testing, evaluation, and analysis of the solar plus storage system and the novel control strategies to operate these assets in ways that serve the needs and safety of both the customer and the grid.

CONFIGURATION

The system consists of three X11402 Smart Inverters, each capable of outputting 11.4 kW, and four Harbor Smart battery cabinets, each with 15 kWh energy capacity, for a total of 60 kWh. The rooftop solar PV system rests at an angle on the building's flat white roof and faces south. The total power capacity of the solar PV arrays is 33.66 kW DC and 34.20 kW AC.

The solar and storage systems are DC-coupled, with two of the three inverters each connected to two of the four battery cabinets. The third inverter is a solar-only inverter and operates consistently in Grid Tie mode. The battery inverters are able to function in more operating modes, including—but not limited to—Priority and Clean Backup, Self-Supply, and Time-of-Use mode.

CONTROL MODES

Control modes tested include Zero Export, Time-of-Use, Self-Supply, Clean Backup and Priority Backup. Certain modes, particularly the backup power modes, allow for the powering of essential-loads panels during grid outages. The system topography also allows circuits on the essential-loads panels to be powered from solar PV and/or battery energy storage without needing to have power routed through the building's main AC bus.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

TEST PLAN

OVERVIEW

The test plan was designed to demonstrate and validate various modes of operation for the installed Pika Battery Energy Storage System (BESS), and to provide performance test results for characterization of BESS qualities such as round-trip efficiency and battery degradation. Appendix B provides step-by-step test plan details.

TIME-OF-USE OPERATION

Setting up the Time-of-Use (TOU) operating mode requires prior communication with Generac and an understanding of the community's utility rate and tariff. Generac controls use Rebus beacons installed at the inverter to switch remotely between operating modes, such as Self-Supply and Clean Backup during on-peak (or mid-peak) and while accounting for off-peak prices and times. Generac curates a selection of TOU schedules that they support, which can be chosen for one's system. Many of these schedules are specifically aligned to particular utilities throughout the country, but others are generic schedules that can be used in various service territories and contexts. Although this implies that Generac is able to create many different, custom schedules to suit the unique and varied requirements of various utilities, service territories, and applications, such custom schedules cannot be created by end users. If an end user desires a specific schedule different from those available from Generac's curated selection, they could request it from Generac, but the final decision on whether to produce such a schedule would be by the manufacturer or technology provider rather than the end user or customer. For this project, a standard schedule approved and provided by Generac was used.

Description of TOU Test

The Generac PWRcell battery at Linc Housing's Mosaic Gardens at Pomona was set to Schedule #29. This generic selection schedules the energy storage system differently on weekdays and weekends. On Saturdays and Sundays, the system remains in Clean Backup, presumably because different on-peak and off-peak pricing periods do not normally occur during weekends.

On weekdays, Monday through Friday, the energy storage system is set to begin the day in Clean Backup operating mode. Then at 4 pm, it should transition to Self-Supply mode. At 8 pm, the system sets to Sell mode, which will discharge the battery until its state of charge (SOC) reserve limit, which is set at 30% by default. This SOC reserve limit can be adjusted in the inverter settings from the inverter LCD screen. Finally, at 9 pm, the system returns to Clean Backup mode. Presumably, this operating sequence assumes a peak Time-of-Use window from 4 pm to 9 pm. When, at 9 pm, the battery returns to Clean Backup mode, it would be able to charge only from solar PV generation. Given that solar PV is unlikely to be producing at this time, this means that the battery is unlikely to be able to provide significant backup power during the evening hours, as its SOC would be limited to the 30% reserve limit, and significant solar generation will not occur after 9 pm. Allowing the energy storage system to charge from the grid, or increasing the SOC reserve would allow the system to provide greater backup power capabilities over the evening hours, after being discharged during the Time-of-Use period. Such adjustments are possible with an energy storage system, but that was not part of the procedures in this case.

Expected TOU Results

On weekdays, the system is expected to charge up during the morning hours, starting around when the PV begins to generate. Assuming a typical, sunny Southern California day, the 60 kWh battery connected to an inverter rated for a maximum charge power at around 20 kW should be able to charge the battery system in approximately 4 hours, starting from first sunlight (this accounts for the ramp-up of solar generation in the morning hours). The actual system topology of the site is two sets of 11.4 kW rated battery-connected inverters that are each connected to two 15 kWh battery cabinets, though the simplified, high-level configuration and calculation holds. With the battery system fully charged at that time, any remaining rooftop generation produced would be used to power other community loads. The battery would remain fully charged throughout the afternoon until 4 pm, when the TOU schedule shifts the system into the Self-Supply operating mode. The means that the battery will discharge in a way that makes up for whatever building load is not covered by solar PV generation during those hours. Because the sun is not completely set at 4 pm, the battery would not initially discharge at a high power or current level, but as the sun continues to set, the battery will proceed to discharge at a higher rate and power, following the net building load, up to its maximum output current rating. At 8 pm, any energy left in the battery above its SOC reserve limit will be discharged for an hour at the battery’s maximum discharge rate, which will likely be reached by the end of the hour. Finally, at 9 pm, the battery will hold at its SOC reserve limit throughout the night until the following morning, when it begins to be charge from solar PV again, and the cycle continues.

During weekends, the Clean Backup operating mode will have the battery recharge from solar PV production. The battery will remain at full charge throughout the duration of the weekend unless a utility outage occurs. Of course, throughout the course of the weekend, some energy will be lost in the form of self-discharge losses, which should be relatively small, but nonetheless measurable.

Self-Supply Operation

The Self-Supply operating mode is the Generac PWRcell’s solar self-consumption and load following mode. Solar self-consumption endeavors that every unit of energy generated by solar PV is used to power on-site loads, rather than being sent to the grid. This means that any energy stored and charged into a storage system originating from solar will ultimately be used to power an on-site load. A key point of solar self-consumption is that, unless the battery has reached its charging capacity, no solar energy will be delivered to the grid; every unit of energy must be consumed on-premises to achieve complete solar self-consumption.

This mode can be particularly useful to customers when the utility compensates customers at less than the retail rate when solar energy is exported to the grid.

Description of Self-Supply Test

Proper operation in Self-Supply mode is contingent on having properly calibrated system current transformers (CTs) that are carefully measuring the state of not only the energy storage system but also the power flows throughout the local network of inverters, disconnects, and load panels. This mode does not differentiate between weekdays and weekends. The battery system is set to discharge when solar PV power is less than the building or backup load demand and the batteries are above the SOC reserve limit. Otherwise, if the batteries are already at their SOC reserve limit, grid power will be used to power the backup load panel demand and the rest of building load.

On the other hand, if solar PV production is greater than the building load or load demanded by the backup load panels and the batteries are less than fully charged, then excess solar will be used to charge the battery to its maximum SOC limit (generally 100%).

Expected Self-Supply Results

In this mode, the battery will discharge to minimize the amount of load demanded by the building from the grid by prioritizing powering local loads using solar and/or stored power first. Moreover, the battery will only charge from energy generated by rooftop solar PV production. Because this mode does not differentiate between weekend days and weekdays and has no dedicated discharge sequence scheduled, this mode is the most dynamic and reactive to the actual load and demands of the building. Daily cycling of the batteries from full charge to SOC reserve limit is expected.

Clean Backup Mode

In Clean Backup mode, islanding inverters prioritize keeping batteries charged and ready for grid interruption, using only solar power. If the battery is not fully charged, the battery inverters will use all available solar power to charge the battery. Grid power will not be used to charge batteries in this mode. When the batteries are fully charged, solar power is exported to the AC terminals of the inverter, providing power to the building and potentially the grid. When grid service is interrupted, the system will immediately enter Islanding Mode, powering protected loads with solar and battery power together. If there is enough solar power available, the solar will simultaneously charge the battery and support the loads.

Description of Clean Backup Test

In Clean Backup mode, the battery will only discharge in the event of a grid outage, to support loads connected to the inverter via the backup loads panel. This panel is sometimes referred to as the essential-loads panel or critical-loads panel, though the exact use and definitions of these nomenclatures differ across the industry. The battery may also discharge slightly due to battery self-discharge losses, which occurs over the course of many days. All battery charging is from green, renewable energy sources, which in this case is rooftop solar PV, hence the operating mode itself is referred to as clean.

Expected Clean Backup Results

Because outages are rather rare on the modern utility distribution grid, a battery energy storage system is unlikely to experience much cycling while on Clean Backup. Every so often, the system will recharge during the day via solar power due to SOC dips caused by the batteries' self-discharge losses, but this would only occur once or twice a week, and for a very short time, as the system would recharge the batteries before their SOC dips below 90%.

Priority Backup Operation

Priority Backup is similar to Clean Backup, but does not rely exclusively on renewable generation for battery charging and backup. In priority backup, islanding inverters prioritize keeping batteries charged and ready for grid interruption, using solar power or grid power. Batteries charge using solar power as it is available and take additional power from the grid to expedite battery recharging as quickly as possible. In the event of a grid failure, the inverter will enter Islanding Mode. Protected loads are supported by solar and battery power. If there is enough solar power available, the solar will simultaneously charge the battery and support the loads.

Description of Priority Backup Test

Due the Priority Backup mode commanding the batteries to charge at maximum power from solar PV generation and grid power, testing on this operating was rather limited. SCE specifically requested a non-import constraint, but extensive testing during times with little or no sunlight would cause the energy storage system to import power from the grid.

Expected Priority Backup Results

For the most part, this mode should operate very similarly to the clean backup operating mode, with the only difference being that the battery would charge immediately from the combination of solar PV and grid power rather than just the former. This would mean, in standard, grid-connect condition, the battery would be fully charged in the least amount of time possible. After being fully charged, priority and clean backup modes would be identical, in that the energy storage system will not discharge unless put into a backup or resilience state, generally caused by a grid outage or disconnect event.

Zero Export and Non-Export

This mode is designed for markets where solar PV systems are prohibited from back-feeding the AC grid. With Zero Export enabled, the inverter will not send excess solar power to the grid. Instead, the system will limit solar power generation such that it exactly matches the power consumed by local loads, resulting in no exported power. Current transformers are required for this mode.

Description of Zero/Non-Export Test

No direct or explicit test is required to evaluate the efficacy and operation of the Zero Export and Non-Import constraints, because these operating rules should always be active through inverter controls and commands. The Mosaic Gardens at Pomona system received custom firmware updates and controls to fulfill these operating rules and constraints in order to obtain approval and permission to operate (PTO). The need for these special firmware controls and constraints delayed the interconnection and PTO of the system for several months. That is because a test plan had to be developed, approved, and executed to demonstrate the efficacy of these firmware controls.

Expected Zero/Non-Export Results

The operating constraints of zero export and non-import are relatively common for interconnected energy storage systems, particularly in industry-leading utilities that have begun to research, deploy, document, and implement programs for emerging technologies and solutions. Energy storage companies are generally able to adjust to the dynamic requirements of different utility service territories and their interconnection rules and agreements. As such, this and other storage systems are expected to operate as intended and in accordance with these constraints.

Compensation for Disconnected Inverter

While not a specific and settable operating mode, the size and configuration of this battery energy storage system is unique in that it has multiple inverters that are connected, communicating, and sharing information about the site and each other's status. As such, this system has the ability to compensate and to continue to reliably operate even in the event that one (or multiple) inverters are disconnected or otherwise become inoperable.

Description of Disconnected-Inverter Test

This unplanned test occurred during the late summer of 2021, while the battery inverters had been operating under a TOU operating mode schedule. When one of the battery inverters was disabled, the other battery inverter compensated to the extent possible to achieve proper TOU operations.

Expected Disconnected-Inverter Results

Because the remaining battery inverter is not directly connected to the disabled inverter's pair of battery cabinets, the remaining inverter is not expected to charge, discharge, or otherwise control those pair of batteries. However, the backup-loads panels of the disconnected inverter still need to be supported via the grid, so the remaining inverter should still be able to supply power to the backup loads panels. Thus, the pair of batteries on the remaining inverter should also supply power to a greater amount of load (its own backup loads panel and its sister inverter's) and should discharge faster, i.e., at a higher rate.

Instrumentation Plan

Instrumentation for these tests consisted of utility meters in place, measurements provided by the Generac Pika CT and naak eGauges. See Appendix B for respective wiring diagrams and the sensors used in the detailed test plan.

The inherent monitoring system is provided by Generac to report data directly to the PWRview and PWRfleet dashboards, viewable online via an internet browser or mobile device application. This monitoring system records and report the amount of solar power generated by the PV Links, which are generally associated with each string of solar PV panels, overall solar production, battery charge and discharge, state of charge, grid power and consumption, inverter input and output power, temperature, control modes, and terminal voltages. However, not all of this data is immediately viewable from the dashboards; some can only be analyzed with data provided directly from the Generac technical team. This data is likely also available through the inverters' Modbus registers and addresses, though the Modbus address and register maps for the equipment has yet to be published. There is no indication that this will happen in the near future, and attempting to access this data might constitute voiding any active warranty with the manufacturer.

In additional to the built-in monitoring system, other third-party, external monitoring was installed as the naak monitoring platform with eGauge. This monitoring system sought to capture DC bus voltage data, DC currents for individual battery and solar terminals, solar production, backup loads panel consumption, and inverter output and input power. This data is viewable online and can be downloaded for further recording and analysis. However, this system must be precisely set up and configured in order for the data to have significant utility.

RESULTS

TIME-OF-USE OPERATION

The system was placed in TOU mode for the majority of the 2021 calendar year, and remains in this mode at the time of this writing. The data and results show that the system, for the most part, operated as expected. However, the system and TOU mode did not initially perform correctly. Only after additional troubleshooting with the manufacturer, product provider, and electrician installers was the system able to work as intended. Figure 2 shows an average TOU operation day.

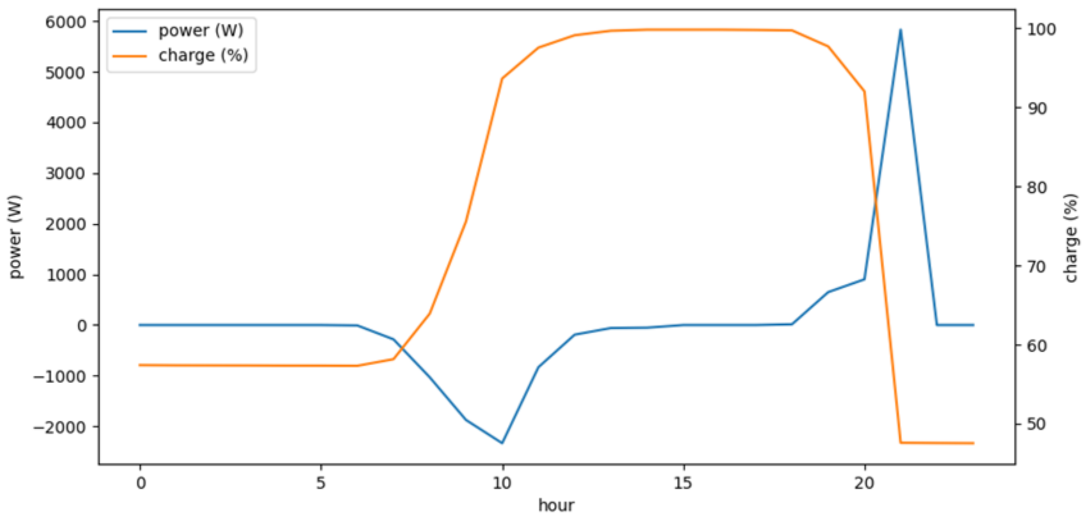


FIGURE 2. POWER AND SOC DURING AN AVERAGE DAY OF TOU OPERATION

Because the battery is in Clean Backup for 19 hours of the day and only takes about 4 hours to charge from solar, the batteries are idle for 15+ hours of the day. Even after Self-Supply is activated, the battery will not immediately discharge when solar PV is producing enough power to serve the building load.

After the sun sets, Self-Supply mode directs the batteries to discharge to match the demand of the home/facility based on measurements from system CTs. In the final hour, the batteries enter Sell mode and attempt to discharge at full capacity. Batteries reenter Clean Backup at the end of the Time-of-Use window.

SELF-SUPPLY OPERATION

The battery energy storage system was placed in Self-Supply for over a month in 2021. The data and results showed that the system did operate as expected. It is important to note, that due to placement of the CTs, the battery energy storage system was tracking and responding to the loads on the backup-loads panels, rather than the entire building load. Figure 3 shows an average day's operation under Self-Supply.

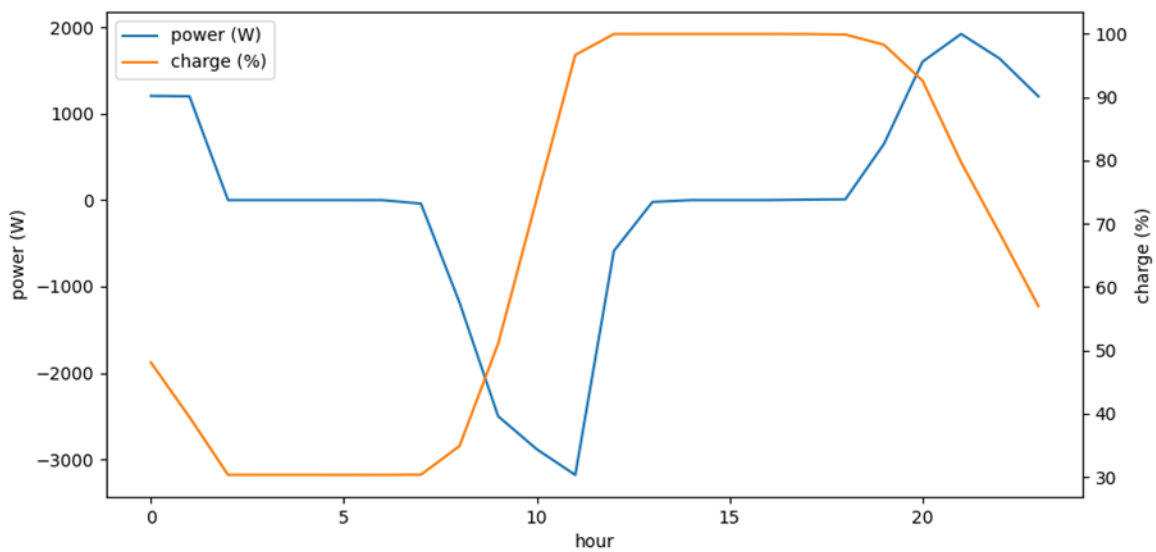


FIGURE 3. POWER AND SOC DURING AN AVERAGE DAY OF SELF-SUPPLY OPERATION

During daylight hours, the batteries are charged by excess solar generation in the morning and then remain idle at 100% SOC until evening hours. As the sun begins to set, the battery begins to discharge to support the loads of the building that can no longer be supplied exclusively from solar PV

After the sun sets, Self-Supply mode directs the batteries to discharge to match demand, based on measurements from system CTs. This load-following discharge continues until the batteries reach their SOC reserve limit in the middle of the night.

Only a subset of the building's loads is being properly tracked with the system CTs. This means during the on-peak period, some amount of demand that could be supported by the batteries is not supported, because of the CT configuration.

CLEAN BACKUP OPERATION

The batteries in this energy storage system spent the majority of 2020 in the Clean Backup mode. The data and results show that the battery energy storage system operated as expected while in Clean Backup mode. However, not much backup was required, and the depth of discharge in each cycle is very shallow. The battery is charged up to 100% SOC from solar PV generation from time to time, whenever the self-discharge losses of the system cause the battery to lose a few percentage points of SOC. Moreover, the batteries are not used to support any load, and because they spend most of their time fully charged, they cannot be used to store any access solar. However, this building appears to have enough community loads to prevent excess solar from going back to the grid, as the generated solar PV power would be used up by loads on the other side of the battery and solar inverters, but before the utility meter.

PRIORITY BACKUP OPERATION

Priority Backup operating mode was shown to be largely identical to Clean Backup mode, with the exception that the battery charging is not dependent on solar, and thus charging occurs as soon as possible, as fast as possible, even during the evening. Due to the non-import constraints of this particular installation, testing was conducted during the day, so the system still charged from solar PV power.

ZERO EXPORT AND NON-IMPORT

The data and results from the meter and measurement equipment show that the battery never charges directly from grid and only charges from rooftop solar PV production, the batteries never discharge directly to grid and past the community's SCE utility meter, and any energy discharged from the battery is consumed by building loads.

COMPENSATION FOR DISCONNECTED INVERTER

The battery energy storage system operated as expected while compensating for the disconnected inverter. (See Figure 4.) Unfortunately, the batteries connected to the offline inverters are unable to contribute at all. Still, the unified configuration of the system allows the other pair of batteries to recognize the need to compensate for addition load not being serviced on the disconnected inverters on the backup load panel. As a result, the still-connected batteries discharge at a higher rate and reach lower SOC in less time.

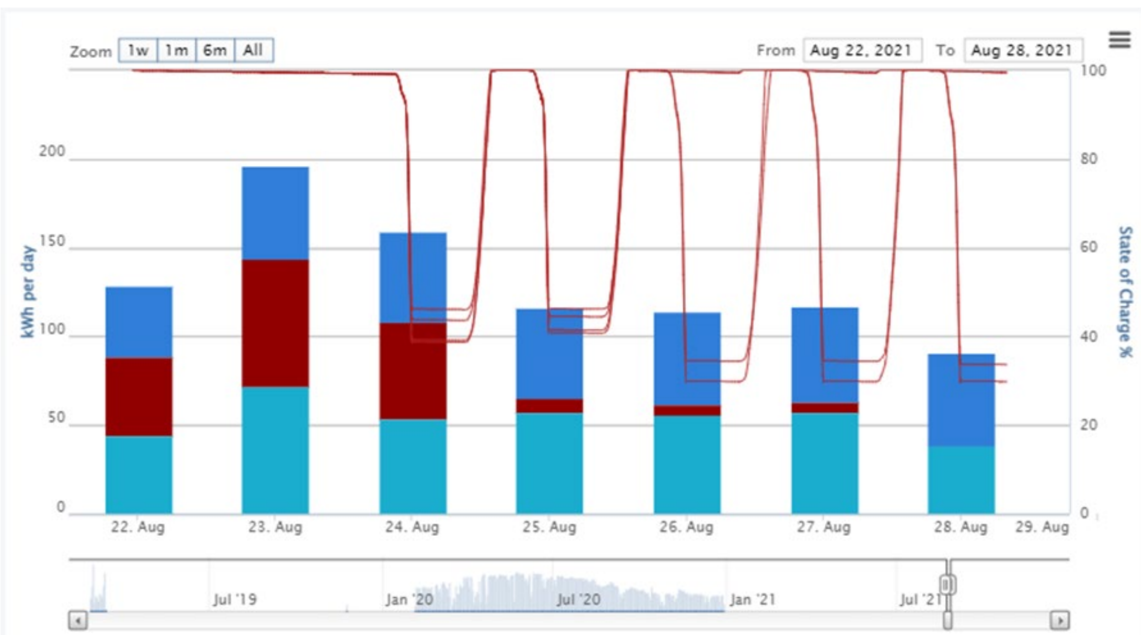


FIGURE 4. CONNECTED INVERTER BATTERIES COMPENSATE FOR DISCONNECTED INVERTER BATTERIES

DISCUSSION

OBSERVATIONS FROM OPERATIONAL TESTING

In *Time-of-Use operation* in typical residential installations, all home/building loads will be tracked by system CTs. This allows greater utilization of stored energy from batteries, while minimizing the impact of those loads on the grid. Larger shared housing facilities can make installation more complex, and not all loads may be monitored by the batteries' CTs. If this is the case, it is possible that neither the building nor the grid experiences the full benefit of the system.

In *Self-Supply operation*, having all building loads tracked by system CTs will allow greater utilization of stored energy from batteries and minimize the amount of power needed required from the grid. Regular discharges to batteries' SOC reserve also allows for greater utilization of the battery. More economic value is realized when batteries discharge during on-peak periods as much as possible.

Self-Supply mode is likely to be beneficial to the grid because it helps to mitigate and flatten peaks in demand by tracking and matching customer loads. Self-Supply is most beneficial to customers for whom PV export is compensated at less than the retail price of electricity.

For a broad-based discussion of TOU and Self-Supply control algorithms, and their potential consequences for customers and grid operators, please see the section below, Control Algorithms for Time-of-Use and Self-Supply.

Battery energy storage systems that remain in *Clean Backup* operating mode present a distributed energy resource with minimal positive or negative impact to the grid. This is primarily because in Clean Backup, the charging is done through solar PV production, so grid power is not used. Moreover, the batteries do not discharge unless a grid outage or disconnect occurs. Thus, the system spends most of its time fully charged and idle. The battery does not mitigate load customer load.

Many of the impacts of the *Priority Backup* operating mode are the same as for Clean Backup, with the exception being the ability of this operating mode to charge from the grid as well as solar PV. If many battery owners and operators are active in this mode, an issue might occur immediately following a grid outage. Having many systems charging as soon as possible after an outage could be a challenge to the grid.

The ability for a battery energy storage system software to implement important interconnection constraints, as in *zero-export/non-import operation*, is beneficial for utilities and the scalable growth of the energy storage industry in general. Allowing these and other interconnection constraints and rules to be tested remotely, rather than having to affirm compliance via in-person inspections and tests, may benefit the industry financially over time.

Testing the capability for *Compensation for Disconnected Inverters* showed that inverters of the same installation are able to adapt and adjust to errors and disconnects of the battery energy storage system as a whole. This is a positive sign for the flexibility and extensibility of this emerging technology. If hardware devices and other energy-related equipment can identify when another piece of equipment is inoperable, notification of such an event could potentially be relayed to utilities or other battery operators and entities in order to make any necessary adjustments to upcoming schedules or dispatches. This will be especially important if and when battery energy storage systems become relied upon to provide critical power and energy services to local loads and even to other nearby buildings and customers.

OBSERVATIONS FROM SYSTEM COMMISSIONING

Having a vendor-provided commissioning test plan is highly valuable in verifying the proper operation of the system especially during on-site testing. However, on-site testing, though thorough and beneficial, is a time-consuming process and does not scale well. The development of remote-control capability and a properly monitored and metered system could make way for an automated testing and commissioning verification process. For this to happen, a clear commissioning process and recommendations must be developed and clearly communicated to technology providers and installers.

During the installation, commissioning, or site visits, proper photo documentation should be developed addressing all system components and should clearly show how equipment is connected and working together, if possible. The accuracy of documentation should also extend to diagrams and technical drawings, which need to be updated and sent to site managers and relevant parties for quick access and reference. The importance of up-to-date and easily accessible documentation cannot be overstressed, as these aid every party in accuracy and clarity of communication, which then speeds up correspondence and task execution.

Lastly, where possible, utility resources should be leveraged to further validate and accurately monitor the proper operation of the system. This means using utility AMI meters and their data to track and monitor system performance and operation. To do this, enough meter heads need to be installed for the utility to get a clear and comprehensive dataset on the site. In Mosaic Gardens at Pomona, a number of meter head sockets were installed, but few, if any, of the sockets had meters installed in them. The importance of the data validation and monitoring battery and inverter operation should be evaluated. Subsequently, resources should be allocated accordingly.

BACKUP LOAD EVALUATION

OVERVIEW

Mosaic Gardens at Pomona is multi-family apartment complex with a wide variety of community loads. Lights and outlets in hallways and stairways, and the garage, exterior lights and outlets, data and communication closets, and elevator loads represent a significant portion of these loads. Further, the complex's community center includes common rooms, offices, lights, outlets, computers, televisions, space conditioning, a security closet, and a refrigerator. Adjacent to the community center is the laundry room, where washers and dryers also contribute to overall community loads. For the complex owner, Linc Housing, these loads represent significant operating costs.

The DC-coupled solar-plus-storage system installed and commissioned at this apartment complex features the capability of providing backup power to essential community loads in the event of a grid outage. (See Appendix C for a detailed system commissioning report.) Using energy from the battery and solar PV system, rooftop inverters can produce a 120 V / 240 V, single- / split-phase AC voltage source, effectively forming a grid to supply power to essential-loads backup panels connected to the inverter.

Two of the three inverters are equipped with both energy storage and solar PV systems that can supply and store power on-site in the event of a grid outage. The Pika Islanding Inverter X11402 (also known as the Generac Model APKE00013), coupled with the Pika Harbor Smart Battery SB15P (also known as the Generac PWRcell 15) and solar PV panels, are a critical portion of the hardware required to enable backup power.

Just as critical is the selection of essential loads to be supported by the backup power system. In general, lighting, outlets, refrigerators, and freezers are the primary loads targeted for backup, followed by security and communication systems, provided that none of these loads are particularly energy intensive. Circuits with historically large load draws, such as space conditioners, motors, heating, and cooking appliances, are often bypassed due to large startup loads that may exceed the power capacity of a particular battery or due to the significant energy draw associated with these loads that may quickly drain a battery of its stored energy. Of course, it is ultimately an end-user's usage profile that determines the length of time that any backup power system or islanded site can remain operational before requiring a grid- or solar-sourced recharge.

CONFIGURATION

Providing backup power to the loads based at the community center would be ideal. However, due to the physical layout of the electrical system, it is prohibitively difficult to realize this technically and practically. The primary issue is the vertical separation of key system component across multiple levels in the building.

Batteries and the solar disconnect are located in the basement (see Figure 5), along with community load hallway lighting, exterior lighting, garage gate motor, service receptacles, sump pumps, etc. Community center loads for the common room, including lights, computers, televisions, communications and security closets, space conditioning, and the common kitchen area, are located in panels on the first floor beside the washers and dryers. The smart inverters and solar PV are on the roof.

FIGURE 5. ESSENTIAL LOADS BACKUP PANEL (LEFT) AND PIKA HARBOR SMART BATTERIES (RIGHT)

Panels and loads being backed up by the DC-coupled battery and solar system must have a way to connect their circuits to the inverters on the roof of the apartment complex. Conduit piping electrically connects power and data for resources on the roof to those in the basement.

However, with the exception of the electrical connections run through the walls during initial construction, no such connecting conduit exists between the community panels on the first floor (see Figure 6) with those in the basement or those on the roof. Creating a connection would require boring through a foot of concrete to provide passage for electrical wiring and conduit between the first floor and basement. This separation from the inverters means that the community load in the community center cannot be directly powered by the inverter's backup load panel and connection.

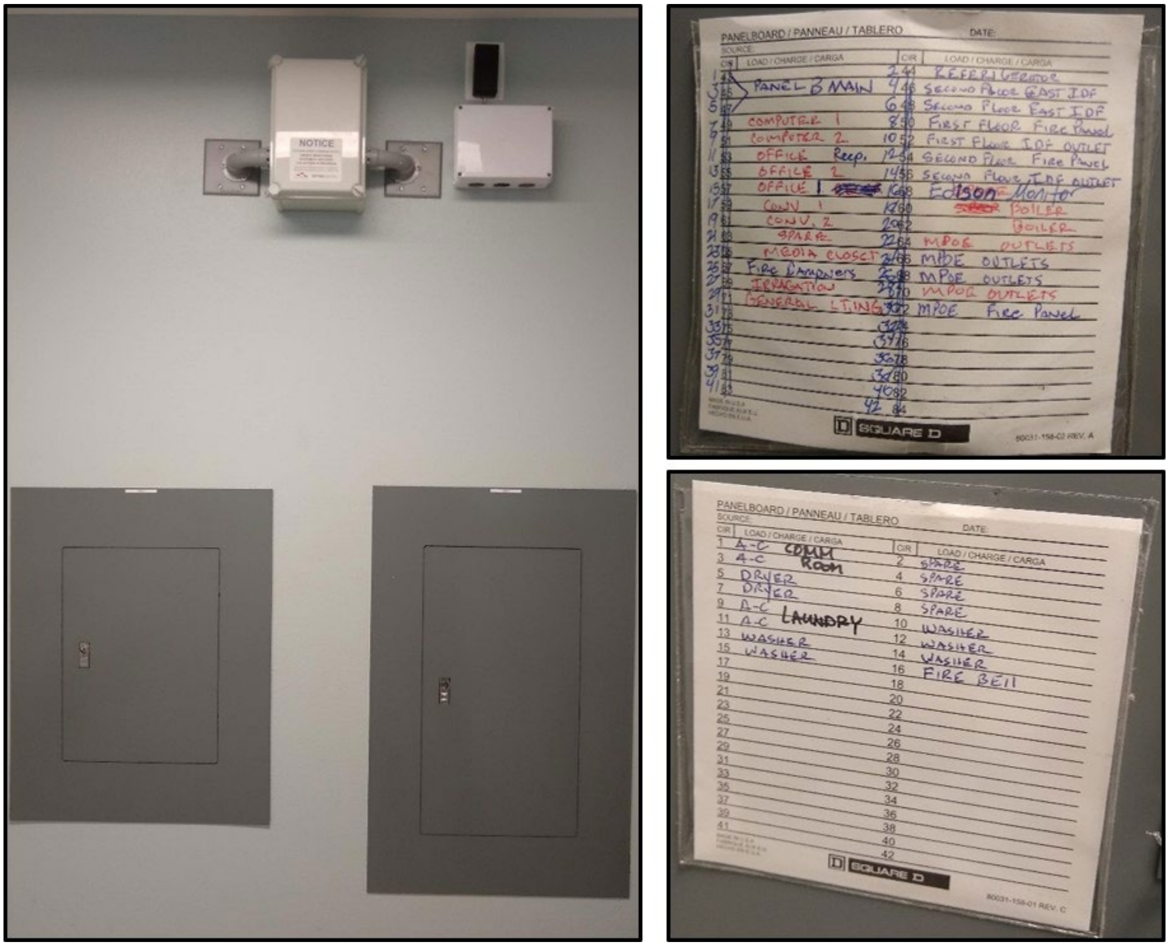


FIGURE 6. COMMUNITY PANELS LOCATED ON THE FIRST FLOOR

SITUATION

Due to this physical limitation and logistical difficulty, only the community loads present in the basement panel could be reconfigured for backup power on the inverter essential-loads panels.

The community basement electric load panel primarily hosts circuits related to hallway and exterior lighting, hallway and exterior plug outlets, garage door motors, and sump pumps for water pumping. (See Figure 7.)

Motorized loads can present issues for backup, due to potentially high startup currents. In discussions with Generac, who acquired Pika in 2019, EPRI and K&A teams determined that the inclusion of high-current startup, inductive motor loads on the backup panel would likely not negatively impact the inverter and battery systems. The short-duration, high-current spikes that would be experienced during motor start up would be manageable and within the operating capabilities of the inverter and batteries.

The possibility of high startup currents is not the only barrier encountered. At this site, there was particular interest in the potential to provide backup power to the garage gate motor, because that gate serves as the single entry and exit point for vehicles to the complex’s underground garage.

Backing up this load would allow tenants to move in and out the garage without losing the security provided by the gate. However, the garage gate motor is a three-phase load and is unable to be backed up by the Pika / Generac system, because the inverters provide only a single-phase / split-phase 120 V / 240 V AC voltage source when islanded from the grid.

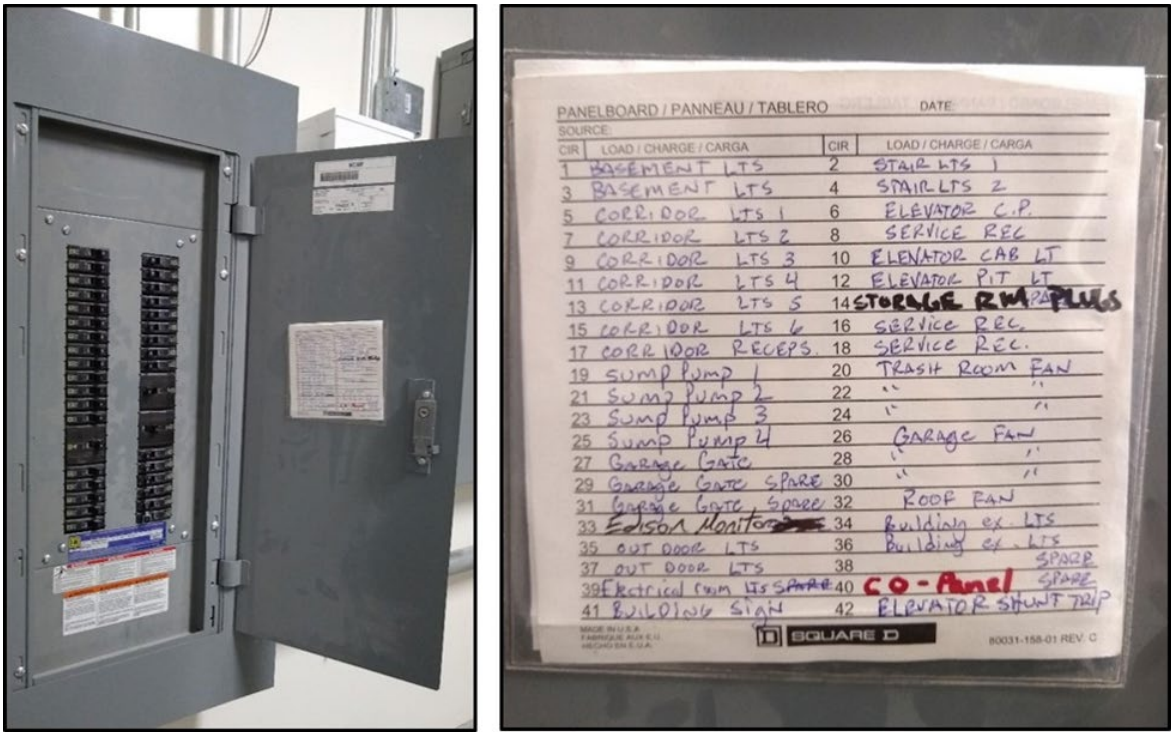
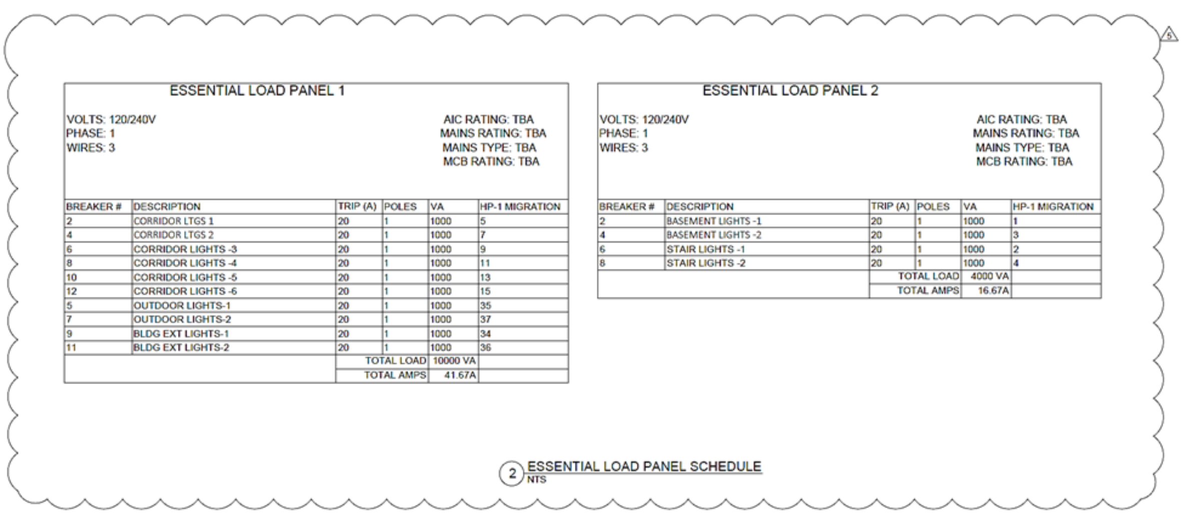


FIGURE 7. BASEMENT PANEL

After these discussions, and recognizing that the garage gate motor load could not be served, the project team decided to move only the primarily resistive loads to the inverters' essential loads backup panels. (See Figure 8.) Hallway and stairway lighting loads were placed on the backup power panels, while pumps and door motors were omitted and remain on the original basement load panel.



ESSENTIAL LOAD PANEL 1

VOLTS: 120/240V
PHASE: 1
WIRES: 3

AIC RATING: TBA
MAINS RATING: TBA
MAINS TYPE: TBA
MCB RATING: TBA

BREAKER #	DESCRIPTION	TRIP (A)	POLES	VA	HP-1 MIGRATION
2	CORRIDOR LTGS 1	20	1	1000	5
4	CORRIDOR LTGS 2	20	1	1000	7
6	CORRIDOR LIGHTS -3	20	1	1000	9
8	CORRIDOR LIGHTS -4	20	1	1000	11
10	CORRIDOR LIGHTS -5	20	1	1000	13
12	CORRIDOR LIGHTS -6	20	1	1000	15
5	OUTDOOR LIGHTS-1	20	1	1000	35
7	OUTDOOR LIGHTS-2	20	1	1000	37
9	BLDG EXT LIGHTS-1	20	1	1000	34
11	BLDG EXT LIGHTS-2	20	1	1000	36
		TOTAL LOAD		10000 VA	
		TOTAL AMPS		41.67A	

ESSENTIAL LOAD PANEL 2

VOLTS: 120/240V
PHASE: 1
WIRES: 3

AIC RATING: TBA
MAINS RATING: TBA
MAINS TYPE: TBA
MCB RATING: TBA

BREAKER #	DESCRIPTION	TRIP (A)	POLES	VA	HP-1 MIGRATION
2	BASEMENT LIGHTS -1	20	1	1000	1
4	BASEMENT LIGHTS -2	20	1	1000	3
6	STAIR LIGHTS -1	20	1	1000	2
8	STAIR LIGHTS -2	20	1	1000	4
		TOTAL LOAD		4000 VA	
		TOTAL AMPS		16.67A	

(2) ESSENTIAL LOAD PANEL SCHEDULE
NTS

FIGURE 8. INVERTER BACKUP PANELS' LOAD SCHEDULE

FOCUSED TESTING FOR RESILIENCE AND BACKUP

Because to resilience and backup power is one of the most critical applications and use cases for a solar and storage system, several levels of testing were planned for the system, each focused on a specific aspect of resilience and backup power.

- *Priority Backup with PV Connected*: The battery prioritizes charging from PV power on the DC bus, and then charges from the grid as required to meet the BESS charging capacity. In this test, the battery attempted to fully charge.
- *Priority Backup without PV Connected*: The battery is directed to charge exclusively from the grid as required to meet the BESS charging capacity, and to fully charge if possible.
- *Clean Backup with PV Connected*: With backup loads disconnected from the grid, the battery energy storage system is directed provide backup power while continuing to charge only from PV.
- *Clean Backup without PV Connected*: With backup loads disconnected from the grid, the battery energy storage systems are directed to provide backup power until stored energy is fully exhausted. In this case, the battery is unable to recharge from any source.

KEY OBSERVATIONS

Although the Pika/Generac system is grid-connected to three-phase power, it is only able to provide single-phase backup power. This ability is a useful feature, but the context of installation must be noted. This means that three-phase loads, which are common in commercial contexts, cannot be supported by the system in the event of an outage. This limitation must be noted and if such loads are critical to a facility, then an alternative system must be considered.

The inverter and battery backup system is also limited in its ability to support inductive or motorized loads. This a known and common limitation in such systems, as startup inrush currents in motor loads can be many multiples of current in regular operating conditions. Inverters need to be properly sized to accommodate these loads in order to prevent damage to power electronic systems, although this is, unsurprisingly, costly. If such inductive and motorized loads are critical to facility operations, then an alternative system and possibly a completely different approach should be used, such as uninterruptable power supplies specific to backing up elevator operation.

Moreover, the design of the backup loads themselves and even their physical locations within the building plan and layout need to be carefully considered. In Mosaic Gardens, the community center load panels were located on the first floor, while the batteries were installed in the basement and the inverters on the roof. Such separation does not automatically mean backing up the community center loads is not possible, but there must exist a conduit or wiring connection between the inverter and load panels they desire to support. In this case, no connection between the community center load panels and roof existed, so those loads could not be supported during an outage. Instead, a few common lighting and outlet loads that were connected in the basement were placed on the backup panel, which though useful for testing purposes, did not have as much value to the building owner as the community center loads.

In addition, having the batteries and inverters separated by four floors created challenges for maintaining and troubleshooting the system, including ensuring the system maintained network connection at all times. Lastly, the inability to backup three-phase loads may contribute to unbalanced loads and current across the phases when they are powered normally via the grid-based three-phase power.

CONTROL ALGORITHMS FOR TIME-OF-USE AND SELF-SUPPLY

TIME-OF-USE

OVERVIEW

Time-of-Use operation provides value in regions with TOU rates. These rates consist of two or more pricing periods during a typical day. (See Figure 9.) Battery operation is incentivized by TOU rates to charge from solar or the grid during off-peak hours when energy prices are low, and discharge during on-peak hours, when energy prices are high.

In most areas of the country today, Time-of-Use operation is one of the only standard energy storage options that provide potential energy bill savings for residential customers. Commercial and industrial (C&I) customers can also benefit from storage under Time-of-Use schedules. The wider the price differential between on- and off-peak rates, the more savings can be created by shifting metered energy use from on-peak hours to off-peak hours.

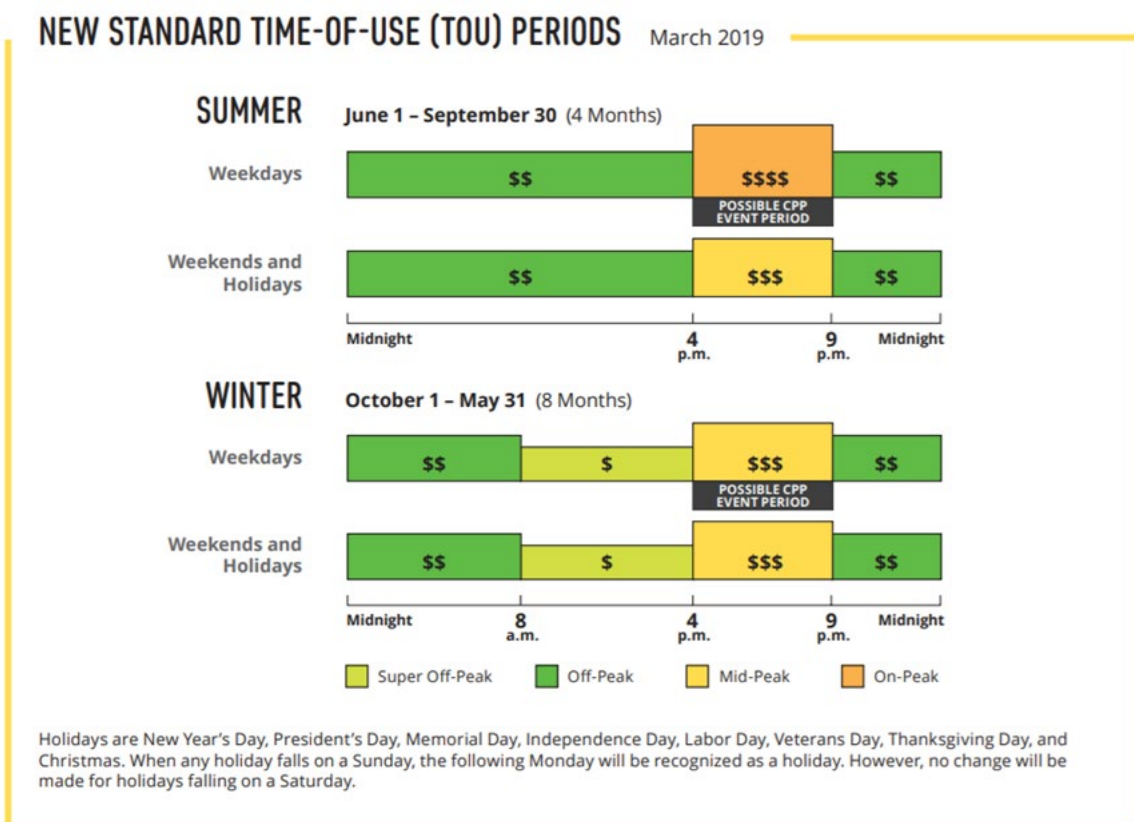


FIGURE 9. SCE TIME-OF-USE TARIFF

In the residential space, or for customers on Time-of-Use tariffs who do not have demand rates, almost all energy storage systems are also associated with a PV system on the same premises. In most cases, PV provides the vast majority of value by avoiding net energy consumption. PV can also help to reduce customer costs under Time-of-Use rates, especially in the summer when PV may still generate between the typical Time-of-Use on-peak hours of 4-9 pm. Because PV lowers net load during these hours, energy storage systems have less potential to shift consumption of energy from on-peak to off-peak. Because of this, the value created by energy storage systems participating in the management of Time-of-Use rates typically decreases when PV is installed on the same site. However, customers may also derive value from other energy storage services, such as resilience, demand charge reduction, or self-consumption.

How the Generac Time-of-Use Application Works

The Generac PWRcell TOU operating mode is technically the scheduling of multiple operating modes at the appropriate times. Generac provides a variety of TOU schedules that correspond to different utility TOU rates and tariffs. The TOU schedules are also able to differentiate between weekends and weekdays, as well as winter and summer seasons. There are currently 30 preset TOU schedules that can be selected, some that are generic and others that align with specific utilities. These schedules are assigned and activated at a per-inverter level, not a per-installation site level. At the time of writing, there is no defined process to create custom TOU schedules. However, correspondence with Generac technical support teams seems to suggest that, if necessary, custom scheduling and software can be developed for applications and customers that require it, though this process may be time consuming.

On a hardware level, the Generac PWRcell requires consistent network connectivity to the internet in order for the TOU schedule to properly switch between operating modes. Reliable communication, operation, and data collection requires the Generac inverter and REbus Beacons to remain online and connected to the Generac PWRcell servers. This allows Generac technical support to change which TOU schedule is active remotely and also provides troubleshooting support if needed. However, this is currently the only known way to modify the configuration of the TOU schedule on the system. There is no end-user capability to change which TOU schedule is active. The functionality could exist, but it is not available on the PWRview dashboard via desktop browser, on the mobile app, or at the inverter display and human machine interface (HMI).

Time-of-Use Observations & Potential Areas for Progress

Matching BESS Time-of-Use Schedules to Utility Tariffs

Time-of-Use tariffs vary across the country and change over time. Energy storage vendors have good reason to keep track of these rates, and they ensure that the battery energy storage systems they provide will save their customers as much money as possible. This encourages them to demonstrate sufficient savings associated with PV and energy storage installations to encourage customer adoption. However, there is no guarantee that the energy storage system is programmed to the best Time-of-Use period when a system is deployed, or later, as tariffs change.

Utilities have an opportunity to provide value to customers by ensuring their batteries' Time-of-Use settings are programmed properly. This could come in the following forms:

- *Rate Notifications*: Customers who go through the battery energy storage interconnection process can be notified of their current and potential rates, and informed of the optimal energy storage settings for those rates. Thereafter, utilities may want to continue updating customers of optimal rates and storage settings at a regular frequency.
- *Energy Storage Optimization Notifications*: When consumption patterns do not appear to be optimized by energy storage installations, customers could be notified.

Utilities may also have the opportunity to provide value to customers in the following:

- *Resilience Notifications* would inform customers of potential resilience events, whether due to weather, public safety power shutoff (PSPS), or planned outages. For customers with energy storage systems, these notifications may come with a notification that the customer may want to forego the energy storage systems typical Time-of-Use operation, in favor of leaving the energy storage system fully charged for a potential event. Reminding customers to re-engage their Time-of-Use operation may also provide value to the utility and the customer.

  Rate Optimization Notifications beyond TOU. Time-of-Use applications are not the only way for customers to save money with energy storage systems. Notifying customers of these circumstances and monitoring loads for optimization may provide customers and the utility with value. For instance, customers may also benefit from the self-consumption mode of operation, especially in circumstances where energy storage import or export constraints exist. If customers are compensated for the export of PV at a lower rate than the price they are charged for energy use, self-consumption may also benefit the customer.

  Figure 10 demonstrates how shifting from self-supply to Time-of-Use throughout the day may benefit customers. Extending the charging period over time provides value to the utility by reducing peaks.

- Note that customers may save the most money, and may also provide the most value to the utility, by taking their battery off self-supply mode in time to fully charge their batteries prior to a Time-of-Use on-peak period. This will ensure that the energy storage system has enough capacity to offset load during the on-peak Time-of-Use Period.
- Customers may also derive benefit by taking their energy storage systems off self-supply mode after the on-peak Time-of-Use period. At the end of a typical Time-of-Use period from 4-9 pm, solar generation does not exist to charge the energy storage system, and the battery may not be available for resilience events overnight.

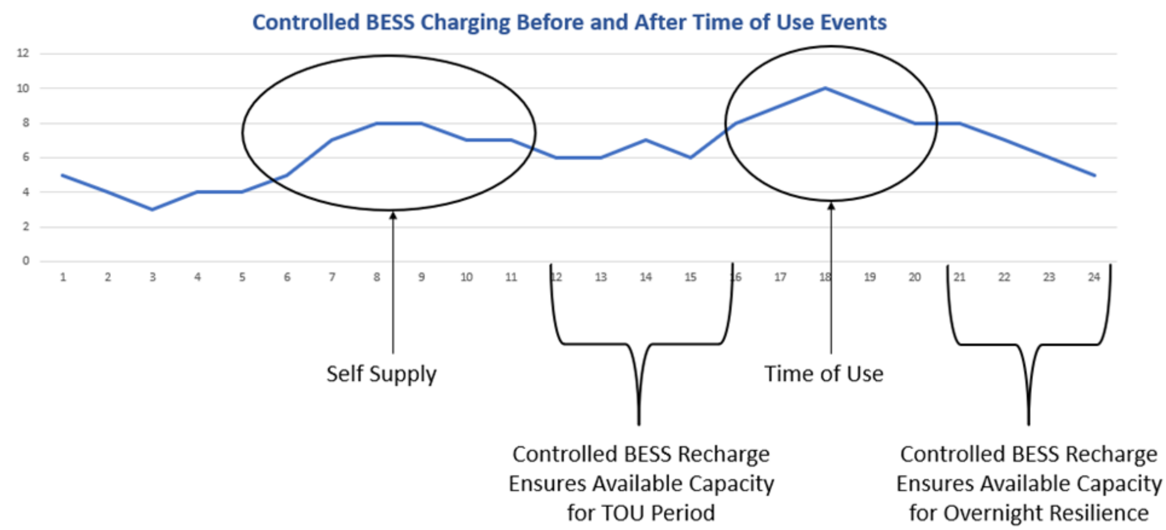


FIGURE 10. CONTROLLED BESS CHARGING BEFORE AND AFTER TIME-OF-USE EVENTS

Increasing the Capacity Factor and Hours of Use of Customer-Owned Energy Storage

Combining Time-of-Use with other applications, such as Self-Supply or Demand Response applications will increase the capacity factor of energy storage systems. This may come at a cost for energy storage users, as an increased capacity factor results in increased battery degradation, both via increased use of the battery energy storage systems and the potential of increased depth of discharge, which can add to battery degradation. Should the increased capacity factor of distributed energy storage units benefit the utility, the utility may consider compensating customers for the additional use (and potential degradation) of their batteries may exist.

Encouraging Longer Duration Charge/Discharge & Low Ramp Rates for Customer-Sited Storage

Customers may be incentivized to charge and discharge customer-sited energy storage systems at full power before, during, and after Time-of-Use events. In aggregate, this may reduce grid benefits associated with Time-of-Use periods.

- *Customers may be incentivized to discharge* their energy storage systems as quickly as possible during a Time-of-Use period, to ensure they maximize their savings. For example, many customer-sited systems have two-hour durations, meaning that they are capable of fully charging and discharging in two hours. When large numbers of disaggregated energy storage systems charge and discharge at the same time, unintended impacts could be seen at the utility level. For example:
- Non-export clauses created during interconnection, or non-export incentives created via tariffs will encourage energy storage systems to discharge more slowly over the typical four-hour on-peak Time-of-Use period, rather than discharging as quickly as possible over the first two hours.

- *Note: A potential disadvantage to non-export incentives is that some customers may never discharge 100% of the useable capacity of their energy storage system over the four-hour on-peak period, should their load not be great enough. This may protect the distribution system from reverse power flows, but will not allow these energy storage systems to fully contribute to reducing wholesale demand during these on-peak windows of time.*

- Incentivizing customers to reduce or limit the capacity of battery export during on-peak Time-of-Use periods may allow for a more uniform discharge of battery systems over the length of the on-peak Time-of-Use period.
- *Customers may be incentivized to charge* their energy storage systems as quickly as possible at the end of a Time-of-Use on-peak period. This can create a new spike in energy consumption, from disaggregated energy storage systems all being incentivized to charge at the same time. The incentive to charge comes from the end of the on-peak window and associated reductions in energy cost, combined with the incentive to charge customer batteries so that they may assist in potential resilience events. Several potential solutions exist:
- Time-of-Use mid-peak or shoulder periods can reduce the incentive to charge directly after an on-peak Time-of-Use Window, delaying the new spike to later evening hours when the grid will be less impacted.
- Non-import interconnection mandates resulting in the use of Self-Supply modes for operation result in battery systems held at a low state of charge until the following morning, when solar charging is possible. However, this is likely to leave customers without the potential to ride through a resilience even overnight.
- By incentivizing customer-sited energy storage systems to reduce or limit the power the battery charges with after the Time-of-Use period, new peaks could be avoided. This would result in batteries requiring a longer period of time to recharge, which will reduce for a limited time the battery's availability for resilience events.
- Reliably informing customers of potential resilience events may reduce their desire to charge quickly as soon as Time-of-Use on-peak periods end.

SELF-SUPPLY

OVERVIEW

Self-Supply operation orders the battery to charge whenever PV generation would otherwise be exported to the grid, and to discharge whenever net load exists at a site.

From the utility's perspective, Self-Supply limits the impact of solar PV and battery homes on the grid. From the customer perspective, Self-Supply may have a variety of benefits. For example:

- Self-Supply allows customers to use their own solar generation, rather than exporting it to the grid. Even without financial incentives, some customers prefer to consume their own solar energy. However, this mode of operation is likely to result in greater battery energy storage use, and may reduce the life expectancy of the unit.

- Some utilities have developed, or are developing, tariffs that compensate customers differently for PV energy exported to the grid compared to what customers pay for their electricity consumption. In California, this is referred to as NEM 3.0. When customers are compensated at a lower rate for exporting energy than they pay for importing it, a battery provides value by saving their otherwise-exported energy for on-site use at a later time. In Germany, policies that compensated customers less and less for the export of PV resulted in significant energy storage adoption. Additionally, almost all new residential PV systems installed in Hawaii are paired with an energy storage system for this reason.
- Some tariffs require that energy storage must not charge from or discharge to the grid. Self-Supply generally ensures that the BESS is only charged from on-site generated solar, and only discharges such that it replaces load that would otherwise come from the grid.

Self-Supply tends to have little or no economic value to customers, unless on-site PV generation is compensated for at a lower rate than consumption. As the differential between what a utility compensates for PV production and what it charges for consumption increases, the demand for energy storage should increase.

How the Generac Self-Supply Application Works

The Generac Self-Supply application, also known as solar self-consumption, endeavors to ensure that every unit of energy generated by solar PV is used to power an on-site load and not sent to the grid. This also means that any energy stored and charged into a storage system originating from solar will ultimately be used to power an on-site load.

During Self-Supply operation, on-site PV generation will power local loads first. If there is excess PV generation, the battery will charge and use that energy later to supply on-site loads with 'green electrons' when there is not enough PV generation to power local loads. PV will only be exported to the grid after all on-site loads have been powered and the battery has reached full capacity and cannot store more energy.

Self-Supply Observations & Potential Areas for Progress

Encouraging Self-Supply in Combination with Time-of-Use Management

As discussed in the Time-of-Use section, the use of Self-Supply improves the capacity factor of customer-sited energy storage systems, and may provide additional grid value throughout the day. Furthermore, using Self-Supply throughout the day may leave the energy storage system with less capacity for offsetting load during on-peak Time-of-Use Periods or periods of time when demand needs to be reduced for Demand Charge Management operations.

Topics for consideration include:

- *Customer Economic Tradeoffs Between Self-Supply and Time-of-Use Management*: For customers who are compensated equally for energy produced and consumed, there is no economic benefit to the Self-Supply mode of operation.

- *Grid Benefit Tradeoffs Between Self-Supply and Time-of-Use Management*: The balancing of self-supply and TOU operation also has an impact on the utility capturing maximum value from customer-sited energy storage units.

  Studies of the benefits and drawbacks associated with Self-Supply and the negative impacts it may have on reducing grid load during peak periods may be valuable.

Assisting Customers with Understanding & Using Self-Supply

Customers may choose to use a battery's Self-Supply operation because they desire to use their own solar power, or because they are financially incentivized to do so. Financial incentives for the use of Self-Supply are most often present when customers are compensated at a lower rate for exported energy, as compared to the rate they pay for consumed energy from the distribution system. In California NEM 3.0 tariff discussions are likely to create rates that pay solar customers less for exported power, which will incentivize energy storage adoption as a means of using Self-Supply to consume solar energy rather than exporting it for less than full retail compensation. Customers may benefit from understanding the following:

- *Backup Power Limitations of Self-Supply*: The use of Self-Supply means that the battery will only charge during times when PV generation is greater than load. This leaves most battery systems charged at less than 100% for the majority of the day. In fact, during evening hours the battery may have little to no remaining energy capacity available. Customers who use the Self-Supply operation may be disappointed to learn that their battery is less available for resilience scenarios.
- *Financial Impacts of Self-Supply*: Assisting customers with understanding the financial repercussions of using Self-Supply as new tariffs are created may provide value.
- *Environmental Impacts of Self-Supply*: Assisting customers with understanding the environmental impacts of Self-Supply may provide value.

CONCLUSIONS

OPERATING MODES

The value obtained by operation in TOU or Self-Supply mode is heavily dependent on effective load monitoring. For example, Time-of-Use operation in a shared-housing application is unlikely to be able to monitor all loads on the system, so the full potential benefit may not be realizable. Similarly, in Self-Supply mode, having all building loads tracked by system CTs would allow greater utilization of stored energy from batteries and minimize the power taken from the grid. In either case, battery operation provides more economic value to the customer when batteries discharge as much as possible during on-peak periods.

Self-Supply mode is likely to be beneficial to the grid, because it helps to mitigate and flatten peaks in demand by tracking and matching customer loads. Self-Supply is most beneficial to customers for whom PV export is compensated at less than the retail price of electricity.

Batteries used in backup mode tend to operate very little, and primarily to recharge batteries due to losses, because outages are relatively rare. Operating storage in clean backup mode has minimal effects on the grid, either positive or negative, because all charging is done by the solar PV system and all discharging occurs during outages. Priority-backup operation could pose some issues if many battery systems are using this mode: in the event of an outage, all of these systems would be attempting to charge as soon as possible after the outage. This could be a challenge to the grid in some instances.

BESS software that is capable of implementing key interconnection constraints, such as zero-export/non-import operation, provides direct benefits to the grid and will support scalable growth of the energy storage industry in general. To the extent that these and other interconnection constraints and rules can be tested remotely, rather than through in-person compliance inspections and tests, the industry will be able to obtain these benefits at lower cost.

The unplanned tests of inverters compensating for lost inverters at a given installation demonstrated that this emerging technology offers useful flexibility and extensibility. This will be more important if and when battery energy storage systems become increasingly relied upon in larger installations such as shared-housing applications.

Overall, for those utilities experiencing difficulty interconnecting and mitigating the impact of a PV system on the grid, Clean Backup may not be ideal. Self-Supply and Time-of-Use operations are likely to provide far more value to the grid. Fortunately, the vast majority of available energy storage systems are capable of operating in Self-Supply or Time-of-Use modes, while also providing backup to customers. Although the energy storage system is less likely to have 100% SOC during an outage, when it is also operating in Self-Supply or Time-of-Use mode, it is benefiting the grid more.

SYSTEM COMMISSIONING

System commissioning is a slow process and one with significant costs for the utility and the end-user, and one that does not scale well with a rapidly-expanding technology. If a clear commissioning process and procedures are implemented, it is possible that these barriers could be lowered through remote testing and inspections. Throughout, clear communication between inspectors, operators, and vendors is essential to executing the required tests and verifications. Utilities have useful resources to further validate and accurately monitor the proper operation of the system, such as using utility AMI meters and their data to track and monitoring system performance and operation.

BACKUP LOADS

The limitations of battery backup systems should be recognized. For example, in this case, the Pika/Generac system cannot provide three-phase backup power. As a result, three-phase loads, such as the apartment complex security gate, could not be served. It is also a known limitation of many such systems that inductive or motorized loads can be problematic, as inrush currents can be much higher than regular operating current. This means that either inverters must be upsized to address these issues or an alternative system—perhaps an entirely different solution—is needed to backup key power needs such as a building elevator.

Further, planning for backup power should begin with the building design, as interconnectivity between batteries, generation sources, and loads needs to be provided. In this project, the Mosaic Gardens design placed community center load panels on the first floor, batteries in the basement and inverters on the roof. Without a proper pathway, such as conduit for wiring, it was impossible for some loads to be supported during outages. Moreover, the physical separation of the components made it more difficult to maintain the system, including ensuring network connectivity.

RECOMMENDATIONS

BATTERY AND SOLAR INTERCONNECTION

Interconnection can be a time-consuming and difficult process for energy storage projects. Grid reliability can be compromised by uncontrolled charging and discharging of customer-sited battery energy storage systems in aggregate, so steps must be taken to ensure these systems act predictably and responsibly in the aggregate. One way of ensuring that distributed, customer-sited energy storage systems do not create negative impacts on the grid is to require that they do not charge from or discharge to the grid via the interconnection agreement. (For details on the interconnection process for the Mosaic Gardens at Pomona system, see Appendix D.)

In addition to creating non-export and sometimes non-import requirements for customer-sited energy storage systems during the interconnection process, utilities want to have confidence in the ability for the third-party energy storage software being installed to carry out these requirements. Testing of this functionality may be required prior to utilities granting Permission to Operate (PTO).

EPRI observed a lack of clarity, on behalf of the installer and vendor, regarding what was needed to complete the interconnection process. It is important to note that EPRI was not a part of all interconnection discussions as part of this project, and that EPRI entered interconnection discussions later in the process. EPRI is not familiar with the entirety of SCE's interconnection process. Some of the recommendations below may already be implemented by SCE, or may not be implemented for reasons not immediately clear to the EPRI team from its experience with this particular project.

While the lack of clarity on behalf of the installer and vendor may have had nothing to do with SCE processes, the following processes may help installers and vendors moving forward.

- Specifying best practices and requirements for interconnection applications involving new battery energy storage technology may help clarify the steps required of installers and vendors in advance. For example, it is not known whether the installer or vendor understood early in the process that they would have to demonstrate the non-import capability of the Generac energy storage system in order to achieve PTO. Developing means to inform third parties that their system is not currently approved for the type of interconnection being sought early in the interconnection process, will help to avoid delays after installation is complete. For instance, SCE may or may not have a public list of energy storage vendors that are approved for specific interconnection requirements and tariffs. The development of a public list that can be referenced by installers and vendors may help to expedite the process of interconnection.
- Once an installer/vendor understands that they will have to demonstrate a particular capability prior to PTO, a test plan is to be developed. In this case, the vendor and installer were tasked with creating a test plan for non-export constraints. Having the vendor and/or installer create test plans can be a time-consuming process, that creates delays. Should SCE provide sample test

plans for specific criteria, such as non-export of a DC-connected solar and storage system behind a net-meter, the process for test plan completion and demonstration is likely to be quicker.

ENERGY STORAGE OPERATION FOR CUSTOMER VALUE

In Time-of-Use operations, it is essential to select the correct TOU schedule that matches the TOU rate/tariff of customer, because there is currently no way to have utility signals reach the PWRcell system directly. Operators should routinely review Generac TOU schedule options to ensure the best selection has been chosen

The battery discharge rate in Sell mode can be adjusted by contacting Generac technical support. It may be beneficial to seek a more self-directed process in the future.

Further customer value is achieved if Self-Supply can eliminate a customer’s need for power from the grid during on-peak periods. Additional value can be achieved if demand rates are present and the battery capacity is sufficient to lower building demand. Comprehensive and properly configured CTs are critical to achieving optimal operation and reaching the full potential of any battery energy storage system

Utilities are able to incentivize Self-Supply and Time-of-Use operations with a variety of rates. Additionally, Demand Response programs can incentivize customers to allow use of their energy storage systems by the grid when most useful.

One other note is that not allowing energy storage systems to take advantage of Priority Backup Modes that charge from the grid may disincentivize some customers from participating in Time-of-Use or Self-Supply modes of operation. That is because, if unable to charge their battery from the grid, these customers are more likely to be at a minimum state of charge during the overnight hours and have less access to the resilience they want from their energy storage system.

While not immediately possible, the potential for Pomona Mosaic Garden’s solar-plus-storage system to provide backup power to loads in the community center is of interest. Investigation and research into how this can be enabled at this site would garner valuable insight into understanding the requirements for enabling community-center backup power through retrofits for other multi-family apartment complexes and other multi-tenant spaces in general.

APPENDIX A: DESIGN DOCUMENTATION

Over the course of the project's deployment, installation, and execution, a number of diagrams, drawings, and technical records have documented the implementation and augmentations to the system for data monitoring, commissioning testing, program applications, troubleshooting, and design.

1. Self-Generation Interconnection Application: SGIP Application SCE-SGIP-2019-5053_210217
2. Solar Battery Wiring and Monitoring Diagram
3. Naak eGauge Wiring and Configuration Diagram
4. Generac Pika CT Measurement Points Diagram
5. Generac Time-of-Use Schedule Selections
6. SGIP Energy Storage Inspection Protocol 20190119

APPENDIX B: DETAILED TEST PLAN AND RELATED RESOURCES

PURPOSE

The purpose of this test plan is to fulfill the requirements of the Pomona Mosaic Battery Control and Optimization supplemental project with SCE. These goals would be accomplished by demonstrating and validating various modes of operation for the installed Pika Battery Energy Storage System (BESS), as well as performance testing for characterization of BESS qualities such as round-trip efficiency and degradation.

SCOPE

APPLICATION

Test and validate the following modes of operation for the Pika BESS and confirm which modes include the ability to not charge from or discharge to the grid, as defined by the point of common coupling (POC) otherwise defined as the SCE retail meter.

- Priority Backup
- Clean Backup
- Grid Tie/Connect
- Self-Supply
- Zero Export
- Sell
- Islanding
- Black start
- Time-of-Use

Provide characterization of the BESS over the course of the project

- Round Trip Efficiency
- Battery Module Degradation
- Depth of Discharge
- Power Capacity at Variable States of Charge

TEST RESULTS

Testing will provide information for determining:

- Ability of Pika BESS system to provide the modes of operation listed above
- Ability (and lack thereof) for the modes of operation to charge from and discharge to the grid

- Ability to control various priorities and settings within each mode of operation
- Round trip efficiency of the battery over time
- Battery module kWh degradation over time
- Depth of Discharge
- Power Capacity at Variable States of Charge

DATA COLLECTION

Data collection will occur via two systems:

1. Generac.com PWRcell Monitoring portal
    a. Provides battery and PV information consisting of:
        i. DC bus and battery voltage
        ii. Solar PV energy production
        iii. Inverter consumption and output power
        iv. PV module temperatures
2. Naak Carbon Track Online Portal (provision and installation by Promise Energy)
    a. 3-phase AC monitoring
        i. at community utility meter
        ii. at output of all three (3) Pika Islanding inverters
        iii. at two (2) inverter panels, 120 V / 240 V single- / split-phase
    b. DC bus monitoring for consumption and generation
        i. bidirectional, four (4) Pika Harbor Smart 15P Batteries
            1. eight (8) CTs for battery energy storage system
        ii. monodirectional monitoring of fifteen (15) solar PV strings
            1. six (6) CTs for solar monitoring at the inverter
3. Modbus Datapoints (under investigation)
4. On-site measurement and verification (when necessary)

RESPONSIBILITIES

EPRI personnel shall:

- Coordinate and lead testing
- Coordinate and provide for record collection
- Provide final test report

Generac personnel shall:

- Provide technical support and assistance
- Provide Installer Tools for the Beacon

TESTING EQUIPMENT & PROCEDURE

The team may elect to initially perform each of these tests with a single live inverter, then with multiple inverters to log variations in functionality and response between hardware that might arise.

SGIP INSPECTION TEST PROCEDURE

ENERGY STORAGE POST-INSTALLATION INSPECTION AND DISCHARGE TESTING PROTOCOL

This test procedure summarizes the required tasks for the SGIP inspection and approval of the battery storage system. The full version of the required test procedures and tasks can be requested and reviewed in its separate documentation.

1. Pre-Inspection Discharge Data
    a. One-Week of Operational Data
    b. Continuous Discharge Test
        i. Field Test
        ii. Factory Test
2. Pre-Inspection Verification
    a. Equipment Information Verification
    b. Configuration and Operation Verification
        i. Interconnection Agreement Review
        ii. Charge and Discharge Data Review
        iii. Electrical Single Line Diagram
        iv. On-Site Field Demonstration of Parallel Operation
3. Field Post-Installation Verification
    a. Visual Inspection of Service of On-Site Load
    b. Verification of Installation of Proper and Documented Equipment
    c. Live Discharge Demonstration
4. Virtual Post-Installation Inspection
    a. Continuous Video Documentation
        i. Street View
        ii. Building Address
        iii. Nameplate Information
        iv. Batteries and Inverters
        v. Serial Numbers
        vi. Electrical Equipment
        vii. User Display Panels

viii. Electric Load Panels
ix. Utility Smart Meters

b. Geotagged Photos of
   i. Project Site
   ii. Nameplate Information
   iii. Batteries and Inverters
   iv. Serial Numbers
   v. Electrical Equipment
   vi. User Display Panels
   vii. Electric Load Panels
   viii. Utility Smart Meters

APPLICATION/BATTERY MODE TESTING

PROCEDURE 1: ROUND-TRIP EFFICIENCY OBSERVATIONS VIA SELL AND PRIORITY BACKUP MODES

This test plan procedure will focus on determining the round-trip efficiency of the four Pika Smart Harbor 15P battery cabinets by activating and testing the sell and clean backup inverter operating modes of the Pika X11402 Smart Inverters.

1. It is preferred to perform this test during clear weather and sunny skies so solar is used for charging batteries and powering loads.
   a. This is not necessary since we will use the Priority Backup mode rather than Clean Backup mode
2. Log the initial state of charge (SOC) levels of each battery and the start time of the test procedure.
   a. Confirm that numbers shown on inverter are the same as logged on Generac's online PWRview dashboard
   b. The inverters and batteries are properly connected to the network and reporting to Generac servers.
   c. Logging will also be done here automatically.
   d. Also perform system configuration checks that ensure the MIN and ABSOLUTE setpoints of the inverters do not over discharge the inverters batteries.
   e. Throughout the entirety of the test, temperatures shall be continuously performed with a thermal camera.
3. From the inverters' LCD screen set the operating mode to Priority Backup
   a. This will direct the batteries to charge up to prioritize the ability for provide backup power.
   b. Log the time at which inverter operating modes was changed
   c. Keep the inverters in Priority Backup mode until all batteries are charged up to 100%

   d. Log the time at which batteries were charged to 100 percent
      i. Ideally each battery should be logged individually
4. From the inverters' LCD screen set the operating mode to Sell
   a. This will direct the batteries to discharge to the essential-loads panels and common are loads.
   b. Discharge the batteries to about 20%-25% SOC, staying in Sell operating mode, documenting SOC at completion.
      i. Alternatively: discharge the batteries for 30 minutes to 60 minutes, staying in Sell operating mode.
   c. Log the time and SOC at which the batteries stopped discharge operations.
5. Afterward, set the inverters back to the Priority Backup operating mode.
   a. The batteries should charge up from rooftop solar PV production
   b. Be sure all batteries charge at least back up to 100% SOC level they were at when the test procedure began.
   c. Log the time at which batteries (ideally, individually) return to 100 SOC%.
   d. Measure the duration of time it took to return to 100% charge.
6. Calculate the RTE from using Generac PWRview and naak eGauge dashboard and reported data
   a. Calculate the amount of power discharged from the batteries during the Sell operating mode
   b. Calculate the amount of power charged into the batteries to get back to the original SOC level during the Clean Backup operating mode
   c. Divide the quantity from a. over the quantity from b. to estimate the batteries' RTE
   d. Repeat multiple times for more data points / observations

PROCEDURE 2: CHARACTERIZING BATTERY OPERATION AND PERFORMANCE IN ZERO EXPORT MODE

Designed for markets where solar PV systems are prohibited from back feeding the AC grid. With Zero Export enabled, the inverter will not send excess solar power to the grid. Instead, the system will limit solar power generation such that it exactly matches the power consumed by local loads resulting in no exported power. Battery may still be able to export power to the grid, but unclear and unlikely. Current transformers are required for this mode.

1. It is preferred to perform this test during clear weather and sunny skies so solar is used for charging batteries, powering loads, and test no solar export.
   a. Additionally, for completeness, we should determine if battery export is allowed.
   b. Although per the interconnection agreement with SCE and custom firmware loaded up by Generac, battery discharge to grid should not be observed.
2. Log the initial state of charge (SOC) levels of each battery and the start time of the test procedure.

   a. Confirm that numbers shown on inverter are the same as logged on Generac's online PWRview dashboard
   b. The inverters and batteries are properly connected to the network and reporting to Generac servers.
   c. Logging will also be done here automatically.
   d. Also perform system configuration checks that ensure the MIN and ABSOLUTE setpoints of the inverters do not over discharge the inverters batteries.
   e. Throughout the entirety of the test, temperature checks may be continuously performed with a thermal camera.
3. From the inverters' LCD screen set the operating mode to Zero Export
   a. This will direct the system to disallow solar power (as well as battery power) from discharging to grid
   b. Solar power will be prioritized to power local / community loads and charge batteries.
   c. Log the time at which inverter operating modes was changed
4. Keep inverters in Zero Export mode during the duration of the test (ideally at least an hour or longer)
   a. Observe the power flows during this time.
   b. All solar power generated should go to powering loads of charging batteries.
   c. Batteries might be discharging, but likely only to power loads that cannot be fully supported by power generated from solar.
   d. If any power is being exported, then is should be less than or equal to battery discharge power.
      i. Any more, would indicate that at least some solar power was being exported back onto grid.
5. From the inverters' LCD screen, set the operating mode back to the initial mode (likely Clean Backup) to conclude the test.
   a. Log the time at which the inverters were set back / the test was completed
   b. Log the SOC of the batteries
   c. Check that data has been reporting and recording
6. During analysis, be sure that solar power was never discharged to the grid.
   a. Power exported to the grid should generally be zero throughout the entire duration of the test.
   b. Some power may be imported by the grid.

PROCEDURE 3: CHARACTERIZING BATTERY OPERATION AND PERFORMANCE IN PRIORITY BACKUP MODE

Islanding inverters prioritize keeping batteries charged and ready for grid interruption, using solar power or grid power. Batteries charge using solar power as it is available, and take additional power from the grid to expedite battery recharging as quickly as possible. In the event of a grid failure, the inverter will enter Islanding Mode. Protected loads are supported by solar and battery power. If there is enough solar power available, the solar will simultaneously charge the battery and support the loads

1. It is preferred to perform this test during clear weather and sunny skies so solar is used for charging batteries and powering loads while connected to and disconnected from grid.
    a. This might not be necessary, however, since this mode technically allows the batteries to be charged from the grid.
        i. Though this is not intended by the SCE interconnection agreement.
2. Log the initial state of charge (SOC) levels of each battery and the start time of the test procedure.
    a. Confirm that numbers shown on inverter are the same as logged on Generac's online PWRview dashboard
    b. The inverters and batteries are properly connected to the network and reporting to Generac servers.
    c. Logging will also be done here automatically.
    d. Also perform system configuration checks that ensure the MIN and ABSOLUTE setpoints of the inverters do not over discharge the inverters batteries.
    e. Throughout the entirety of the test, temperature checks may be continuously performed with thermal camera.
3. From the inverters' LCD screen set the operating mode to Priority Backup Mode
    a. This will direct the system to charge the up the batteries using solar power as primary source and grid power a secondary source.
    b. Charging the batteries will take priority over power loads with solar.
    c. Log the time at which inverter operating modes was changed
4. Keep inverters in Priority Backup mode during the duration of the test (ideally at least an hour or longer)
    a. Observe the power flows during this time.
    b. All solar power generated should go to charging the batteries, unless the batteries are already charged up.
    c. Batteries should not be discharging.
    d. Solar power should only be exporting excess power if batteries are fully charged and local load demand is less than solar power and are fully met.
5. Test the Backup ability of this mode by simulating a grid outage via opening the solar disconnect that connects the three inverters to the community AC bus.
    a. Log the time at which this simulated grid outage occurs as well as the SOC of each of the batteries.
    b. Be sure to engage the disconnected safely, observing all safety procedures, with other personnel that can assist if the situation arises.
6. After the system is in Backup mode, confirm the proper operation of the islanded system
    a. Loads on the essential backup loads panels should be powered by solar and/or battery power.

   b. No power should be flowing / exporting to the grid, especially since it should be physically disconnected because of the opened solar disconnect.

7. Simulate grid recovery / reenergization by reconnecting / reclosing the solar disconnect so the inverters are connected back to the community's AC bus.
   a. Mark the time this occurs
   b. Should allow for sufficient time in Backup mode to see the batteries discharge to power the essential loads backup panel, etc.
8. Observations during post-procedure analysis
   a. Battery power should never discharge to grid.
   b. Solar power should prioritize charging of batteries.
   c. After batteries are charged solar power can power loads and charge to the grid.
   d. In backup mode, both battery and solar can and should be used to power local loads of the essential load backup panel

PROCEDURE 4: CHARACTERIZING BATTERY OPERATION AND PERFORMANCE IN CLEAN BACKUP MODE

Islanding Inverters prioritize keeping batteries charged and ready for grid interruption, using only solar power. If the battery is not fully charged, X7602/X11402 will use all available solar power to charge the battery. Grid power will not be used to charge batteries in this mode. When the batteries are full, solar power is exported to the AC terminals of the inverter, providing power to the building along with the grid. When grid service is interrupted, the system will immediately enter Islanding Mode, powering protected loads with solar and battery power together. If there is enough solar power available, the solar will simultaneously charge the battery and support the loads.

1. It is preferred to perform this test during clear weather and sunny skies so solar is used for charging batteries and powering loads while connected to and disconnected from grid.
   a. This is very necessary, however, since this mode does not allow the batteries to be charged from the grid, only solar.
2. Log the initial state of charge (SOC) levels of each battery and the start time of the test procedure.
   a. Confirm that numbers shown on inverter are the same as logged on Generac's online PWRview dashboard
   b. The inverters and batteries are properly connected to the network and reporting to Generac servers.
   c. Logging will also be done here automatically.
   d. Also perform system configuration checks that ensure the MIN and ABSOLUTE setpoints of the inverters do not over discharge the inverters batteries.
   e. Throughout the entirety of the test, temperature checks may be continuously performed with thermal camera.
3. From the inverters' LCD screen set the operating mode to Clean Backup Mode

  a. This will direct the system to charge the up the batteries using solar power as sole source.
  b. Charging the batteries will take priority over power loads with solar.
  c. Log the time at which inverter operating modes was changed
4. Keep inverters in Clean Backup mode during the duration of the test (ideally at least an hour or longer)
  a. Observe the power flows during this time.
  b. All solar power generated should go to charging the batteries, unless the batteries are already charged up.
  c. Batteries should not be discharging.
  d. No grid power should be used for charging batteries.
  e. If batteries are not fully charged, all solar power should be used to charge them.
  f. Solar power should only be exporting excess power if batteries are fully charged and local load demand is less than solar power and are fully met.
5. Test the Backup ability of this mode by simulating a grid outage via opening the solar disconnect that connects the three inverters to the community AC bus.
  a. Log the time at which this simulated grid outage occurs as well as the SOC of each of the batteries.
  b. Be sure to engage the disconnected safely, observing all safety procedures, with other personnel that can assist if the situation arises.
6. After the system is in Backup mode, confirm the proper operation of the islanded system
  a. Loads on the essential backup loads panels should be powered by solar and/or battery power.
  b. No power should be flowing / exporting to the grid, especially since it should be physically disconnected because of the opened solar disconnect.
7. Simulate grid recovery / reenergization by reconnecting / reclosing the solar disconnect so the inverters are connected back to the community's AC bus.
  a. Mark the time this occurs
  b. Should allow for sufficient time in Backup mode to see the batteries discharge to power the essential loads backup panel, etc.
8. Observations during post-procedure analysis
  a. Battery power should never discharge to grid.
  b. Solar power should prioritize charging of batteries.
  c. After batteries are charged solar power can power loads and charge to the grid.
  d. In backup mode, both battery and solar can and should be used to power local loads of the essential load backup panel

PROCEDURE 5: CHARACTERIZING BATTERY OPERATION AND PERFORMANCE IN SELF-SUPPLY MODE

Prioritizes powering local loads using solar and/or stored power first. Solar power will be used to charge batteries before any power is exported to the grid. This mode is optimal in markets in which net metering is unavailable or unfavorable, making battery-stored power economically more attractive than grid-provided power.

1. It is preferred to perform this test during clear weather and sunny skies so solar is used for charging batteries and powering loads while connected to and disconnected from grid.
    a. This is very necessary, however, since this mode does not allow the batteries to be charged from the grid, only solar.
2. Log the initial state of charge (SOC) levels of each battery and the start time of the test procedure.
    a. Confirm that numbers shown on inverter are the same as logged on Generac's online PWRview dashboard
    b. The inverters and batteries are properly connected to the network and reporting to Generac servers.
    c. Logging will also be done here automatically.
    d. Also perform system configuration checks that ensure the MIN and ABSOLUTE setpoints of the inverters do not over discharge the inverters batteries.
    e. Throughout the entirety of the test, temperature checks may be continuously performed with thermal camera.
3. From the inverters' LCD screen set the operating mode to Self-Supply Mode
    a. Log the time at which inverter operating modes was changed
    b. This will direct the system to charge the up the batteries using solar power as sole source.
    c. Power local loads with solar will take priority over charging the batteries with solar.
    d. Grid power only used if solar and storage cannot provide enough power to local loads.
4. Keep inverters in Priority Backup mode during the duration of the test (ideally at least an hour or longer)
    a. Observe the power flows during this time.
    b. If more power is being produced by the solar array than is needed by local loads, inverter will store energy in the battery for later use.
    c. If the battery is full and a surplus of power is available, that surplus is exported to the grid.
    d. When local demand exceeds available solar-generated power (e.g. at night), the battery supplies power to support local loads.
    e. If the building requires more power than the battery and solar can provide, then the excess demand is supported by the grid.
5. Test the Backup ability of this mode by simulating a grid outage via opening the solar disconnect that connects the three inverters to the community AC bus.

   a. Log the time at which this simulated grid outage occurs as well as the SOC of each of the batteries.
   b. Be sure to engage the disconnected safely, observing all safety procedures, with other personnel that can assist if the situation arises.
6. After the system is in Backup mode, confirm the proper operation of the islanded system
   a. Loads on the essential backup loads panels should be powered by solar and/or battery power.
   b. No power should be flowing / exporting to the grid, especially since it should be physically disconnected because of the opened solar disconnect.
7. Simulate grid recovery / reenergization by reconnecting / reclosing the solar disconnect so the inverters are connected back to the community's AC bus.
   a. Mark the time this occurs
   b. Should allow for sufficient time in Backup mode to see the batteries discharge to power the essential loads backup panel, etc.
8. Observations during post-procedure analysis
   a. Battery power should never discharge to grid.
   b. Solar power should prioritize the powering of loads, then the charging of batteries, the exporting to grid.
   c. Grid power should only be pulled if the full output of solar and battery power cannot support local loads.

Procedure 6: Characterizing Battery Operation and Performance in TOU Mode with REbus Beacons

TOU mode requires prior communication with Generac and an understanding of the community's rate / tariff plan. Generac will use the Rebus beacons, and presumably other hardware devices to intelligently switch the inverters' operating mode between Self-Supply and Clean/Priority Backup during high price/rate and low price/rate times respectively.

Procedure 7: Characterizing System Ability and Response for Black Start Operation

Black Start allows the Harbor BESS to power up a system that is powered down and has no other sources of available power. If Harbor is disabled, perform a Manual Enable as part of the Black Start process. Manual Enable allows one to enable Harbor without powering on the inverter. Once enabled, Harbor can Black Start the system.

APPENDIX C: SYSTEM COMMISSIONING TEST REPORT

BACKGROUND

On March 9, 2020, representatives of Promise Energy, Kliewer and Associates, and the Electric Power Research Institute met at Linc Housing's Mosaic Gardens multifamily apartment complex in Southern California Edison electric service territory, where four Pika Harbor Smart Batteries had been installed and DC-coupled with on-site solar PV generation through three Pika Islanding Inverters. The battery and solar interconnection installation itself had already received Permission to Operate (PTO) on January 29, 2020. The signed PTO document is attached.

The plan of the day was to work through the commissioning test plan provided by Generac that had been reviewed, edited, approved by Southern California Edison. Promise Energy would be responsible for manipulating the electrical equipment based on the testing plan; Kliewer Associates would record the measurements of the test plan in the spaces the document allows, and EPRI would document these measurements through photographic media, as well as provide technical guidance on verifying the soundness of the test procedure and recorded measurements.

PROCEDURE

The test procedure our team followed is detailed, together with the recorded measurements, in Attachment 2 (test plan and commissioning documents) The procedures focused on testing for satisfaction of Rule 21 Non-Export requirements. The most recent Single Line Diagrams (SLD) are also attached (see Attachments 3 and 4), which include labels and layout that are referred to throughout this discussion.

The system passed all tests in the procedure except for one, and the recorded measurements support this conclusion. An explanation for the single non-passing test is presented here, but still requires inquiry and corroboration with Generac to confirm our understanding of the Pika system's configurations and topology.

The apparent failure arises when both battery inverters, designated INV1 and INV2, are set in the Self-Supply operating mode. The Self-Supply mode states that it will limit the battery to charge only from renewable sources and will NOT charge from the grid.

Power from the grid is determined by CTs that monitor all three inverters at once at the PV disconnect, marked as AC DISCONNECT VISIBLE. The CT measurement is shared across all three inverters. The inverters are all connected at a common AC bus marked as PV SUBPANEL before the AC DISCONNECT VISIBLE where the inverter CTs are installed.

Thus, it is possible for power from one inverter to be delivered to another inverter without having to pass through the common CT metering point. This reality seems to be recognized by the inverters. (See Figure 11.)

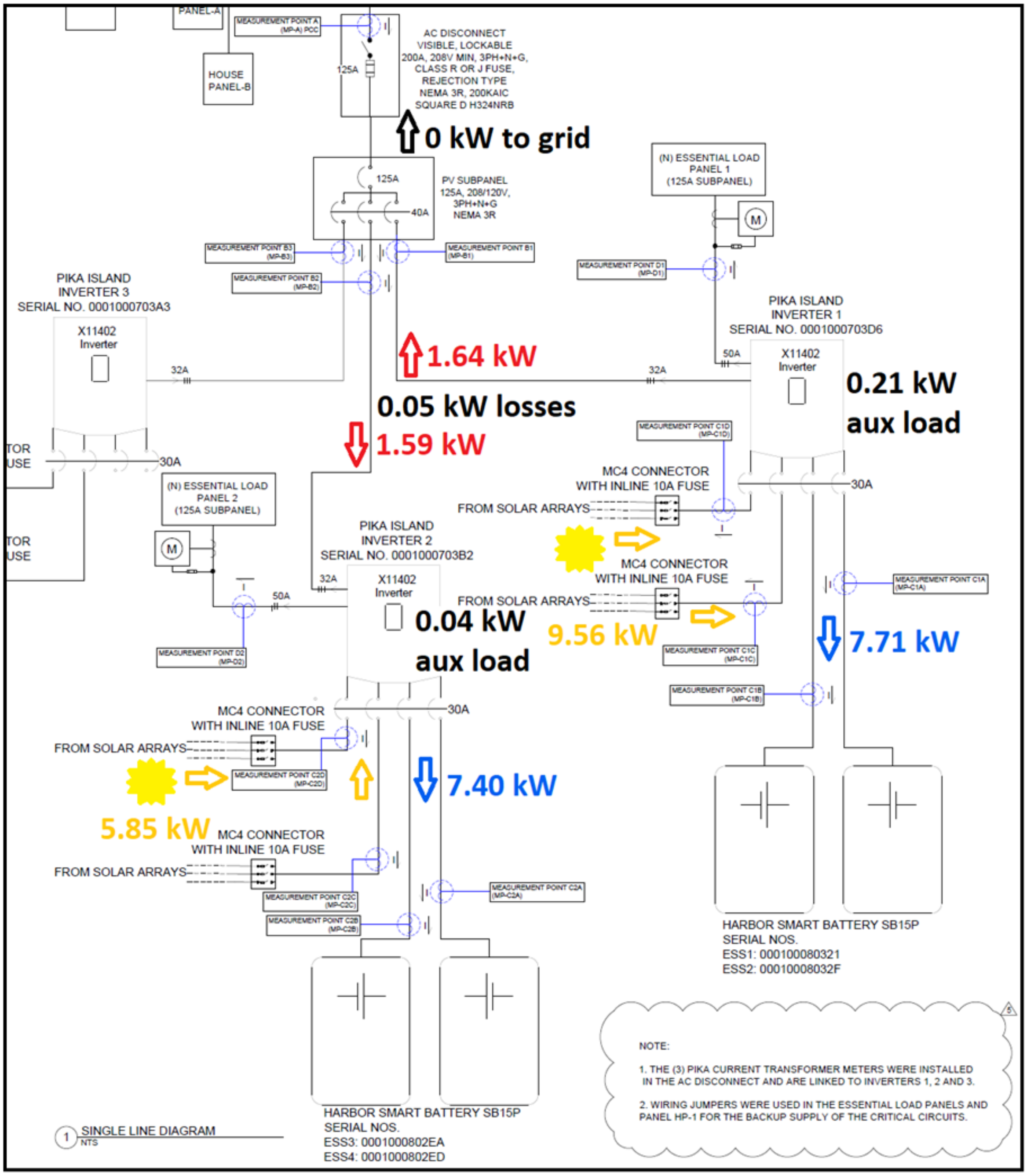


FIGURE 11. SOLAR POWER GENERATED ON THE PV PANELS OF INV1 IS DELIVERED TO CHARGE THE BATTERIES OF INV2

On both inverters, the bottom right corner icon is the grid, and the display indicates 0.00 kW, meaning power is not being exported nor imported. The top right icon is colloquially known by the installer as the house, and for INV1, power was being leaving/being exported by the inverter, going to the house icon at 1.64 kW. For example, in Figure 12, this is inferred by seeing that 9.56 kW is being produced by the solar PV yet only 7.71 kW is being charged to the batteries of INV1.

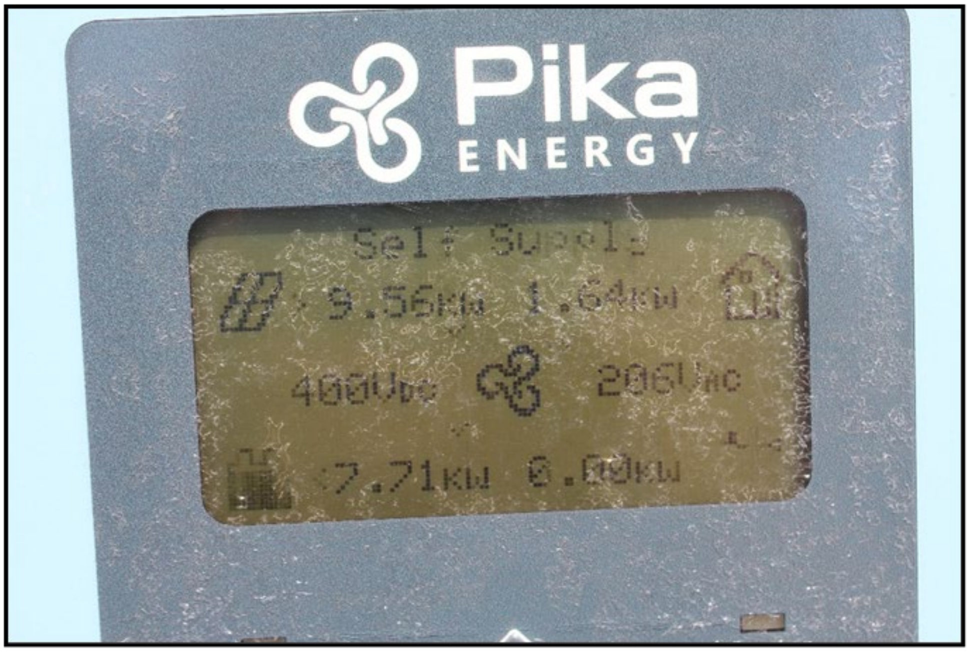


FIGURE 12. INVERTER 1 (INV1) SENDING SOLAR PV TO INVERTER 2 (INV2)

Complementarily, Figure 13 shows INV2 taking 1.59 kW from the house and 5.85 kW of the PV production to pour in 7.40 kW to the batteries of INV2. Initially, this appeared to constitute a test failure, because it could be thought that the batteries on INV2 were pulling in power through the inverter and charging from the grid. However, in fact the system was passing the test, because the inverters were taking advantage of the common CT metering point to share PV power production to charge up the installation's set of batteries equally.

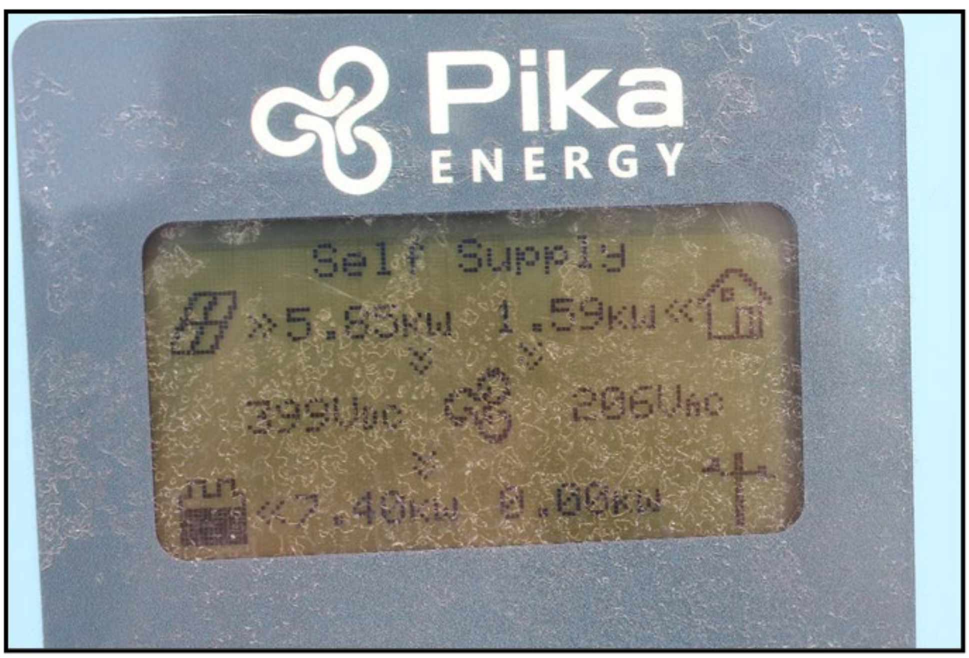


FIGURE 13. INVERTER 2 (INV2) RECEIVING SOLAR PV FROM INVERTER 1 (INV1)

Conclusions

Over the course of the commissioning and subsequent operation of the system, the research team has provided various observations and recommendations.

Having a vendor-provided commissioning test plan is highly valuable in verifying the proper operation of the system especially during on-site testing. However, on-site testing, though thorough and certainly beneficial, is a time-consuming process and does not scale well. The development of remote control and properly monitored and metered system could make way for an automated testing and commissioning verification. To do this, a clear commissioning process and recommendations must be developed and clearly communicated to technology providers and installers.

Moreover, during the installation, commissioning, or site visits, proper photo documentation should be taken of all system components and should clearly show how equipment is connected and work together, if possible. The accuracy of documentation should also extend to diagrams and technical drawings, which needed to be updated and sent to site managers and relevant parties for quick access and reference. The importance of up-to-date, and easily accessible documentation cannot be over-stressed, as they aid every party in accuracy and clarity of communication, which then speeds up correspondence and task execution.

Lastly, where possible, utility resources should be leveraged to further validate and accurately monitor the proper operation of the system. This means using utility AMI meters and their data to track and monitoring system performance and operation. To do this, enough meter heads need to be installed for the utility to get a clear and comprehensive dataset on the site. In Mosaic Gardens at Pomona, a number of meter head sockets were installed, but few, if any, of the sockets had any meters actually installed in them. The importance of the data validation and monitoring battery and inverter operation should be evaluated. Subsequently, resources should be allocated accordingly.

Photographic Record

Figures 14–24 were gathered by project participants in the course of conducting this work. They illustrate the in-situ placement of controls, measurement devices, and the BESS and inverter equipment.

FIGURE 14. ESSENTIAL LOADS BACKUP PANEL (LEFT) AND PIKA HARBOR SMART BATTERIES (RIGHT)

FIGURE 15. UTILITY SOLAR PV DISCONNECT (CENTER) AND JUMPERED METER SOCKET (RIGHT)

FIGURE 16. INVERTER 1 LID IS OPEN AND INVERTER 2 LID IS CLOSED

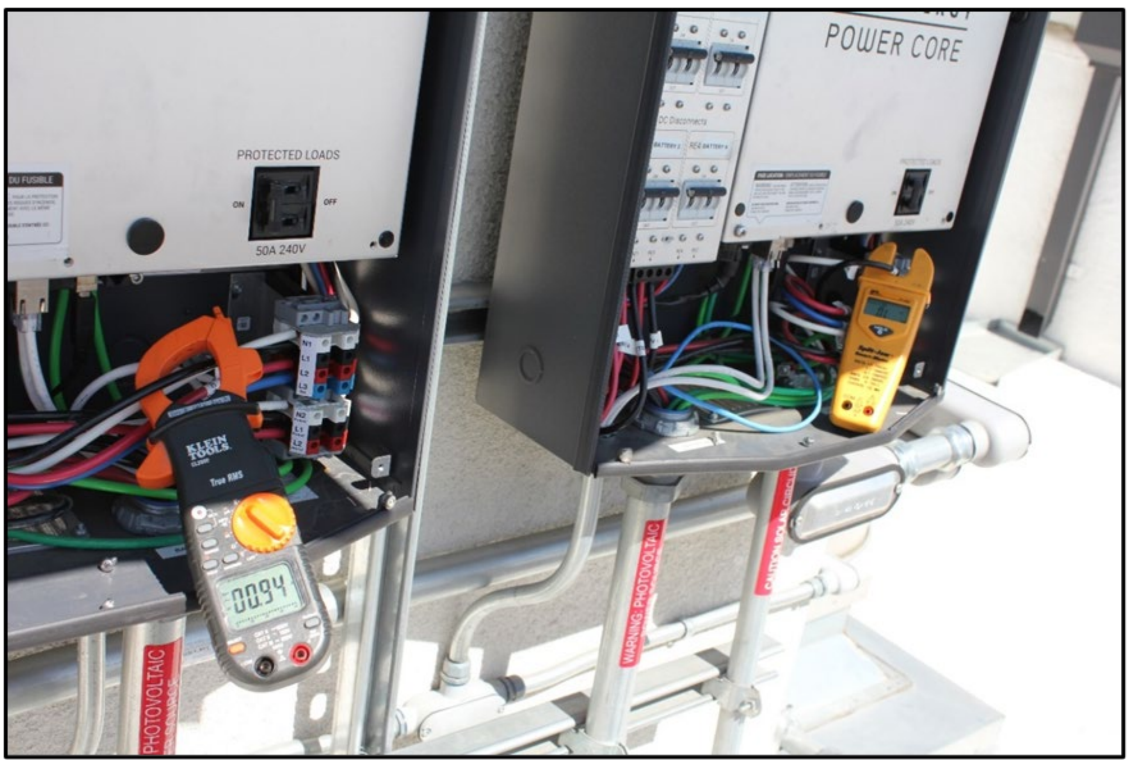


FIGURE 17. MEASURING AND RECORDING CURRENT VALUES DURING COMMISSIONING TESTING

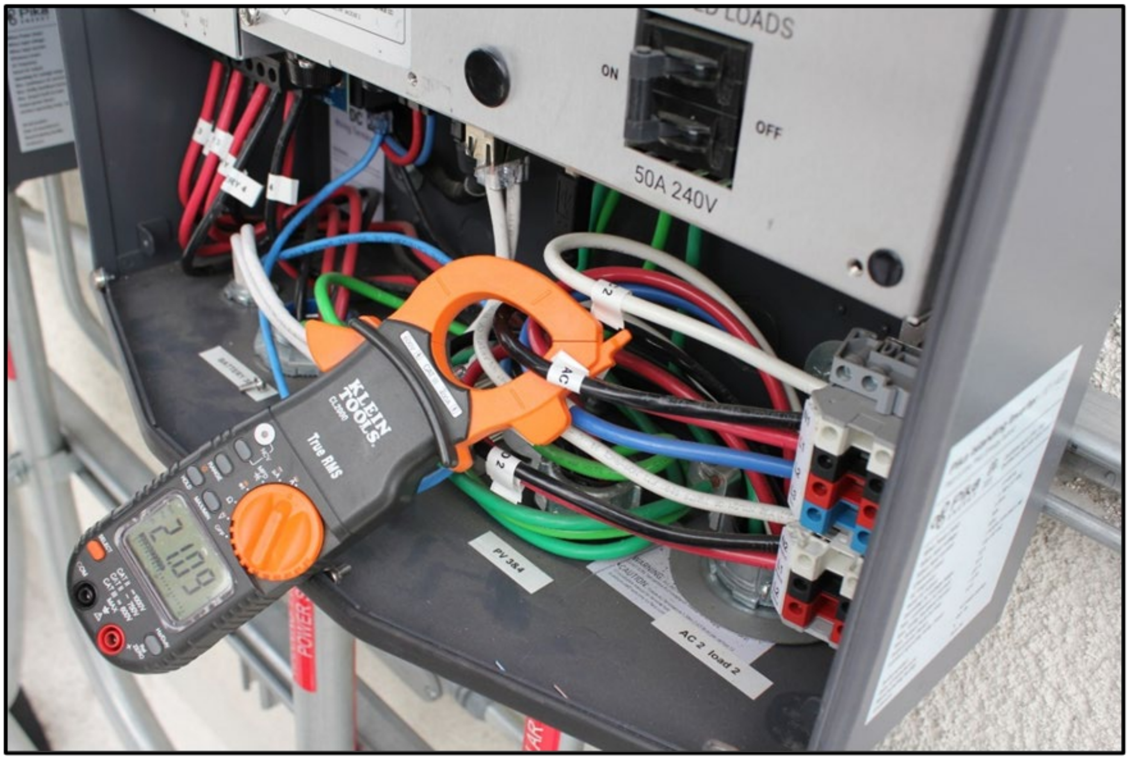


FIGURE 18. TERMINALS FOR DC-COUPLED SYSTEM. BATTERIES AND SOLAR PV (LEFT). GRID AND ESSENTIAL LOADS BACKUP (RIGHT).

FIGURE 19. PIKA REBUS BEACON HARDWARE USED FOR GENERAC-ONLY REMOTE COMMANDING

FIGURE 20. INVERTER 1 DISPLAYING INDICATING CHARGE CONTROLLER HARDWARE

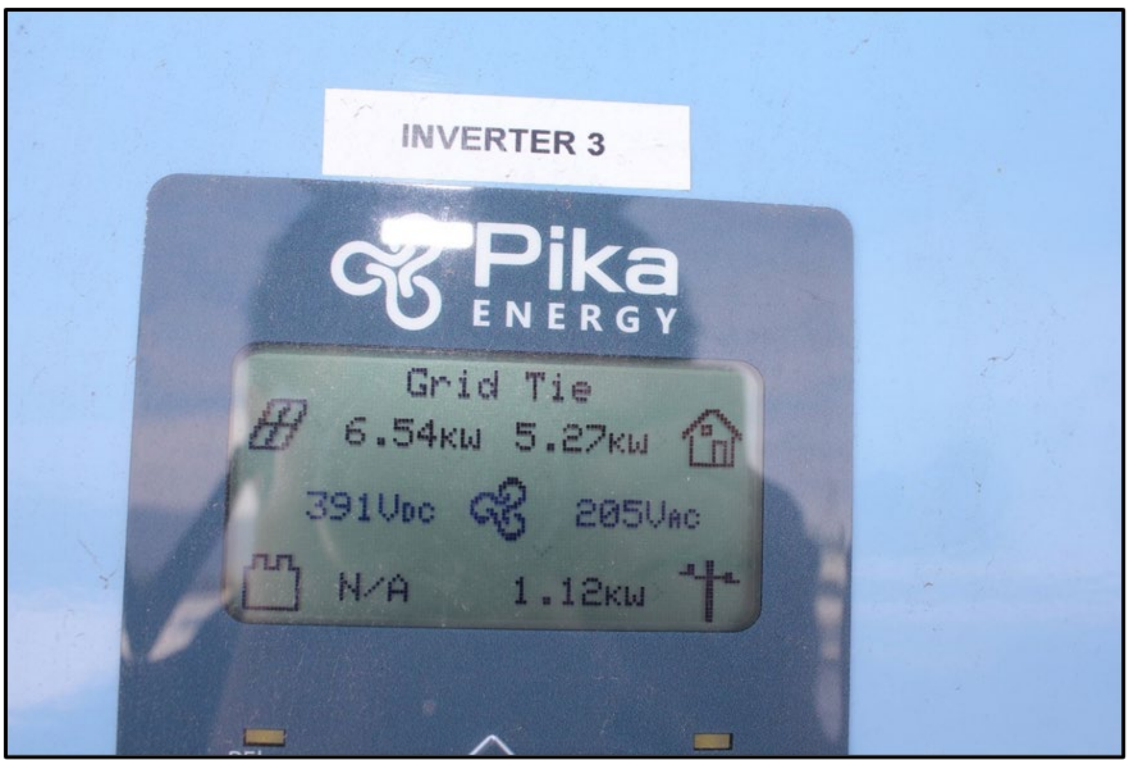


FIGURE 21. INVERTER 3 IS SOLAR-ONLY, HAS NO BATTERIES, AND OPERATES IN GRID TIE MODE

FIGURE 22. INVERTER NAMEPLATE STICKER AND INFORMATION

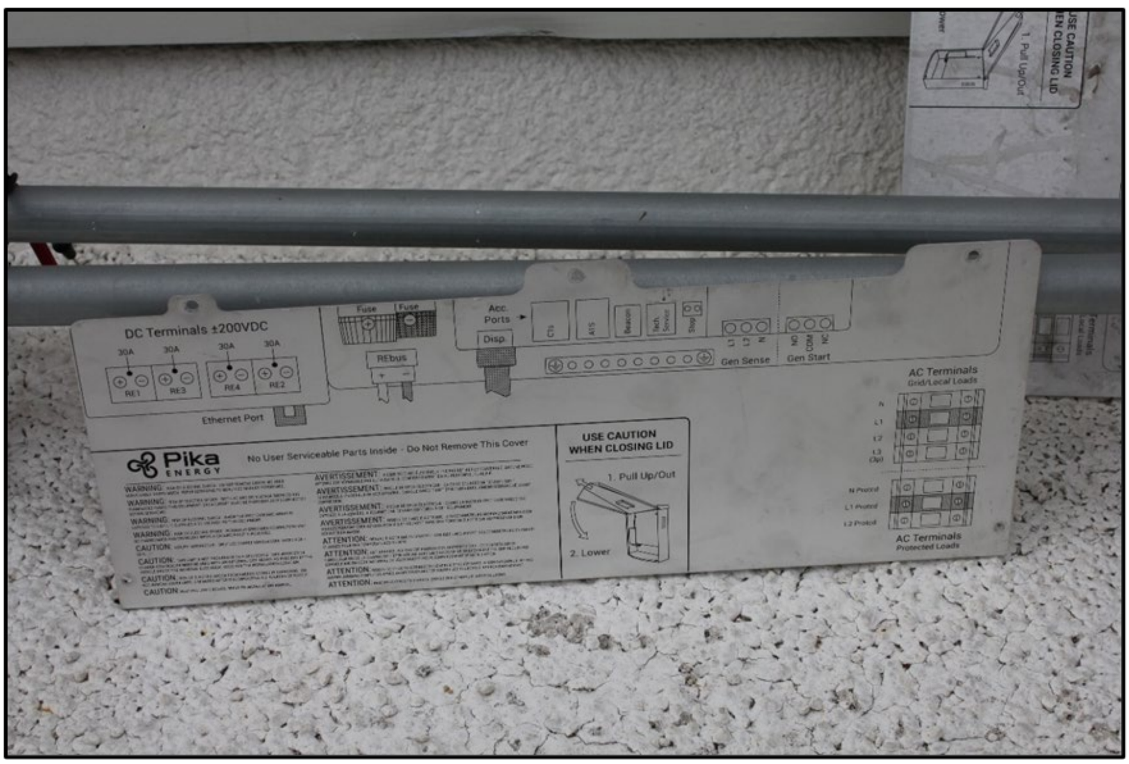


FIGURE 23. TERMINAL ACCESS COVER ALSO DOUBLES AS LAYOUT DIAGRAM/SCHEMATIC

FIGURE 24. BOTH BATTERY INVERTERS WITH OPEN LID COVERS WITH CONDUIT HARDWARE DISPLAYED

PDF attachments:

1. Permission to Operate
2. Test Plan and Commissioning Documents
3. Electrical System Single Line Diagram for Mosaic Gardens Pomona
4. Single Line Diagram for Solar Battery and Monitoring

APPENDIX D: SOLAR AND INTERCONNECTION

OVERVIEW

This appendix addresses EPRI's efforts to complete the SCE interconnection process and obtain permission to operate this solar-plus-storage project. Through the efforts and assistance of project partners Kliewer and Associates, equipment installers Promise Energy, and product provider Generac, the PTO was obtained in January 2020 following a series of discussions, demonstrations, and exchanges of documentation, which are outlined here.

TIMELINE

2017

Approved NEM interconnection agreement acknowledges solar, not energy storage

The solar PV system was installed at the same time as initial building construction

Q2 2019

Pika Energy Island installed at Linc Housing's Mosaic Gardens at Pomona

DC-coupled, solar + storage replaces previous non-battery system

Q3 2019

SCE requests EPRI, K&A to engage Promise to secure PTO for NEM agreement

Generac acquires Pika Energy affecting status of open action items with Pika

Q4 2019

Generac delivers interconnection test plan to SCE and following review is approved

Team performs preliminary inspection of Pomona facility ahead of testing

Q1 2020

Following review and demonstration of another Pika installation, SCE issues PTO

K&A, Promise, EPRI on site to execute test plan and complete system commissioning

BUILDING CONSTRUCTION AND SOLAR PV INSTALLATION

Prior to the installation of the Pika Energy Island, now Generac PWRcell, Linc Housing's Mosaic Gardens at Pomona apartment complex had already installed the 33.6 kW rooftop solar PV system under a Net Energy Metering (NEM) Interconnection Agreement approved in June 2017. This agreement made no mention of the eventual installation of battery energy storage at the site. The solar PV system was installed at the same time as initial building construction, completed in late 2017.

This NEM interconnection agreement identifies the site as a Generating Facility, referring to the power generating ability of the site's rooftop solar PV. It also requires that the system adhere to IEEE Standard 929, UL Standard 1741, and SCE Electric Rule 21.

ENERGY STORAGE PERMITTING AND INSTALLATION

Afterward, efforts for the installation battery energy storage system began in earnest and culminated in the selection of the Pika Energy Island. Pika inverters, capable of accepting solar PV and batteries, would replace the SolarEdge inverters that had already been installed but were only able to accept solar PV.

Following the permitting and installation of three (3) Pika Islanding Inverter X11402 (also known as the Generac Model APKE00013) and four (4) Pika Harbor Smart Battery SB15P (also known as the Generac PWRcell 15) in Q2 2019, efforts began to finalize the interconnection of these distributed energy resources and obtain permission to operate the equipment. The SCE interconnection group required that the installer, Promise Energy, and product provider, Pika Energy, demonstrate that the installation complied with Rule 21 and NEM 2.0.

COMMISSIONING DELAYS AND TEST PLAN DEVELOPMENT

However, the recent acquisition of Pika by large generator producer Generac in July 2019 introduced delays in the interconnection process. Thus, in Q3 2019, the SCE emerging technology group requested EPRI and K&A to assist in the interconnection and PTO process, in preparation for future analysis and operational testing of the solar-plus-storage system at the site in Pomona, CA.

In Q4 2019, the SCE interconnection group was awaiting a solar and storage test plan to approve. SCE was primarily seeking a test plan that would provide sufficient proof that the battery would not charge directly from the grid, only from the on-site solar. Upon approval of this test plan, SCE interconnection team would come in person to witness this system's or another Generac installation in SCE service territory) operation and testing.

Generac and Promise Energy had communicated with SCE regarding the development of the test plan and they were given a test plan template and tasked with developing a simple test plan to ensure the no-import constraint on the battery would be met.

EPRI and K&A began to engage Promise Energy and Generac representatives to facilitate communication and align objectives with SCE as well as to prepare gaining access to system dashboard, inverter controls, and battery and solar data.

By December 2019, the SCE interconnection group had received the Generac-developed and Promise-reviewed test plan via submission on the PowerClerk portal. SCE had commented and requested edits to the test plan, which Generac later added to and revised. The primary requirement requested by SCE interconnection group was to demonstrate that the system would only charge the battery using power from the solar PV panels via the implementation of custom firmware and controls.

Also, Generac determined that Pika-specific CTs were needed for the inverters in order for the inverter controls to function properly, which they then sent to Promise Energy to install on all three inverters.

PERMISSION TO OPERATION OBTAINED AND SYSTEM STARTUP

In late January 2020, after witnessing in person the successful operation and testing of the no-grid export and no-grid import for battery charging at another Generac installation in SCE service territory, the solar-plus-storage project at Linc Housing's Mosaic Gardens at Pomona obtained permission to operate from the SCE interconnection group.

Some additional work was completed prior to commissioning: the essential loads backup panels were installed and loads transferred, and meter jumpers were installed in previously blank meter head sockets.

In early March 2020, the battery and solar system was commissioned via the SCE-approved Generac test plan. Measurements were recorded and all tests were shown to be passing. See Appendix C for details of the commissioning procedures and test results.

DOCUMENTATION

The original NEM agreement, the test plan as reviewed by SCE, and the final Permission to Operate are appended here, for reference.

1. Net Energy Agreement
2. SCE-Reviewed Test Plan
3. Permission to Operate