CALIFORNIA
ENERGY COMMISSION

CALIFORNIA
NATURAL
RESOURCES
AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Integrating Building-Scale Solar + Storage Advanced Technologies to Maximize Value to Customer and the Distribution Grid

March 2024 | CEC-500-2024-018

PREPARED BY:

Peng Zhao
Viswanath Ananth
David Eskinazi
Sunil Chhaya
Corey Shono
Siva Sankaranarayanan
Electric Power Research Institute (EPRI)
Primary Authors

Eric Ritter
Project Manager
California Energy Commission

Agreement Number: EPC-17-005

Kevin Uy
Branch Manager
ENERGY SUPPLY BRANCH

Jonah Steinbuck, Ph.D.
Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission (CEC). It does not necessarily represent the views of the CEC, its employees, or the State of California. The CEC, the State of California, its employees, contractors, and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the CEC, nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

The authors thank:

- Elise Ersoy, The California Energy Commission
- Lily Gin, Pacific Gas and Electric
- Joe Barton & Jason Lewis, Boy Scouts of America
- Adam Yeomans, American Red Cross
- Vipul Gore, Mark Ariello, and, Dhruvin Patel, GridScape Solutions
- Bob Chaudhuri, First Edison
- Rich Fox, InTech Energy
- George Hernandez, R&B Technology Group

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Solar+: Integrating Building-Scale Solar + Storage Advanced Technologies to Maximize Value to Customer and the Distribution Grid is the final report for the project (EPC 17-005) conducted by The Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

This project assessed the performance and benefits of integrated solar photovoltaic, battery storage, and microgrid control technologies for small commercial buildings. A standard solution was developed in which solar + storage is improved with flexible load control to reduce capital, operating, and management costs while supporting distribution grid functions. While COVID-19 and other external factors constrained accomplishing the project’s full objectives, this solution establishes a basis to replicate for similar buildings across the state.

The project developed and validated the open building autonomous tuning system or OpenBATS, an open-source software employed to simulate operations at a field demonstration site. Artificial intelligence/machine language (AI/ML) data-based algorithm was added and trained to minimize cost. The electric bill and simulation results showed significant energy and demand charge reductions for three more rigorous control cases (compared to baseline). The operations optimization, however, using AI/ML offered a cost reduction only slightly better than that of simple rule-based controls.

Keywords: solar, storage, demand flexibility, commercial building, distributed energy resources, interconnection, Rule 21, DER, time-of-use, TOU, demand response, DR, controls, artificial intelligence, AI, machine learning, ML, Grid-interactive Efficient Building, GEB

Please use the following citation for this report:

Zhao, Peng. Viswanath Ananth, David Eskinazi, Sunil Chhaya, Corey Shono, Siva Sankaranarayanan. 2024. *Solar +: Integrating Building-Scale Solar + Storage Advanced Technologies to Maximize Value to Customer and the Distribution Grid*. California Energy Commission: Publication Number: CEC-500-2024-018.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Customer-owned behind-the-meter solar photovoltaic systems have been an important part of California’s energy transition, powering building loads with clean energy and feeding power back onto the distribution grid during times of excess solar generation. However, as more building owners install these systems, uncoordinated backflow of solar energy onto the distribution system could negatively impact grid stability and reliability. Utilities’ immediate response to this issue has been to require ‘smart’ inverters that curtail renewable energy production during periods of excess renewables supply. This is resulting in a slowdown of renewable penetration because the installed base of renewable generation cannot be fully exploited.

A potential solution to this problem is adding an onsite battery energy storage system and proactively managing building loads to reduce solar curtailment. One can think of such an integrated installation as a unit where storage and flexible loads are two “knobs” that system operators turn to shift or shed loads. Reshaping the building load profile in this way optimizes the use of solar energy when it is available. Managing a range of energy assets, responding to changing ambient and grid conditions, saving energy, avoiding peak demand charge penalties, and meeting changing occupant needs present challenging optimization and coordination problems. Although these systems may offer benefits to the distribution grid, the additional capital expense involved may be uneconomical for building owners considering installing solar. Demonstrations were needed to assess the economic tradeoffs and measure the other potential benefits including peak power reduction potential, increased resiliency, grid-side advantages, and environmental benefits.

Project Purpose and Approach

This project assessed the performance and benefits of integrated solar photovoltaic + battery storage + microgrid control technologies for a small commercial building. The project team developed a standard, repeatable solution in which solar + storage is co-optimized with flexible load control to reduce electricity costs for an individual building while supporting distribution grid functions. The team designed and validated an open building autonomous tuning system, called OpenBATS, a supervisory controller that oversaw the operation of solar + storage + flexible load management. The team set up a field demonstration by installing a solar photovoltaic system with battery storage at a small commercial building followed by a case study simulation.

The field demonstration site was a small, single-story office building, owned by the Boy Scouts of America, and located in a disadvantaged community in San Leandro, California. Constructed in 2001, the building occupies 23,425 square feet of space on 1,234 acres of land accommodating 65 parking spaces. The installed system combined high-efficiency solar photovoltaic panels with battery energy storage managed through a microgrid controller that interconnects with the distribution grid.

After analyzing the physical layout, financial considerations, and load characteristics for the demonstration site, the project team chose a battery size of 64 kilowatt hours (kWh) with a

rated power of 29kW and a solar photovoltaic size of 75kW. This was viewed as optimal, as over-or under-sizing the battery can degrade storage capacity and shorten lifespan.

The project team planned to collect field data from the demonstration site to support a cost-reduction analysis. However, several significant external factors occurred shortly after the integrated system was installed that delayed the project's monitoring period and negatively impacted the field demonstration results. In March 2020, the city/county issued "shelter-in-place" order due to COVID-19 that closed the host site building. This prevented data collection under normal conditions. In June 2021, the host site building was closed in anticipation of building sale which was completed in August 2021. It remained vacant while the new owner considered and implemented repurposing changes through the full test period eliminating the opportunity for any data collection under normal conditions.

The project team responded to these challenges by conducting artificial intelligence-based data modeling of site operations. OpenBATS was used to simulate operations at the field demonstration site. The OpenBATS system was enhanced with a machine-learning algorithm programmed to minimize cost. Predictions of energy use included total import power, export power, and peak consumption for May 2021. The team used OpenBATS to predict the historical data and compared four case studies:

- Case 1: Baseline: No solar, no storage.
- Case 2: Solar only.
- Case 3: Solar combined with storage using a rule-based, fixed schedule algorithm.
- Case 4: Solar combined with storage using a data-based cost reduction optimization algorithm employing artificial intelligence/machine language to predict constraints for the day ahead.

The simulated cost analysis is based on Pacific Gas and Electric's medium commercial building B-10S rate and demand charges.

Key Results

As expected for the baseline (Case 1), power consumption is always positive and represents the highest cost to the user compared to the other cases. Adding solar (Cases 2–4) generates excess energy to sell to the distribution grid, reducing costs.

The cost optimized schedule (Case 4) offers the maximum benefit to customers. It reduces peak consumption and exports more power to the distribution grid than other cases, for a better return on investment.

Still, the data-based optimized schedule (Case 4) delivered only a marginal reduction in peak consumption compared to the rule-based fixed schedule (Case 3). This may be because the May 2021 data required Pacific Gas and Electric's winter, higher time-of-use rate in the analysis.

Other successful results included:

- OpenBATS is a significant improvement over traditional heat transfer calculation-based approaches to optimize performance, reduce manual data collection/input, and is readily transferrable to other building applications. This algorithm is available on GitHub Inc. for interested developers to use and improve.
- Integrating solar + storage + flexible load management can reduce the electric bill for small commercial buildings.
- This project demonstrated the opportunity to maximizing benefits to the customer. The electric utility has better ways through planning and operation to maximize benefits to the grid.

Beyond the successes communicated above, several additional lessons were learned including the following:

- Interconnection options can be complex and either incomplete or unclear. Engaging utility and city personnel early on is helpful, as the approval process can take time. Pay particular attention to battery power export requirements.
- It’s important to proactively seek and understand available incentive programs to support any project. The incentive programs can be complex to decipher.
- A dedicated construction manager should be assigned, as with any significant construction project to ensure weekly progress meetings, proactive management of permitting and the maintenance of the overall schedule.
- Ensure the load estimates used to size the combined solar + storage system reflects current operating conditions. Develop scalable use cases for successful laboratory and field tests of islanding and reclosers. Understand that adequate data are the key to system optimization artificial intelligence/machine language. Identify the effects of parameters on training and prediction. Test more than one type of optimization model to find the best performance.

Knowledge Transfer and Next Steps

The project team consulted regularly with a Technical Advisory Committee that included a cross section of relevant market players, representing utilities, government, research, and industry across the United States. As part of their committee charge, the attendees provided feedback and steering to the project team based on their technical or market expertise.

The project team presented learnings from the project in all spring and fall meetings from 2021 and 2022. The project team also presented details about the project at numerous industry conferences that are listed in more detail in Appendix B.

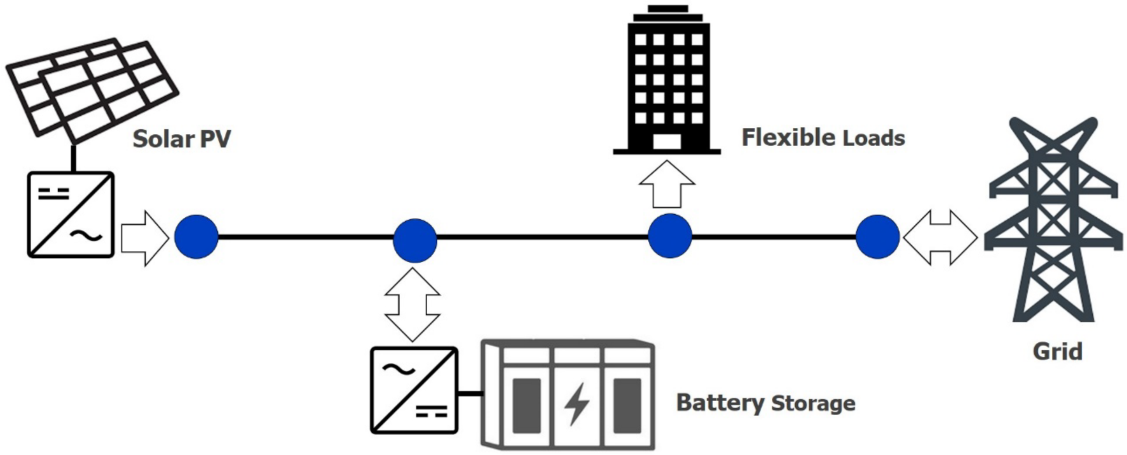
CHAPTER 1: Introduction

If a small commercial business owner already has solar panels and is considering adding battery storage and a microgrid controller, how would they determine what their cost savings would be and how would they go about setting the system up for optimum performance? This report aims to help answer these questions by documenting the results of a field demonstration and a subsequent case study simulation at a small commercial building in San Leandro, California.

The purpose of this project was to assess the performance and benefits of integrated solar photovoltaic (PV) + battery storage + microgrid control technologies for small commercial buildings. The project team developed a standard, repeatable solution in which solar + storage is co-optimized with flexible load control to reduce costs for individual buildings while supporting distribution grid functions.

One can think of the integrated system (Figure 1) as a unit where storage and flexible loads are two "knobs" that system operators turn to shift or shed loads. Reshaping the building load profile in this way optimizes solar energy use when it is available.

Figure 1: Schematic of Building-Scale System Integration



Source: EPRI

When the project began in 2016, solar installations were a popular response for meeting California's renewable energy portfolio objectives. Some owners also decided to install storage batteries in their buildings, but very few thought of coordinating them with solar to optimize benefits. Then, it was difficult to find a site for the field demonstration. Now, solar + storage + microgrid controller installations are much more common and offer an answer to concerns about the impact of uncoordinated distributed energy resource (DER) installations on distribution grid stability and reliability.

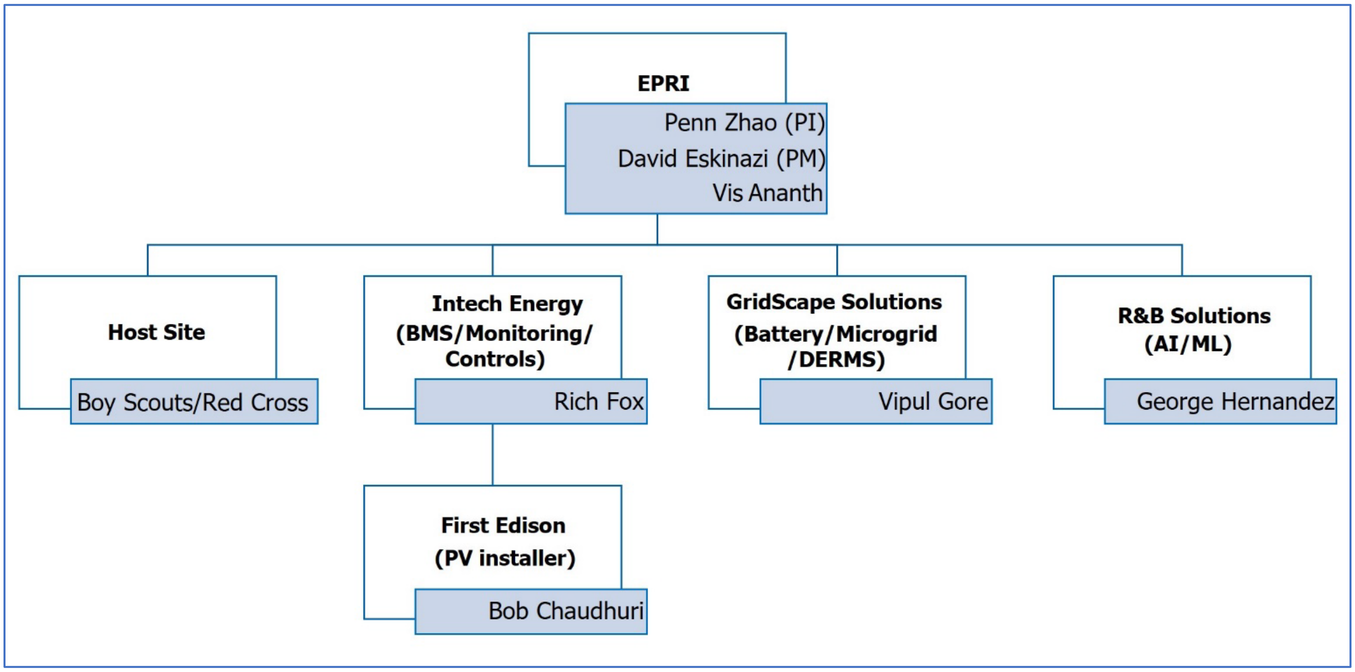
The system design features affordable, commercially available components and employs advanced energy efficiency and demand response technologies. Complete disconnection from the distribution grid produces a "microgrid" or "island."

Managing a range of energy assets, responding to changing ambient and grid conditions, saving energy, avoiding peak demand charge penalties, and meeting changing occupant needs present challenging optimization and coordination problems. Tackling these tasks requires advanced supervisory control, supported by sensing, modeling, and data analytics.

The project team addressed these challenges by developing the open building autonomous tuning system (OpenBATS), an advanced supervisory control software that simulates integrated systems by coordinating solar, storage, and flexible loads through the use of real-time data and artificial intelligence/machine language (AI/ML) modeling. OpenBATS supports scaling for optimized solutions and avoids the need to customize energy modeling for every building.

Members of the project team cluster in Figure 2.

Figure 2: Project Organization Chart



Source: EPRI

CHAPTER 2:
Field Demonstration

Approach

Site Selection

To select a demonstration site, the team reviewed seven buildings, all located within the service area of the Pacific Gas and Electric Company (PG&E). The chosen small commercial building offered several advantages:

- It was in a disadvantaged community[1] where local businesses and citizens could benefit from knowledge of and access to advanced renewable energy technology.
- It met important requirements for installing and operating a building-scale solar + storage system. The roof area was flat with no shade from adjacent trees or structures. A secure indoor electrical room was available to house the storage battery, inverters, microgrid controller, and transformers needed for the project.
- There was an enthusiastic building manager on site.
- The owners supported the demonstration and looked forward to a reduced energy bill resulting from the research.

Site Description

The demonstration site was a single-story office building located in San Leandro, California (Figure 3). Constructed in 2001, the building occupies 23,425 square feet of space on 1,234 acres of land accommodating 65 parking spaces. When research began, the Boy Scouts of America (BSA) San Francisco Bay Area Council owned and operated the building. The project team used Helioscope software to design the optimal configuration for panel placement and generate detailed drawings for their rooftop installation.

---

[1] The project site owner accepted a $29,253 incentive from the Self-Generation Incentive Program (SGIP) for location of the site in a disadvantaged community and the size of the battery installed. The SGIP is offered by the California Public Utilities Commission and California's Investor-Owned Utilities (IOUs) to provide incentives for customer-side distributed energy systems.

Figure 3: Aerial View of Demonstration Site

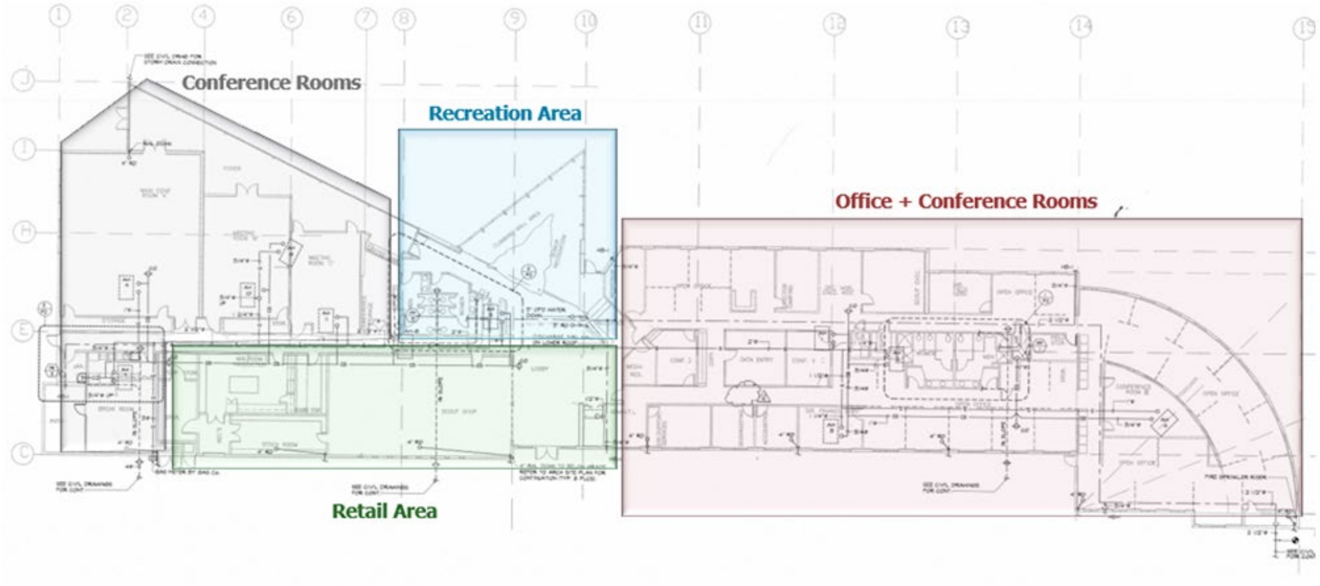
Photo Credit: InTech Energy

The floor plan of the demonstration site (Figure 4) shows four major areas:

- Small offices and conference rooms—heavily used during the week by BSA employees but largely empty on weekends.
- Large conference rooms—heavily used on the weekend to host activities for boy scouts who filled the rooms to capacity, but quiet during the week.
- A retail facility—open seven days a week, with heaviest traffic on the weekend.
- A recreational facility—open seven days a week, with heaviest use on the weekend.

The most efficient and cost-effective plan for energy use in the building must take these patterns of activity into account. The project team used Helioscope software to design the optimal configuration for panel placement and generate detailed drawings for their rooftop installation.

Figure 4: Floor Plan of Demonstration Site



Source: Boy Scouts of America San Francisco Bay Area Council

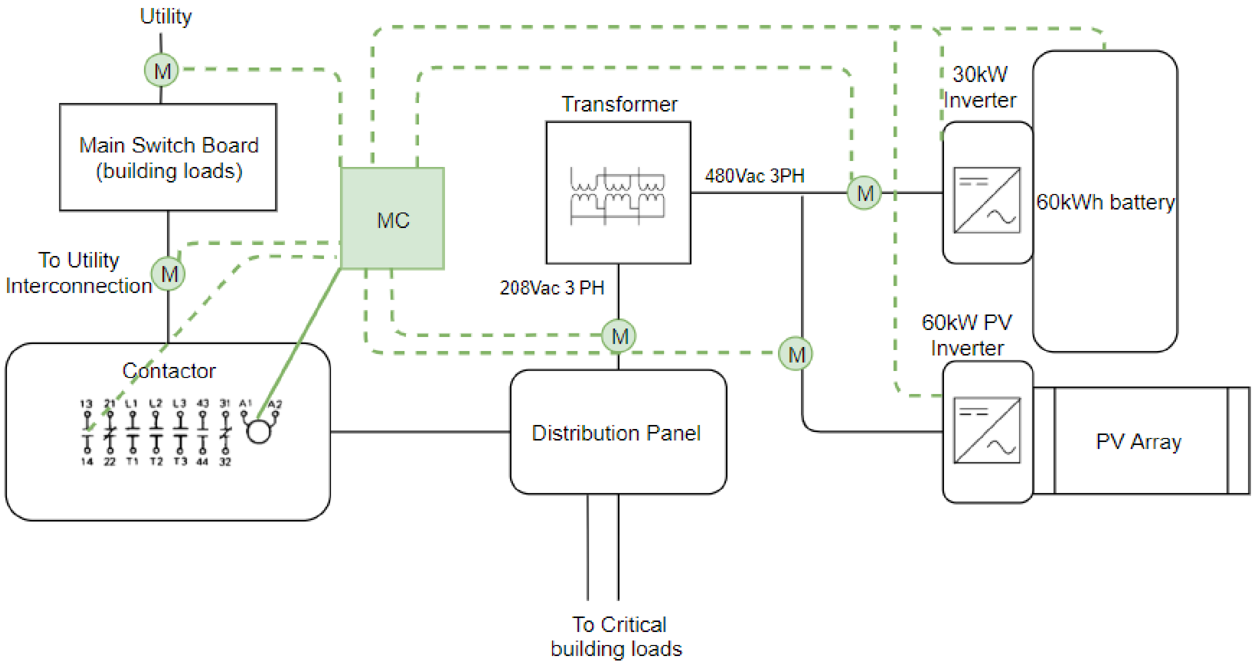
Important External Factors Affecting Data Collection

Data collection commenced with standard operation (no solar, no storage) on May 2019 and continued until March 2020 when the county issued a COVID "shelter in place" order and, in compliance, the BSA vacated the building. The COVID-prompted vacated building data collection continued until the Fall 2020. During this time, building loads were low/near zero, atypical of normal operation. In the Fall 2020, the building reopened but with limited occupancy due to continuing COVID concerns combined with BSA layoffs during the shutdown period. Solar + storage operation began February 2021 when PG&E approved the interconnection application. Data collection, with solar+storage continued, albeit with a nearly vacant building, until June 2021 when the BSA closed the building in anticipation of its sale. The American Red Cross (ARC) took ownership in August 2021 but kept the building closed to plan for facility repurposing. Data collection continued, albeit still with a vacant building, until May 2022 when the solar and storage system was shut down for safety reasons following vandalism at the site.

Integrated Solar PV + Battery Storage + Microgrid Controller

The DER system installed at the demonstration site combines high-efficiency solar PV panels with battery energy storage managed through a microgrid controller (MC) that interconnects with the distribution grid (Figure 5). The design featured affordable, commercially available components and employed advanced energy efficiency (EE) and demand response (DR) technologies. Load meters (M) are shown, placed for data acquisition.

Figure 5: Simplified Electrical One-line (black) and Communication (green) Diagram



Source: GridScape Solutions

The solar PV panels were rated at 21.1 percent efficiency with 78 kilowatts (kW) of peak power, and the AC-coupled Delta M60U solar-side inverter were installed on the rooftop of the demonstration site. One solar panel included 204 modules, each rated at 386 watts (W) (Figure 6) yielding a total of 78 kW.

Figure 6: Solar PV Panels on Rooftop

Photo Credit: EPRI

The EnergPort L3060 lithium-ion 29 kW/64.5 kilowatt hour (kWh) battery and the AC-coupled Sinexcel 29 kW battery-side inverter were housed in the electrical room of the demonstration site (Figure 7). They were accompanied by GridScape Solution's EnergyScope microgrid controller that communicates with system components and interconnects with the distribution grid. Other electrical room equipment included a transformer to convert solar panel voltage (480/27 volts [V]) to load panel voltage (120/208V), a solar subpanel, a PG&E lockable visible generator disconnect switch, a critical load distribution panel, and an eGauge circuit-level load monitor.

Figure 7: Battery Storage and Other Equipment in Electrical Room

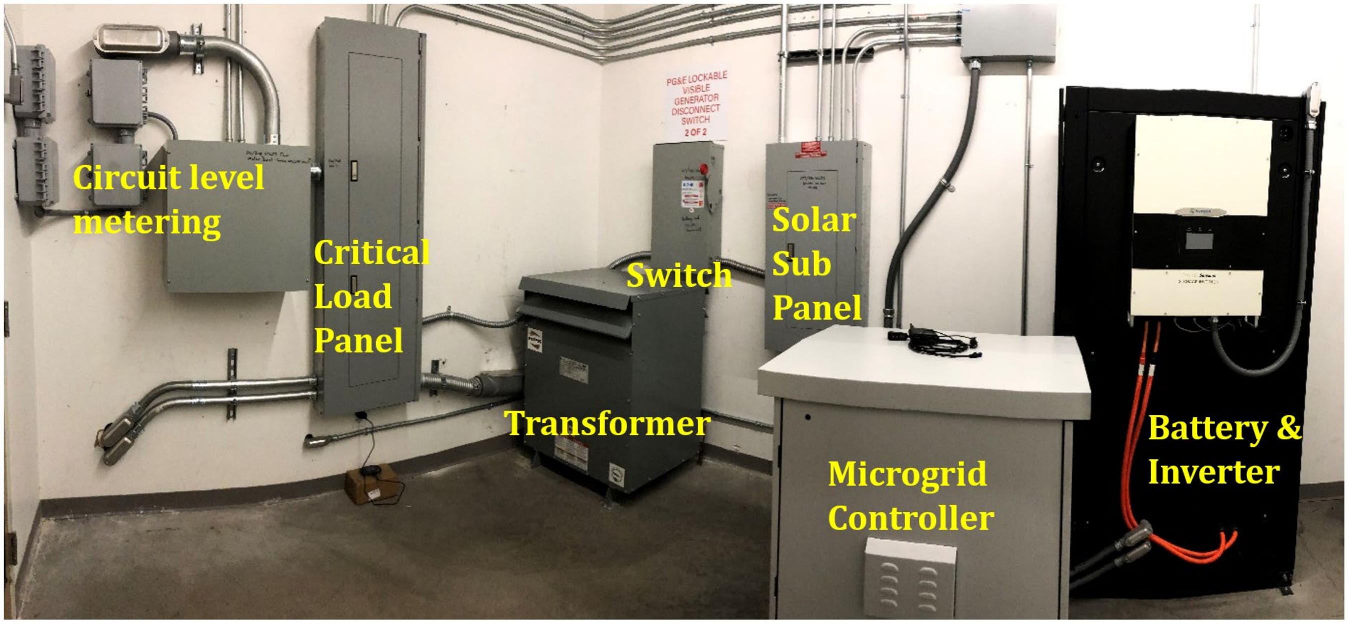


Photo Credit: EPRI

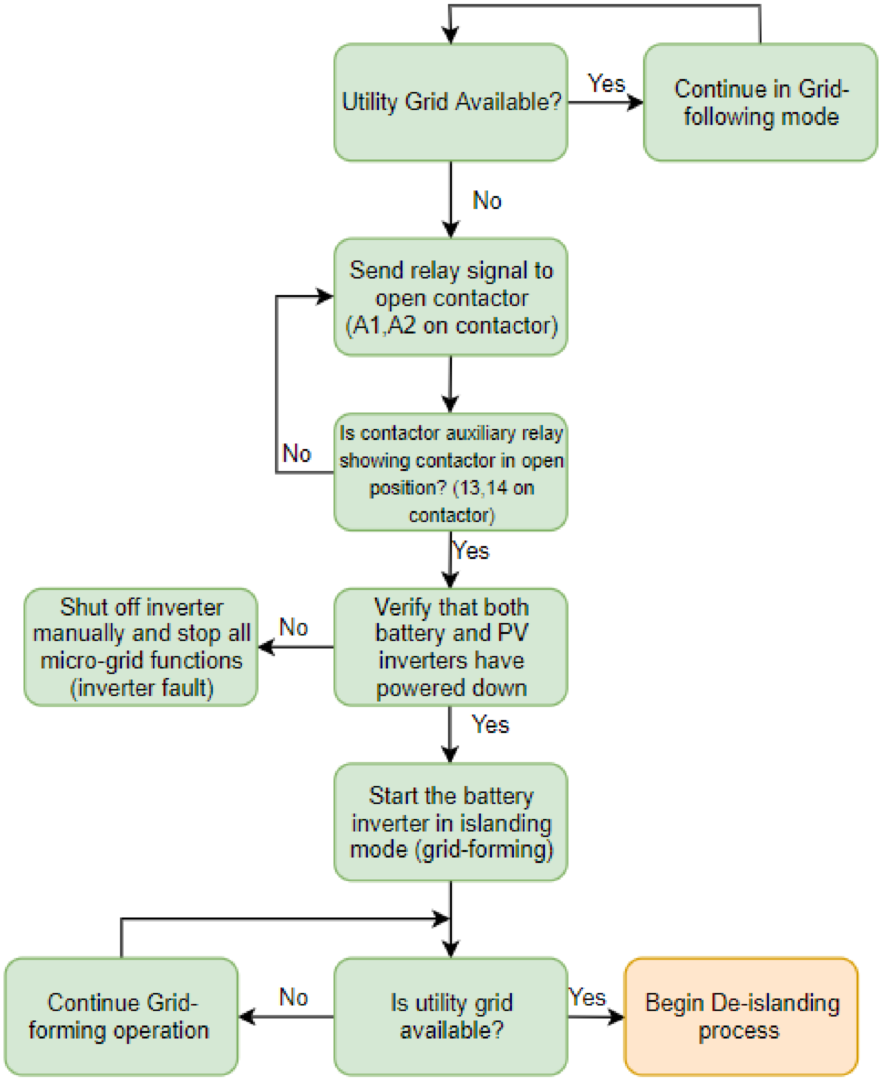
The site owner was able to choose to shift or reduce electricity use in the building in response to time-based rates or other incentives. Implementing such a DR strategy is accomplished by programming the microgrid controller to change the setpoints of networked Pelican thermostats (not shown) on a predetermined schedule.

After receiving triggering communications from system components, the microgrid controller can use the contactor (an on-off relay switch, not shown) to disconnect the building's electrical system from the distribution grid. This disconnect creates a "microgrid" or "island" that functions as a backup if the distribution grid power fails. During islanding, the critical load distribution panel feeds power to loads preselected as critical by the building owner. For example, during daytime operation, when grid power is available, the energy generated by the PV array flows through the PV side inverter into the critical load panel, and the excess energy flows through the battery side inverter either into the battery or into the grid. During power outages, the battery side inverter activates an internal transfer switch, which opens the circuit connecting to the grid, preventing the inverter from powering the grid. Then, the battery side inverter powers the PV side inverter to power the critical loads. During nighttime operation, when the PV system is not generating electricity, the energy stored in the batteries will power the critical loads panel.

Because the battery stores and supplies electricity, its bi-directional inverter can be charged from the solar installation or the distribution grid.

Figure 8 outlines the decision-making scheme to transition to microgrid islanding. This is the protocol the microgrid controller used to guide the transition. It included a vital "break before make" safety function in which the controller opens the contactor to verify disconnection from the distribution grid before starting to form the microgrid island. Later, when stable distribution grid power was restored, the controller automatically turned off power to the microgrid island and verified disconnection before starting the "de-islanding" process that returned control to the distribution grid.

Figure 8: Decision Making Scheme for Transition to Microgrid Islanding



Source: Gridscape

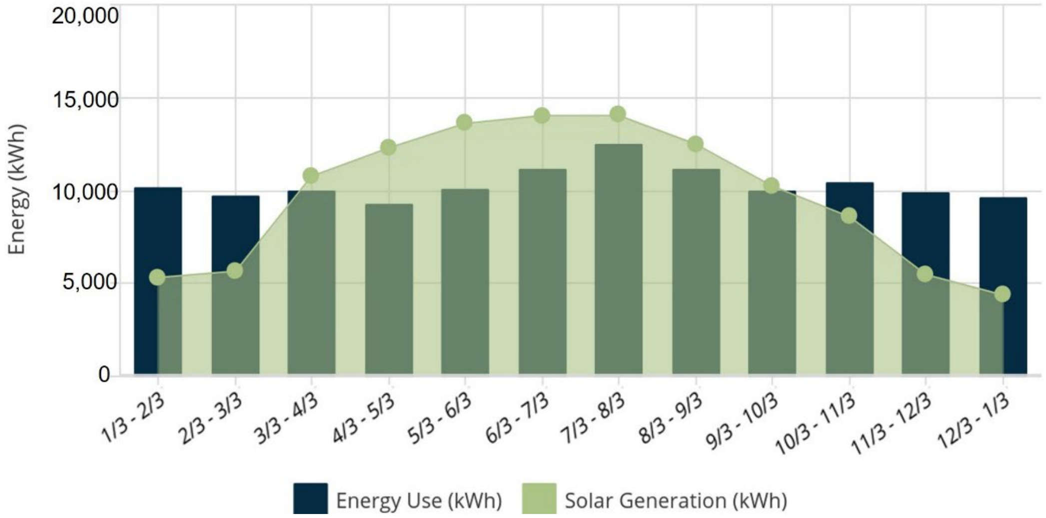
The solar + storage + microgrid controller system described above satisfied PG&E's requirements for Rule 21, Option 6, "a tariff that describes the interconnection, operating and metering requirements for generation facilities to be connected to PG&E's distribution system while protecting worker safety and grid reliability". EPRI's Single Line Diagram (Appendix A) was approved by PG&E and certified by the U.S. Occupational Safety and Health Administration (OSHA) Nationally Recognized Testing Laboratory (NRTL). For this project, the approval process took about one year. Similar projects in PG&E's service territory can now use this diagram to bypass a sometimes lengthy, case-by-case review process.

Since coordinating solar + storage produced the most efficient and cost-effective energy package for a building owner, it was important to size both components optimally for the site where they were installed. After analyzing the physical layout, financial considerations, and load characteristics of the demonstration site, the project team chose a battery size of 64kWh with a rated power of 29kW and a solar PV size of 75kW in total. Selecting the correct battery size was critical as either over- or under-sizing will degrade storage capacity and shorten lifespan. The project team chose the battery size above for the following reasons:

- The site's typical peak load of a summer day was 50 kW. A battery rated power of 29kW will be able to reduce the demand charge by more than 50 percent.
- After considering solar energy generation, the maximum required power was 26kW, which was well under the power rating of the battery system. That means the solar system could feed the entire load during the days solar power was generated.
- The battery was designed for two-hour discharge allowing to shift the peak demand to late evening hours.

Figure 9 compares the demonstration site's 2018 electric bill with a bill simulating charges after solar and storage are installed. The simulated bill predicts the energy produced beyond building needs during peak solar generation hours. This excess energy represents significant cost savings for a small business hoping to conserve cash flow.

Figure 9: Simulated Monthly Energy Use vs Solar Energy Generation



Source: inTech

Costs

The project benefitted from CEC funding to cover most equipment costs. A Self-Generation Incentive Program (SGIP) grant to paid for the microgrid demonstration. A Power Purchase Agreement (PPA) was established between the 501(c)(3) non-profit BSA (later the American Red Cross) and a commercial company, with a pre-negotiated price to purchase electricity.

Results

Tests of Microgrid Interconnections

The project team tested microgrid interconnections in the laboratory and after field installation at the demonstration site to ensure that they functioned properly and met Rule 21 requirements. Satisfactory test results were measured in number of seconds taken to make or break a connection. Tests of the microgrid controller focused on safe transitions between distribution grid control and microgrid islanding.

The following tests passed Rule 21 requirements, including:

- Battery Charging Test
- Battery Discharge Test
- Communication Failure Test
- Grid Forming Enable Signal Loss Test
- Grid to Island Changeover Test
- Island to Grid Changeover Test
- Isolation Contactor Failure Test
- Worst Case Battery Discharge Tests

Example: Grid to Island Changeover Test

The microgrid controller at the demonstration site was programmed to automatically detect distribution grid outages and safely create a microgrid island. The integrated system passed all interconnection tests and began communicating with the distribution grid. This transition from distribution grid control to microgrid islanding successfully passed this test more than 50 times.

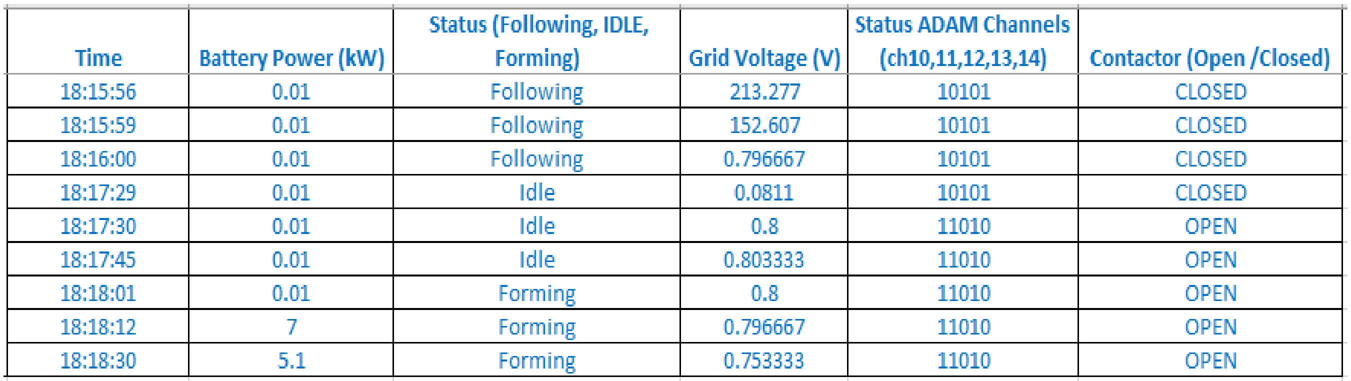
Test Procedures:

1. Ensure the system is operating in grid-tied mode.
2. Record status of all meters, relay positions and contactor position.
3. Open the main breaker in the Main Switch Board to simulate a grid outage.
4. Observe and record the status of the battery inverter and PV inverter.
5. Record status of all meters, relay positions and contactor position.
6. Verify the contactor has opened.
7. Record the duration of time from step #3 to step #6 ("Grid outage → contactor open time")
    a. Duration of time shall be a minimum of 90 seconds
8. Wait for the battery inverter to form an island.

9. Record the duration of time from step #6 to step #8 ("Contactor open → grid-forming time").
    a. Duration of time shall be a minimum of 30 seconds.
10. Record status of all meters, relay positions and contactor position.
11. Island the emergency loads for 3-5 minutes.
12. Record status of all meters, relay positions and contactor position.
13. Repeat steps #1-10 for 2–3 times.

The laboratory data in Table 1 illustrates a successful transition from distribution grid control to island formation. At 18:15:59, a distribution grid outage occurs. The grid meter voltage begins to fall to below 1V by 18:16:00. The system then waits 90 seconds before opening the contactor at 18:17:30. Mechanically interlocked relay signals change states at this time, verifying that the contactor did open. The system waits another 30 seconds before enabling the battery inverter to begin forming the microgrid at 18:18:01.

Table 1: Laboratory Test Data for Grid to Island Changeover



Time	Battery Power (kW)	Status (Following, IDLE, Forming)	Grid Voltage (V)	Status ADAM Channels (ch10,11,12,13,14)	Contactor (Open /Closed)
18:15:56	0.01	Following	213.277	10101	CLOSED
18:15:59	0.01	Following	152.607	10101	CLOSED
18:16:00	0.01	Following	0.796667	10101	CLOSED
18:17:29	0.01	Idle	0.0811	10101	CLOSED
18:17:30	0.01	Idle	0.8	11010	OPEN
18:17:45	0.01	Idle	0.803333	11010	OPEN
18:18:01	0.01	Forming	0.8	11010	OPEN
18:18:12	7	Forming	0.796667	11010	OPEN
18:18:30	5.1	Forming	0.753333	11010	OPEN

Source: Gridscape

A similar analysis of field data in Table 2 indicates that an outage occurred at 17:36:35.696 and the contactor opened at 17:38:07.013, which was roughly 92 seconds after distribution grid outage. The inverter formed the island at 17:38:39.327, which was roughly 30 seconds after the contactor opened. These data also show a successful transition from distribution grid control to microgrid island formation.

Table 2: Field Test Data for Grid to Island Changeover

Time	Battery Power (W)	Status (Following, IDLE, Forming)	Grid Voltage (V)	Status ADAM Channels (ch10,11,12,13,14)	Contactor (Open /Closed)
2020-08-18 17:36:33.706	-27854	Following	211.67	10101	CLOSE
2020-08-18 17:36:34.106	-27862	Following	211.69	10101	CLOSE
2020-08-18 17:36:34.299	-27689	Following	211.7033333	10101	CLOSE
2020-08-18 17:36:34.503	-27558	Following	211.63	10101	CLOSE
2020-08-18 17:36:34.890	-27564	Following	211.6833333	10101	CLOSE
2020-08-18 17:36:35.084	-27515	Following	211.7166667	10101	CLOSE
2020-08-18 17:36:35.286	-27367	Following	211.73	10101	CLOSE
2020-08-18 17:36:35.696	**-17737**	**Following**	**58.62666667**	**10101**	**CLOSE**
2020-08-18 17:36:35.890	4	Following	58.62666667	10101	CLOSE
2020-08-18 17:36:36.089	0	Following	0	10101	CLOSE
2020-08-18 17:36:36.461	0	Following	0	10101	CLOSE
2020-08-18 17:36:36.639	0	Following	0	10101	CLOSE
2020-08-18 17:36:36.855	0	Following	0	10101	CLOSE
2020-08-18 17:36:37.046	0	Following	0	10101	CLOSE
2020-08-18 17:36:37.252	0	Following	0	10101	CLOSE
2020-08-18 17:36:37.459	0	Following	0	10101	CLOSE
2020-08-18 17:38:06.412	0	Following	0	10101	CLOSE
2020-08-18 17:38:06.829	0	Following	0	10101	CLOSE
2020-08-18 17:38:07.013	**0**	**Idle**	**0**	**11010**	**OPEN**
2020-08-18 17:38:07.212	0	Idle	0	11010	OPEN
2020-08-18 17:38:07.581	0	Idle	0	11010	OPEN
2020-08-18 17:38:07.781	0	Idle	0	11010	OPEN
2020-08-18 17:38:07.980	0	Idle	0	11010	OPEN
2020-08-18 17:38:08.535	0	Idle	0	11010	OPEN
2020-08-18 17:38:08.740	0	Idle	0	11010	OPEN
2020-08-18 17:38:08.936	0	Idle	0	11010	OPEN
2020-08-18 17:38:09.130	0	Idle	0	11010	OPEN
2020-08-18 17:38:09.951	0	Idle	0	11010	OPEN
2020-08-18 17:38:10.147	0	Idle	0	11010	OPEN
2020-08-18 17:38:10.355	0	Idle	0	11010	OPEN
2020-08-18 17:38:35.328	0	Idle	0	11010	OPEN
2020-08-18 17:38:35.523	0	Idle	0	11010	OPEN
2020-08-18 17:38:35.725	0	Idle	0	11010	OPEN
2020-08-18 17:38:36.627	0	Idle	0	11010	OPEN
2020-08-18 17:38:36.814	0	Idle	0	11010	OPEN
2020-08-18 17:38:37.024	0	Idle	0	11010	OPEN
2020-08-18 17:38:37.220	0	Idle	0	11010	OPEN
2020-08-18 17:38:37.426	0	Idle	0	11010	OPEN
2020-08-18 17:38:37.621	0	Idle	0	11010	OPEN
2020-08-18 17:38:39.327	**0**	**Forming**	**0**	**11010**	**OPEN**
2020-08-18 17:38:39.521	0	Forming	0	11010	OPEN
2020-08-18 17:38:39.718	0	Forming	0	11010	OPEN
2020-08-18 17:38:41.720	0	Forming	0	11010	OPEN
2020-08-18 17:38:44.629	0	Forming	0	11010	OPEN
2020-08-18 17:38:44.837	0	Forming	0	11010	OPEN
2020-08-18 17:38:46.239	0	Forming	0	11010	OPEN
2020-08-18 17:38:46.447	0	Forming	0	11010	OPEN
2020-08-18 17:38:46.678	0	Forming	0	11010	OPEN
2020-08-18 17:38:46.860	0	Forming	0	11010	OPEN
2020-08-18 17:38:47.055	0	Forming	0	11010	OPEN
2020-08-18 17:38:47.259	0	Forming	0	11010	OPEN
2020-08-18 17:38:47.458	0	Forming	0	11010	OPEN
2020-08-18 17:38:47.652	4736	Forming	0	11010	OPEN
2020-08-18 17:38:47.852	6839	Forming	0	11010	OPEN
2020-08-18 17:38:48.049	7229	Forming	0	11010	OPEN
2020-08-18 17:38:48.256	7550	Forming	0	11010	OPEN
2020-08-18 17:38:48.452	8293	Forming	0	11010	OPEN
2020-08-18 17:38:48.659	8051	Forming	0	11010	OPEN

Source: Gridscape

CHAPTER 3:
Simulation

Approach

Field Demonstration Data Collection Constraints

Extensive data collection and analysis from the demonstration site was planned to support a cost-reduction analysis of four case studies, as follows:

- Case 1: Baseline: No Solar, no storage.
- Case 2: Solar only.
- Case 3: Solar combined with storage using a rule-based, fixed schedule algorithm.
- Case 4: Solar combined with storage using a data-based cost reduction optimization algorithm employing AI/ML to predict parameters for the day ahead.

The system operated in Case 1 mode without incident for four weeks before COVID-19 disrupted normal operation when the building was vacated.

Several external factors initially constrained data collection to atypical conditions only (basically a vacant building), then stopped data collection due to building shut down for repurposing analysis and later vandalism (Table 3).

Table 3: Data Collection Constraint Summary

Activity	Dates
Data collection begins	May 2019
Standard operation (no solar, no storage), normal Boy Scouts occupancy	May 2019 - March 2020
Standard operation, low/zero load due to COVID evacuation order	March 2020 - February 2021
Solar + storage operation begins (following PG&E approved interconnection on 2/10/21), continued low/zero load due to COVID	
February 2021 – June 2021	
Solar + storage operation continues, low/zero load due to building closure for sale, repurposing	June 2021 – May 2022
All data collection ceased due to system shutdown due to vandalism	May 2022

Source: EPRI

Open Building Autonomous Tuning System (OpenBATS)

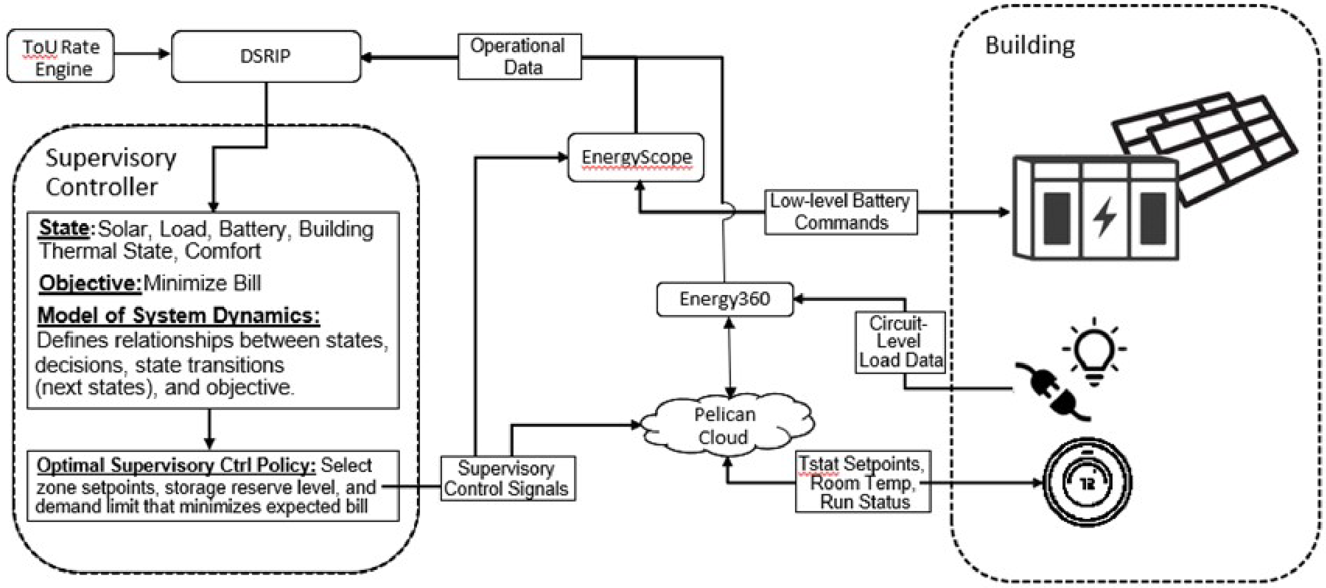
In the absence of sufficient field data, and field data constrained by atypical load operation for valid before/after comparisons, the project team decided to simulate energy use at the demonstration site. A state-of-the-art simulation was completed, using EPRI-developed software called open building autonomous tuning system (OpenBATS). This software is a supervisory controller that integrates solar, storage, and flexible loads.

OpenBATS (Figure 10) receives data from EPRI's open demand side resource integration platform (OpenDSRIP) representing a myriad of DR and other sources. The software controls two platforms:

- GridScape Solution's EnergyScope governing the microgrid controller and storage.
- InTech Energy's Energy360 controlling thermostats and monitoring solar generation.

OpenBATS works equally well with control platforms from other manufacturers that perform the same functions. It exchanges information with both platforms and sends optimized control signals forward for execution. In other words, it "supervises" the function of the solar and storage components to achieve the objective—a reduced bill and improved energy efficiency for a small commercial building.

Figure 10: Supervisory Control to Coordinate Solar, Storage and Loads – OpenBATS



Source: EPRI

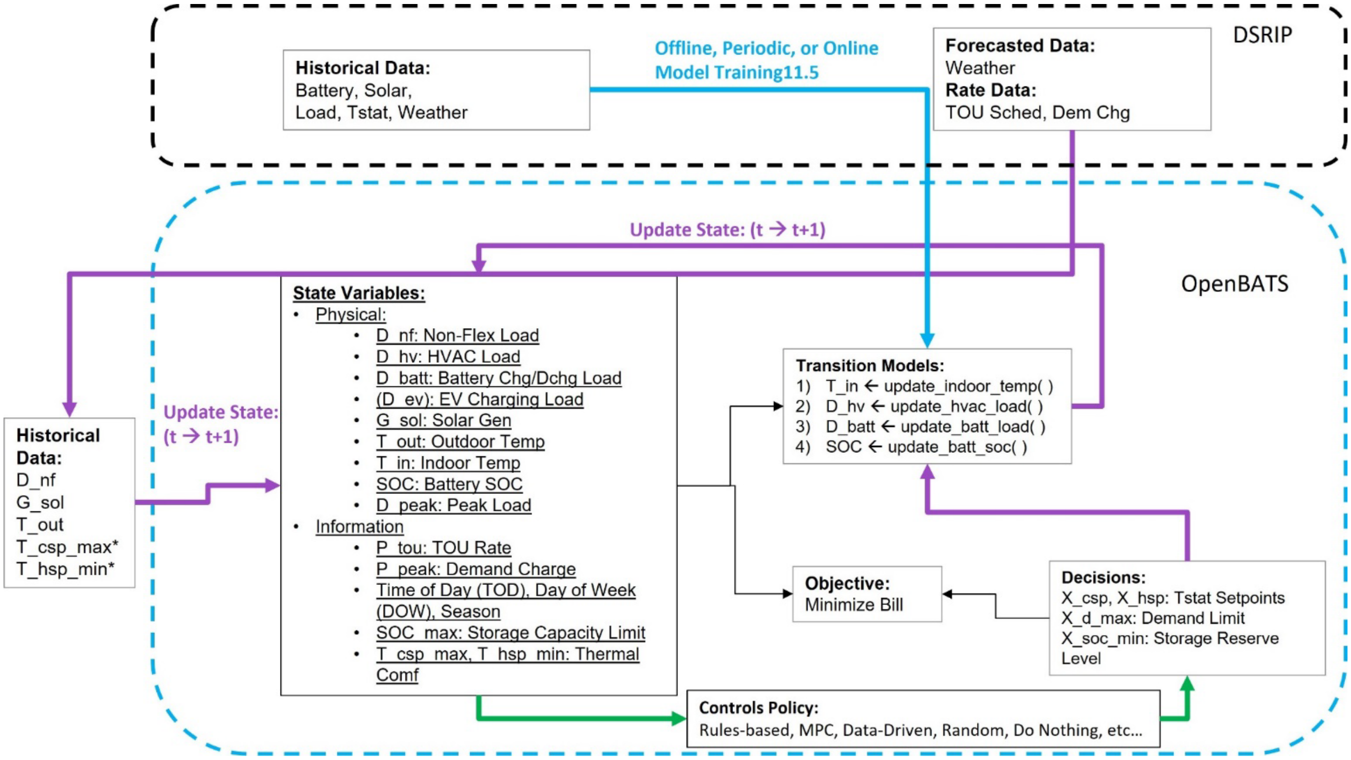
The superior control offered by OpenBATS is not tied to a particular building location, size, or equipment manufacturer. This supervisory control software simulates energy outcomes at various commercial sites without additional modeling to fit unique site conditions.

OpenBATS in a Virtual Testbed

Had the BSA building functioned as planned, the project team could have installed OpenBATS, let it “learn” on site, and then run simulations to find efficient, cost-effective operating conditions. Instead, a virtual testbed was created to mimic the context and training opportunities that were lost.

The virtual testbed leverages the four months of data collected under normal conditions at the BSA building. OpenBATS is the core of the virtual testbed, represented in Figure 11 (bottom panel, blue dashes) as a simulation loop that cycles through state variables, controls policy, decisions, and transition models. The cycle repeats for each timestep in a simulation to represent the sequential control actions made by the supervisory controller and the corresponding response of the building.

Figure 11: Virtual Testbed for OpenBATS Performance Evaluation



Source: EPRI

OpenDSRIP (top panel, black dashes) provides a wealth of historical data, forecasted data, and rate data used to update changes at each timestep. These data are also used to train and validate transition models that must accurately represent system dynamics, including:

1. **Thermal Envelope (update_indoor_temp):** Given a historical set of indoor temperatures, weather, and thermostat setpoints, predict the next step’s indoor temperature.
2. **HVAC Electrical Load (update_hvac_load):** Given a historical set of indoor temperatures, weather, thermostat setpoints, and electrical loads of the heating,

ventilating, and air conditioning (HVAC) system, predict the next step's HVAC system electrical load

3. **Battery Charging Profile (update_batt_load):** Given the system's current states of electrical loads, generation, and storage configuration (demand limit and storage reserve level), predict the battery's charge/discharge rate for the next timestep.
4. **Battery State of Charge (update_batt_soc):** Given the battery's historical state and current charge/discharge rate, predict the next step's state of charge.

Each virtual testbed module is described in Table 4.

Table 4: Virtual Testbed Module Descriptions

Module	Description	Inputs	Outputs
Historical Data	Historical building operational data used to train system transition models that describe the building dynamics prior to simulation, as well as provide state variable updates to observed historical building operational parameters during simulated controls testing.	Raw data sources and servers	Transition model training data, simulated state variable updates
Forecasted Data	Historical weather forecasts that would have been available to the control system to inform controller actions.	Raw data sources such as National Weather Service	Simulated State Variable Updates
Rate Data	Information describing the electric billing rates.	Electric Billing Information	Simulated State Variable Updates
State Variables	All of the information needed at each timestep to generate a controller action and corresponding objective (billing cost) impact at any point in time of the system operation. The state of the system can describe parameters that are either physical or informational in nature.	Historical data, forecasted data, rate data, transition models	Controls Policy, Objective, Transition Models
Controls Policy	The logic that generates a supervisory control decision given a current state of the system.	State variable	Decision
Decisions	The direct actions taken by the supervisory controller to coordinate the operation of solar, storage, and controllable loads. In this demonstration, the applicable actions include thermostat setpoints and high-level battery controller settings such as demand limit and reserve charge level.	Controls Policy	Objective, Transition Models

Module	Description	Inputs	Outputs
Transition Models	Represents all of the physical dynamics of the building and energy systems within the supervisory control loop. For each timestep in the simulation, this module takes the control decisions and current states of the building thermal loads, electrical loads, and the battery storage system to produce the next set of values to describe the next state variable. Prior to simulated controller testing, this module is trained on historical operational data.	State variables, Decisions, Historical Data	Simulated State Variable Updates
Objective	The metric for which the controller is optimizing. This metric provides the basis for overall evaluation of controller performance in the simulated testbed. For this application of supervisory control, control policies are optimizing for the minimum electrical bill which is comprised of time-of-use energy charges as well as a peak demand charge.	State variables, Decisions	Performance evaluation metrics

Source: EPRI

In the virtual testbed example, OpenBATS used a fixed timestep schedule to offset peak prices each day. For even greater potential cost savings on a building's electric bill, the software was able to switch to a data-driven AI/ML algorithm to predict parameters governing the next day's performance. The AI/ML software developed can predict solar PV, battery and load patterns, limit monthly peaks, and reduce costs more efficiently than today's more traditional EE and DR-focused energy management practices.

EPRI posted this machine learning algorithm for the optimization of OpenBATS as an open-source code on GitHub Inc. so others can use and improve the code.

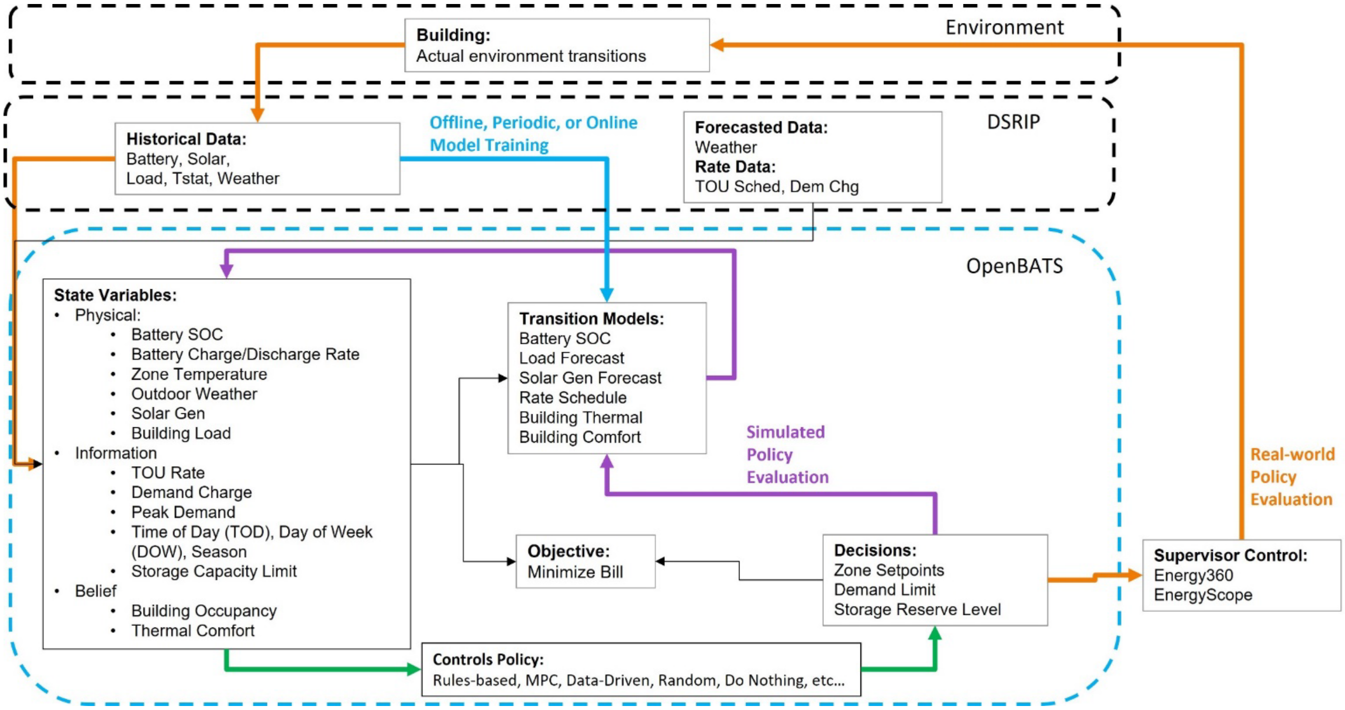
OpenBATS in the Real World

Demonstration of the OpenBATS virtual testbed in the real world can be accomplished in two steps:

- First, replace simulated transitions with actual environmental transitions in the OpenBATS control loop, as shown in the top panel of Figure 12. This updates physical and informational state variables with current news from the real world.
- Then, update the control policy by replacing all preset simulation parameters on the EnergyScope and Energy360 platforms with real-time inputs from the field, as well as current pricing signals and weather data.

Enterprising owners can use OpenBATS simulations to screen promising buildings for solar + storage installation. For instance, evaluating only buildings with the highest potential for minimizing their electric bills might merit capital investment.

Figure 12: Real-World Application of OpenBATS Testbed



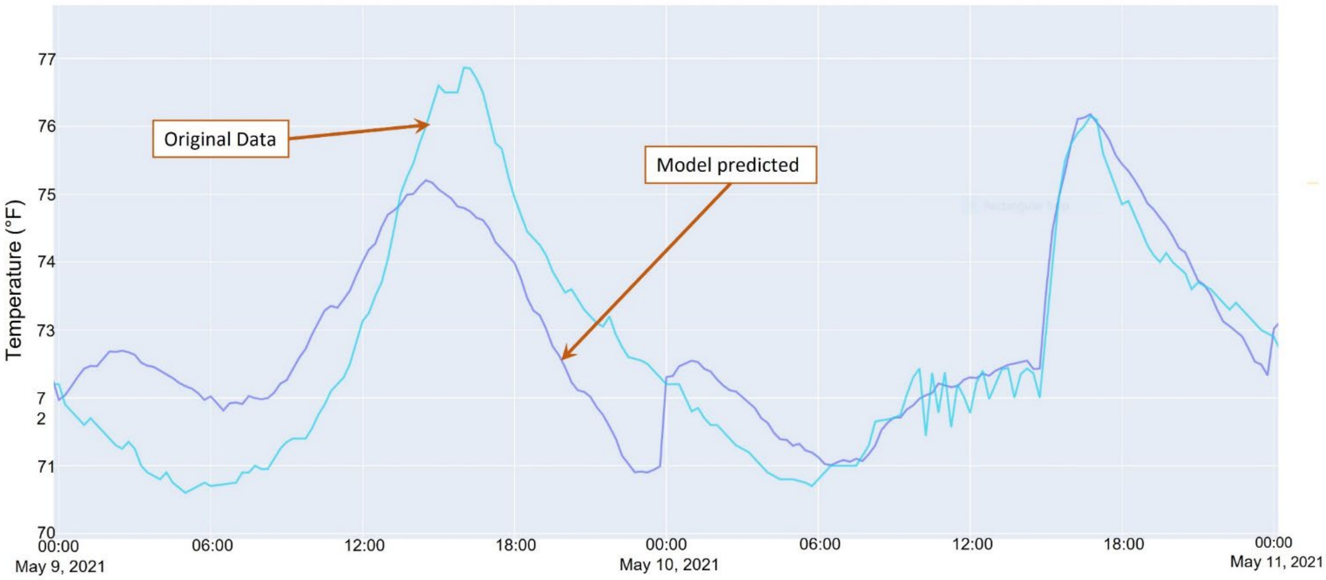
Source: EPRI

Results

Validation of OpenBATS Predictions

To verify OpenBATS functionality, predictions should match historical observations collected at the demonstration site, before COVID 19 closure. For example, Figure 13 compares predicted temperatures in BSA building zone 3 with historical temperatures for two days in May 2021, where a good fit between the OpenBATS predictions and the historical data can be seen.

Figure 13: BSA Building Zone 3 Model-Predicted and Field-Collected Temperature Data



Source: EPRI

Case Studies

Once verified, OpenBATS was employed to assess cost-reduction for four case studies (this time in prediction mode).

- **Case 1:** Baseline: No solar, no storage.

  Strategy—Compare all other cases to this non-optimized case.

- **Case 2:** Solar only.

  Strategy—Use a simple rule-based algorithm that utilizes solar energy when it's available to power loads in the building and export the remaining power to the distribution grid.

- **Case 3:** Solar combined with storage using a rule-based fixed schedule algorithm.

  Strategy—(a) Start charging during the day at 11:00 AM until the battery is completely charged or 3:00 PM is reached. (b) At 4:30 PM start discharging the battery to power building loads, reducing the power consumed from the distribution grid. Between 4:30 PM and 8:00 PM, discharge the battery so the net load is 2.5kW or the battery runs out of available power. From 8:00 PM, discharge the battery so the net load is 4kW until the battery runs out of available power. Available power is the minimum state of charge that ensures long battery life.

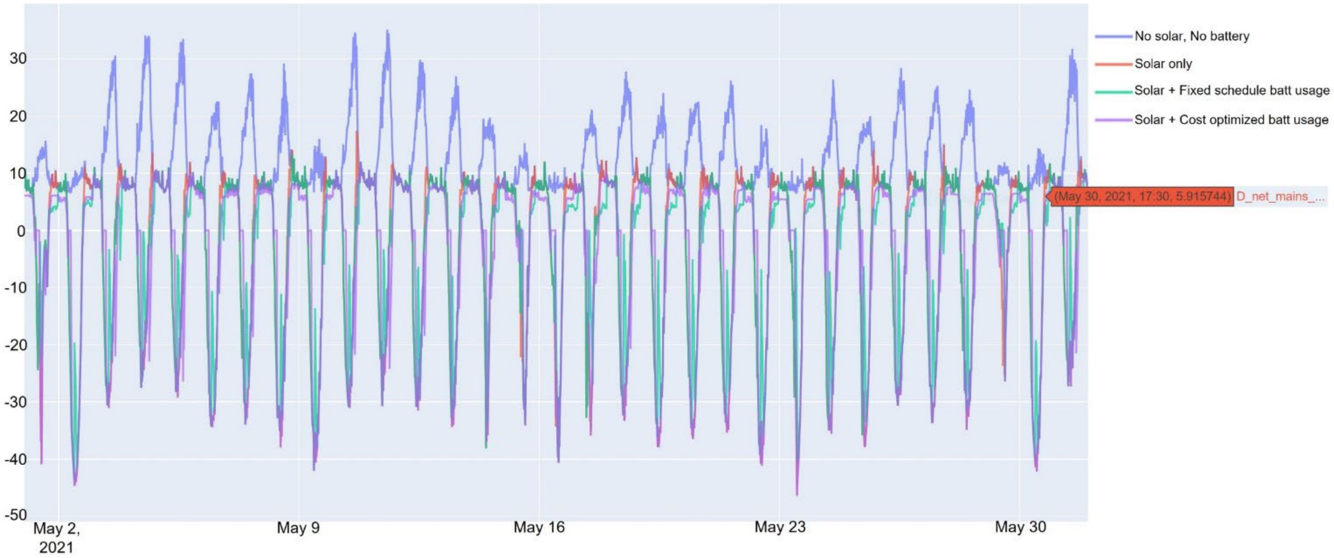
- **Case 4:** Solar combined with storage using a data-based AI/ML optimization algorithm for cost reduction to predict parameters for the day ahead.

  Strategy—Use the optimization algorithm to predict the load for the day. When that value is available, the optimization algorithm will seek to optimize battery discharge to reduce the total cost for the day. Compute the total cost to the user for that day and repeat each day.

Case study results evaluation began with plotting the power consumption of the BSA building for the month of May 2021 (Figure 14). The power consumption, or net load, is the load at the utility meter where the building connects to the distribution grid.

Compared to baseline (Case 1, blue), solar only installation (Case 2, red) reduced power consumption during the day and generated excess power that was exported to the distribution grid. Including a battery in addition to solar (Case 3, green) used some of the solar power to charge the battery as well as to service building loads, still leaving excess solar power for export. This saved money because exported solar power fetches a fixed price throughout the day. But an even better strategy is to consume the excess solar power and use the battery as a generator during peak price periods. Since peak import cost is always higher than export cost, this strategy results in an overall lower cost for the user.

Figure 14: BSA Building Power Consumption for May 2021 for Four Cases

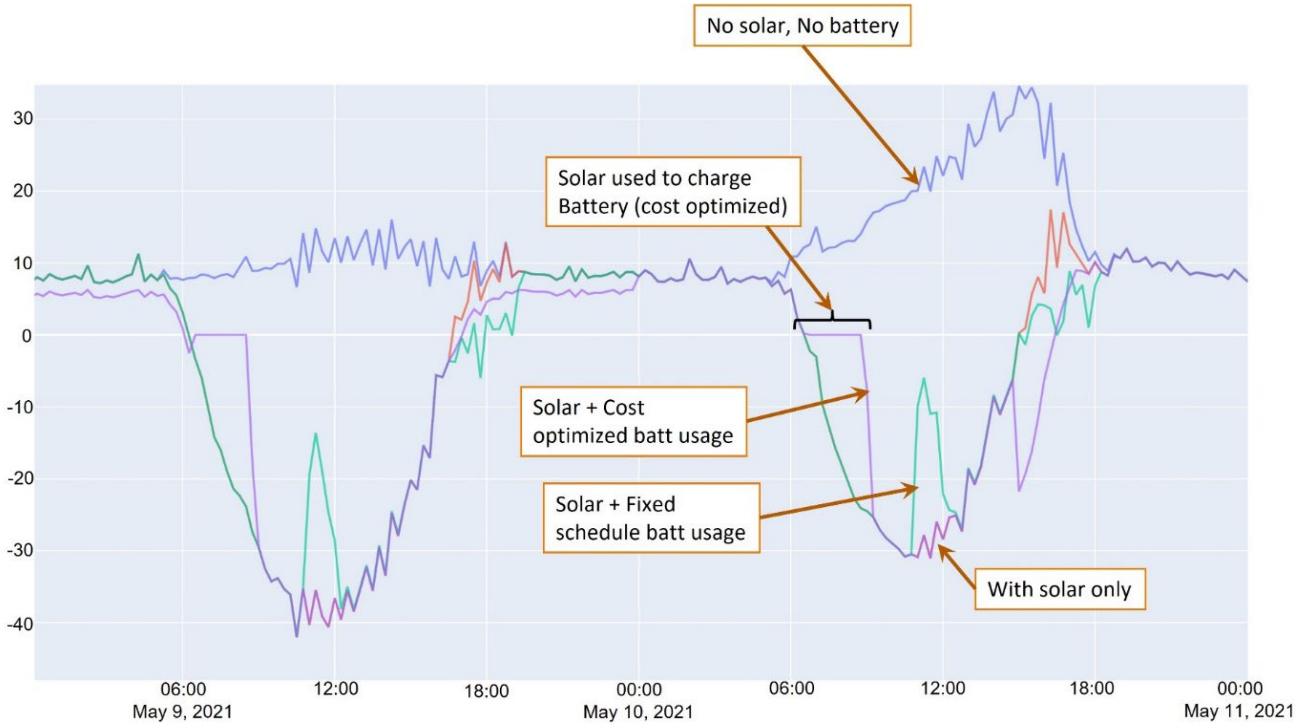


Source: EPRI

Figure 15 offers a detailed look at the effects of the various case study strategies. The figure predicts operations at the BSA building for two days in May 2021. For the baseline (Case 1, blue), power consumption is always positive and represents the highest cost to the user, compared to the other cases.

Adding solar (Cases 2–4; red, green, and purple) generates excess energy to sell to the distribution grid when the sun shines. Among this group of case studies, the cost-optimized schedule (Case 4, purple) is best because it uses battery energy during maximum-cost hours, compared to the fixed schedule (Case 3, green) which sometimes imports energy from the distribution grid during high-cost periods. Choosing the best time to use solar power to charge the battery also influences case study outcomes. Higher building loads occur in the afternoon and late evening, so having a battery charged and ready to deliver energy at those times offers an advantage, as seen with the cost optimization algorithm (Case 4, purple)

Figure 15: Two Typical Days to Compare Operation Cases



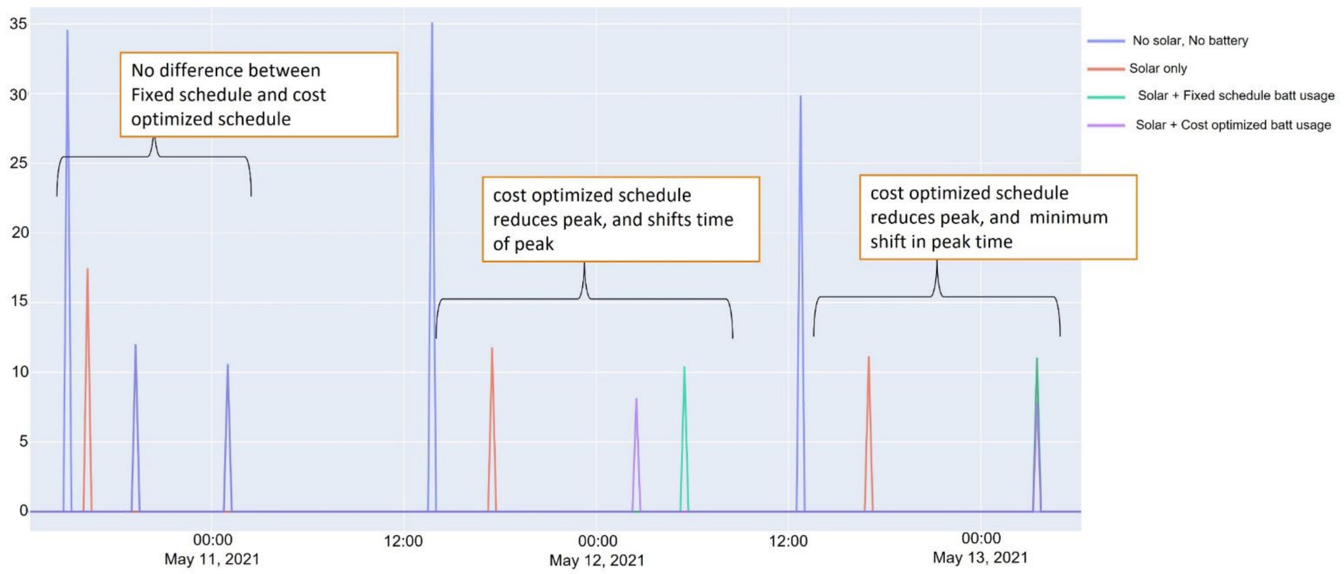
Source: EPRI

Another important aspect of a building's utility bill is the demand charge, which was $18.26 during the study period in PG&E's medium commercial building B-10S rate and demand charge. Demand charge, measured in kW, is based on the maximum power over the whole month or the billing period. Reducing the peak demand charge would help building owners save on their energy bill. Figure 16 shows how the demand charge varies with different case study algorithms. Peak demand coincides with higher costs, so improving cost savings also reduces peak demand. To do this, the battery was used as a generator during high-cost periods.

Figure 16 displays three outcomes:

- power peaks affecting the demand charge did not change.
- power peaks reduced and shifted with the cost optimized algorithm.
- power peaks occurred at the same time (did not shift), but at reduced intensity with the cost optimized algorithm.

Figure 16: Effects of Different Algorithms on Peak Consumption



Source: EPRI

Total cost to the building owner, reflecting the impact of integration and optimization at DER facilities, appears in Table 5. This proof-of-concept exercise—based on the same rate and tariff for all the cases—identifies the total import power, export power, and peak consumption (kW) for the month of May 2021 at the BSA building. The cost optimized schedule (Case 4) offers the maximum benefit to the customer. It reduced peak consumption the most and exported more power to the distribution grid than the other cases, for a better return on investment.

Table 5: Energy Bills of Four Simulated Cases for Proof-of-Concept Comparison

System	Total cost of imported power ($)	Total cost of Exported power ($)	Peak consumption (kW)	Transmission cost ($)	Total Bill ($)
Case 1—No Solar, no storage	1210.82	0	34.43	1605.19	3407.96
Case 2—Solar only	524.46	1071.00	17.5	678.84	433.12
Case 3—Rule-based fixed schedule with storage	404.61	919.58	13.54	529.13	246.92
Case 4—Data-based cost optimized schedule with storage	389.68	920.78	10.98	507.13	164.84

Source: EPRI

CHAPTER 4:
Conclusion

This project suggests that integrating solar + storage + microgrid with flexible load management can reduce a small commercial building's electric bill by reducing both peak load and overall energy use which has companion environmental benefits.

In addition, these specific learnings were realized from the project:

- A streamlined, integrated solar + storage + microgrid controller system was designed, sized, purchased, and installed at a small commercial building demonstration site in California. The resulting engineering drawing, or "Single Line Diagram", can be scaled and replicated for other small commercial applications potentially saving up to a year for the PG&E interconnection approval process.
- An open building autonomous tuning system, called OpenBATS, a supervisory controller, was designed and validated that oversees the operation of solar + storage + flexible load management. This open-source software was employed to simulate operations at the field demonstration site after several external factors constrained field data test collection. The OpenBATS system was enhanced with an artificial intelligence/ machine language algorithm trained to minimize cost. Such a system is a significant improvement over traditional heat transfer calculation-based approaches to optimize performance, reduce manual data collection/input, and is readily transferrable to other building applications. This algorithm is published on GitHub Inc. for interested developers to use and improve.
- A virtual testbed was developed for training OpenBATS models and the artificial intelligence/machine language cost optimized algorithm. This testbed supports scaling and extension of the software, including "what if" scenarios to screen candidate buildings for integrated system installation.
- This project demonstrated the opportunity to maximizing benefits to the customer. The electric utility has better ways through planning and operation to maximize benefits to the grid.

Benefits to California include:

- *Lower Costs*. For individual small-to-medium commercial buildings, based on this demonstration, an annual electric bill savings of about $2,500 might be expected with a bit larger savings for the optimized scenario (Case 4).
- *Greater Reliability*. This would result from peak load reductions employing smart battery charging and discharging to address periods of excess generation or periods of steep demand in the evening which flattens the building's load and thus improves reliability. It also can smooth the use of distribution capacity during peak demand periods to avoid overstressing the network.

- *Improved Resiliency for Energy Security*. The battery and microgrid capabilities can increase resiliency.
- *Customer Appeal*. Gives commercial customers greater ability to manage energy with economical, off-the-shelf technologies because OpenBATS is open-source software and agnostic to controller algorithm class. It is designed to accept a range of strategies (for example rule based, model predictive control, data driven).
- *Environmental Public Health*. Reduces greenhouse gas and air pollution emissions, particularly by curtailing electricity purchase during periods of peak power use.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AHJ	Authority having jurisdiction
AI/ML	artificial intelligence/machine learning
ARC	American Red Cross
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BSA	Boy Scouts of America
CEC	California Energy Commission
CPUC	California Public Utility Commission
DER	Distributed energy resource
DR	Demand response
EE	Energy efficiency
EPIC	Electric Program Investment Charge
GEB	Grid-Interactive Efficient Building
HVAC	Heating, ventilating, and air conditioning
IOU	Investor-owned Utility
kW	Kilowatt
kWh	Kilowatt-hour
LADWP	Los Angeles Department of Water and Power
MT	Megaton
NRTL	Nationally recognized testing laboratory
NYPA	New York Power Authority
OpenBATS	Open Building Autonomous Tuning System
OpenDSRIP	Open Demand Side Resources Integration Platform
OSHA	U.S. Occupational Safety and Health Administration
PG&E	Pacific Gas and Electric Company
PNNL	Pacific Northwest National Laboratory
PPA	Power Purchase Agreement
PV	Photovoltaic
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SGIP	Self-Generation Incentive Program
ToU	Time of use
W	Watt

CALIFORNIA
ENERGY COMMISSION

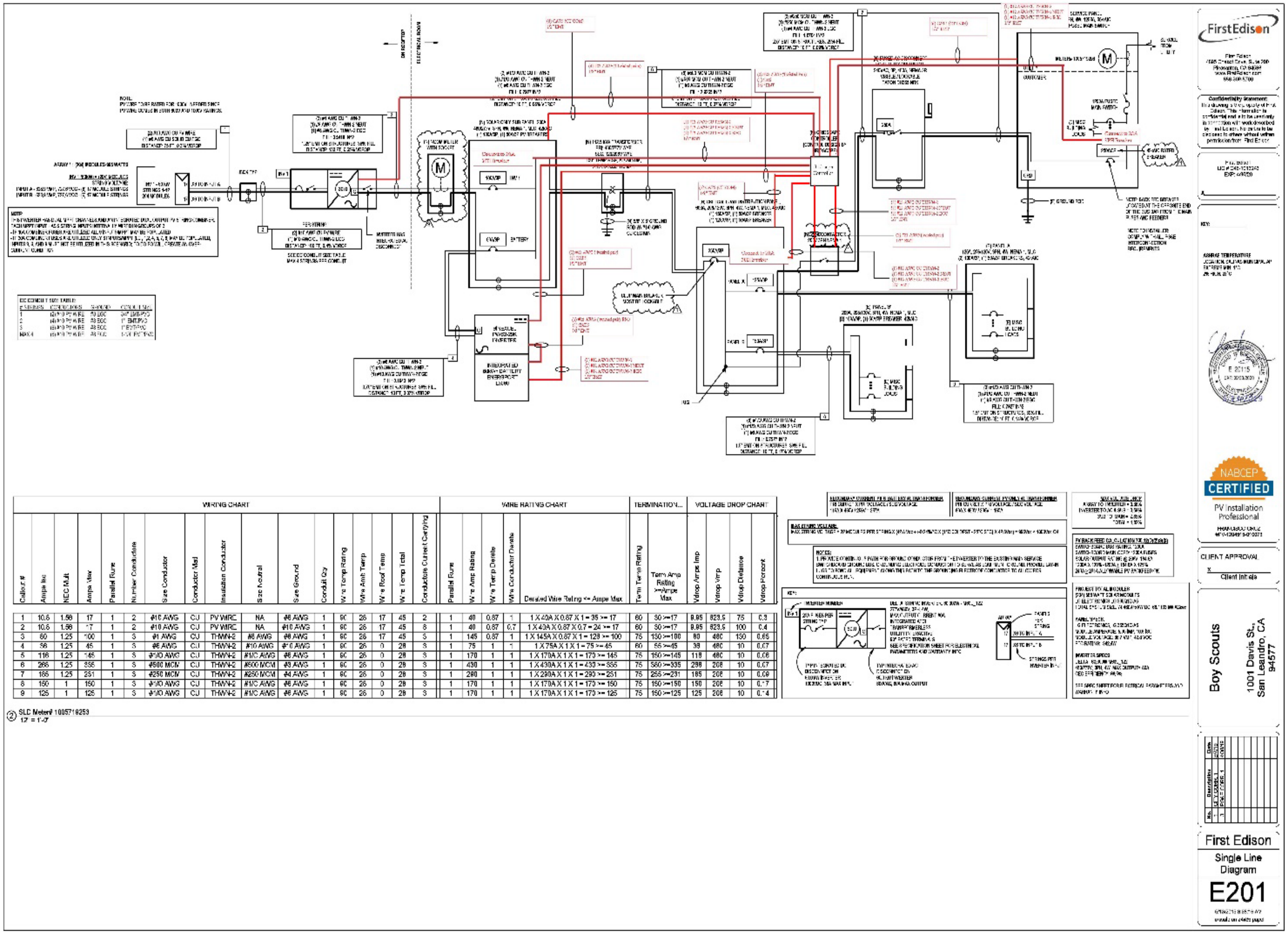
CALIFORNIA
NATURAL
RESOURCES
AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A: NRTL Certified Single Line Diagram of Solar, Storage and Microgrid

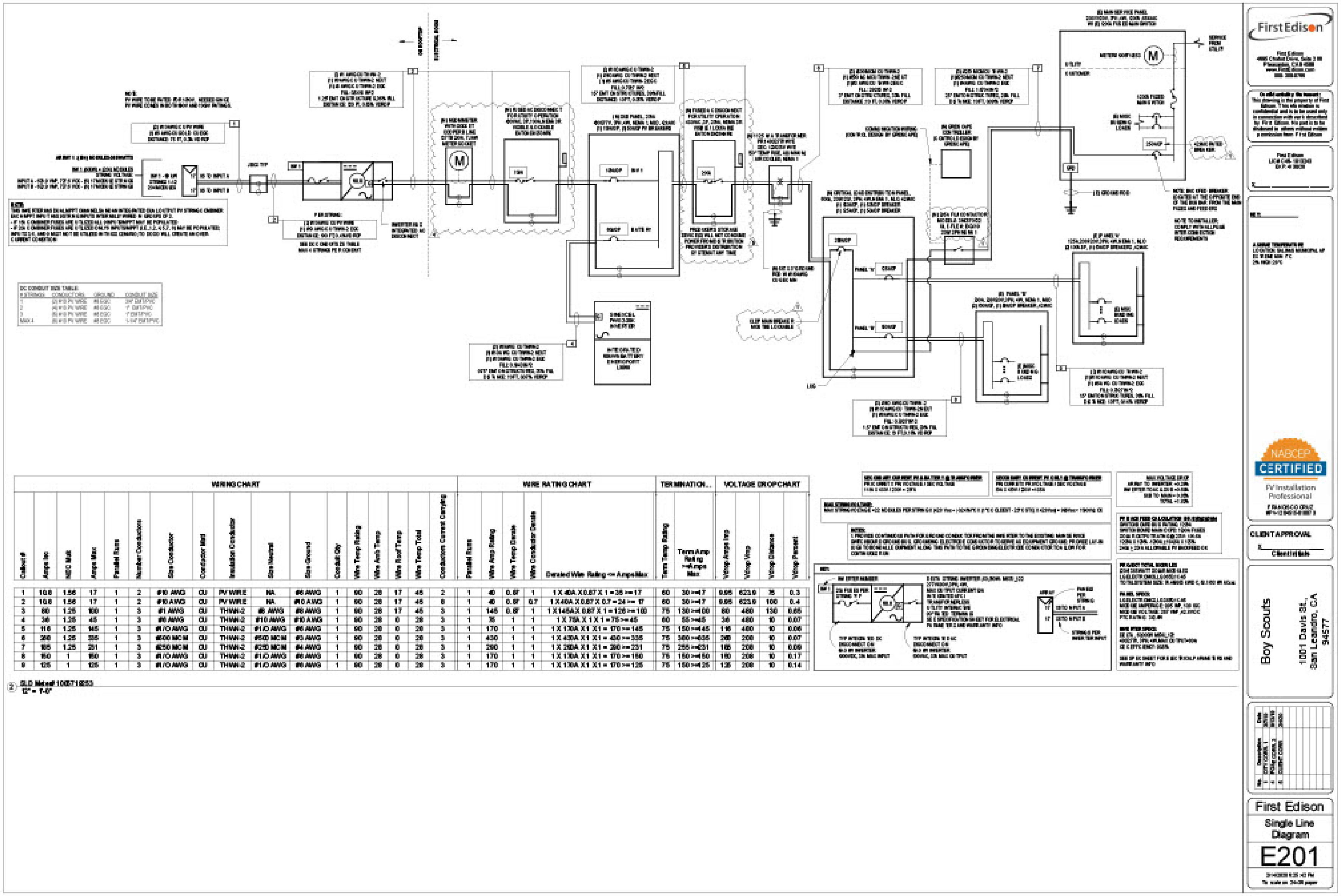
March 2024 | CEC-500-2024-018

APPENDIX A:
NRTL Certified Single Line Diagram of Solar, Storage and Microgrid



								WIRING CHART										WIRE RATING CHART					TERMINATION...		VOLTAGE DROP CHART			
Callout #	Amps Isc	NEC Mult	Amps Max	Parallel Runs	Number Conductors	Size Conductor	Conductor Mat	Insulation Conductor	Size Neutral	Size Ground	Conduit Qty	Wire Temp Rating	Wire Amb Temp	Wire Roof Temp	Wire Temp Total	Conductors Current Carrying	Parallel Runs	Wire Amp Rating	Wire Temp Derate	Wire Conductor Derate	Derated Wire Rating <= Amps Max	Term Temp Rating	Term Amp Rating >=Amps Max	Vdrop Amps Imp	Vdrop Vmp	Vdrop Distance	Vdrop Percent
1	10.6	1.56	17	1	2	#10 AWG	CU	PV WIRE	NA	#6 AWG	1	90	26	17	45	2	1	40	0.87	1	1 X 40A X 0.87 X 1 = 35 >= 17	60	30 >=17	9.95	823.5	75	0.3
2	10.6	1.56	17	1	2	#10 AWG	CU	PV WIRE	NA	#10 AWG	1	90	26	17	45	8	1	40	0.87	0.7	1 X 40A X 0.87 X 0.7 = 24 >= 17	60	30 >=17	9.95	823.5	100	0.4
3	80	1.25	100	1	3	#1 AWG	CU	THWN-2	#6 AWG	#8 AWG	1	90	26	17	45	3	1	145	0.87	1	1 X 145A X 0.87 X 1 = 126 >= 100	75	130 >=100	80	480	130	0.65
4	36	1.25	45	1	3	#6 AWG	CU	THWN-2	#10 AWG	#10 AWG	1	90	26	0	28	3	1	75	1	1	1 X 75A X 1 X 1 = 75 >= 45	60	55 >=45	36	480	10	0.07
5	116	1.25	145	1	3	#1/0 AWG	CU	THWN-2	#1/0 AWG	#6 AWG	1	90	26	0	28	3	1	170	1	1	1 X 170A X 1 X 1 = 170 >= 145	75	150 >=145	116	480	10	0.06
6	266	1.25	335	1	3	#500 MCM	CU	THWN-2	#500 MCM	#3 AWG	1	90	26	0	28	3	1	430	1	1	1 X 430A X 1 X 1 = 430 >= 335	75	380 >=335	266	208	10	0.07
7	185	1.25	231	1	3	#250 MCM	CU	THWN-2	#250 MCM	#4 AWG	1	90	26	0	28	3	1	290	1	1	1 X 290A X 1 X 1 = 290 >= 231	75	255 >=231	185	208	10	0.09
8	150	1	150	1	3	#1/0 AWG	CU	THWN-2	#1/0 AWG	#6 AWG	1	90	26	0	28	3	1	170	1	1	1 X 170A X 1 X 1 = 170 >= 150	75	150 >=150	150	208	10	0.17
9	125	1	125	1	3	#1/0 AWG	CU	THWN-2	#1/0 AWG	#6 AWG	1	90	26	0	28	3	1	170	1	1	1 X 170A X 1 X 1 = 170 >= 125	75	150 >=125	125	208	10	0.14

Source: EPRI



WIRING CHART																	WIRE RATING CHART					TERMINATION...		VOLTAGE DROP CHART			
Callout #	Amps Isc	NEC Mult	Amps Max	Parallel Runs	Number Conductors	Size Conductor	Conductor Mat	Insulation Conductor	Size Neutral	Size Ground	Conduit Qty	Wire Temp Rating	Wire Amb Temp	Wire Roof Temp	Wire Temp Total	Conductors Current Carrying	Parallel Runs	Wire Amp Rating	Wire Temp Derate	Wire Conductor Derate	Derated Wire Rating <= Amps Max	Term Temp Rating	Term Amp Rating >=Amps Max	Vdrop Amps Imp	Vdrop Vmp	Vdrop Distance	Vdrop Percent
1	10.8	1.56	17	1	2	#10 AWG	CU	PV WIRE	NA	#6 AWG	1	90	28	17	45	2	1	40	0.87	1	1 X 40A X 0.87 X 1 = 35 >= 17	60	30 >=17	9.85	623.9	75	0.3
2	10.8	1.56	17	1	2	#10 AWG	CU	PV WIRE	NA	#10 AWG	1	90	28	17	45	6	1	40	0.87	0.7	1 X 40A X 0.87 X 0.7 = 24 >= 17	60	30 >=17	9.85	623.9	100	0.4
3	80	1.25	100	1	3	#1 AWG	CU	THWN-2	#6 AWG	#8 AWG	1	90	28	17	45	3	1	145	0.87	1	1 X 145A X 0.87 X 1 = 126 >= 100	75	130 >=100	80	480	130	0.65
4	36	1.25	45	1	3	#6 AWG	CU	THWN-2	#10 AWG	#10 AWG	1	90	28	0	28	3	1	75	1	1	1 X 75A X 1 X 1 = 75 >= 45	60	55 >=45	36	480	10	0.07
5	116	1.25	145	1	3	#1/O AWG	CU	THWN-2	#1/O AWG	#6 AWG	1	90	28	0	28	3	1	170	1	1	1 X 170A X1 X1 = 170 >= 145	75	150 >=145	116	480	10	0.06
6	268	1.25	335	1	3	#500 MCM	CU	THWN-2	#500 MCM	#3 AWG	1	90	28	0	28	3	1	430	1	1	1 X 430A X1 X1 = 430 >= 335	75	380 >=335	268	208	10	0.07
7	185	1.25	231	1	3	#250 MCM	CU	THWN-2	#250 MCM	#4 AWG	1	90	28	0	28	3	1	290	1	1	1 X 290A X1 X1 = 290 >= 231	75	255 >=231	185	208	10	0.09
8	150	1	150	1	3	#1/O AWG	CU	THWN-2	#1/O AWG	#6 AWG	1	90	28	0	28	3	1	170	1	1	1 X 170A X1 X1 = 170 >= 150	75	150 >=150	150	208	10	0.17
9	125	1	125	1	3	#1/O AWG	CU	THWN-2	#1/O AWG	#6 AWG	1	90	28	0	28	3	1	170	1	1	1 X 170A X1 X1 = 170 >= 125	75	150 >=125	125	208	10	0.14

② SLD Meter# 1005718253
12" = 1'-0"

Source: EPRI

CALIFORNIA
ENERGY COMMISSION

CALIFORNIA
NATURAL
RESOURCES
AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix B: EPRI Technology Transfer

March 2024 | CEC-500-2024-018

APPENDIX B: EPRI Technology Transfer

Technical Advisory Committee Meetings

These meetings included influential utility members and are used to shape EPRI research, develop demonstration and marketing opportunities for technologies, and provide a conduit for the advisors to impart information to colleagues at their “home” utilities. Advisory meetings are held twice a year (spring and fall), usually in February and September.

EPRI presented learnings from the project in all spring and fall meetings from 2021 and 2022. The meetings were attended by a cross section of relevant market players, representing utilities, government, research, and industry across the United States. As part of their committee charge, the attendees provided feedback and steering to the project team based on their technical or market expertise.

Table 6: EPRI Technical Advisory Committee

Organization	Organization Type	Name
California Energy Commission	Government/Funder	Eric Ritter
Electric Power Research Institute	Research/Prime	Sunil Chhaya, Peng Zhao
SCE	Utility	Mark Martinez
Linc Housing	Non-Profit Housing Developer	Michelle Tirto
PG&E	Utility	Lydia Krefta
PG&E	Utility	Mark Esguerra
Sacramento Municipal Utility District	Utility	Jeanne Duvall
Sacramento Municipal Utility District	Utility	Gabriell Leggett
SDG&E	Utility	Chris Roman
SDG&E	Utility	Kate Zeng
Snohomish County Public Utility District	Utility	Suzanne Frew
Southern Company	Utility	Justin Hill
National Renewable Energy Laboratory	Research Lab	Roderick Jackson
Boy Scouts of America	Non-Profit/Property Owner	Jason Lewis
GridScape	Technology Provider	Mark Aiello

Organization	Organization Type	Name
Humboldt University	University	James Zoellick
InTech Energy	Technology Provider	Rich Fox
University of Colorado Boulder	University	Gregor Henze
Pennsylvania State University	University	Gregory Pavlak

Source: EPRI

Technology Transfer Meetings

- On June 24, 2023, EPRI presented conference paper #33689 "Integrating Building-Scale Solar + Storage + Flexible Advanced Technologies to Maximize Value to Commercial Buildings" at the 2023 ASHRAE Annual Conference. in Tampa, FL.
- On October 12, 2022, EPRI was invited to Eaton Electric's Warrendale office to talk about *Integrating Smart Devices at the Building Level*. This project was presented at the meeting and the lessons learned were shared. Eaton is looking at developing advanced algorithms at the smart panel level and this project's development helped Eaton to shape its future products.
- On September 29, 2022, EPRI shared the project results and lessons learned with PG&E's DER, microgrid, and distribution teams. EPRI discussed the industry challenges and the breakthrough that the project has developed and demonstrated. PG&E also has provided feedback on what they consider to be important to their distribution operation and planning for DER-integrated grid interactive buildings.
- On September 28, 2021, EPRI presented this project at AI and Electric Power Summit, with the title *AI/ML Applications and Demonstrations in Grid-Interactive Efficient Commercial Buildings*. The presentation was advertised on Energy Central and brought in discussions with many industry leaders.
- On June 22, 2021, EPRI presented this project, along with National Renewable Energy Laboratory (NREL) and BluWave-ai, to report to industry leads and interested utilities on the latest developments. The presentation was titled *Demystifying AI/ML Applications and Demonstrations in Grid-Interactive Efficient Buildings*. The session was well attended by representatives from, but not limited to, SCE, SDG&E, Southern Company, Seattle City Light, LADWP, First Energy, NYPA, PNNL, University of Drexel, University of Texas Austin, and many others.
- On January 29, 2021, EPRI presented this project in an invited talk, along with Southern Company, to discuss *Opportunities and Challenges of Buildings-to-Grid Integration to Achieve DOE's GEB Goals in Commercial Buildings*.

EPRI Workshops

Commercial Buildings Interest Group:

EPRI held multiple workshops through EPRI's Commercial Buildings Interest Group targeting solar+storage, technology integration, and barriers to overcome. The workshops were well attended by utility members including, but not limited to, SCE, LADWP, Southern Company, First Energy, and NYPA. The utility representatives are program managers who lead their respective companies' sustainability programs, energy efficiency programs, smart building programs, and demand response programs.