Field Studies for Enabling Sustainable Resiliency: Leveraging Innovative Building Technologies for Grid Reliability Across California's High-Risk and Vulnerable Communities

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ABSTRACT

Early adopters of advanced decarbonization technologies are often more economically advantaged across all customer classes due to the higher first costs of hardware and implementation. The adopters also possess the resources necessary to implement the long-term investments they envision to enhance their sustainability and resiliency goals. So, how can advanced building technologies be implemented for the disadvantaged societal sectors, and what reasonable and affordable strategies can successfully be leveraged to promote decarbonization equity and improve community-scale resilience?

The Demand Response Emerging Technology (DRET) collaborative, funded by Emerging Technology Programs of California's electric investor-owned utilities (IOUs), is investigating, through scalable deployments, the innovative models of technological investment for underserved communities to maximize deployment of enabling technologies and their socioeconomic and financial benefits. Demonstration of technical feasibility and quantification of return on investment (ROI) are key first steps in achieving investment viability and greater technology adoption in these underserved communities.

SDG&E's Shelter Valley Virtual Power Plant Project is a demonstration that leverages real-time, cloud-based signaling of building technologies with smart thermostats, energy storage, and well-water pump controllers supporting grid needs during peaks and providing backup power during emergencies. SCE's Willowbrook Project pioneers a DC minigrid integrating DC-coupled appliances, bi-facial solar, and batteries in a disadvantaged, multifamily housing community to support critical loads like medical devices during outages. This paper draws from both DRET projects to provide experiential learnings and data, that identify operational recommendations and cost-effective strategies to accelerate scalability and broaden the adoption of solutions for sustainable community resiliency.

Introduction

As California utilities navigate the transition towards a more sustainable and resilient energy landscape, a key focus lies in maximizing the economic and environmental benefits of renewable energy technologies for underserved populations. The DRET Collaborative's two projects represent groundbreaking efforts to address these imperatives with in-situ technology scaled deployments in both rural and urban customer regions. SDG&E's project aims to enhance electric reliability and community resilience in a desert community. SCE's Willowbrook project deploys a scalable urban community model to maximize the economic benefits of solar photovoltaic (PV) energy systems among low-income multifamily housing, while enhancing grid flexibility and seeking customer energy affordability. These initiatives underscore the critical role of how utilities demonstrate innovative technologies and pricing mechanisms for advancing resiliency goals and facilitating greater equity in energy access for both local governments and industry stakeholders. It also highlights customer engagement responsiveness and quantifies the community value proposition to improve program design. By examining how advanced technologies can enable the intersection of system sustainability, social equity, and energy affordability, this trifecta of conjoined benefits exemplifies how the IOUs' DRET research is focused to address the complex challenges posed by a changing grid while promoting inclusive socio-economic benefits and environmental stewardship.

SDG&E's Shelter Valley Virtual Power Plant Project

Background

When energy demands are high during the summer, power plants ramp up often requiring the energization of peaker power plants to increase grid capacity and ensure reliability. These peaker plants generate electricity by combusting fossil fuels such as oil, coal, or natural gas, causing an increase in GHG emissions and contributing to global warming.[1] A Virtual Power Plant (VPP) is a network of Distributed Energy Resources (DERs) all interconnected and operating together as a single "virtual" power plant to provide reliable power, on demand. VPPs can combine the capabilities of various DERs and serve as a potential solution and resource to support varying grid needs and customer demand. By avoiding generation buildout, decreasing wholesale energy costs, and avoiding or deferring transmission and distribution investments, VPPs can help reduce annual power sector expenditures by $17 billion in 2030 (Brehm, 2023).

As part of its Sustainability Strategy and commitment to reach net zero greenhouse gas (GHG) emissions by 2045, SDG&E launched a Virtual Power Plant (VPP) Project in 2021 in a rural community to demonstrate local grid resiliency with (DERs). Over an 18-month period, the VPP project investigated how DERs such as smart thermostats, smart load controllers and battery energy storage function in real-world conditions, and how they can serve as a resource to help strengthen community resilience and electric reliability in the unincorporated community of Shelter Valley. It is a small and remote community situated at the end of a transmission line that runs through a high fire threat region, occasionally requiring power to be turned off in periods of high winds. Furthermore, it has only one cellular provider, making telecommunications difficult.

Project Purpose & Objectives

This project took place 12 miles east of Julian in the high desert, rural area within East San Diego County to investigate the real-world potential of behind the meter (BTM) DERs in a traditionally hard-to-reach, remote community. Data analysis and observations from this project inform future VPP endeavors necessary to meet SDG&E's sustainability goals and to inform ongoing strategies for BTM resource management. The project goal was to analyze a VPP's operational performance and demand impacts upon SDG&E's grid via the following objectives:

- Recruit VPP participants and establish the initial BTM resources in the field.

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[1] Based on the CAISO grid emergencies history report from 1998 to present, there has been a substantial increase in alerts and warnings in the years 2020 and 2022 (CAISO, 2024).

- Deploy and operate a VPP providing a management solution for BTM resources, then dispatch Demand Response (DR) signals based on test, simulated, or actual DR events.
- Analyze VPP operational performance and document for future endeavors (Pratt, 2020).

Project Approach

The DERs in this project included residential and commercial battery energy storage systems (BESS) with automated load controllers such as well pump controllers and smart thermostats, which were used by SDG&E to improve grid resilience. These technologies were installed at eight single family homes, and a community facility that serves critical needs for the community and surrounding areas as a cool zone, a food drive distribution center and a venue for meetings and events. In particular, the VPP's batteries provided power to the community facility, providing a place to seek refuge in a region where resiliency is often tested by environmental conditions. All the automated devices were integrated into the Generac Concerto VPP software platform which served as a gateway controller for communications to these end assets. The assets were signaled to shed or shift their load during several simulated and actual DR events.

Featured Technologies, Eligibility, & Siting

Battery storage. The battery storage and inverter system used in this project consists of six 3 kWh lithium-ion battery modules with a total storage capacity of 18 kWh. The inverter is rated at 7.6 kW; however, the inverter can discharge at a higher rate for short periods of time to support the large inrush current required to start equipment. The inverter connects to PV Link optimizers and batteries to form the grid-interactive solar and storage system.

> For selecting sites for BESS installation, customers with existing solar PV were shortlisted and priority was given to Medical Baseline Allowance Program and Access and functional needs (AFN) customers. Out of the five residential sites selected, two customers were enrolled in Medical Baseline, and the other three customers were selected based on the size of their solar system and usage profile throughout the year. The community facility was selected since it serves as a community support service location and cool zone during extreme heat, and hosts several events like food drives, community coffee/potluck events and church services.

Well pump controller. A control module was used in this project to control customer's well pump operation. The power control module consists of a line-voltage power relay module and a low voltage wireless control module. The power relay module is mounted either inside an electrical sub panel or in its own dedicated electrical box and has five dry-contact relays which can be scheduled to turn electrical loads on or off. The wireless control module has a wireless antenna used to bridge communication between the wireless mesh network and the power relay module installed at the site.

> The eligibility criteria for the well pump controller installation were that the site should have a ground water lift pump, a recirculation pump, and a water storage tank. Well pump controllers were installed at four residential sites and the community facility.

Smart thermostats. Smart thermostats were installed and connected via Wi-Fi to remotely control the central air conditioning (AC) system during DR events. When signaled, the thermostat lowered the cooling setpoint temperature by 4°F to pre-cool the home for one hour before the DR events. At the start of a DR event, the setpoint was increased 4°F from the original setpoint (or 8°F from the pre-cool setpoint). To control the central HVAC systems, smart thermostats were installed at three residential sites with one site receiving two thermostats.

Implementation Approach

A field study was chosen over laboratory testing because the technology performance needed to be evaluated in real-world conditions to understand aggregated load reduction and net metering to the grid. SDG&E contracted with Alternative Energy Systems Consulting, Inc. (AESC) to assist with administration of the project including recruitment of study participants and installation of devices inside participating customers' homes and the community facility.

This project required residential customer participation to effectively test VPP operation. In the Shelter Valley area, there are 212 SDG&E customers, primarily residential with a community facility and a fire station. Therefore, SDG&E implemented marketing and customer recruitment strategies such as a VPP project fact sheet, an informational VPP web page, community event flyers, and email/postal mailings. An enrollment web page was created for customers to sign up for this pilot with an option to view in Spanish to be accessible for the Hispanic community. The community outreach and recruitment process started in March 2022 with a series of community events like coffee events, food drives and board meetings to promote the project and encourage residents to participate in this pilot.

Once interested customers were identified and agreed to participate, the equipment and/or control devices were installed at the customer sites. All the control devices and battery storage systems were provided by SDG&E at no cost to the customers. An independent contractor was hired by SDG&E to install the batteries and control devices. The installation times varied for different components with thermostats and well pump controllers typically taking two to three hours while batteries required a couple of days. However, BESS installations required additional steps such as obtaining County permits, interconnection agreements, and acquiring permission to operate from SDG&E, making the overall process between three and four weeks. Once the devices were installed, they were integrated into the Concerto platform. The batteries and smart devices communicated to the VPP signaling platform via customer Wi-Fi and in cases where customer Wi-Fi was not available, a router was provided.

Numerous challenges, including poor Wi-Fi signals and changes in customers' internet service providers, were identified during the testing period. Consequently, the communication mode for all batteries was eventually switched to cellular SIM cards towards the project's conclusion. At one residential site, a router was replaced with a more sophisticated networking device to ensure a more reliable internet connection.

Test Processes

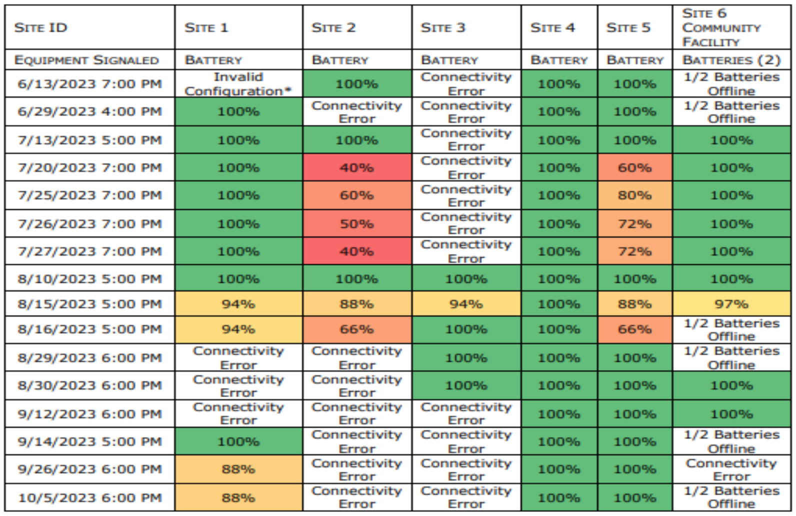
The VPP testing started in December 2022 after initial equipment was installed at the first few sites. The first five test events were scheduled from December 2022 to April 2023 with an additional 20 simulated or actual events from May 2023 to November 2023. The events were two or four hours long, and the start times varied for each event. The test schedule leveraged a combination of actual DR events called by SDG&E's DR Programs, and simulated events. For all events, customers were notified a day before the event, typically 24 hours ahead via e-mail and/or text message using the VPP platform's notification system. To develop an accurate and robust baseline and account for day-to-day variances, the baseline was developed for each DR event and customer type using advanced metering infrastructure data collected from each VPP customer net meter.

In this study, solar power was used to charge the battery during the day using the Self Supply Mode. During normal operation, the battery would discharge during the evening and overnight to sustain any site loads. However, when a DR event was called, the battery switched to Priority Backup Mode to charge during the day and hold its charge until the DR event started. During the DR event, the battery switched to Sell Mode and discharged to the grid until it reached the minimum state-of-charge. The batteries had a minimum SOC of 20%, a maximum discharge power of 7.6 kW while grid tied, and a maximum energy capacity of 18 kWh. This means that the average theoretical load reduction for each fully charged battery is 6.3 kW for a 2-hour event, and 3.15 kW for a 4-hour event.

Results & Key Findings

Out of the six sites with batteries, only two sites had a 100% signaling success rate during the 16 DR event days. Others had connectivity issues that prevented DR signals from being received during some events.[2] Site 3 only had a 31% (five out of 16) success rate in receiving DR event signals due to connectivity issues, stressing the importance of telecommunications infrastructure in DR programs. Looking at the VPP as a whole, the battery equipment signaling success rate is highly correlated with the calculated impacts since the battery acts as the main resource in the VPP. In Table 1, the DR event with the highest impact (8/10/2023) was seen on the day where all batteries were signaled successfully with 100% SOC. To support more success in signaling the batteries, another form of connectivity was added to prevent disconnection error.

Table 1. DR event signaling success rate and SOC% before event for battery equipment



Site ID	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6 Community Facility
Equipment Signaled	Battery	Battery	Battery	Battery	Battery	Batteries (2)
6/13/2023 7:00 PM	Invalid Configuration*	100%	Connectivity Error	100%	100%	1/2 Batteries Offline
6/29/2023 4:00 PM	100%	Connectivity Error	Connectivity Error	100%	100%	1/2 Batteries Offline
7/13/2023 5:00 PM	100%	100%	Connectivity Error	100%	100%	100%
7/20/2023 7:00 PM	100%	40%	Connectivity Error	100%	60%	100%
7/25/2023 7:00 PM	100%	60%	Connectivity Error	100%	80%	100%
7/26/2023 7:00 PM	100%	50%	Connectivity Error	100%	72%	100%
7/27/2023 7:00 PM	100%	40%	Connectivity Error	100%	72%	100%
8/10/2023 5:00 PM	100%	100%	100%	100%	100%	100%
8/15/2023 5:00 PM	94%	88%	94%	100%	88%	97%
8/16/2023 5:00 PM	94%	66%	100%	100%	66%	1/2 Batteries Offline
8/29/2023 6:00 PM	Connectivity Error	Connectivity Error	100%	100%	100%	1/2 Batteries Offline
8/30/2023 6:00 PM	Connectivity Error	Connectivity Error	100%	100%	100%	100%
9/12/2023 6:00 PM	Connectivity Error	Connectivity Error	Connectivity Error	100%	100%	100%
9/14/2023 5:00 PM	100%	Connectivity Error	Connectivity Error	100%	100%	1/2 Batteries Offline
9/26/2023 6:00 PM	88%	Connectivity Error	Connectivity Error	100%	100%	Connectivity Error
10/5/2023 6:00 PM	88%	Connectivity Error	Connectivity Error	100%	100%	1/2 Batteries Offline

The battery behavior on a DR event day is shown for a residential site in Figure 1 below. Since the battery is operating in Self Supply Mode, excess solar power is not dispatched to the grid and instead used to charge the battery throughout the day until it reaches 100% SOC. This

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[2] Observing the disruptions to signal testing, a cell card was installed for all the batteries, utilizing customer Wi-Fi as an additional layer of connectivity and to enhance resiliency beginning December 2023.

example shows the battery discharging to the grid at 7 p.m. when the DR event began. The battery continued to discharge until just before 9 p.m. when the DR event ended.

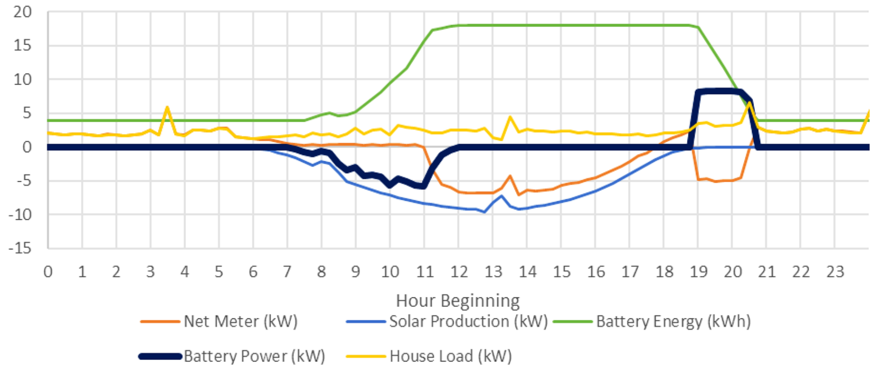


Figure 1. Site 1 Battery behavior during DR event (07/26/2023, 7 – 9 P.M.)

For the community facility, the two batteries behaved similarly to the residential sites, charging during the day and discharging during the DR events. However, there were intermittent connectivity issues with the inverters, sometimes preventing batteries from discharging or receiving signals properly. An example of a successfully executed DR event can be seen in Figure 2 compared to a non-event day shown in Figure 3. On the non-event day, the community facility batteries discharged slowly, especially if the facility was not in use. However, during a DR event, the community facility batteries discharged completely until the minimum SOC was reached. During both cases, the batteries charged to 100% SOC during the day through solar.

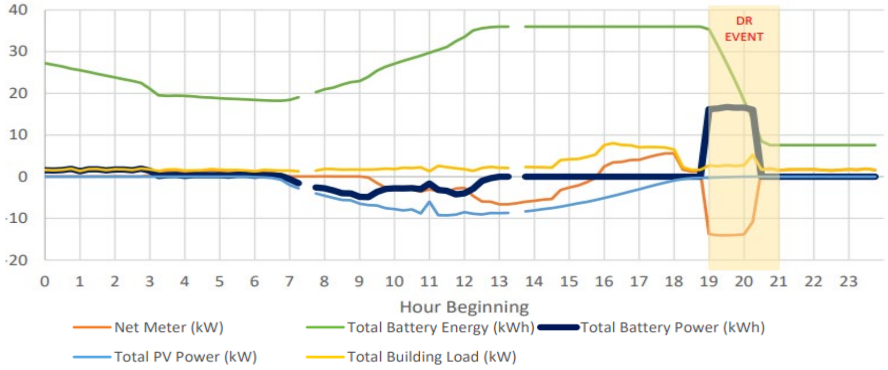


Figure 2. Community facility (Site 6) battery behavior during DR event (7/20/2023, 7 – 9 P.M.)

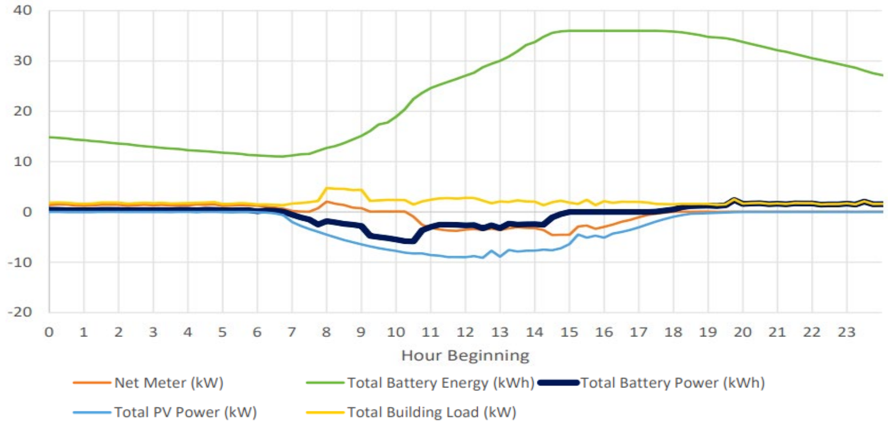


Figure 3. Community facility (Site 6) battery behavior during Non-event day (7/19/2023)

VPP Demand Impact. Table 2 below shows the summary of demand reduction across all events of the VPP during the 2023 DR season (6/13/2023 – 10/5/2023). The test results showed that the VPP was able to have a maximum combined demand impact of 41.9 kW on 8/10/2023 and a minimum combined demand impact of 7.1 kW on 8/16/2023. The average demand impact across the 14 two-hour DR events analyzed during the DR season (06/13/2023 – 10/05/2023) was 29.0 kW, while the average impact across the two four-hour events was 10.1 kW. The battery equipment was the main contributor to the VPP impacts, with a specified 14.4 kWh in usable storage and a maximum theoretical discharge power of 7.6 kW when grid tied. However, some sites were not able to maintain a 100% SOC before every DR event. This was caused by an undersized solar system, solar availability due to weather conditions, or increased building loads during the day. Also, there were several events where batteries could not work to their full capacity because of connectivity or configuration issues like the battery going into shutdown mode instead of Sell Mode.

Table 2. Summary of VPP demand reduction

	Average residential baseline load (kW)	Average residential demand reduction (kW)	Average non-residential baseline load (kW)	Average non-residential demand reduction (kW)	Average combined baseline load (kW)	Average combined demand reduction (kW)
2-Hour DR Events	13.5	22.2	0.4	6.8	13.9	29.0
4-Hour DR Events	7.8	8.0	0.6	2.1	8.4	10.1

Thermostat behavior was also monitored during the DR events observing successful pre-cooling to shift AC demand when there was connectivity. However, connectivity of the smart thermostat devices over Wi-Fi was unreliable at times depending on the site. Additionally, some customers opted out of DR events, prioritizing their comfort over the DR event. Since power metering of AC units was not done, the exact impacts of thermostat controls were not calculated for the DR events and simply reflected in meter data for each event analyzed.

The demand impacts of controlling the well pumps were found to be minimal. Due to their sporadic operating behavior, their average daily load was only 123W for all pumps. The pumps were also found to have an idle load of 20W, meaning their operating load was minimal compared to the battery impacts for this VPP. The well pumps were found to have a peak load of around 4 kW. However, the infrequent use of the well pumps made their impacts insignificant in this VPP. One recommendation may be to schedule well pump operations to turn on only during non-peak hours to avoid the need for automated DR.

Lessons Learned

The solar and battery equipment was identified as the primary contributor to the demand impacts observed in the VPP. The battery storage showed a significant amount of potential during DR season to act as a dispatchable resource particularly when remotely controlled, enabling valuable contributions to grid services. From customer recruitment challenges to equipment connectivity issues and communication network considerations, each phase of the project provided insights that contribute to a more nuanced understanding of the intricacies of deploying residential energy solutions. The project recommends the following considerations and best practices be thoroughly contemplated for the implementation of VPPs at larger scale.

Equipment Reliability: Battery energy storage systems are generally reliable in a single use backup capacity, however signaling these devices for numerous event days uncovered unexpected technical issues. For example, on several occasions, a battery would not revert back to standard operations after an event was called, which required a technician to go on site.

Address Distrust: A number of customers voiced concerns about the utility having control over their equipment, such as HVAC systems and well pump operation. Customers were provided with the capability to override both thermostats and the well pump controller. The override feature was emphasized to ensure all customers were aware of this capability.

Assess Communications & Emphasize Connectivity Responsibility: Conducting a comprehensive assessment of the cellular network coverage or Wi-Fi signals in the targeted areas is a critical step in ensuring the successful implementation of technology. It is also crucial to ensure that the customer is well-informed about the significance of having and maintaining reliable and robust Wi-Fi connectivity as well as emphasizing the importance of customer engagement for feedback is equally vital for the optimal operation of the technology and the overall success of the project. Thus, customer agreement forms should highlight the significance of maintaining device connectivity.

Interoperability: Reliable communication technology beyond Wi-Fi and LTE should be explored. Over the course of the project, the interoperability of various devices was assessed, finding many of the devices from external sources required additional API development to be controlled. Standardization of device communications is key to providing a VPP at scale.

SCE's Willowbrook Pilot: Enabling Clean Energy in Disadvantaged Communities with Integrated Photovoltaics and Storage

The Purpose of this Project

This project sought to identify scalable innovative building technology models to maximize the economic benefits of advanced energy systems for low-income (LI) multifamily (MF) populations and to evaluate how these technologies could enable grid flexibility and environmental benefits for their underserved communities. Emphasis was placed on business models that supported resiliency s and maximize energy affordability, as California IOUs transitioned all residential customers, including those on affordable discount rates, to time of use (TOU) rates with time-differentiated pricing signals. The project developed a set of physical and virtual energy system models in a multi-family residential building test site providing assessments of innovative emerging building technology systems. This resource integration project serves as a demonstration of integrated technology innovations and resilient energy systems that align with California's policy direction targeting the hard-to-reach LI urban multifamily sector.

Background

Most low-income Californian residents are on California Alternate Rates for Energy (CARE) discounted electrical rates. In a 2017 pilot program to understand TOU impacts, the California Public Utilities Commission (CPUC) found that all Pacific Gas and Electric Company and SCE CARE customers in hot climates experienced higher total annual electricity costs under TOU pricing, ranging from \$20 - \$40 in average monthly bill increases (Hawiger, 2017). SCE CARE customers were also generally found to be unable to offset a significant portion of the bill increases by load shifting. Thus, the variable rates effectively lead to greater overall bills for an already burdened sector, especially during peak summer times.

This project took place during a confluence of program and policy initiatives in California advancing decarbonization, solar and storage in the multifamily segment, and equitable access to energy innovations to all sections of society. This project was designed to demonstrate an implementation pathway where possible for these important policy initiatives:

- 2022 State Energy Code: This provides critical learnings anticipating a requirement that new MF buildings be equipped with solar AND storage (CEC, 2021).
- AB 693: This project provided implementation strategies in low-income multifamily housing to address both the two major constraints for implementing solar in affordable housing – site fit and the business models (Waldron, 2023).

The project was located at the Mosaic Gardens facility at Willowbrook (Willowbrook) which is an affordable multifamily housing property in Compton, California, a highly disadvantaged community (DAC) in Southern California. Constructed in 2017 by Linc Housing and achieving LEED Silver certification, Willowbrook provides 61 housing units to low-income families, with 31 units reserved for individuals or families transitioning from homelessness. Installation of the solar + storage project scope officially began in the fall of 2020, only after all necessary plans and building approvals were secured. The site was selected because it was representative of the target market of affordable multifamily housing, and the owner was motivated to investigate the benefits of solar + storage for their larger portfolio of similar housing developments.

Featured Technologies

The research team principals for this project, consisting of EPRI and SCE staff, successfully deployed and tested a resource integration demonstration comprised of the following technologies and illustrated in Figure 2:

- 2 behind-the-meter electric battery EnergPort cells 60 kW / 2-hour
- 2 60-kW bifacial solar PV arrays DC-coupled to batteries with Bi-directional inverters
- Inverter meeting CA Rule 21 Phase mandates for grid supportive functions
- Multi-Level Controls Integration through a Cloud-Based Open Demand Side Resources Integration Platform (OpenDSRIP), developed by EPRI coordinating system controls
- A Community-Sharing Virtual Net Energy Metering (VNEM) model: The production and operation of the PV and battery is distributed (allocated) across each of the residential unit meters and the main site premise meter
- Common-area lighting and air conditioning DC-based system loads

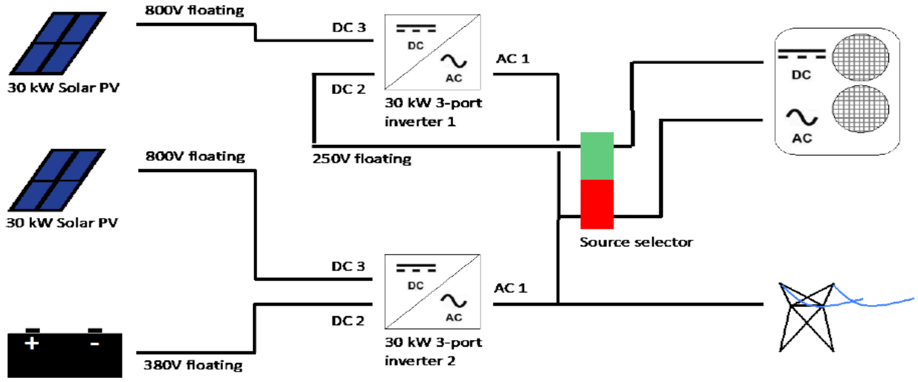


Figure 2. System electrical diagram.

Eighteen 24VDC Lamar lighting units were installed along exterior hallways common area. The DC mini-grid also included 24VDC Lamar lighting, Amatis bridge, sensors and switches, and 2 Nextek power hubs. Specifically, the DC system installed by this project models a means for bolstered resiliency as it provided backup power for a standalone resiliency center during local outages to support critical loads like oxygen support devices and air conditioning.

Deployment Process

As solar PV, storage and DC loads are naturally compatible, the team demonstrated a DC electrical distribution and DC appliance system to compare the energy use to a traditional AC distribution system with compounding energy losses estimated to be as high as 33 percent. This is noteworthy considering residential applications have particularly high potential as one-third of US residential loads are native DC and could be higher with electric vehicles (Pantano, 2016).

This project was unique in its DC side connection of solar and storage with a single inverter. Getting through the permitting process required a significant amount of work with the County of Los Angeles, the local permitting authority, as it was unfamiliar with a DC side connection. It was also difficult to obtain local utility SCE approval (due to the unprecedented building design), but it was enabled by prior work the vendor had completed with PG&E on a software-based monitoring solution for non-export Rule 21 interconnect. On the DC demonstration, several iterations of plans were submitted, and parts were not readily stocked or available as market demand was low. For example, DC lighting in this project used low voltage, low power controls that are being used and accepted elsewhere but with no UL listing in the United States. LA County officials required the project team to obtain a UL field evaluation for low voltage lighting controls.

Evaluation Approach

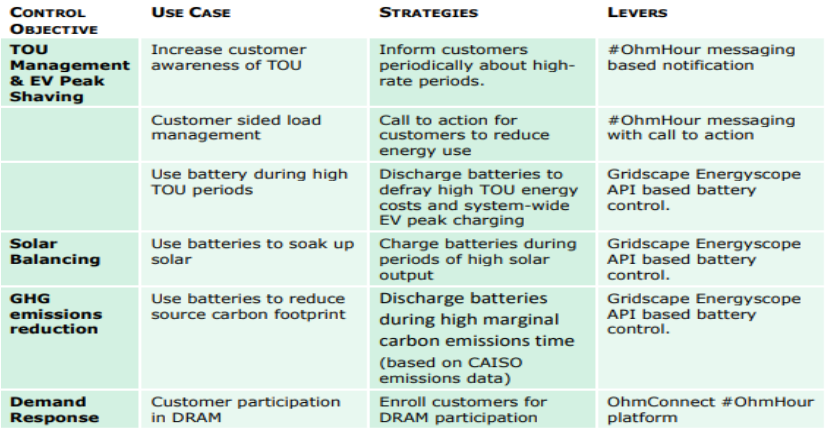
The project team was required to investigate alternate business models or arrangements to engage IOUs more effectively in community-scale, customer-sited DER for both end-customer and grid-support benefits. The team conducted distribution system analysis to evaluate the cost effectiveness of community-scale BTM PV + Storage resources for the rate payers as well as utility grid especially when these solutions are distributed across other multiple locations within a utility's distribution feeder. EPRI designated the primary control objectives, which include:

1. Local load balancing with solar PV, to get ready for electrification of buildings, while avoiding upgrade of distribution transformers and secondaries
2. Managing storage to reduce GHG emissions from the California Electric system

The project team evaluated multiple battery control scenarios including one simulated at scale across multiple communities on the same residential feeder, in which it was able to reduce peak load by 10 percent while meeting other controls objectives (TOU rate offset, EV peak shaving and GHG emission reduction) 97 percent of the time throughout the year. It bore the highest financial returns of all the scenarios evaluated as part of this project.

As depicted in Table 2, the test plan employed controls strategies using levers of the battery system controller (Gridscape Energyscope API) as well as customer notifications through an online behavioral DR platform (OhmConnect's #OhmHour messaging platform).

Table 2. Summary of Controls Strategies



Control Objective	Use Case	Strategies	Levers
TOU Management & EV Peak Shaving	Increase customer awareness of TOU	Inform customers periodically about high-rate periods.	#OhmHour messaging based notification
	Customer sided load management	Call to action for customers to reduce energy use	#OhmHour messaging with call to action
	Use battery during high TOU periods	Discharge batteries to defray high TOU energy costs and system-wide EV peak charging	Gridscape Energyscope API based battery control.
Solar Balancing	Use batteries to soak up solar	Charge batteries during periods of high solar output	Gridscape Energyscope API based battery control.
GHG emissions reduction	Use batteries to reduce source carbon footprint	Discharge batteries during high marginal carbon emissions time (based on CAISO emissions data)	Gridscape Energyscope API based battery control.
Demand Response	Customer participation in DRAM	Enroll customers for DRAM participation	OhmConnect #OhmHour platform

The Measurement and verification plan was informed by the project objectives and the need and requirements to verify that the systems were operating as expected. EPRI collected data at 1-sec, 1-min, or 15-min intervals (depending on metric and sensor device) and reported to the data server to provide remote technical support for tracking and modeling the deployed systems. For both sets of batteries, the DC monitoring points for energy storage and PV systems included:

- DC voltage (V) and current (A) at inverter's battery bus: 1-second resolution
- Battery module and/or cabinet temperature (°C): 1-minute resolution, up to quantity 8
- State of charge (percent), operating mode, and other parameters available via inverter's communication interface: 1-minute resolution.

An example of data collected is summarized in Figure 3, where the basic timeline of charging, discharging, and TOU rate changes is quantified. The study analyzed metrics using a measurements-based, statistical approach for the following:

- Battery and PV functionality, along with solar energy performance
- PQ implications: study of common power quality factors
- Comparison of energy utilization pre- versus post- treatment
- Load shed DR performance and evaluation of multiple battery control scenarios

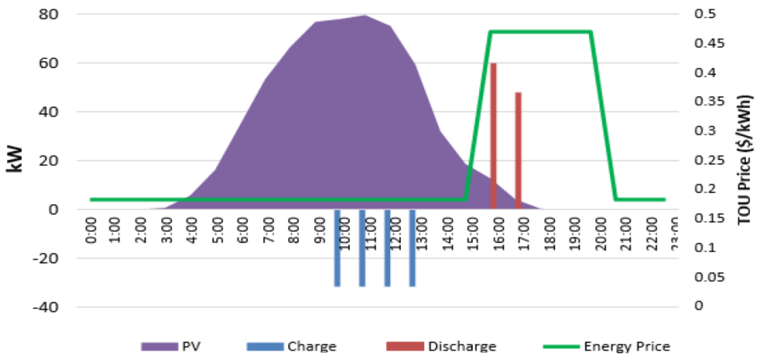


Figure 3. Energy and rate chart per hour.

Results & Findings

Battery Operation for GHG Reduction: During the TOU Winter months (Oct 1– May 31), the battery system was set to a "GHG Emissions Reduction" profile where the battery discharges from 3am to 8am, which is the time range with the highest average grid GHG emissions based on CAISO 2019 emissions data. It then charged itself when renewable solar energy was more available during daylight hours. By charging the battery with renewable power and discharging it during the periods of highest GHG emissions, the GHG Emissions profile attempts to zero out the building's source GHG emissions (Scope 2 emissions) during the periods of highest GHG intensity in the grid. For example, the battery profile after the battery was set to "GHG Emissions Reduction" profile is shown for Building 1 in Figure 4. The battery discharges between 3-8am, then charges from solar PV and holds charge steady during the TOU peak hours.

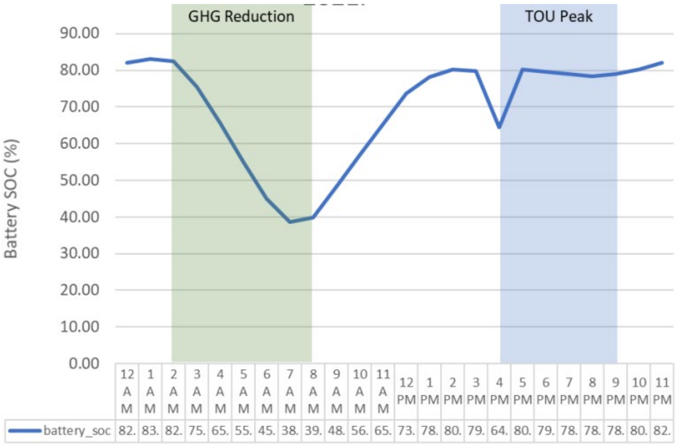


Figure 4: Battery SOC profile for building #1 Sept 1 to Nov 30, 2021.

Reliability From Controlled Battery Dispatch: The research team modeled 3 battery management scenarios to address project control objectives to determine which offered the greatest benefits to the property and the local grid. Ultimately, Scenario 3 (a top-down scenario prioritizing 10% annual peak load reduction at the feeder level while only secondarily addressing other control objectives) proved that the stacked benefit approach was most effective at providing the most notable annual bill savings and net annual peak load reduction for a residential distribution circuit. With load-shifting from the 4-9pm timeframe to the 12-3pm timeframe, the reduction in energy use is estimated at 1.48 MWh over the summer period (June 1 – Sept 15). Of the energy consumption data set of 21 residents that the project team had access to, only six had data going back to summer of 2020. A method of scaling the data from these six units was employed alongside detailed hourly common area meter data available to develop an energy performance pre-retrofit. This pre-retrofit performance (2020) was compared to the post-retrofit performance (2021). The result of the comparison is shown in Figures 5 and 6.

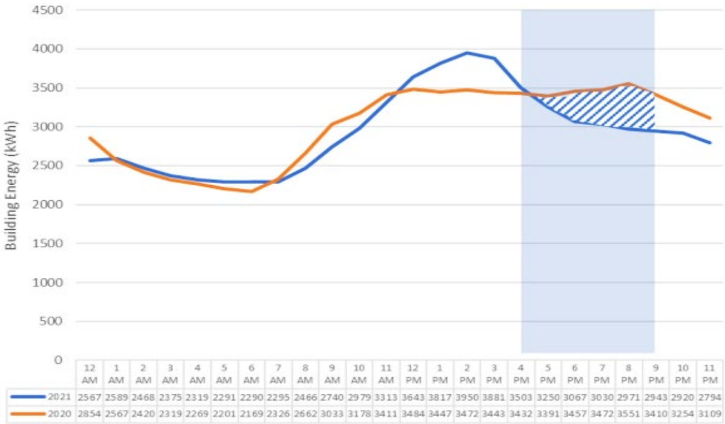
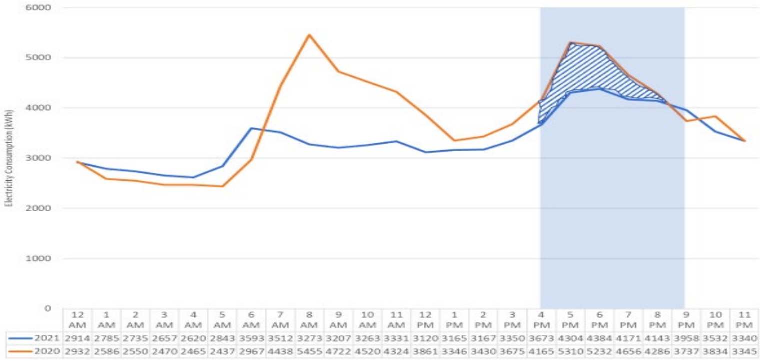


Figure 5: Pre-retrofit (2020) to post-retrofit (2021) energy performance comparison June 1 - Sep. 15.



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2914	2785	2735	2657	2620	2843	3593	3512	3273	3207	3263	3331	3120	3165	3167	3350	3673	4304	4384	4171	4143	3958	3532	3340
2020	2932	2586	2550	2470	2465	2437	2967	4438	5455	4722	4520	4324	3861	3346	3430	3675	4165	5310	5232	4656	4286	3737	3834	3345

Figure 6: Pre-retrofit (2020) to post-retrofit (2021) energy performance comparison Dec 1 – Feb 28.

The community was subject to active TOU energy management via messaging done through the OhmConnect messaging platform, to evaluate “How does this performance compare to the time before these renewables, storage, and active load management methods were employed?” Figure 4’s energy performance between June – Sept 2020 and June to Sept 2021 shows a 9% reduction in energy usage from customer behavioral energy management during the 4-9pm window. This downward shift in the entire load profile over 24 hours is more attributable to energy efficiency than to signaling or TOU management.

This trend continues and is more heavily pronounced in Winter where there is a downward shift in peak as well as overall energy performance. In Figure 5’s winter period, there is an elimination of a morning peak as the peak shifts to the evening hours but is also lower in 2021 compared to 2020 by about 13% (900kWh reduction on the basis of 5200 kWh for 2020). There is load-shifting that is evident from the 4-9pm timeframe to the 12-3pm timeframe which leads to the peak around 2pm in summer. Winter’s project performance demonstrates an overall reduction in load (over 24 hours) of 11% (9.7 MWh) and 13% (2.9 MWh) during the 4-9pm timeframe. The significant winter energy reduction is indicative of a behavioral shift.

DC Distribution and Appliances: The DC-coupling demonstration at Willowbrook evaluated the avoided conversion losses and the associated reduction in inverter capacity and cost by using DC power direct from the solar and battery system to feed 24V lighting and a DC-enabled 4-ton variable speed mini split heat pump. The complex implementation of hybrid AC/DC resilient systems and scarcity of DC components, calls for more time set aside in future construction for testing and interconnection. Substitution of 24W DC light fixtures resulted in a 3.6 percent efficiency gain in of lumens per watt, thus the project found that keeping the system “all-DC” was equivalent to the traditional AC lighting systems in the expected efficiency gains.

Demand Side Resources Integration Platform (OpenDSRIP): The issued custom messaging on behavioral energy and demand reduction recommendations to prime residents for TOU rates coming into effect. From June to September 2021, there were 42 unique events, with 619 resident opt-ins or an average of 16 opt-ins per event. The performance suggests that residents were actively engaged and that monetary incentives and gamification mechanisms used in the behavioral program are motivating (and effective) factors for participation.

Discussion of Results

EPRI further collected energy performance data during a summer and shoulder month season, finding post-installation energy performance resulting in a net benefit to the community in terms of reducing their energy costs as well as Scope 1 and Scope 2 emissions. Roughly one-third of the site host residents also enrolled in the Willowbrook-specific behavioral DR program.

Energy consumption during the 4-9pm TOU peak pricing period fell 25 percent compared to the previous year as a result of behavioral reductions in energy use.

The economics of solar + storage for low-income communities is nascent or non-existent with current rates. This project utilized a VNEM tariff that enables the property owner to choose how to allocate production from behind the meter systems to different resident accounts. Employing the VNEM rate structure meant that the benefits of solar PV accrue mainly to the tenants. The Solar on Multifamily Housing (SOMAH) program, which also influenced the project design, effectively prevents the landlord from charging the tenants for the benefits of solar, which means that the property owners have to justify solar just based on the common area usage (CPUC, 2015). Often, common area usage is very limited (in this case just 10,000 kWh a year), and that means that property owners, if they lease solar cannot cover lease payments.

This demonstration proved that the scope was not as easy as it appeared on paper due to a number of factors such as limited product availability, lack of familiarity by permitting authorities and stakeholders, code limitations and compatibility issues. A case in point was the requirements of a field evaluation for a low voltage controls system of which simply the cost and scope would have prevented most customers from considering such a deployment. The host site also experienced a relatively high number of outages during the project that disrupted the property's electrical supply and HVAC operations.

Recommendations

The project revealed the design and construction challenges in initiating a solar + storage project in a disadvantaged community's multifamily property, but also demonstrated the business case for a property owner in meeting the due diligence requirements of its property lenders for environmental stewardship. The emerging technologies utilized required additional time and resources compared to industry-standard technologies to source, integrate, interconnect, and operate, but identifying barriers was one of the research intents of the demonstration. Funding research such as this paves the way for future policy considerations for making low income multifamily solar and storage integrated buildings financially feasible.

Recommendations for scaling solar + storage + DC + controls at low-income multifamily properties taken from the lessons learned at the Willowbrook demonstration site are many, but the research team's key strategies are summarized below:

- Prepare and fund a close-knit team, with an on-site presence. Having a specialized facility resident engagement coordinator with a social service/welfare background is highly recommended for transacting with a community of affordable housing residents. A local construction team and dedicated construction manager well trained in the specialization of new technologies is important, along with continuous communications and backup support for technical challenges associated with non-traditional energy systems.
- A list of stakeholders for LI multifamily properties (especially lenders for tax credit financed properties) should be established at project onset to ensure all are consulted on project terms. It is important to communicate the potential for Scope 1 and 2 emission reductions and greater resilience through the DC demo, providing for vulnerable populations in need of continuous power. This would better socialize the challenges and benefits of future investments in similar projects.
- The return on investment of the affordable housing property owner/manager's financing needs to be improved to enable future solar + storage + DC construction with new technologies financially viable. While offering clear benefits to the property and local

grid, outcomes such as GHG reduction, net peak load reduction, and added resiliency cannot be easily monetized into cash flows. Incentive structures and modifications to existing and future utility and State programs should be explored to help property owners or project financiers better adopt the business case of doing solar + storage + DC. Education, training, changes to building codes and credits/incentives could help the affordable housing community monetize benefits to improve the NPV and value proposition of solar + storage + DC especially where there are clear, overlapping stakeholder benefits and alignment with state policy.

This project shows us that DC sources and loads show great promise as part of a future electrical system for added resiliency and efficiency. Each DC-coupling application must be evaluated for technical feasibility within available hardware and codes limits as well as economic feasibility comparing the costs and risks to the potential benefits. The Willowbrook project is proving the technical feasibility through demonstrations of DC-coupled solar, storage, and controlled loads. Demonstration of technical feasibility is often one of the first steps in achieving financial viability for new technologies. Furthermore, it can inform future electrical code updates and represents another workforce training opportunity.

This exercise provided valuable insight into the design process of hybrid AC/DC resilient systems with the primary lesson of how the design of these systems is more complex than it appears. The demonstration validated a resilience strategy in DAC communities through the DC distribution and appliance demonstration, which theoretically can help with populations in need of continuous power for medical devices during an outage. While it was not possible to accurately measure DC/DC conversion efficiency of the power converter, keeping the system "all-DC" is a strategy that requires more investigation.

Conclusion

Both these DRET projects not only innovated approaches to address the resilience needs of these communities in an equitable manner, but also found indication of energy and demand savings that translate to lower utility costs to provide customer affordability and can result in lower costs allocated to ratepayers. Potential co-benefits of the Willowbrook and Shelter Valley projects further include the creation of new jobs associated with the local labor force at these sites. A reduction in energy bills and DR participation payments also leaves tenants with greater disposable income, which is particularly impactful for low-income populations, which constitute over 13 percent of all California ratepayers (Shrider, 2023).

While both projects demonstrate innovative approaches integrating DERs to contribute to grid stability, they operate in distinct contexts and offer complementary insights. Willowbrook demonstrated findings that illustrate clear affordability benefits to the property manager as well as SCE, including GHG reduction, net peak load reduction and utility bill savings. In contrast, Shelter Valley identified the best-value resiliency investments at a community level and its findings underscore the potential of VPPs to mimic or replace conventional power plants, reduce greenhouse gas emissions, and decrease overall energy costs.

By deploying field demonstrations across residential and rural settings, the DRET Collaborative advances the understanding & potential cost-effective adoption of decarbonization opportunities for hard-to-reach communities. For greater detail on the two projects and their evaluations, there are full reports published on the DRET Collaborative website (dret-ca.com).

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