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Energy Research and Development Division

FINAL PROJECT REPORT

Demonstration of Community Scale Generation System at the Chemehuevi Community Center

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PREFACE

The California Energy Commission's 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 California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & 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 Energy Commission 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.

Demonstration of Community Scale Generation System at the Chemehuevi Community Center is the final report for the Demonstration of Community Scale Generation System at the Chemehuevi Community Center project (Contract Number: EPC-14-003) conducted by the University of California. 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 CEC at ERDD@energy.ca.gov.

ABSTRACT

This project engineered, installed, and demonstrated a solar photovoltaic system and a battery energy-storage system to integrate and manage energy peak reductions, load shifting, demand response, and load control at the Chemehuevi Indian Tribe Reservation Community Center. The demonstration site consists of a single facility with average energy consumption 100,000 kilowatt-hours per year. The facility is a designated emergency response center and provides a variety of services to the Chemehuevi community members. The project features the design and development of a custom energy-management system by University of California, Riverside, with the objectives of reducing overall electricity costs, utilizing renewable solar energy efficiently, and providing additional energy resiliency to the Chemehuevi Community Center building. The project resulted in annual renewable energy generation of 143,368 kilowatt-hours of electricity, annual electricity bill savings of $11,042, a total annual monthly peak-demand reduction of 69 kilowatts, and an annual reduction of 47,455 kilograms of carbon dioxide equivalent greenhouse gas emissions from grid electricity.

Keywords: Microgrid, peak reduction, load shifting, demand response, distributed energy resources, battery energy storage system, island-mode.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Recent wildfires and other extreme climate-change-related weather events have revealed vulnerabilities in some areas of the electric grid and how resulting prolonged power outages disproportionately affect remote communities. A common solution for grid power outages has traditionally been on-demand back-up power from fossil-fueled generators. Despite their widespread use and proven functionality and reliability, diesel and gas generators are expensive sources of energy and the lack of regulatory controls on small- and medium-sized generators make them a major source of greenhouse gas emissions and criteria air pollutants. Nevertheless, most microgrids in California, local energy grids with control capability and can disconnect from the traditional grid and operate autonomously, are routinely equipped with back-up diesel generators.

An alternative energy source for microgrids in even the most isolated areas is solar photovoltaics (PV). One of the benefits of microgrids is the ability to "island," or to operate when disconnected from the larger utility grid. Unfortunately, despite the tremendous growth of solar PV installations, several major obstacles remain in relying upon solar PV to back up power supply and intermittent off-grid operation. The main obstacle, a design feature, is the shutdown of solar PV inverters during grid power losses as an anti-islanding safety measure. Islanding is a critical and unsafe condition in which a distributed generator, such as a solar system, continues to supply power to the grid while the electric utility is down. Another reliability obstacle is that solar PV is, by its nature, intermittent. An energy storage system coupled with solar PV offers solutions for these obstacles; when solar PV is integrated with an advanced energy-management system capable of supporting microgrid energy loads, system management, solar PV and energy storage together can effectively manage both off-grid and grid-tied operations. Energy-storage systems augment solar PV benefits by further increasing solar energy utilization, decreasing peak demand, and reducing both electricity costs and local greenhouse gas emissions.

Project Purpose

The goals of this project were to deploy a 90-kW solar PV system and 60 kWh battery energy system at the Chemehuevi tribe's community center, integrated with demand response capabilities within the facility's energy management system to optimize between PV generation and the battery energy system. The project's microgrid solution consisted of high-efficiency solar PV panels; a novel flow battery energy storage system (FBESS); a direct current-direct current (DC-DC) conversion system; an alternating current-direct current (AC-DC) inverter (with islanding capability); an advanced data historian to predict loads, reporting, and system planning, and an energy management system with microgrid and load-management capabilities. Each of these components has merits; however, a few important characteristics include the DC-DC optimization and conversion system (capable of integrating multiple DC sources or loads on the DC bus at different voltages), and inverters capable of islanded and grid-tied operation, an automated grid-islanding disconnect switch, and a novel chemistry-battery system with a long-cycle life and full depth of discharge.

The main project activities involved integrating individual distributed energy resources into a coherent microgrid solution and developing a custom energy-management system capable of managing both the microgrid components and all aspects of their operation. Additional features of the energy-management system included various energy-management strategies: peak-demand reduction, load shifting, demand response, and load control.

This project assessed the energy needs and challenges faced by remote communities and demonstrated the effectiveness of an integrated microgrid solution consisting of several pre-commercial distributed-energy-resource technologies. The project is of interest to medium-sized commercial electric customers (with annual peak-demand loads of 50 kW) seeking load management, emergency back-up, renewable energy generation and utilization, and lower electricity bills.

Project Approach

The project installed high-efficiency 90.4 kW solar carport PV modules from SunPower, a novel 25 kW/125 kWh zinc-bromine FBESS from Primus Power, and a 100 kW DC-DC energy management system and 125 kW AC-DC inverter from EnSync, all managed by an energy management system designed by the University of California, Riverside. The main project objectives were to reduce overall electricity bills, use solar energy efficiently, and provide resiliency to the Chemehuevi Indian Tribe Community Center building located in Lake Havasu City, California.

The Chemehuevi Indian Tribe reservation is a remote community; electricity is provided by a single Southern California Edison substation and the single 16 kilovolt (kV) Topoc circuit. The Chemehuevi Community Center hosts an afterschool program for children, a kitchen, an exercise room, and various events and celebrations. Southern California Edison’s reliability reports show that the circuit serving the Chemehuevi Indian Tribe community experiences significantly more power outages, and for longer periods, than the utility’s system-wide average. Consequently, the Chemehuevi Community Center building is equipped with a 175 kilovolt-ampere diesel back-up generator that serves as a refuge for community residents during extended power outages.

The project team first evaluated the energy needs and analyzed baseline electricity costs for the Chemehuevi Community Center building. The researchers selected solar PV generation and an electrical battery energy storage system to reduce electricity bills and provide energy resiliency for the tribe.

A 90.4-kW solar carport PV system was installed by GRID Alternatives. The system consists of two arrays. One array is made up of 84 P-Series SunPower modules, the other of 144 E-Series SunPower modules. Both P-Series and E-Series SunPower modules are made for commercial usage, but the larger P-series panels are uniquely well-suited to larger roofs and capture more light. The arrays were designed and installed on carport structures by EcoForce Solutions. The EnSync Energy Matrix system consists of four 25-kW DC-DC conversion modules capable of receiving and optimizing power from multiple DC sources at different voltages, a 125-kW AC-DC inverter, and a grid-islanding disconnect, all managed by EnSync’s energy control module, which in turn is controlled by the energy management system.

The energy management system used building load and solar generation forecasting to automatically determine optimal times to charge the battery with solar energy and discharge it during peak-load periods. Another layer of the energy management system monitored and managed heating, ventilation, and air conditioning (HVAC) units in the building to ensure their efficient operation, thus lowering electricity demand. The energy management system employed multiple strategies including peak reduction, load shifting, controllable load management, and demand-response incentives to lower electric utility charges and increase grid resiliency.

The energy management system received and archived data for: the building net load through the phasor measurement unit; solar PV power data; battery status, state of charge, and power data from the battery management system; weather data from a weather station; and thermostat settings and room temperature data. The system also performed computational and logic operations and transmitted control signals to the HVAC thermostats, flow battery, EnSync system, and inverter.

One major technical challenge overcome by the project was the integration of multiple distributed energy resources developed by different vendors with the energy management system created by the University of California, Riverside team. Although most distributed-energy resource vendors provide an application programming interface and the ability for third-party energy management system control, the management capability was limited and documentation and actual use cases were scarce. As a result, multiple software changes were needed to integrate the controls of the two systems with the energy management system, which were difficult with the Primus Power flow battery control strategy.

Some of the challenges faced by the project team related to distributed energy resource equipment compliance with safety standards; local authorities had jurisdiction over regulations, utility interconnection rules, and net energy-metering agreement requirements. A specific hurdle for this project was the requirement that advanced inverter functions established in California Rule 21 Phase 1 for interconnection applications, be submitted to Southern California Edison after September 2017. The EnSync inverter was not equipped with "smart inverter" functions; however, an exception for the inverter was granted by the utility because the inverter installation occurred before September 2017.

Another major issue encountered during the utility interconnection process was the Southern California Edison requirement for pairing a net-energy metering agreement for energy storage with a solar PV generation system. This agreement mandated that the battery not charged from the grid and export energy back to the grid at a later time. The solution was to always restrict the energy storage system from charging from grid power by modifying the control module of the EnSync system. This modification required a demonstration to utility representatives and a nationally recognized testing laboratory representative, followed by a witness report prepared by the testing laboratory.

Project Results

During the demonstration phase, which spanned more than a year, the microgrid system generated 143,368 kWh of renewable energy and achieved annual electricity bill savings of $11,042. Energy storage was confined mainly to load shifting and peak-demand reductions between the hours of 4 p.m. to 9 p.m. due to several operational constraints and reduced storage capacity. The combination of HVAC management by the energy-management system and peak reduction through the battery resulted in peak-demand reductions of greater than 10 percent. The generated renewable energy of 143,368 kWh in the first year of operation resulted in displacement of 47,455 kilograms of carbon dioxide equivalent greenhouse gas emissions from grid electricity, assuming a greenhouse-gas factor for grid electricity of 0.331-kg CO_2e per kWh.

While the Primus Power flow battery was installed and used in this microgrid system, an additional battery or uninterrupted power supply system was needed to run the flow battery, thus the community center was unable to continue relying on the flow battery. The challenges with the Primus Power battery included: 1) limited dwell time, 2) meeting Southern California Edison operational battery requirement for net energy metering, and 3) several hardware failures. For example, the battery can remain charged for a maximum of 12 hours if charged above a 50-percent state of charge, or for six hours if the state of charge is less than 50 percent. However, the net energy metering agreement required the flow battery to be fully discharged daily and to undergo a refresh cycle after discharging (to strip zinc from electrodes and maintain its rated efficiency). Therefore, the full battery discharge left the flow battery vulnerable to potential damage, such as prolonged power interruptions from the electric grid, and required additional auxiliary AC power to keep the bi-directional inverter on to discharge its energy and perform its refresh cycle. Ultimately, the project team replaced the Primus Power FBESS with a well-established 33 kW/91 kWh lithium-ion battery to ensure the long-term operation and efficient use of the solar PV system. The lithium-ion battery did not have a limited dwell time, was able to meet the requirements of the net metering agreement and did not result in hardware failures. In addition, the project team replaced the bi-directional inverter with solar PV string inverters due to the lack of support from the original inverter manufacturer.

Some of main challenges encountered in this demonstration project were regulatory rather than technical. More specifically, special consideration needs to be given to equipment compliance with safety standards, local jurisdictional regulations, and utility interconnection rules. This technology integration also identified the processes and operations most suitable for adoption. Continued technology adoption requires dissemination of approaches, strategies, and methods for integration within microgrid deployments at critical facilities. Educational facilities, utilities, and energy management system providers should continue to collaborate on transitioning the energy sector to integration of energy system management strategies within critical facility operations. Continued fiscal incentives for reducing energy costs should continue to incentivize adoption of energy management systems and distributed energy resource integration.

Through this microgrid solution, the project achieved lower electricity bills by generating and using renewable solar energy and reducing kilowatt demand from the grid by more than 10 percent of the average daily energy demand during peak-demand periods. This research project additionally demonstrated greater electricity reliability by intelligently managing energy use, large loads (e.g., HVAC), PV generation, and battery energy during daily operation. These measures together mitigate the impact of grid-power disruptions and support critical loads.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The team developed presentations, website reference materials, procedures, and reports to assist agencies in identifying which processes or facilities would benefit the most from adopting this technology. Technology transfers were communicated through public presentations for other technology experts and tribes publications in the trade press, and open access peer-reviewed publications. Face-to-face meetings with stakeholders at industry meetings and conferences included:

- *Gathering of Tribes* in November 2016.
- *Annual UC Riverside Solar Energy Conference* in March 2018.
- *Solar Power International and Energy Storage International* in September 2018.
- *Annual Winston Chung Global Energy Center's Energy Storage Technologies and Applications Conference* in February 2019.
- *Institute of Electrical and Electronics Engineers Power & Energy Society Innovative Smart Grid Technologies Conference* in February 2020.

Benefits to California

This project is of great importance and value to California utility customers and the state's large investor-owned utilities. Native American Tribal facilities often function at remote locations lacking electrical grid resiliency and reliability observed an urban setting. The Chemehuevi Indian Tribe observes greater electrical outages and reduced power quality as a result of their remote location and being supplied by a single substation. This project demonstrates and deploys energy storage, energy generation, and energy management strategies that improve resiliency, reliability, and reduce both peak loads, electricity costs associated with transmission of electricity to a critical facility, and greenhouse gas emissions. The findings of this project and further understanding of the technologies evaluated and demonstrated can together bring long-lasting changes in the electricity energy generation and distribution sectors. These include increased solar PV penetration from increased energy-storage system capabilities, decreased use of fossil-fueled back-up generators, and increased electric grid reliability.

One of the objectives of this project was establishing the technical and practical feasibility of the proposed approach and technologies, proving the reliability and effectiveness of technologies developed and distributed by California companies and ultimately reducing the risk of future investment in these technologies. Proven and widely adopted technologies result in lower costs for later installations. Thus, a future benefit from this project to ratepayers will be the reduction in electricity bills with the wider adoption of these technologies. As microgrid- and distributed energy resource-implementing agencies increase their adoption of energy management systems and distributed energy resource architectures, software development will also evolve with more tools and interfaces. The industry would also benefit from specialized training and tutorials to further advance this integration.

This project also provided the opportunity to review electricity bills from past years, not only for the community center building studied, but for other large community buildings as well. Through this review key members of the tribe have become more aware and better informed about the technologies, their benefits, and billing components and charges for specific electricity tariffs.

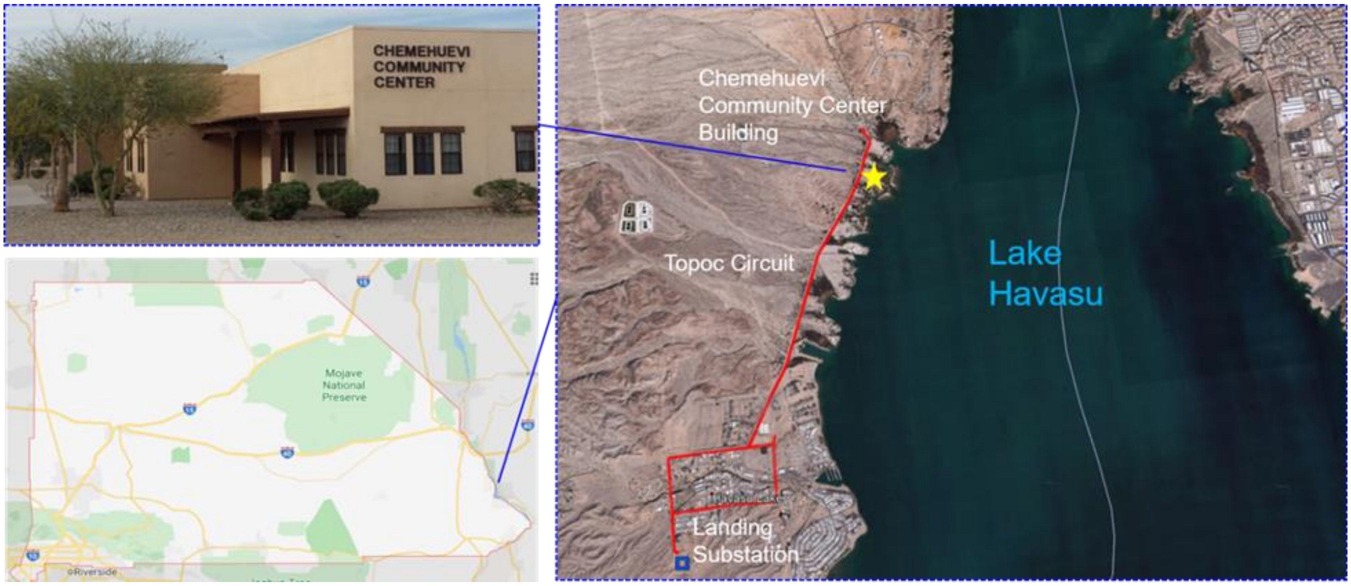
CHAPTER 1: Introduction

The purpose of this project was to deploy and demonstrate a community microgrid to improve site power reliability and resiliency. The goal of the project was to incorporate a 90-kilowatt (kW) solar photovoltaic (PV) system with a 60 kilowatt-hour (kWh) flow battery energy storage system (FBESS), integrated with demand response (DR) capabilities within the facility's energy management system (EMS), which would ultimately reduce peak energy demand for the center by utilizing battery storage to shift building and community loads. The system will also provide uninterruptible power for the center and help maintain the tribe's designation as an emergency response center during blackouts or loss of power.

Chemehuevi Indian Tribe Reservation Community Center Building

The Chemehuevi Indian Reservation is a remote community located on the California side of Lake Havasu in San Bernardino County. Electricity flows through Southern California Edison's (SCE) Landing substation and 16 kilovolt (kV) Topoc circuit. The Chemehuevi Community Center hosts an afterschool program for children, a kitchen, an exercise room, and various events and celebrations. The building, located at the end of a distribution line, is equipped with a 175 kilovolt-ampere (kVA) diesel back-up generator and serves as a refuge for the community residents during extended power outages. A SCE reliability report indicates that the circuit serving the Chemehuevi community experiences considerably more power interruptions, of much longer duration, when compared with the systemwide average for a San Bernardino District 1 customer. A large portion of the events leading to power interruptions are categorized as equipment failure; however, the majority of the events are categorized as "other." Figure 1 shows the location of the project site near Lake Havasu.

Figure 1: Location of Chemehuevi Indian Tribe Community Center Building



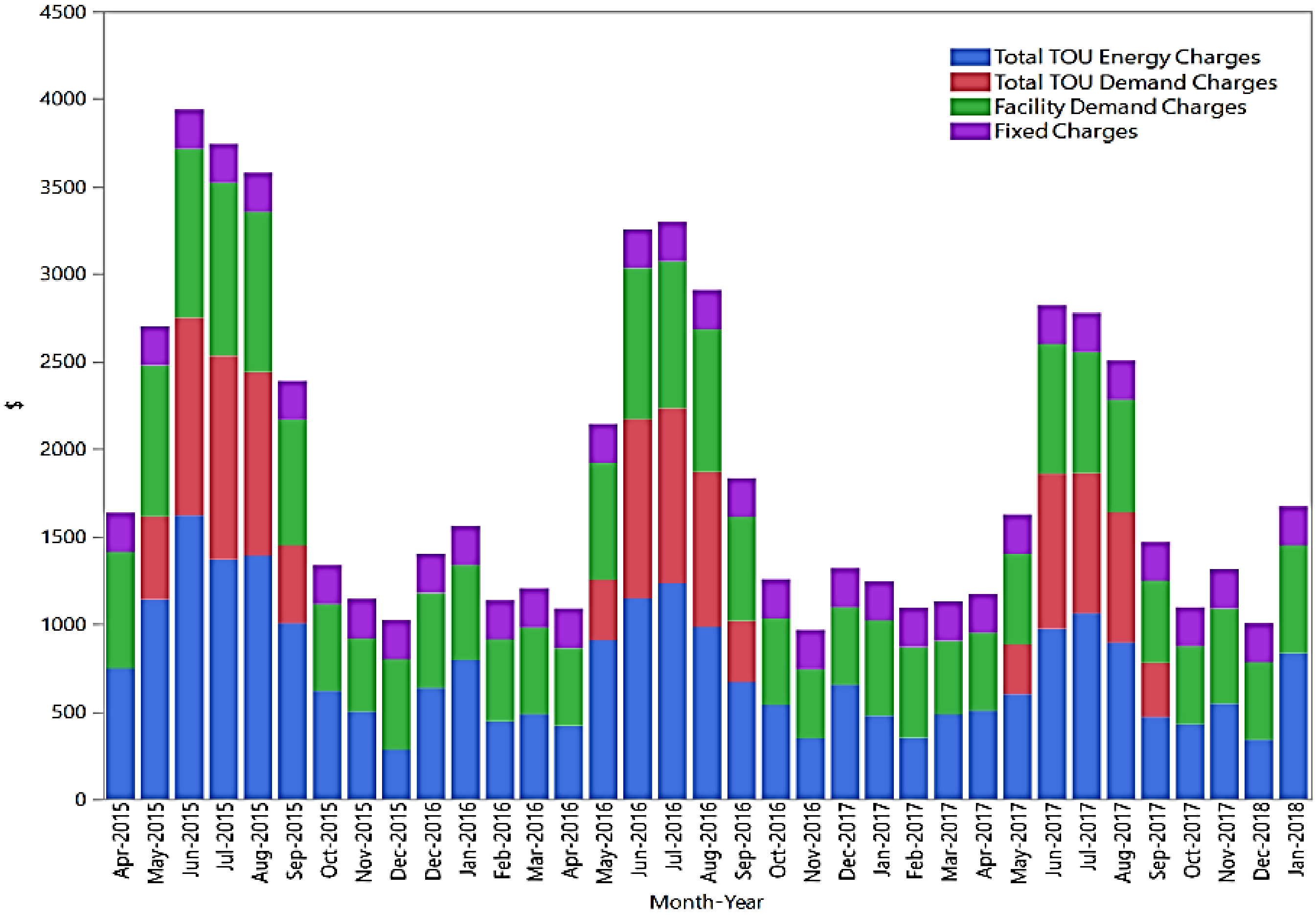
Source: Google Maps, Google Earth

Community Center Building Energy Use

The Chemehuevi Community Center building is supplied with 208 volt (V) 3-phase and 120 V single phase power under “General Service 2 – Time of Use” for commercial customers. The total monthly electricity bill consists of fixed charges, energy charges, and demand charges. The energy, measured in kWh, is priced differently depending on the actual time-of-use (TOU), with highest rates during on-peak periods, lower rates during mid-peak periods, and the lowest rates during off-peak periods.

Under this tariff, the electricity bill consists of facility demand charges and TOU demand charges. Facility demand charges per kW are based on the maximum power consumed, averaged over any 15-minute period during a billing cycle. Time-of-use demand charges are based on the maximum power consumed, averaged over a 15-minute period for a TOU period in a billing cycle. TOU demand charges are added in the electricity bill only during the summer season, while customers are responsible for facility demand charges throughout the entire year. Figure 2 shows the breakdown of a monthly electricity bill for the building. This breakdown shows that energy charges are no more than half of the total electricity bill on any billing cycle, and occupy a significantly smaller portion during summer billing cycles.

Figure 2: Building Monthly Electricity Bill Breakdown



Source: University of California, Riverside

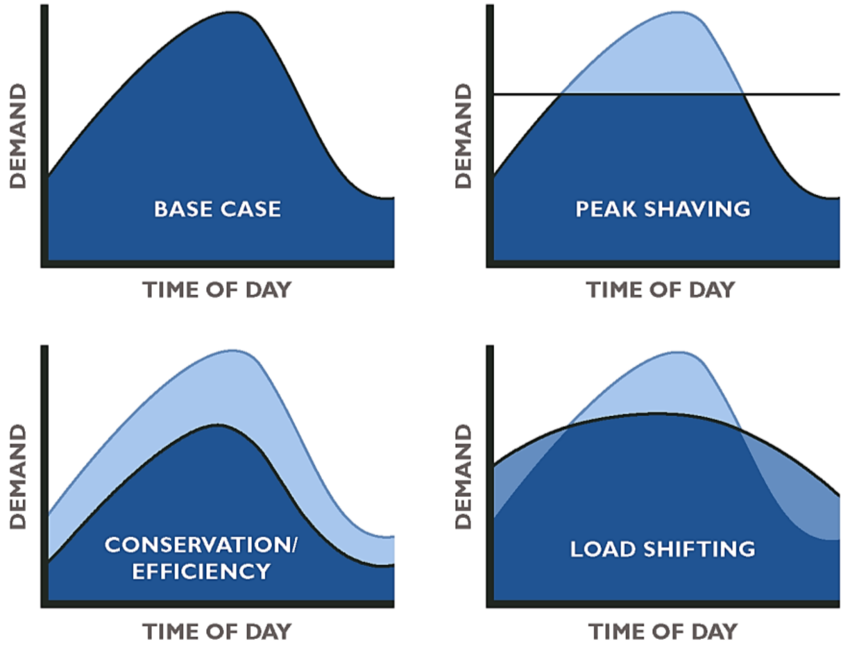
Approach to Increasing Power Reliability

The goal of a microgrid is to operate reliably in both grid-connected and islanded modes when grid power is interrupted. During grid connected mode, the voltage and frequency are set by grid power and distributed energy resources (DERs). In islanded mode, voltage and frequency of the microgrid must be established by DERs: by either a distributed generation (DG) source or a battery. The advantage of using batteries as primary, together with solar PV DG as secondary, is that battery energy storage can reliably provide voltage and frequency to the microgrid while balancing load fluctuations in solar PV output, which is determined by available solar irradiation. The disadvantage of using batteries as primary is limited duration of operation due to their finite energy storage reserves.

Approach to Electricity Savings Through Energy Management Strategies

Since demand charges occupy a significant portion of the electricity bill without necessarily increasing the total amount of energy used, it is often a common practice of energy management programs to reduce demand charges. Figure 3 shows a graphic representation of an electric-demand base case on the top left and peak shaving strategy on the right, which consists of reducing demand only during brief periods of high-energy consumption, leading to a demand peak for the billing period. The graph at the lower left represents a constant reduction of demand due to conservation or energy-efficiency measures. The graph at the lower right represents a load shifting strategy, which consists of transferring some of the energy load from periods of high-energy consumption to periods of low-energy consumption.

Figure 3: Electricity Savings Strategies



Source: https://www.usaid.gov/energy/efficiency/basics

At the Chemehuevi Tribe Community Center building electricity cost reductions were achieved by the EMS primarily through four strategies. These were: direct utilization of energy generated from solar PV during the day, which acted as an energy conservation and efficiency measure; utilization of a battery energy storage system (BESS) to store solar energy during the day and dispatch that stored energy during peak demand periods in the evening; automated thermostat management, effectively performing demand peak shaving by limiting the number of HVAC units running simultaneously at any one time; and monetary incentives for participation in DR programs (requested by a utility) for shedding load or dispatching stored energy from the battery. The second largest potential reduction of the electricity bill, next to the solar PV system, was derived from the battery energy-storage system. While the battery unit added resiliency to the building as an energy backup, the energy storage control strategy also increased the effectiveness of the PV-solar energy through load shifting, peak shaving, and DR.

CHAPTER 2:
Project Approach

Carport Design, Engineering, and Construction

The goal of this project activity was to design and construct the carport where the solar PV system will be mounted.

Carport System Details

The responsible party for carport design and engineering was EcoForce Solutions who is a prominent installer of PV integrated structures and systems. EcoForce Solutions selected a pre-engineered carport design provided by Baja Construction Company, located in Martinez, California. The scope of work completed by EcoForce Solutions included:

- Design: Furnish overall site layout and system size analysis.
- Structural Engineering: Furnish signed and sealed sets of drawings for steel structures, including three copies of permit set, and three copies of final construction set. Design for standard base plate included.
- Materials: Fabricate, furnish and deliver structural steel, including columns, cross beams, purlins, nuts and bolts for all structural steel connections. Panel mounting clips, hardware, and anchor bolts excluded.
- Installation Drawings: Furnish framing plans, panel installation plans and related details.
- Finish: Columns and cross beams: galvanized G90.
- Light Fixtures: 20-watt (W) LED wall-pack light fixtures. Two per structural bay.

Installation requirements included:

- All electrical work and equipment, including trenching, conduit, wiring, PV panels, filler panels, inverters, combiner boxes, and light fixture installation.
- Union labor or any other prevailing wage requirements.
- Removal of light fixtures and associated poles and piers.
- Performance bonds.
- Site surveys, topographical surveys, and utility surveys.
- Geotechnical analysis (e.g., soil conditions, soil-bearing capacity, above- and below-ground obstructions) and any required design changes for the discovery of unforeseen underground obstructions or conditions.
- Potential construction issues encountered during drilling including subterranean rocks or boulders, unstable soil conditions, requiring the use of temporary casing, dewatering of excavations, rock excavation drilling or blasting, and other factors.
- Permitting administration and fees.
- Controlled inspections and testing.
- Signage, branding and decorating of canopy beyond the standard finish.

Specifications and Design

Table 1 summarizes the solar PV carport structure basic dimensions and specifications.

Table 1: System Details

Parameter	Value
System Size	90.36 kW peak DC
Approximate Wing Span	27’-2 5/6” or 4 panels in portrait over width and 20’ – 6 11/16 or 3 panels in portrait over width
Inclination	7.5°
Loading Criteria	Wind load = 110 mph, Exposure B; Occupancy Category: II; snow load = 0 psf
Foundation Type/Soil Bearing	Drilled Piers – 30” diameter / 14’ expected; soil bearing 1,500 psf
Clearance	11’ minimum at the driving aisle assuming relatively level topography
PV Panel	SunPower E-Series 435 W and SunPower P-Series 330 W

Source: University of California, Riverside

Plans and Engineering

Site plans, configuration, and engineering were completed by EcoForce Solutions. Two independent carport structures were oriented east-west with a southerly facing tilt of 7.5 degrees. The cantilever design minimized the number of required vertical supports and provided the aesthetics desired by the host.

Structural calculations were completed by EcoForce Solutions. The cantilever design required soil considerations with appropriate footings. Additionally, the cantilever configuration was dependent upon structure height and roof-beam dimensions. Wind loads were also estimated and considered in structural calculations.

The site plans, configuration, engineering, and carport installation were completed by EcoForce Solutions. This effort was funded by the site owner (Chemehuevi Indian Tribe) and was a cost share within the project budget. The Chemehuevi Indian Tribe was also a minor subcontractor on the overall project. The tribe was the responsible party that oversaw and managed carport siting, installation, approvals, and permitting. Since the Chemehuevi Indian Tribe is an independent nation, it functioned as the regulatory body for both infrastructure and construction projects. The project team followed standard engineering and design protocols and procedures, with submittal to the Chemehuevi building department. The Chemehuevi building department reviewed and approved structural design and construction plans. The Chemehuevi building department also managed site inspections and final construction approval.

Carport Site Installation

The site preparation, installation, and construction of the carport structure were completed by EcoForce Solutions. The construction process was documented with photographs showing the progression of the site installation. Figure 4 shows the installation of the carport structure at the project site, in its final stage.

Figure 4: Carport Installation

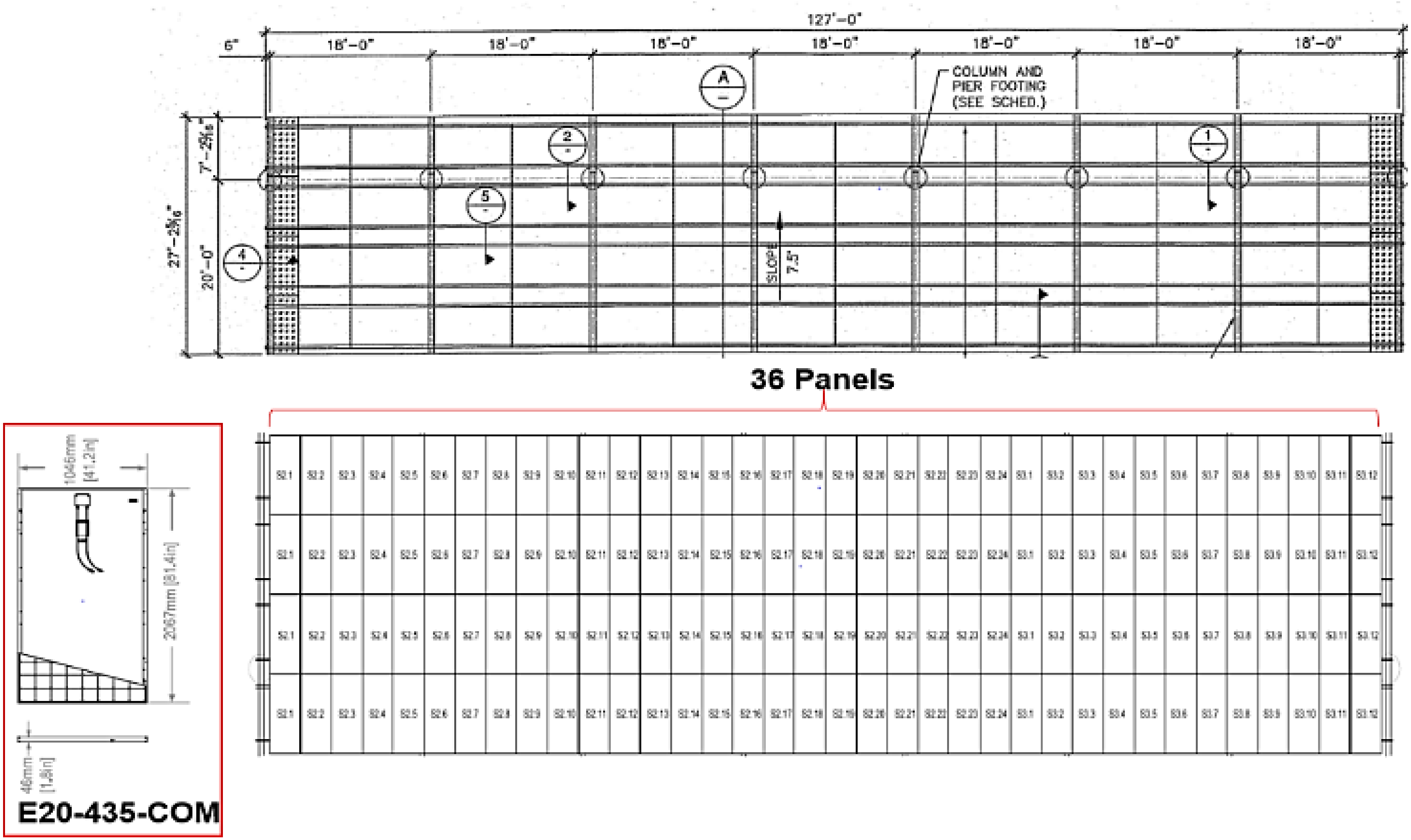
Source: University of California, Riverside

Solar Photovoltaic Integration

90.4 Kilowatt Advanced Solar Photovoltaic Deployment Description

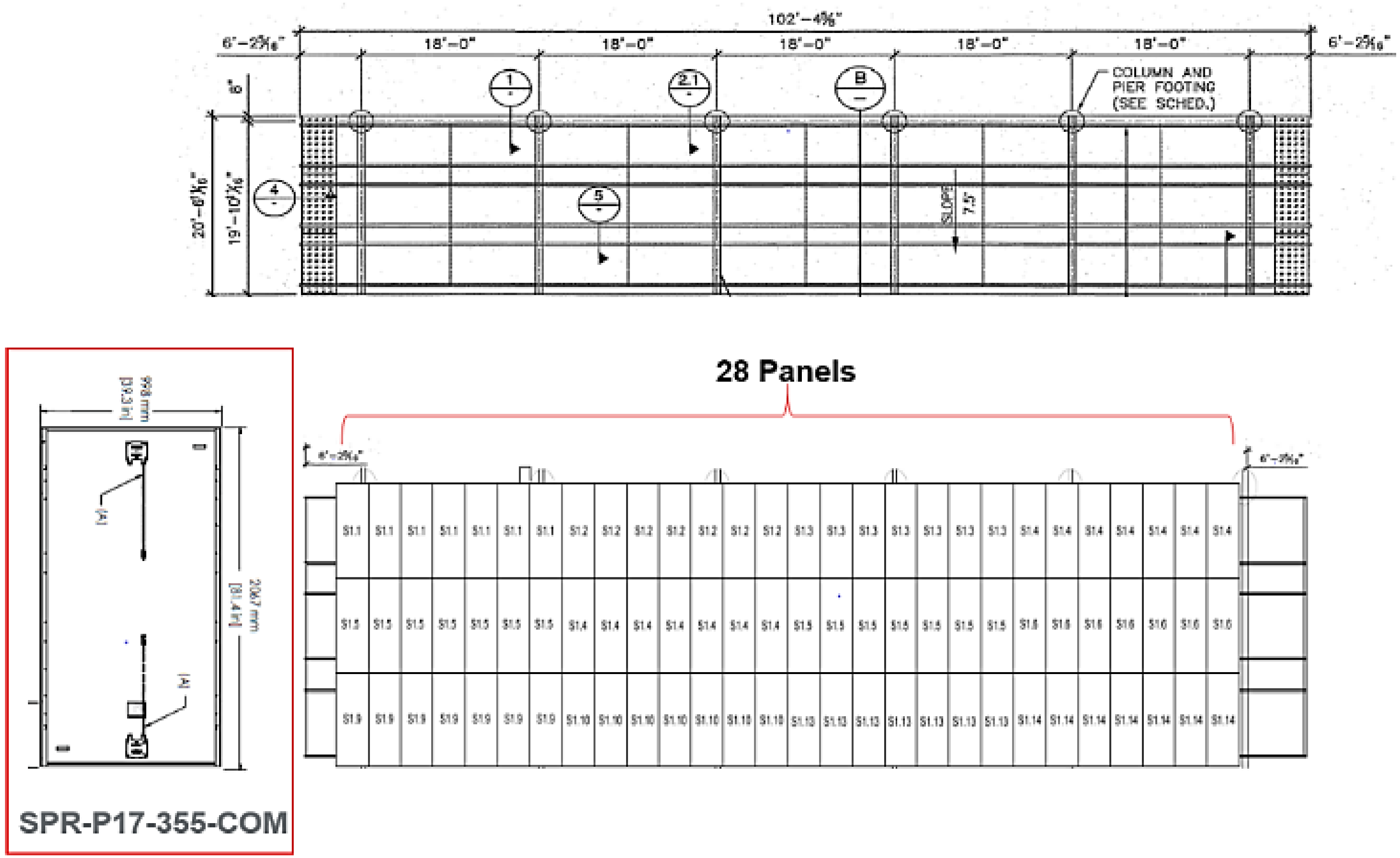
The solar PV panel layout was designed around two separate carport structures with a mounting platform of one large surface positioned with a predetermined tilt and orientation. The structure for the parking space layouts was designed so that it is oriented from east to west. This orientation meant that the solar modules on the carport's surface would face the southern direction in order to maximize energy production throughout the daylight hours as well as provide shade. Figure 5 shows the south carport structure with approximately 144 E-Series SunPower panels. The north carport structure uses approximately 84 P-Series SunPower panels, as seen in Figure 6. Both P-Series and E-Series SunPower modules are made for commercial usage, but the larger P-series panels are uniquely well-suited to larger roofs and capture more light.

Figure 5: SunPower E-Series Panels on Southern Carport Structure



Source: University of California, Riverside

Figure 6: SunPower P-Series Panels on Northern Carport Structure



Source: University of California, Riverside

Solar PV Sizing and Installation

The electrical engineer and contractor, Masters Electric, calculated the power gross nameplate rating based on new nameplate ratings for each series of SunPower panels: the SPR-P17-330-COM (P-Series), and the SPR-E20-435-COM (E-Series). The net nameplate rating indicates how the power output of a particular solar panel type differs from its nameplate rating, based on inverter efficiency.

The site preparation, installation and construction of the carport structure were completed by EcoForce Solutions. The solar PV module installation, circuit wiring, and combiner boxes installation were completed by GRID Alternatives. Figure 7 shows the solar PV installation near completion.

Figure 7: Solar Photovoltaic Carport Structure

Source: Chemehuevi Indian Tribe

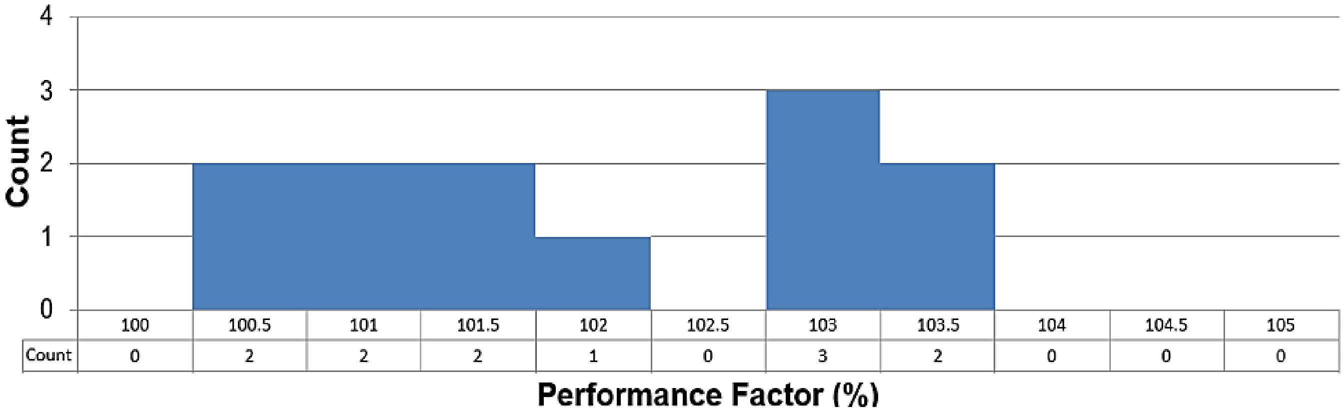
Solar Photovoltaic Source Circuit Testing

Solar PV power production and the performance of individual strings in the arrays were evaluated using Solmetric test equipment. A current-voltage (I-V) curve-tracing test was performed because it is widely recognized as the most comprehensive measurement of PV source-circuit performance. Solar PV array performance measurements were paired with simultaneous measurements of irradiance and module temperature, which provided the basis for evaluating the array performance data. The primary task of array performance evaluation is to measure the maximum output power of the PV source circuits and compare the results, taking into account irradiance, cell temperature, and other factors.

For I-V curve tracing, University of California, Riverside, (UCR) engineers safely made and broke the connection to the PV source circuit for the short circuit current (Isc) measurement. UCR engineers also checked additional performance parameters including a statistic for string data. For irradiance and module PV temperature tests, UCR engineers used the same Solmetric meter to evaluate array performance data (regardless of current and voltage measurement methods). Measurement kits such as the Solmetric SolSensor were designed for PV array measurements, including irradiance and temperature sensors. The results of the I-V tests for each of the three combiner boxes are provided in Appendix A. The I-V curves were constructed by performing 100-point I-V sweep measurements on each individual solar PV module string within a combiner box. The I-V curves exhibited the typical shape of a solar cell I-V curve and were consistent within each group. The data indicated that no strings experienced issues such as shading, current mismatch, cell damage, high-series resistance, or low-shunt resistance.

Another important test PV parameter, the performance factor, was critical metric for determining the efficiency of both solar PV or a string of PV modules. It represents the ratio of the modeled power generation, based on actual solar irradiance and PV module temperature, versus the actual power generated from an I-V sweep measurement. A performance factor of 90 percent or greater was acceptable.
A performance-factor histogram was used to compare performance factor for each solar PV string in a combiner box and identify potential outliers in the distribution. Figure 8 illustrates that there were no outlier PV strings in Combiner Box 1 (SPR-P17-330-COM) and all strings exhibited a performance factor of 100 percent.

Figure 8: Performance Factor Histogram for Combiner Box 1



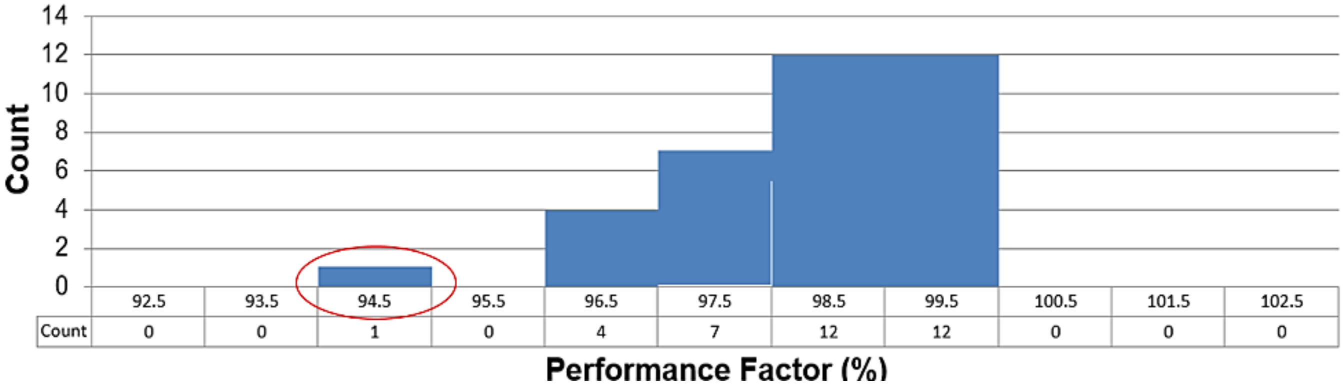
	100	100.5	101	101.5	102	102.5	103	103.5	104	104.5	105
Count	0	2	2	2	1	0	3	2	0	0	0

Source: University of California, Riverside

The histogram of performance factor for solar PV strings in combiner boxes 2 and 3 (SPR-E20-435-COM), shown in Figure 9, suggests that one string was an outlier with a performance factor of 94.5 percent, while the remaining 35 strings exhibited performance factors of 96 percent or greater. Observations during the test revealed that high clouds during the measurement of String 2 on Combiner Box 2, may have been a contributing factor for the observed lower performance factor of 94.5 percent on that string.

During the I-V measurement on Combiner Box 3, it was discovered that String 1 was not connected. Further investigation determined the cause to be a loose wire connection to the fuse holder inside the combiner box. The wiring of this particular string was repaired and the subsequent I-V curve showed no issues with the string.

Figure 9: Performance Factor Histogram for Combiner Boxes 2 and 3



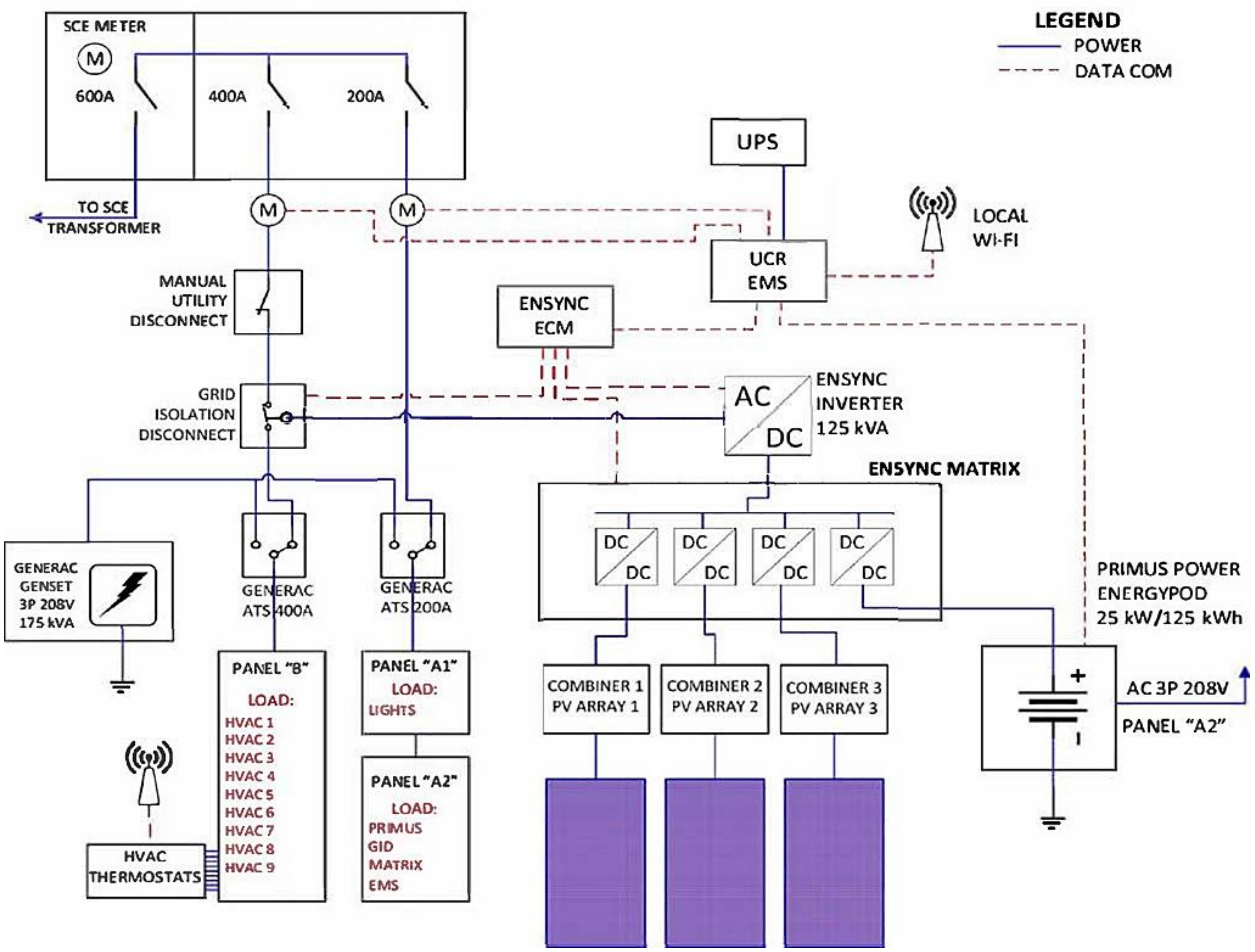
Source: University of California, Riverside

Solar Photovoltaic Control Algorithms

Solar Photovoltaic System Overview

Figure 10 shows the microgrid system at the community center, which is comprised of a 90.4-kW solar carport PV system, a 25 kW/125 kWh Primus Power FBESS, 3 combiner boxes, 1 advanced inverter (Matrix unit), and 1 AC disconnect switch. The Matrix unit is an energy management platform designed by EnSync Energy Systems that integrates the Chemehuevi microgrid direct current (DC) sources (solar PV panels and flow battery) onto a common DC bus. The Matrix unit has four DC-DC converter units. Three of the DC-DC units are connected to the solar PV system and one is connected to the flow battery system. The microgrid also combines OSIsoft's PI software with advanced data analytics and smart energy-management controls developed by UCR. These critical components allowed UCR engineers and researchers to deploy energy management control algorithms and implement optimal power-management strategies through four techniques: peak reduction, load shifting, DR, and storage-to-grid activities.

Figure 10: Chemehuevi Community Center Microgrid System Layout



Source: University of California, Riverside

Solar Photovoltaic and Inverter Control

The Matrix unit shown in Figure 10 was controlled by the EnSync controller, through which any of the three solar PV DC-DC converter drawers could be disabled or enabled to turn solar generation on or off. The controller also ensured that when the battery was being charged, all available solar DC power was diverted to meet the battery power demand first, with any excess solar DC power routed to the inverter and delivered to the building load. Under normal operating conditions all generated solar PV DC power was converter to AC and delivered to the load or grid.

The EnSync inverter was controlled by the Chemehuevi microgrid energy-management system. The energy-management system communicated with the EnSync controller to send commands to the EnSync Matrix and inverter. The AC power command setting on the inverter determined the inverter's AC power output. If the AC power setting exceeded available DC power (solar PV or battery), the inverter provided the only available power. When the inverter AC power setting was set to a value lower than the available DC power, the inverter curtailed DC power. The energy-management system was responsible for controlling the AC power setting on the inverter, while at the same time controlling the battery charging and discharging DC power individually.

Solar Photovoltaic Control Results

Solar PV operation over a period of three days is shown in Figure 11. The graph shows the solar PV DC power, the energy-storage system charge and discharge DC power, and the building's net load AC power. A small portion of the solar PV DC power was used to charge the battery between the hours of 10 a.m. and 4 p.m., the remaining solar PV power was converted to AC and applied to the building load, with excess power exported to the grid.

Figure 11: Solar Photovoltaic Operation

Source: University of California, Riverside

Battery Energy Storage System Integration

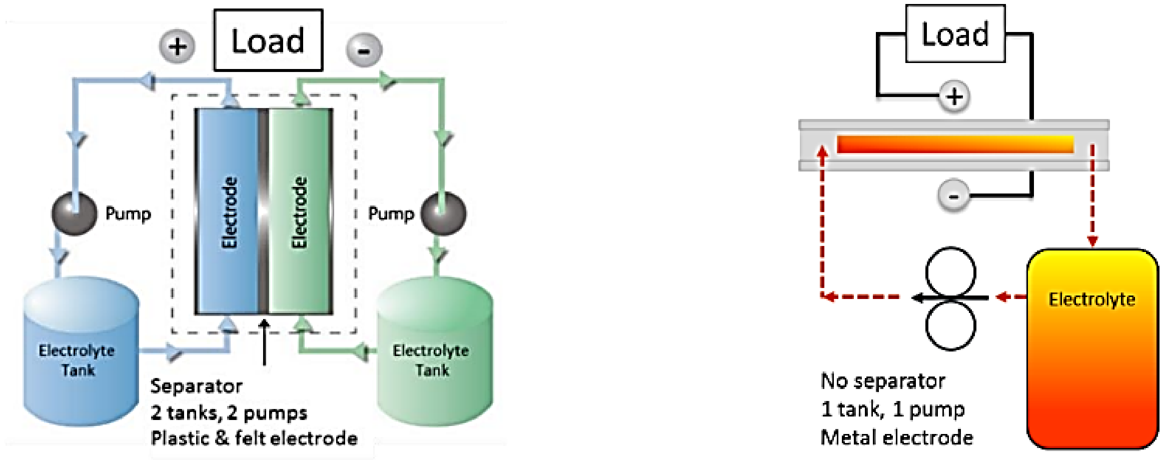
Zinc-Bromine Flow Battery Overview

In 2016, the installed electro-chemical energy storage capacity worldwide was 1.6 gigawatts (GW). Lithium-ion storage technology dominates the electrochemical energy-storage sector with a 59-percent share of the entire sector. From various emerging energy storage technologies, flow batteries occupied about 2 percent of the used electro-chemical energy storage market. Flow batteries are becoming an attractive option for grid-connected applications, although they have not yet been either widely deployed or tested on a large scale. They have several advantages including long lifetimes; appreciable energy capacity without any heating problems; independent scaling of energy and power characteristics; utilization of relatively inexpensive and abundantly available raw materials; very deep discharge rates without greatly impacting total cycle life; and certain safety characteristics, for example operation of the battery can be stopped simply by shutting down the pumps.

Conventional zinc-bromine (Zn/Br) flow battery design utilizes two storage tanks for Zn and Br solutions, respectively. The traditional Zn/Br cell design uses carbon-coated felt paper as the electrode surface and a porous separator membrane between the two electrodes. The separator membrane is one of the main causes for failure in a traditional Zn/Br battery.

The Primus Power Zn/Br flow battery design utilizes solid titanium (Ti) as its electrode material, which allows use of a single flow loop and a single electrolyte storage tank, as seen in Figure 12. In addition, the use of Ti electrodes results in higher energy density compared with traditional electrodes (3.1 kWh/ft^2 vs 1.7 kWh/ft^2). Another notable improvement in the Primus Power Zn/Br cell design is the absence of any separator material, which greatly reduces both system and operating costs and enables longer system life.

Figure 12: Conventional Flow Battery Versus Primus Power Flow Battery



Conventional Flow Battery **Primus Power Flow Battery**

Source: http://www.primuspower.com/assets/pdf/Self-Sufficient-High-Resilience-Micro-Grids.pdf

Primus Power EnergyPod 2 Battery Specifications

The Primus EnergyPod 2 is comprised of an electrolyte tank, a pumping system to circulate the electrolyte, two stacks of 48 titanium electrodes (battery cells), a thermal-management system, and a battery-management system. These components are fully packaged into a self-contained NEMA 3R-rated enclosure that provides protection against weather and unauthorized access. The external dimensions of the EnergyPod are 1.7 m x 2.0 m x 2.2 m. Figure 2.4 provides an external view of the EnergyPod system, as well as a detailed internal view of the system. The EnergyPod system is managed by a battery-management system, which interfaces with a higher-level microgrid controller through a published application programming interface.

Flow Battery Installation

Figure 13 is a photo taken at the project site, after installation of the Primus EnergyPod 2 (on the left), next to the EnSync 125 kVA AC-DC inverter (on the right).

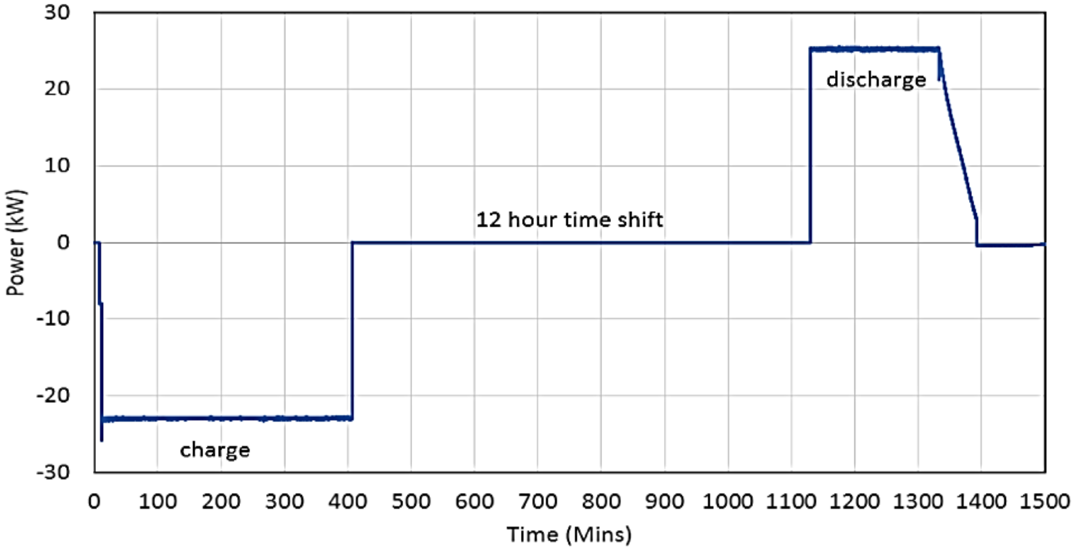
Figure 13: Battery Unit and Inverter Installed at Project Site

Source: Chemehuevi Indian Tribe

Battery Acceptance Tests

One of the primary functions of a grid scale BESS is to shift excess energy generation from off-peak to on-peak. To encompass the projected maximum shift requirement for daily operation, the EnergyPod system was tested with a 12-hour time shift. The battery was charged at 21.5 kW of power starting at 0 percent state of charge (SOC) to a full 100 percent SOC value for approximately 7 hours. The system was then put into a dwell mode for 12 hours. Then a discharge was performed at a 24-kW set point. The results are shown in Figure 14.

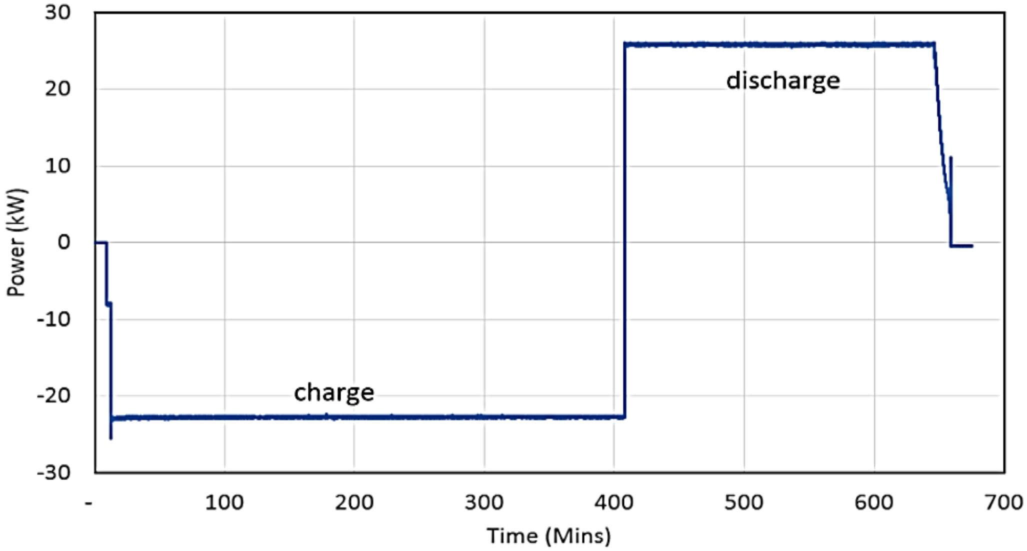
Figure 14: Energy Time-Shift Cycle



Source: University of California, Riverside

The energy storage capacity of the system was tested with a discharge cycle at a full-power set point starting from 100 percent SOC. In this test, the battery was initially charged at 21.5 kW power starting at 0 percent SOC to a full 100 percent SOC value for approximately 7 hours. The battery was then discharged at full-power set points of 24 kW. Test results for this cycle demonstrate a round-trip efficiency of 68.4 percent and discharge energy of 102 kWh. Results are shown in Figure 15.

Figure 15: Continuous Power Profile for Stored Energy



Source: University of California, Riverside

Battery Energy Storage System Control Algorithms

Battery Energy-Storage System Control Algorithm

Considering the utility time-of-use rate schedule, which sets energy prices higher during the hours of 4 p.m. to 9 p.m. and demand charges higher between 4 p.m. and 9 p.m., the best application for the battery was energy shifting from mid-day to the period between 4 p.m. to 9 p.m. Since the Chemehuevi Community Center building is occupied until 7 p.m. during regular weekdays, the battery could be discharged at varying rates over two time periods: 4 p.m. to 7 p.m., and 7 p.m. to 9 p.m.

Several battery operational constrains restricted battery use to energy-shifting operation. Those were mainly that: the battery can only be charged by solar PV power according to a net energy metering (NEM) agreement with SCE, the battery must be fully discharged daily due limited charged dwell time of 12 hours, and the battery needs to be charged at a constant power rate. Daily battery operation can be summarized as follows.

1. The battery starts charging at 10 a.m. at a rate of 20 kW.
2. The battery stops charging at 4 p.m.
3. The inverter is set to provide 20 kW AC power at 4 p.m.; as long as solar PV power generated is above 20 kW the battery will remain idle in standby mode.

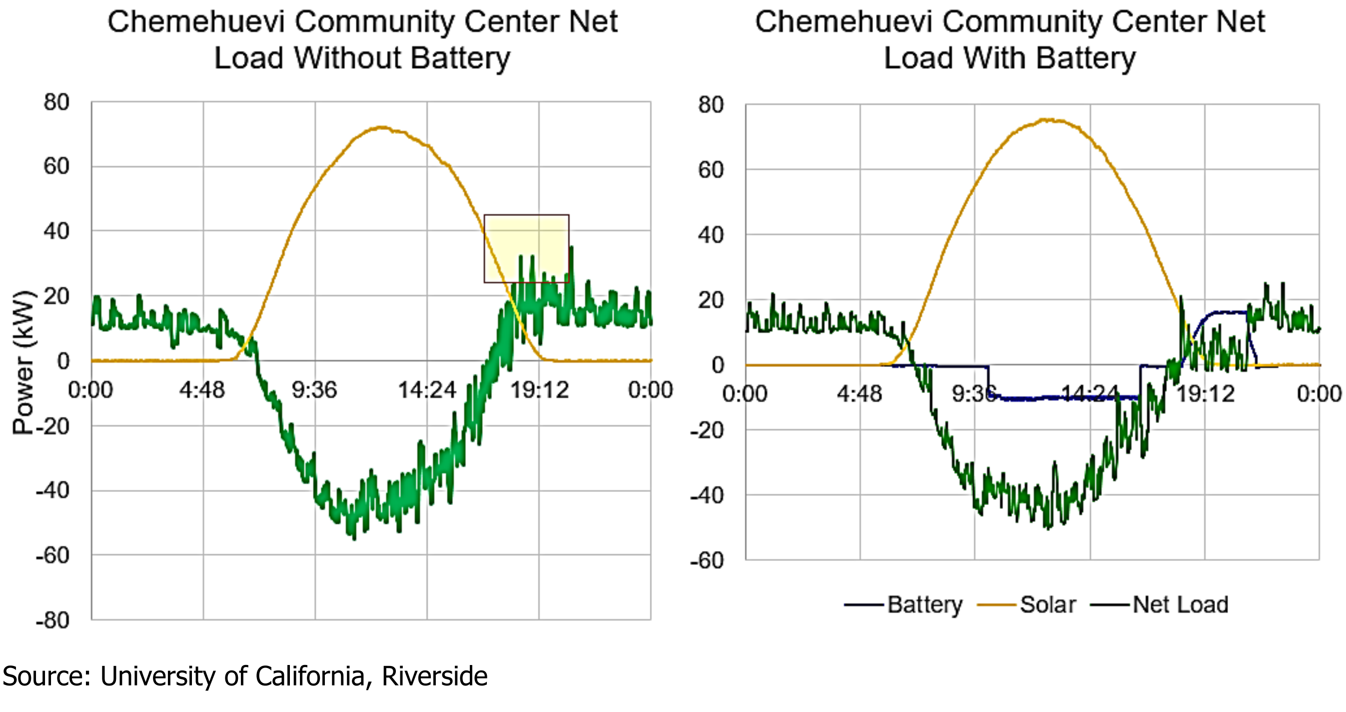
4. When solar PV generation drops below 20 kW the battery starts discharging at the rate of 20 kW minus a solar PV generation rate.
5. At 7 p.m. the inverter is set to 15 kW and the battery discharges at 15 kW if no solar power is available.
6. When battery SOC reaches 0 percent the battery enters a refresh cycle. (A refresh cycle is a maintenance cycle during which residual zinc is completely removed from the titanium electrodes.)
7. When the refresh cycle is complete the battery transitions to idle mode. (Refresh cycle normally lasts about one hour; therefore the battery remains idle during the night.)

Battery Energy Storage System Control Results

The results of operating the battery using the strategy and algorithm are shown in Figure 16. The graph on the left shows a scenario without battery operation. As the solar PV power decreases below 20 kW, sometime after 5 PM, the

of the Chemehuevi Community Center building peaks at around 30 kW. The graph on the right demonstrates the effect of the battery operation on the building's net load. Battery is charged during 10 a.m. to 4 p.m., with little impact on overall net load. When solar PV power starts decreasing below 20 kW the battery discharge rate gradually increases until it reaches 20 kW. With battery operation the net building load can therefore be maintained below 20 kW until 9 p.m.

Figure 16: Battery Energy Impact on Net Load



Source: University of California, Riverside

Energy Management System

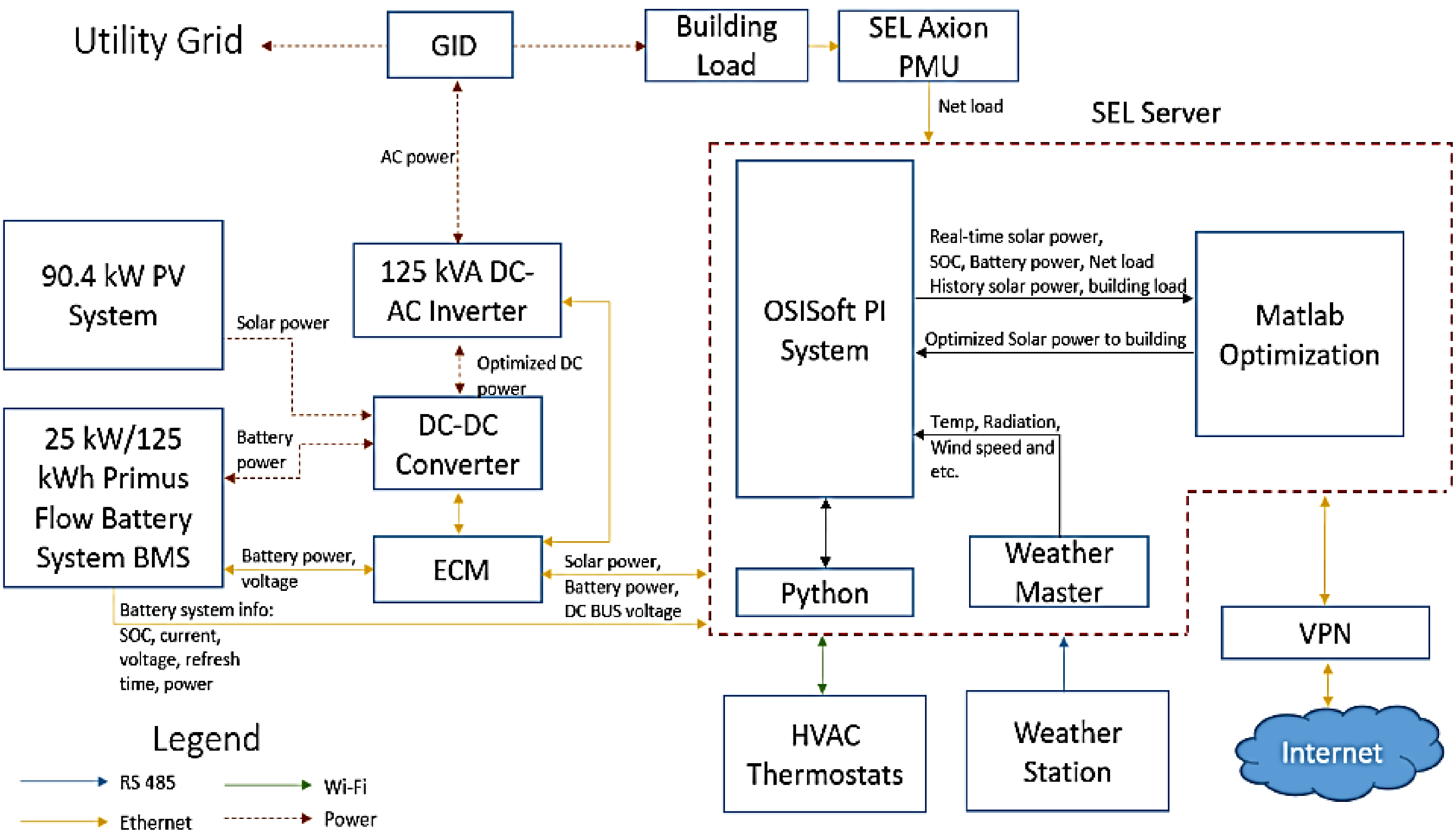
The project team configured and implemented energy management software and associated hardware, implemented DR, PV generation, and BES functions based on facility daily energy profile and projected energy use, and defined communications and control algorithms and coordinate with utility and project partners for energy requirements.

Energy Management System Architecture Overview

The EMS designed by UCR met the main objectives of reducing overall electricity bills, utilizing renewable solar energy efficiently, and providing additional resiliency to the Chemehuevi Community Center building. The EMS utilizes building load and solar generation forecasting to automatically determine the optimal times to charge the battery from solar energy and discharge the battery at peak-load periods. EMS also receives DR event notifications from the utility company and reacts by utilizing battery-stored energy during those events. Another layer of the EMS monitors and manages HVAC units in the building to ensure optimal operation and thus lowering electricity demand. As a result, the EMS uses multiple strategies such as peak reduction, load shifting, controllable load management, and automated DR incentives to lower utility charges and increase power-grid resiliency.

Figure 17 shows a layout of microgrid components and EMS control architecture with its respective software components. The EMS software components (including OSIsoft PI Server, MATLAB, and Python) were installed on the server PC and shown by the red dotted line. Communications data transmission lines between various microgrid components and EMS are indicated in the diagram by solid lines, using different color coding. Power transmission lines between the main components of the microgrid are indicated by a dotted brown line.

Figure 17: Microgrid Layout



Source: University of California, Riverside

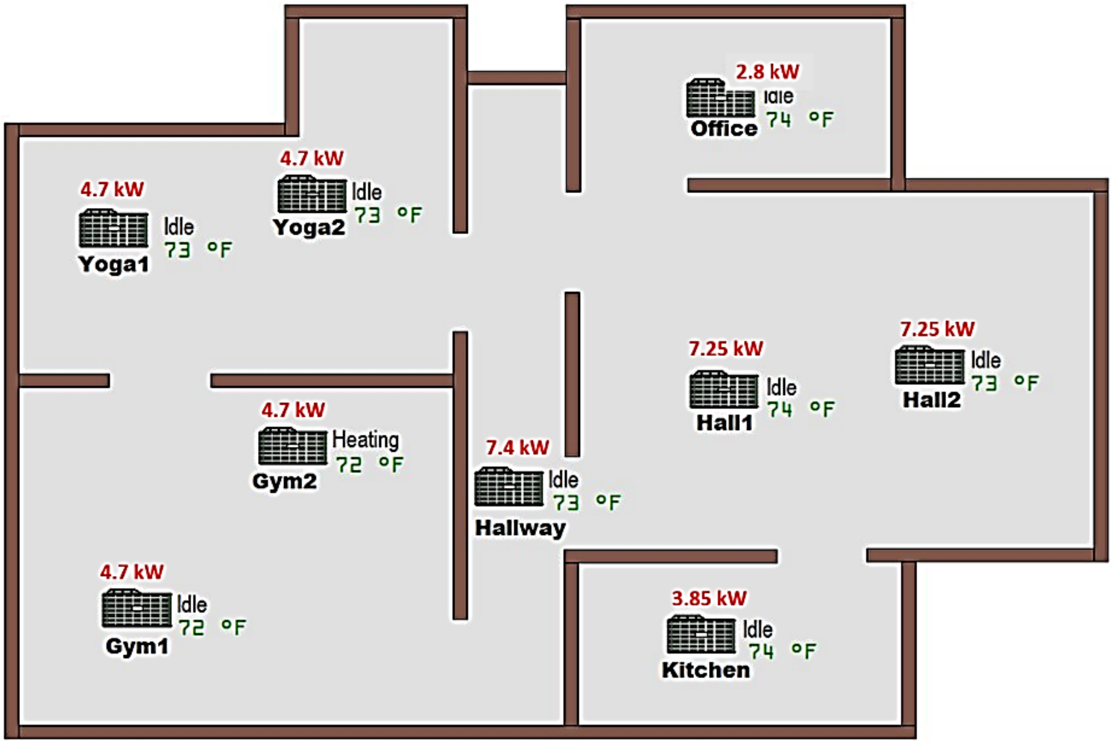
The EnSync energy communications module (ECM) controls the Matrix DC-DC converter unit, the 125 kVA DC-AC inverter unit. The OSIsoft PI suite, running on the Schweitzer Engineering Laboratories (SEL) server computer, receives and archives data for: 1) the building net load through the SEL phasor measurement unit (PMU); 2) solar PV power data; 3) battery status and power data from battery management system (BMS); 4) weather data from weather station; 5) thermostat settings and room temperature data; 6) DR event notifications from utility company. An OSIsoft PI server is also used to perform computational and logic operations and transmit control signals to HVAC thermostats, flow battery unit, Matrix system, and inverter through the ECM module. The battery control algorithms and DR algorithms run on the MATLAB platform and device control decisions are passed to OSIsoft PI for execution. Communication between Wi-Fi thermostats and the PI Server is established through Python scripts. The SEL server PC is connected to the internet through a secure virtual private network (VPN) tunnel.

At the heart of the EMS system is the OSIsoft PI Server. The PI server handles the storage, collection, integration, processing, computation, and delivery of data throughout the microgrid at a very fast rate. The application offers an extensive list of communications protocols and interfaces that facilitate integration with numerous third-party systems. The PI system consists of three main components: interfaces and connectors, a server, and clients.

Heating, Ventilation, and Air Conditioning Automated Control Architecture

The Chemehuevi Community Center building utilizes nine electric HVAC units for cooling during summer months and heating during winter months. Figure 18 depicts the building floorplan, indicating the location of each HVAC unit and their respective power ratings. According to these values the total power consumption could reach 44.5 kW if all units ran together simultaneously. If this event were to occur for a relatively brief period (15 min or longer) during a billing cycle, it could drive up the electricity bill for this billing period due to increased demand charges. Demand charges for a billing cycle are based on the maximum demand averaged over any 15-minute period during the billing cycle. The EMS uses a strategy of rotating HVAC units operation to prevent all or most of them from running simultaneously, while maintain a maximum comfort level to the occupants of the building. By utilizing this strategy, it could ensure that total HVAC power consumption would not exceed 27.75 kW, resulting in potential savings of 16.75 kW. A flow chart of the HVAC control algorithm is shown in Appendix B.

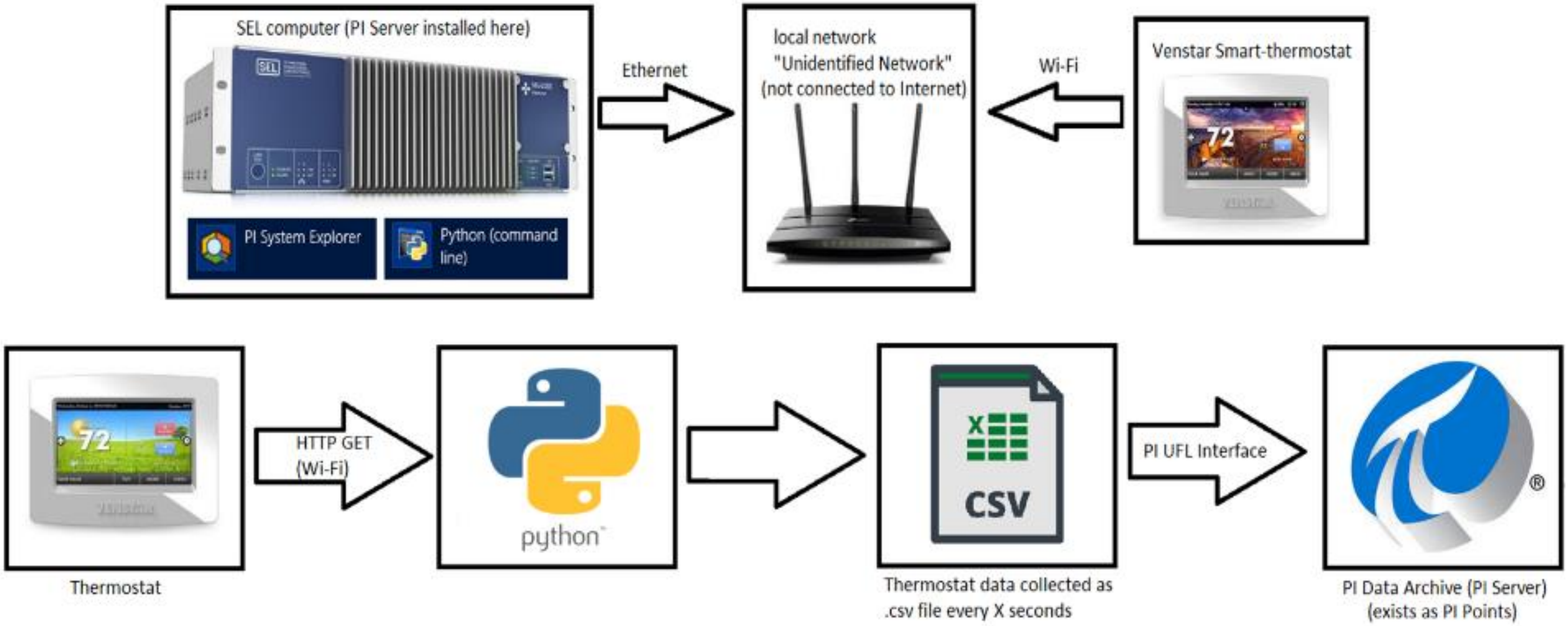
Figure 18: Building Floor Plan with Heating, Ventilation, and Air Conditioning Units



Source: University of California, Riverside

The control of the HVAC units by the EMS was through Venstar smart Wi-Fi thermostats. The communication between Python (running on the SEL server computer) and the Venstar thermostats was established over a local, private, Wi-Fi protected access (WPA) point, using HTTP communication protocol with basic authentication. The device setup is depicted in Figure 19. Thermostat data is stored by Python script in CSV files, which are then parced by an OSIsoft PI UFL interface and stored on the PI server.

Figure 19: Heating, Ventilation, and Air Conditioning Control System Components



Source: University of California, Riverside

Demand Response Control Architecture

Participation in a DR program with a utility company or an aggregator could reduce participating customers’ electricity bills and improve the overall reliability of the grid during periods of extremely high-power demand and high power prices. Shedding unused electric loads and utilizing stored energy, when requested by the utility company during a DR event, is usually compensated in the form of credits or reduced energy cost.

One such SCE DR program is the Critical Peak Pricing program. The DR events are requested on the day prior to the event before 4 p.m. These events are limited to 12 per year, last from 4 p.m. to 9 p.m., are requested only on weekdays, and normally occur during the hottest days of summer. The event notification is sent by a phone call accompanied by a courtesy email notification. The scheduled event information is provided as an input in the MATLAB battery and solar PV control application. MATLAB control optimization algorithms determine the period the battery would be charged and the period it would be discharged, and specific charge and discharge power rates. In addition to the battery utilization during DR events, the thermostat temperature in the Chemehuevi Community Center building was increased by 2 degrees between 4 p.m. and 7 p.m. and further increased by two degrees after 7 p.m., when the building is unoccupied. Figure C-1 in Appendix C shows all HVAC thermostat settings during a DR event, while Figure C-1 shows the resulting HVAC operations during the DR event.

CHAPTER 3: Project Results

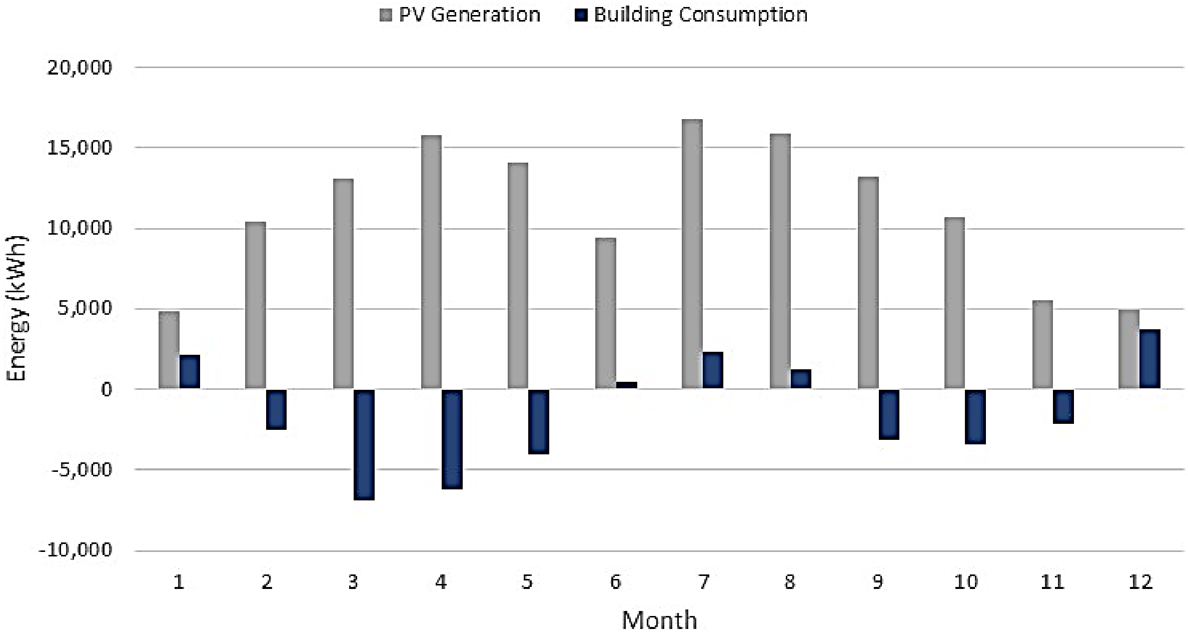
System Operation

The project team operated and demonstrated the system in collaboration with PV generation, facility energy demands, and utility DR while collecting system data.

Solar Photovoltaic System Operation

Solar PV energy generation was recorded by the EnSync inverter and stored on the OSIsoft PI Server. The solar PV system was down during January 2019 due to a DC power supply issue, which was resolved over two weeks. The range of data reported here spans February 2019 to February 2020 for a full year of operation of the solar PV system. Figure 20 shows the total monthly solar PV energy generated in a year when compared with the building net load, which is negative when 31 averaged over the entire year. Net metering allowed excess energy produced by the solar PV system to be stored throughout the year. Over 12 months, the system generated 143,368 kWh AC renewable energy, which was more than the building's average energy consumption of 100,000 kWh per year, and displaced 47,455 kg of CO_2e GHG emissions from grid electricity.

Figure 20: Monthly System Generation and Consumption



Source: University of California, Riverside

There were 27 days, including seven days in June, when either the solar PV system was down or the PI server system did not successfully collect data. These days are recorded in Table 2. The majority of these events were caused by unscheduled system faults that required some troubleshooting and repair. Some system down times were caused by scheduled events for system upgrades and testing.

Table 2: Days When Solar Data Missing or System Down

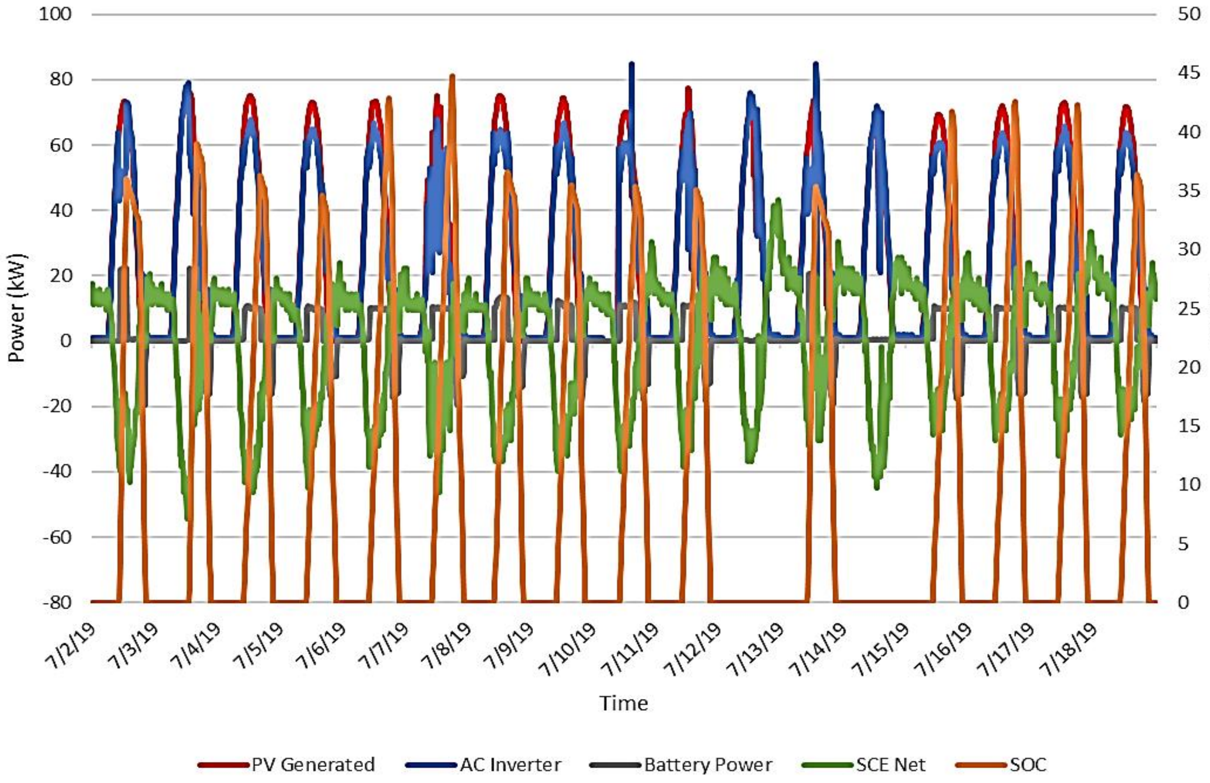
Month in 2019	System Down/Missing Data
January	1/1-1/7,1/15-1/23
February	NA
March	3/12/-3/13
April	NA
May	5/17-5/19
June	6/20-6/26
July	NA
August	NA
September	9/5
October	10/18-10/24
November	11/2-11/7,11/13-11/15
December	12/11-12/13,12/21-12/24,12/27-12/31

Source: University of California, Riverside

Energy Storage System Operation

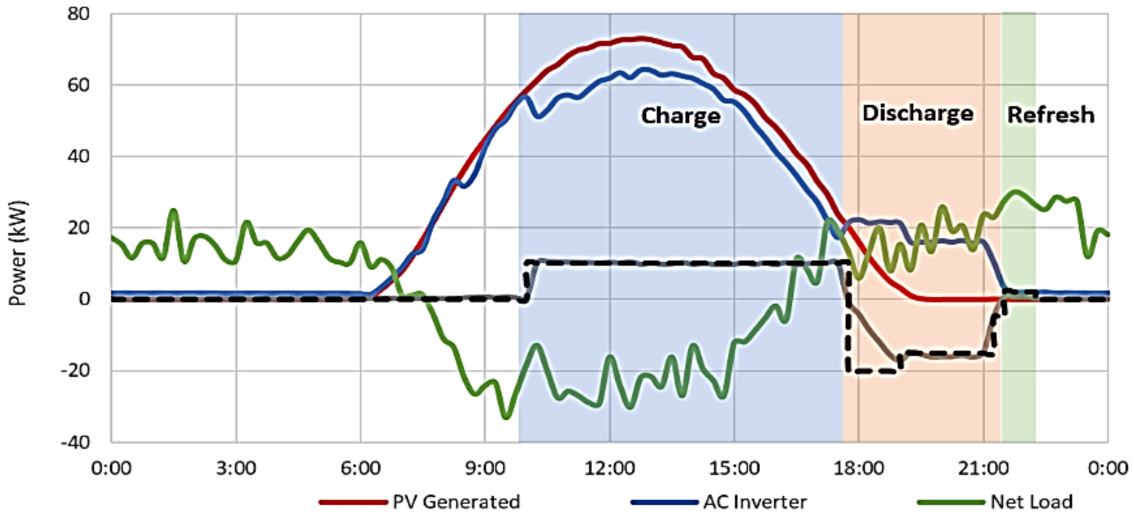
The UCR team operated the battery system for four months from July to October 2019, spanning manual to automated control by MATLAB. Figure 21 represents results of the battery operation during July 2019. Additional plots of battery operation are listed in Appendix D. The PV-generated data represents real-time solar PV output power, which was collected from the EnSync Matrix system. The AC inverter curve represents the AC power flowing to the community center building, which was collected from the DC-AC inverter. The battery power and SOC curves represent the battery charging, discharging power and the SOC, which were collected from the Primus battery system. The SCE net curve represents the 15-minute SCE net load, which was obtained from the utility company. The power value, time of the charge, and discharge and refresh-cycle operational parameters were determined and executed by the EMS control strategy through the MATLAB program. The battery was charged at a constant rate from the solar PV generation in the morning until it automatically stopped, usually around 40-percent SOC. The battery was then fully discharged, during the hours between 4 p.m. and 9 p.m. to minimize on-peak energy and demand charges. Discharge was then followed by a refresh cycle each day. Figure 22 shows one example of the automated control experiment.

Figure 21: Battery Operation in July 2019



Source: University of California, Riverside

Figure 22: Battery Control Automation Experiment

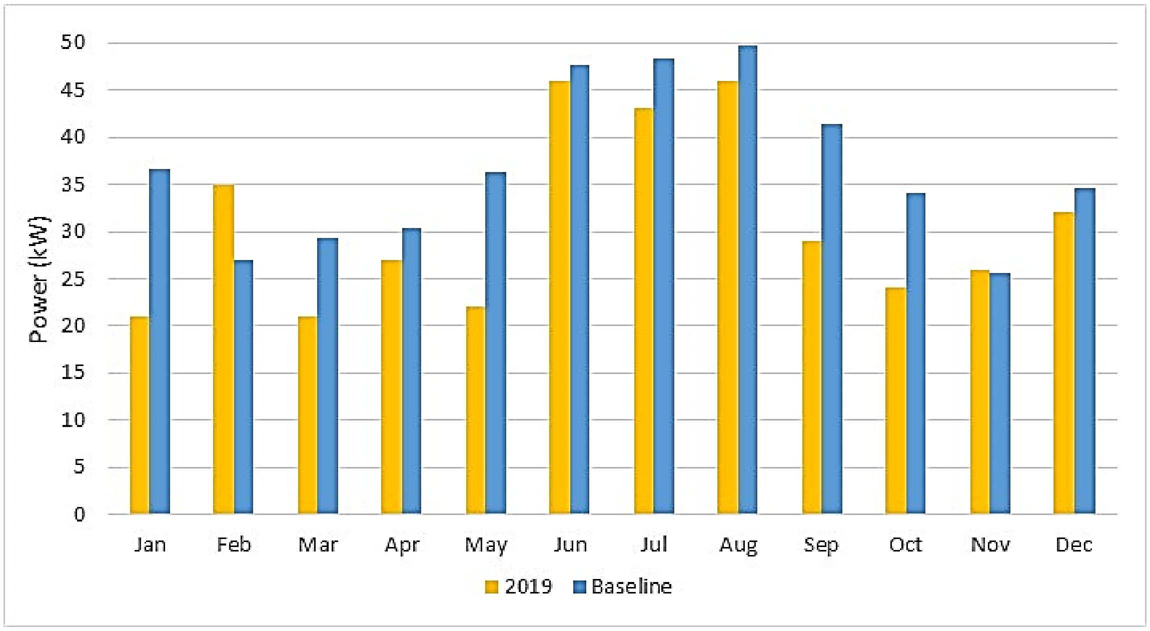


Source: University of California, Riverside

Impact on Electricity Bill

Figure 23 represents the monthly peak demand reduction with the system operating for one year compared with the monthly baseline, averaged over three years. Overall, there was a total 69-kW peak reduction over one year with the introduction of the system.

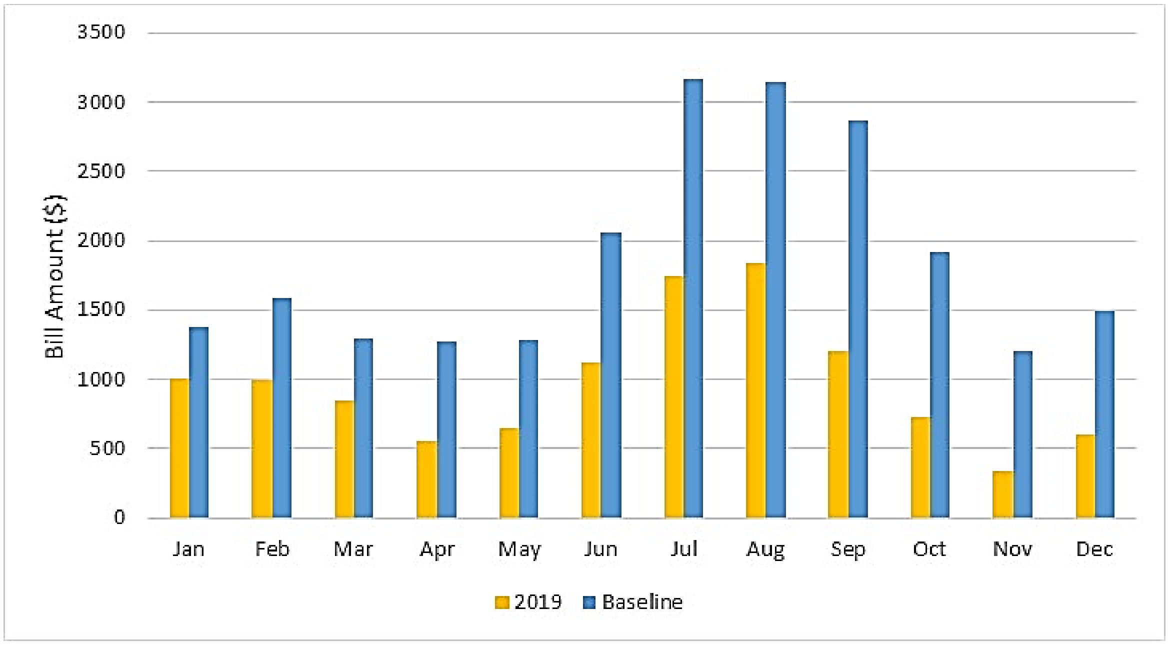
Figure 23: Monthly Facility Demand from Southern California Edison 15-Minute Data



Source: University of California, Riverside

Figure 24 shows the monthly electricity bill for the Chemehuevi Community Center during the 12-month operation of the system, compared to the building's baseline that the project team evaluated and analyzed baseline electricity at the beginning of the project. The total annual electricity cost was reduced $11,042, representing a nearly 50-percent reduction from the average annual electricity cost of the previous three years.

Figure 24: Monthly Electricity Bill Savings



Source: University of California, Riverside

Challenges and Barriers in Operating the Solar Photovoltaic and Battery System

Unpredictable Soft Short

As shown in the just-described figures of battery experiments, the battery stopped charging at unpredictable SOC. Most of the time, it stopped when the SOC reached between 35 percent and 40 percent, which not only limited the battery operational capacity but also hindered any predictive control strategy to fully implement the advantages of the battery system. Therefore, in this experiment the team used the schedule control operation strategy, which utilized a schedule table to charge and discharge the battery system.

Refresh During Solar Generation Time

The power request for refresh cycle was set to retrieve 2 kW from the utility grid to the BESS via the Primus inverter, while the solar PV generated power flows to the building in the opposite way. When the solar system still generates power, and the refresh is needed for the BESS, the two power flows conflict with each other, and the Primus inverter cannot function properly. This fault was identified during an experiment on 8/6/2019. To handle this issue during the automated control, the controller disabled the PV solar system when a refresh cycle was needed. After the refresh was completed, the controller re-enabled the PV solar system.

CHAPTER 4: Original Project Equipment Replacement and Upgrade

Microgrid System Overview

Microgrid System Architecture

Power from the grid to the building is provided over two circuits, rated at 400A and 200A, respectively. The load on the 400A circuit consists mainly of the nine 3-phase HVAC units, which account for the majority of the building load, with an average of 17.5 kW and maximum of 40 kW. The load on the 200A circuit, consists mainly of lighting and the newly added renewable energy generation equipment, such as the EMS, EnSync Matrix, and auxiliary power Primus Power battery. The 200A circuit load averages 5 kW with a maximum of 16 kW.

The building is equipped with a Generac 175 kVA diesel back-up generator, capable of automatically providing power to both building circuits, through the automatic transfer switches (ATSs), as shown in Figure 10, in Chapter 2. A 90-kW DC solar PV generation system, a 25 kW/125 kWh FBESS, and 125 kVA inverter were added to the building as part of this project. The EnSync bi-directional inverter is capable of operating in both grid-tied and islanded modes and utilizes the grid isolation disconnect (GID) to form the microgrid island and provide back-up power in 10 seconds or less. (Figure 25)

Technical Challenges with Original Project Equipment

One of the main operational challenges with the Primus power-flow battery in meeting the project’s goal of providing uninterruptable back-up power to the building was the need for an additional battery or uninterrupted power supply (UPS) system to provide the 3-phase AC auxiliary power necessary to run the flow battery.

Another significant challenge with the Primus power battery in operating as a reliable back-up power source was its limited dwell time. The battery can remain charged for a maximum of 12 hours if charged above 50 percent SOC, or 6 hours if SOC is less than 50 percent. This means the battery cannot be left with any charge on a continuous basis or for prolonged periods of time, as required for a back-up application. This constraint, combined with the NEM restriction to charge the battery using only solar power, forced the operation of the battery into a simple daily charge-discharge pattern, which was suitable only for load shifting and peak-load reduction applications.

Furthermore, the operational constraint of the battery, which requires constant charge DC power, led to the introduction of a buffer between the maximum available solar DC power and the maximum battery rate to account for potential solar DC power drops caused by clouds. This constraint does not allow for optimal solar power utilization when production is limited on cloudy days.

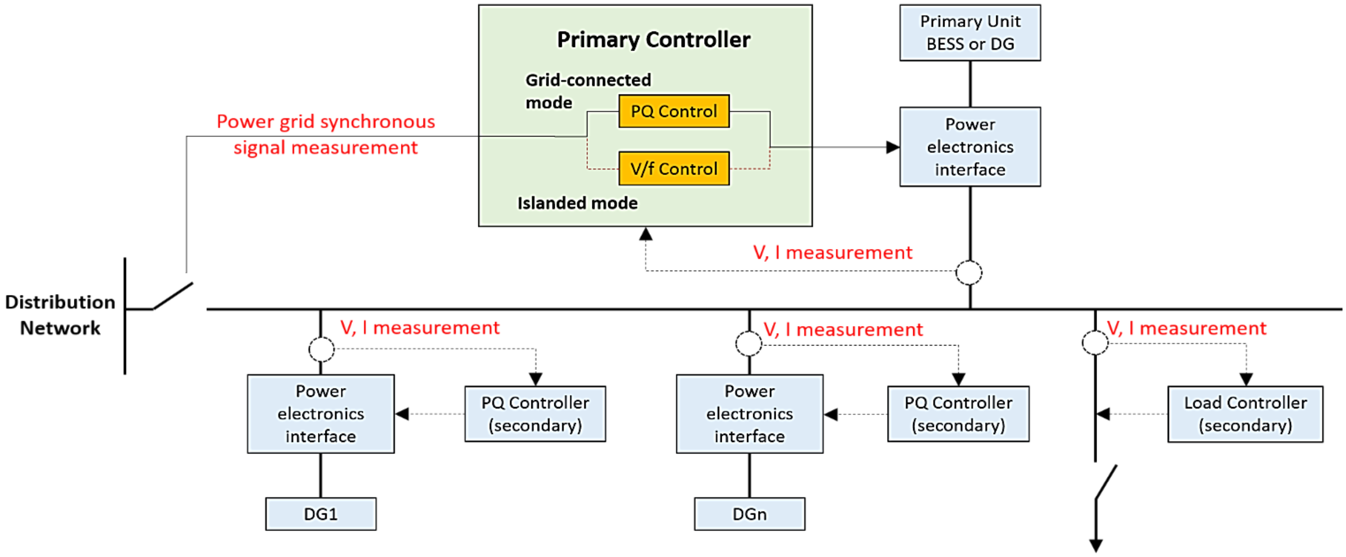
The operational requirement of the battery to be fully discharged daily and undergo a refresh maintenance cycle after discharge, leaves the battery unit vulnerable to potential damage, as in the case of prolonged power interruption from the grid. Since the battery requires the inverter to remain on to discharge its energy and perform its refresh cycle, and it also requires auxiliary AC power to operate, losing AC power from grid and also solar power puts the battery at risk.

Since EnSync Energy Systems is no longer in business, the lack of support and parts from EnSync prevents any further system development, system settings modifications, or integration of a new battery with the existing system. Even continued operation in its current architecture requires technical support, parts, and service from the vendor.

Approach to Microgrid Architecture Design

The goal of a microgrid is to be able to operate reliably in both grid-connected and islanded modes when power from the grid is lost. During grid-connected modes the voltage and frequency are set by the grid power and the DERs operating in constant power (PQ) mode. In islanded mode operation, the voltage and frequency of the microgrid need to be established by a DER, either a DG source or a BESS. There are several common microgrid control architectures such as primary-secondary control, peer-to-peer control, or hierarchical control. Of the three architectures mentioned, the primary-secondary control is the most commonly used. (Gao, 2015) It requires that one of the DGs or BESSs have the ability to switch operation from PQ mode to variable-frequency (V/F) mode when grid power is lost to provide voltage and frequency for the isolated microgrid. The remaining DGs and BESSs can continue to operate in PQ mode. Figure 25 shows the primary-secondary microgrid architecture. The advantage of using BEES as primary, with solar PV DG as secondary, is that the BESS can provide voltage and frequency to the microgrid reliably while balancing PV solar's fluctuating load and the solar PV DG output. Solar PV DG operates in PQ mode and fluctuates with solar irradiation. The disadvantage of using BESS as primary is its limited duration of operation due to finite energy-storage reserves.

Figure 25: Primary-Secondary Microgrid Control



Source: University of California, Riverside

Proposed Microgrid Modifications

Due to the limitations imposed by the existing energy-storage system and the microgrid technical requirements discussed in the previous section, the project team proposed a replacement of the flow battery energy-storage system with a well-established lithium-ion (Li-ion) based chemistry battery, AC coupled to the load through a bi-directional inverter capable of black start and islanded operation.

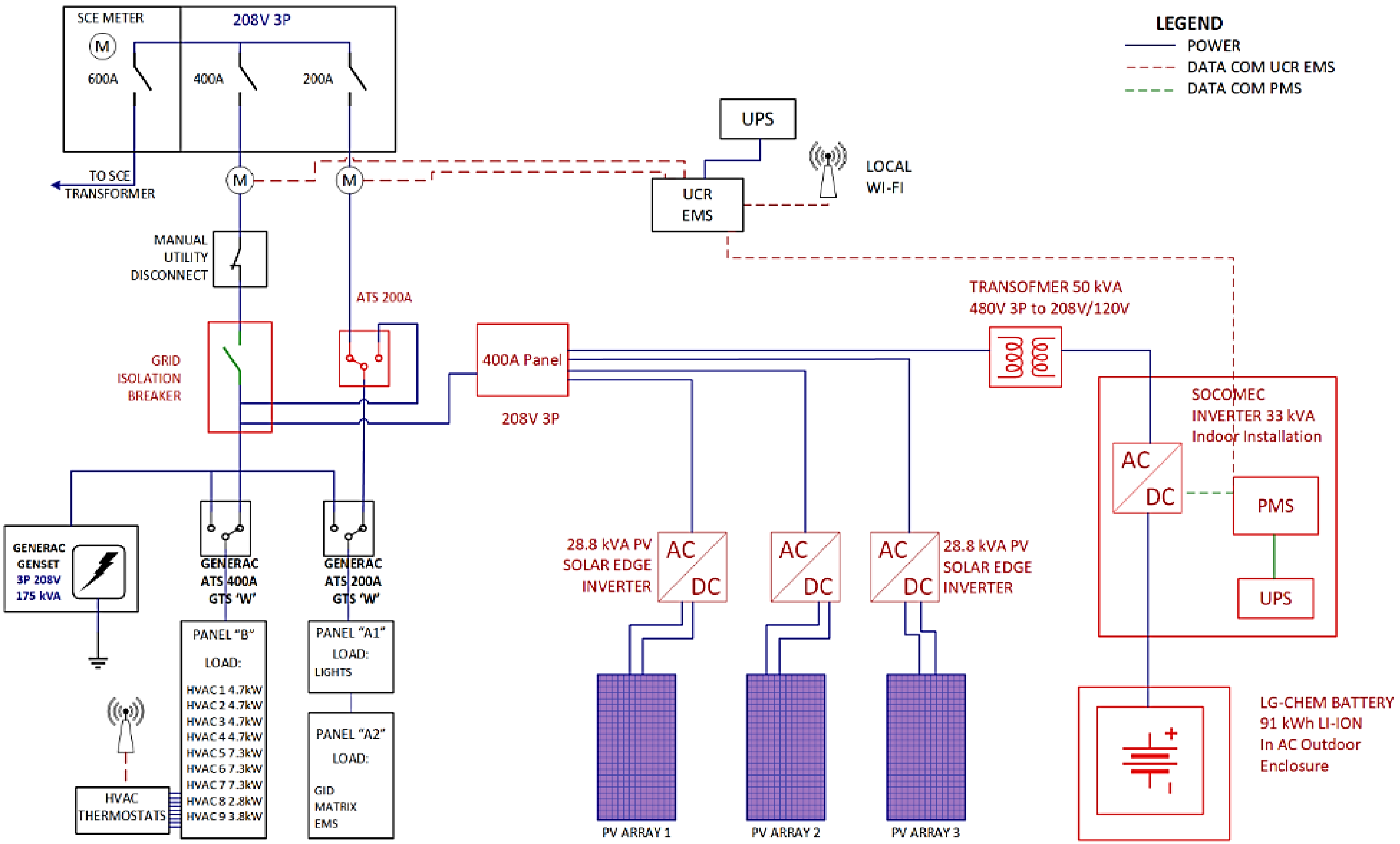
Owing to the lack of support by the original inverter manufacturer, the team proposed replacing the bi-directional inverter and DC-DC conversion system with solar PV string inverters. The proposed microgrid architecture is conceptually illustrated in Figure 26.

Identification of Replacement Equipment

The research team conducted a comprehensive review of equipment products available on the market. The main factors influencing the selection process were black start and islanded operation functionality, budget constraints, project timeline, CA Rule 21 interconnection compliance, energy and power ratings, installation facility requirements, and operations and maintenance (O&M) support.

Figure 26 shows the proposed solution for solar PV inverters and a replacement for BESS with the associated inverter and control system. The new equipment components are shown in red in Figure 26.

Figure 26: Proposed Microgrid System Architecture Upgrade



Source: University of California, Riverside

Equipment Purchases

The 33 kW/91 kWh Li-ion replacement battery, inverter, and islanding controller capable of black start were procured from Socomec Inc. SolarEdge PV optimizers and three 43 kW solar string inverters were purchased from Krannich Solar.

Electrical Contractor Contract Agreements

Contract agreement was executed with the electrical contractor Masters Electric. The scope of the work covered solar and battery equipment decommissioning and removal, system modifications, and installation of replacement equipment.

Microgrid System Upgrades and Modifications

Equipment Decommissioning

The entire EnSync Matrix Energy System, comprised of a 125 kVA AC-DC inverter, 100 kW combined DC-DC conversion modules, controls cabinets, and GID were decommissioned, scrapped, and removed from the site. Figure 27 shows the AC-DC inverter and DC-DC conversion modules cabinet being loaded onto a truck.

Figure 27: EnSync Matrix Equipment Demo

Source: Chemehuevi Indian Tribe

Solar Photovoltaic System Modifications and Upgrades

Due to replacement of solar string inverter DC input voltage requirements, the solar PV module strings had to be reconfigured to achieve required higher DC voltage. Solar arrays 1 and 2 were configured with 6 strings of 12 modules each, while Solar Array 3 was configured with 6 strings of 14 modules. Figure 28 shows the crew working on the string reconfiguration of the lift.

Figure 28: Solar Photovoltaic String Reconfiguration

Source: Chemehuevi Indian Tribe

In addition, SolarEdge power optimizer modules were added, one per PV panel, to assist in maintaining constant current output per PV module regardless of solar irradiation or shading. Figure 29 shows the installed solar PV optimizers.

Figure 29: SolarEdge Optimizer Installation

Source: Chemehuevi Indian Tribe

System Installation

The EnSync DC-DC conversion system and AC-DC inverter were replaced with three 43 kW solar PV string inverters. The three inverters shown in Figure 30 were installed by the solar PV arrays. The solar string inverters, in combination with module optimizers, eliminated the need for DC disconnects and combiner boxes.

Figure 30: SolarEdge Inverter Installation

Source: Chemehuevi Indian Tribe

A new 400 A-rated AC distribution panel, shown in Figure 31, was installed to accommodate output from PV inverters and BESS and connect them to the building's main 400A circuit as shown in the schematic in Figure 26. The panel is equipped with individual breakers for each PV inverter and the battery energy-storage system.

Figure 31: New AC Distribution Panel

Source: Chemehuevi Indian Tribe

Battery Replacement

DC and AC power connections to Primus Power battery were disconnected and the EnergyPod was removed from the site and picked up by Primus Power in February 2020. An outdoor rated enclosure equipped with an HVAC system was installed in the place of the Primus Power EnergyPod to host the LG-Chem battery rack, part of the Socomec BESS. Figure 32 shows the installed battery enclosure with HVAC unit (left) and the LG-Chem battery rack within the enclosure (right). The battery rack enclosure is located approximately 30 feet from the building, and the electrical conduit leading from the battery rack to the inverters is equipped with a surge protective device.

Figure 32: Battery Replacement

Source: Chemehuevi Indian Tribe

Figure 33 shows the installation GID and a new 200A ATS. The original GID design was modified to accommodate the new requirements of the Socomec BESS and islanding controller. As shown in the schematic in Figure 26, the GID disconnects the grid from the 400A circuit in the event of a grid power outage, as directed by the Socomec islanding controller. While the building load on the 400A circuit is directly connected to the solar PV and BESS, the building load on the 200A is not, since it is on a separate circuit from the main service entrance, as shown in Figure 26. Therefore, a new 200A ATS was added to the microgrid to transfer the 200A load in parallel with the 400A load in the event of a grid power outage. Upon detecting power loss from the grid, the 200A ATS transfers load in ten seconds or less to the 400A circuit once microgrid voltage and frequency are established by the BESS in an islanded operation. When the ATS detects that power from the grid is restored it automatically transfers the 200A circuit load back to the grid.

Figure 33: Replacement Grid Islanding Disconnect and New Automatic Transfer Switch

Source: Chemehuevi Indian Tribe

The BESS inverter (Sunsys PCS) was installed inside the electrical room of the CCC building (Figure 34). The AC distribution box, DC distribution box, and the BESS controller box were mounted on the walls inside the electrical room, as shown in Figure 34.

Figure 34: Battery Inverter and Controller Box

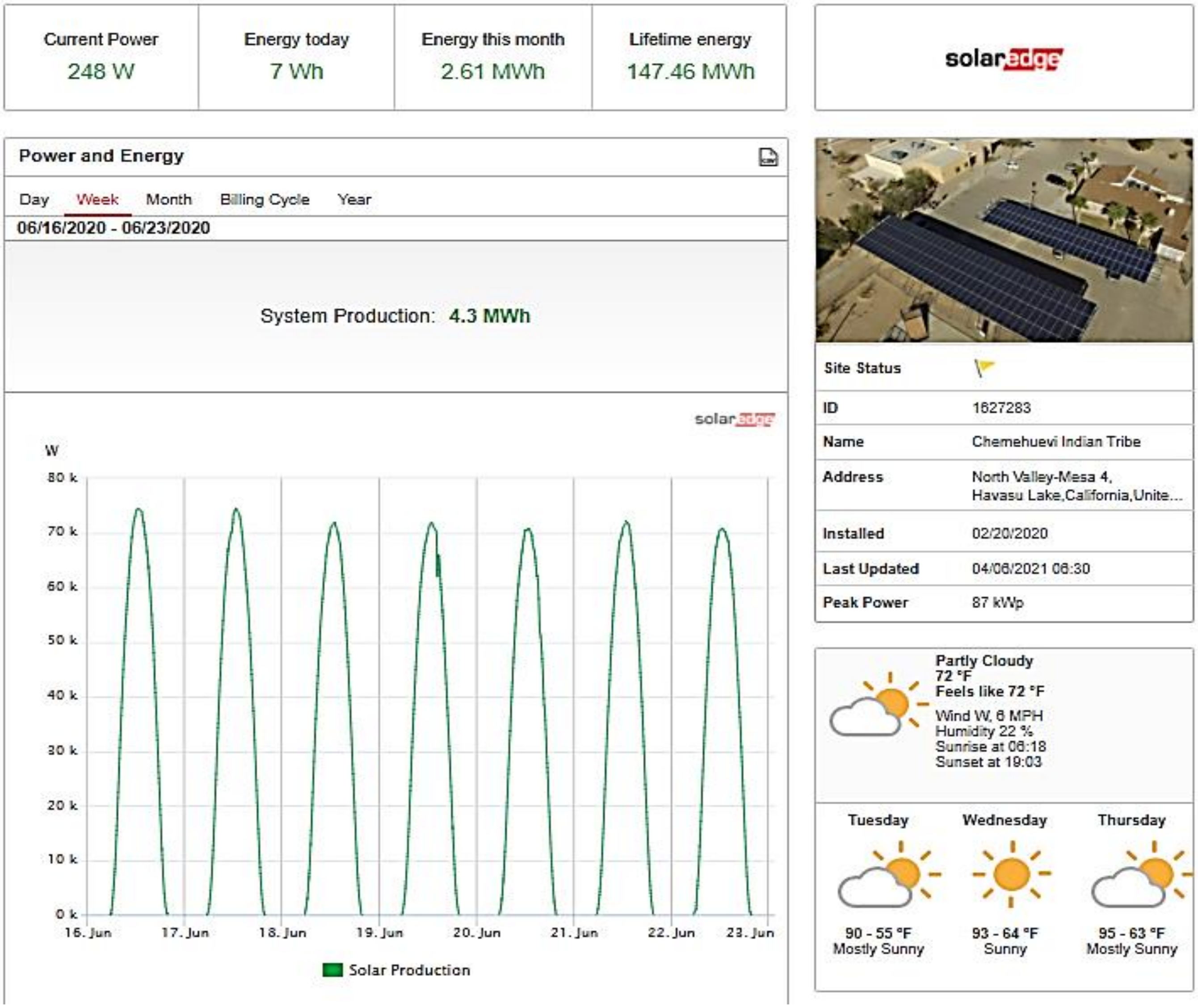
Source: Chemehuevi Indian Tribe

Upgraded Microgrid Operation and Monitoring

Solar Photovoltaic Operation and Monitoring

The upgrade of the solar PV system, consisting of new PV module optimizers and three solar string inverters, was completed in February 2020. The data communication link (RS-485) between the PV inverters and the Solaredge internet-connected gateway was completed in May 2020. Therefore, monitoring capability and PV performance data collection began in May 2020. The web-based Solaredge monitoring platform allows remote monitoring of PV system status, performance metrics, and remote troubleshooting. Figure 35 shows a screenshot of the web dashboard of the tribe's PV system. In addition to the overall PV system status and performance, the monitoring platform provides detailed information on specific operation parameters for each solar string inverter, PV string, and individual PV module.

Figure 35: SolarEdge Web-Based Monitoring Platform



Current Power 248 W

Energy today 7 Wh

Energy this month 2.61 MWh

Lifetime energy 147.46 MWh

06/16/2020 - 06/23/2020

System Production: 4.3 MWh

Site Status	
ID	1627283
Name	Chemehuevi Indian Tribe
Address	North Valley-Mesa 4, Havasu Lake,California,Unite...
Installed	02/20/2020
Last Updated	04/06/2021 06:30
Peak Power	87 kWp

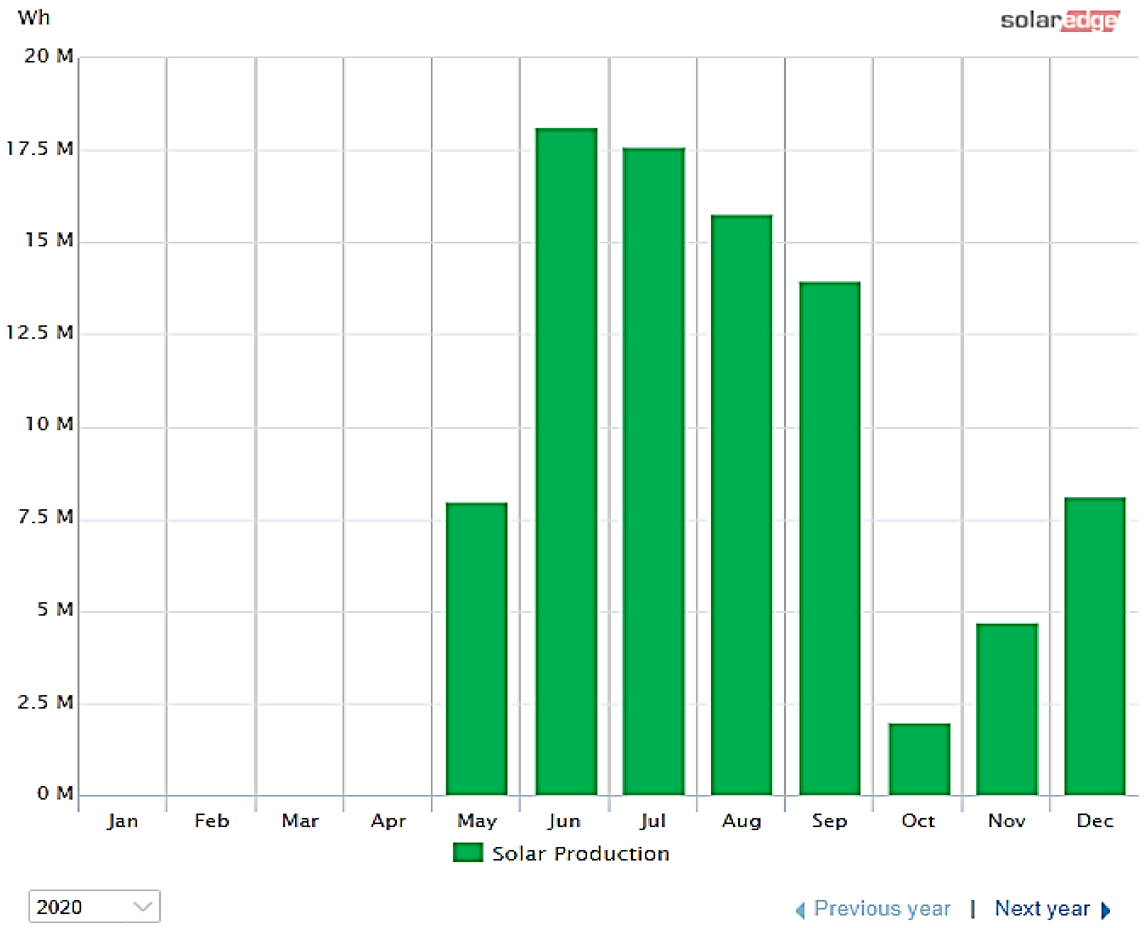
Partly Cloudy
72 °F
Feels like 72 °F
Wind W, 6 MPH
Humidity 22 %
Sunrise at 06:18
Sunset at 19:03

Tuesday	Wednesday	Thursday
90 - 55 °F Mostly Sunny	93 - 64 °F Sunny	95 - 63 °F Mostly Sunny

Source: University of California, Riverside

Figure 36 shows a bar chart of the monthly cumulative energy generated by the tribe's solar PV system in 2020. The system was operational in Febrary 2020 though data collection began in the middle of May. The graph shows lower energy generation for the months of October and November since the solar PV system was down during this time for installation of the BESS and its respective system components.

Figure 36: Solar Photovoltaic System Energy Generation in 2020



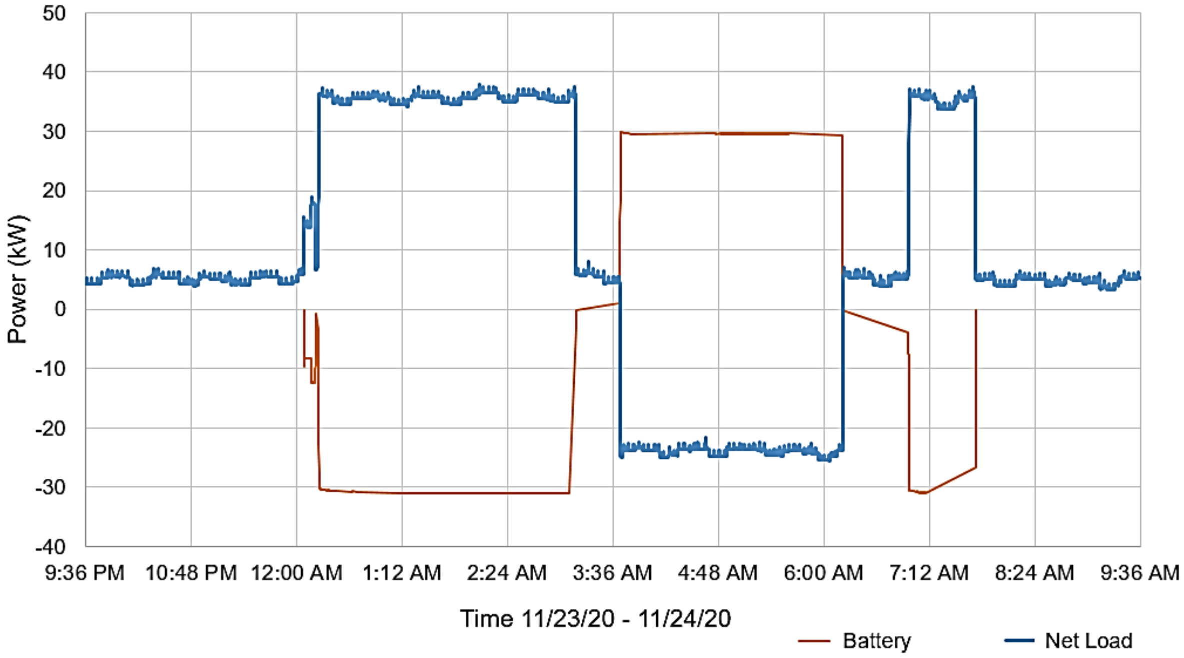
Source: University of California, Riverside

Battery Energy Storage System Operation and Monitoring

The installation of all BESS components was completed in October 2020 and the system was commissioned by the vendor in the middle of November 2020.

Figure 37 shows a plot of the BESS charge/discharge cycle test, used to assess the system energy storage capacity, round-trip efficiency, and maximum power. The plot in Figure 37 displays AC power of the BESS inverter, side-by-side with the total net AC power of the community center building.

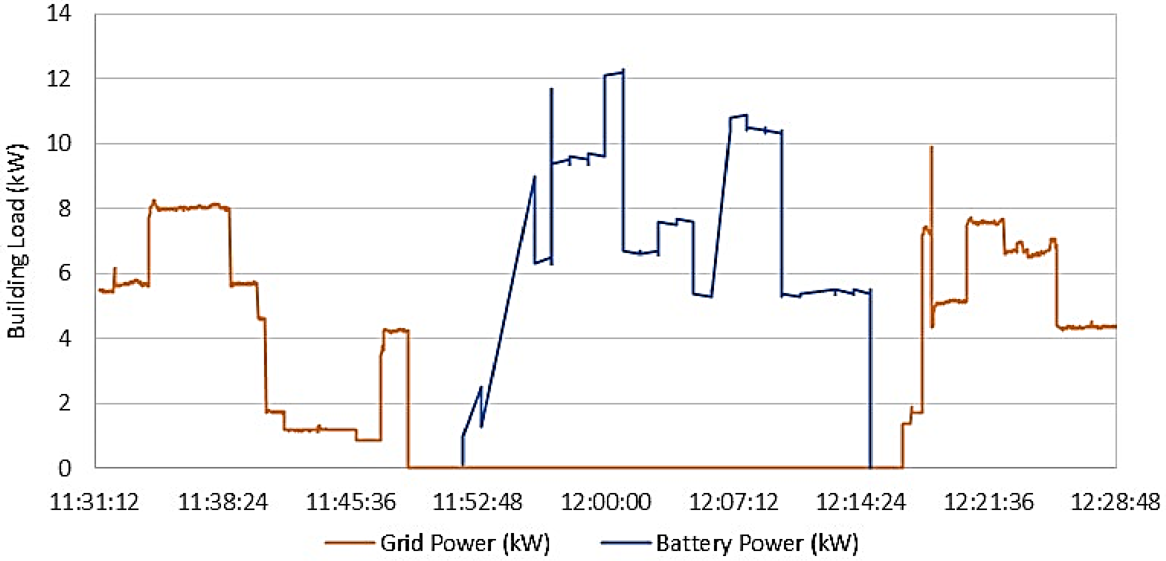
Figure 37: Socomec Battery Energy Storage System Full-Charge and Discharge Cycles



Source: University of California, Riverside

Figure 38 shows the power delivered to the building during a simulated power outage to and from the grid. The red line represents power delivered to the building from the grid, and the blue line represents power delivered to the building from the battery. The building's load was relatively low since the building was closed for public use during this period due to the COVID-19 pandemic.

Figure 38: Building Load During Microgrid Islanded Operation



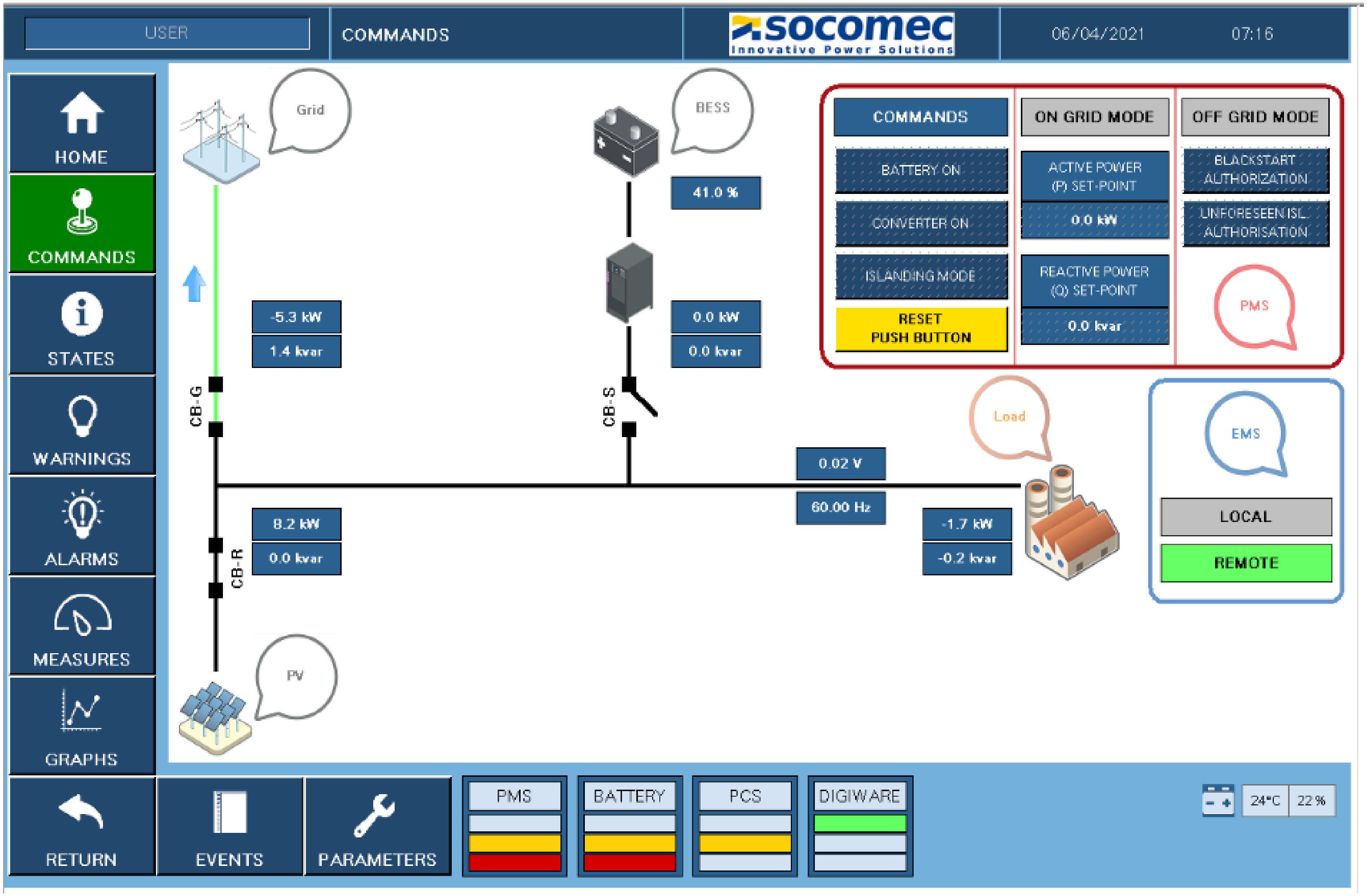
Source: University of California, Riverside

Figure 39 shows a screenshot of the Socomec controller web-based human-machine interface (HMI). The interface is identical to the physical HMI display installed on the BESS controller box and allowed monitoring and control of the BESS. The home screen displays the Socomec system status, alarms, and warnings. The application also shows the status of the tribe’s microgrid including grid voltage, operation mode (either islanded or grid-connected), power generated by solar PV, building load demand, and power delivered to and from energy storage.

Performing charging or discharging of the BESS, as well as initiating black-start command for islanded operation mode, can also be performed via the HMI display.

Figure 40 shows a list of battery states and system parameters, as displayed on the Socomec controller web-based HMI. Similar parameters for the BESS inverter and the BESS controller are also available through the same menu. Additional system configuration parameters and settings related to battery operation and microgrid islanded operation are accessible through the HMI display.

Figure 39: Socomec Battery Energy Storage System Web-Based Monitoring and Control App



Source: University of California, Riverside

Figure 40: Socomec Battery Energy Storage System Controller Display

BATTERY STATES

BATT : Alive
BATT : Can Be Charged
BATT : Initializing
BATT : Can Be Discharged
BATT : Not Connected
BATT : Charging
BATT : Connected
BATT : Discharging
BATT : Racks Balancing
BATT : Warning
BATT : Alarm

BATTERY WARNINGS

Over Current In Chrge Warning
Completed Discharge
Over Current In Dischrge Warning
Cell Over Voltage Warning
Over Voltage Warning
Cell Under Voltage Warning
Under Voltage Warning
At least 1 Rack In Alarm

BATTERY ALARMS

Communication Fault
Critical Fault
Over Charge Current Fault
Over Discharge Current Fault
Cell Over Voltage Fault
Cell Under Voltage Fault
High Temperature Fault
Low Temperature Fault

BATTERY MEASURES		
No. Racks	1	
No. OnLine Racks	0	
No. Warning Racks	0	
No. Fault Racks	1	
No. Disconnected Racks	1	
No. Racks Module Fan On	0	
Connected SOC	41.0	[%]
Average SOC	41.0	[%]
SOH	100.0	[%]
DC Voltage	716	[V]
DC Current	0	[A]
DC Charge Current Limit	0	[A]
DC Discharge Current Limit	0	[A]
Highest Cell Voltage	3.659	[V]
Lowest Cell Voltage	3.649	[V]
Highest Cell Temperature	23	[°C]
Lowest Cell Temperature	20	[°C]

Source: University of California, Riverside

CHAPTER 5: Technology/Knowledge/Market Transfer Activities

To highlight and share the project's findings with other technology experts, researchers, and tribal communities, the research team performed a broad spectrum of activities:

Publications:

- Rule-Based Real-Time Control of a Flow Battery for Preventing Minimum Import Violation, 2019 Control and Optimization of Renewable Energy Systems / 860: Mechatronics and Control, 2019, 10.2316/P.2019.859-025.
- Flow Battery Control Strategy Implementation and Cost Benefit Analysis for Microgrid under Updated Time-of-Use Period, 2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), 2020, pp. 1-5, doi: 10.1109/ISGT45199.2020.9087673.

Posters Presentations:

- Demonstration of Community Scale Low Cost Highly Efficient PV and Energy Management System at The Chemehuevi Community Center, *Gathering of Tribes*, Twentynine Palms, California, November 2016.
- Demonstration of Community Scale Low Cost Highly Efficient PV and Energy Management System at The Chemehuevi Community Center, *2018 Annual UCR Solar Energy Conference,* Riverside, California, March 2018.
- Increasing Community Resiliency with Distributed Generation, Storage and Microgrids, *Solar Power International (SPI) and Energy Storage International (ESI)*, Anaheim, California, September 2018.
- Microgrid Performance Under the New Proposed Time of Use (TOU) Rate Period A Case Study: Chemehuevi Community Center (CCC) Microgrid, *2019 Annual Winston Chung Global Energy Center's Energy Storage Technologies and Applications Conference*, Riverside, California, February 2019.
- Flow Battery Control Strategy Implementation and Cost Benefit Analysis for Microgrid under Updated Time-of-Use Period, *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, Washington, D.C., February 2020.

Invited Talks and Presentations:

- Community Scale Generation at the Chemehuevi Community Center, *Energizing California's Communities with Renewables: A San Bernardino Valley* Perspective, San Bernardino, CA, September 2015.
- Community Scale Generation at the Chemehuevi Community Center, *Energizing California's Communities with Renewables: A Southern California High Desert Perspective*, Victorville, California, September 2015.

- Community Scale Generation at the Chemehuevi Community Center, *EPIC Innovation Symposium*, Folsom, California, December 2015.
- Research, Development and Demonstration Projects to Reduce Greenhouse Gas Emissions, *SunPower Sustainable Energy Symposium*, San Francisco, California, March 2016.
- High Penetration Renewable Distributed Generation, *Solar Spring Break*, Lake Havasu, California, March 2016.
- Learning About Real-life Community-scale/Neighborhood Renewable Energy Projects, *Moving Toward Community-Based Renewable Energy*, Yucca Valley, California, September 2016.
- Beyond UCR's Sustainable Integrated Grid Initiative: Energy Management Projects in Southern California, *2016 UC Solar Research Symposium*, San Francisco, California, October 2016.
- Demonstration of Flow Batteries for the Prevention of Minimum Import Violations, *2018 UC Solar Research Symposium*, San Francisco, California, October 2018.
- Microgrid Research at UC Riverside, *Energy and Climate Change: Developing Human Capital and Strengthening Ties between California and Mexico*, Mexico, CDMX, December 2018.
- Chemehuevi Microgrid, *Workshop on Microgrids for CA Native American Tribes*, San Diego, California, February 2019.

Invited Panels:

- Microgrids: Safe Havens During Crisis, *Grid Evolution Summit*, Washington, D.C., July 2018.
- Solar + Storage and Climate Resilience in Vulnerable Communities, *Inter Solar North America*, San Diego, California, February 2020.
- Building for Resiliency: Adapting to a New Reality, *EPIC Forum: Reimagining Buildings for a Carbon-Neutral Future*, September 2020.
- How Technologies are Supporting Rural Communities, *EPIC Virtual Symposium*, October 2020.
- Energizer Buddies, *2021 Tribal Lands and Environment Forum*, August 2021.

Ph.D. Dissertations:

- Zinc Bromine Flow Battery for PV-battery Microgrid System Utilization: Analysis, Modeling, Performance, and Field Demonstration (June 2021).

Through these technology transfer activities, the microgrid concept and the technical and practical feasibility at community centers was proven, especially with tried-and-true technologies such as the lithium battery. The information gained from this project can help reduce the risk for future investments in these technologies and increase deployment, demonstration, and evaluation of these novel pre-commercial technologies. However, the main barriers to increased adoption of microgrids are related to DER equipment compliance with safety standards since local authorities have jurisdiction over regulations, utility interconnection rules, and NEM agreement requirements. In addition, there may be mandates depending on the investor-owned utility territory, such as the Southern California Edison’s requirement for pairing NEM agreement for energy storge with a solar PV generation system.

CHAPTER 6:
Production Readiness Plan

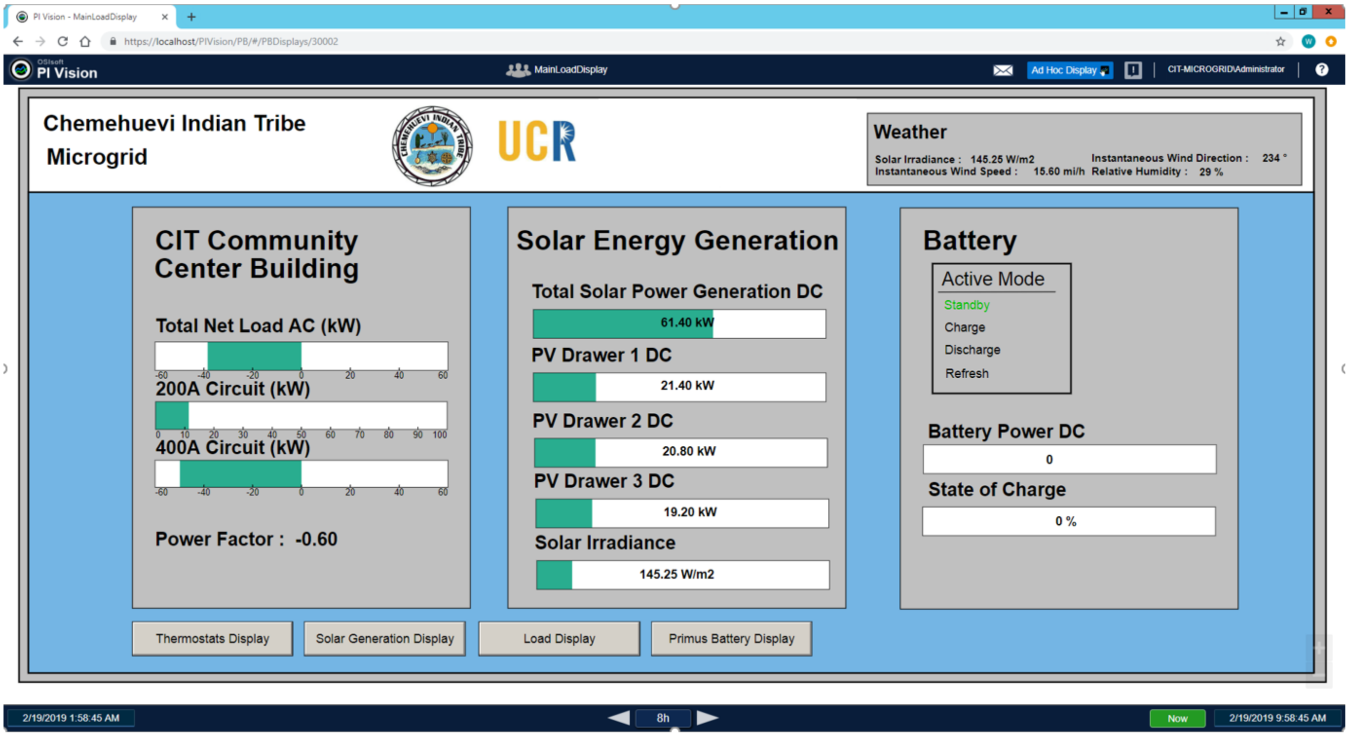
The College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, has completed a demonstration and evaluation of emerging clean energy generation technologies and deployment strategies relevant to deploying and managing energy storage coupled with energy generation in a behind-the-meter setting. The deployment strategy and methodology overlay and incorporate the existing electrical configuration and architecture and allows grid connected services to continue. The Chemehuevi Indian Tribe have collaborated in the deployment, testing, and validation of EMS strategies within the microgrid architecture. CE-CERT and the Chemehuevi Indian Tribe have targeted energy improvement objectives and field implementation of the microgrid and EMS to help minimize peak energy demand at the Community Center. This report details the Production Readiness Plan components, which include:

- Production and manufacturing requirements.
- Production and manufacturing costs.

Production Readiness Plan Overview

Critical facilities must provide community support during times of limited resources. Native American Tribal facilities often function at remote locations lacking electrical grid resiliency and reliability observed an urban setting. The Chemehuevi Indian Tribe observes greater electrical outages and reduced power quality as a result of their remote location and being supplied by a single substation. This project demonstrates and deploys energy storage, energy generation, and energy management strategies that improve resiliency, reliability, and reduce both peak loads and electricity costs in the delivery electricity to a critical facility. This architecture and methodology overlays and incorporates the existing electrical system without disrupting current operations. The technology development within this project focuses on the development of energy management algorithms and methods to be integrated within a microgrid consisting of on-site generation, energy storage, and managed loads. This project has introduced energy costs and DR as an operational factor within the EMS control methods. The primary integration method has been to create an EMS which monitors real time energy generation and loads while managing the battery energy storage. Figure 41 shows the EMS display for the Chemehuevi Community Center. This display provides real time energy consumption for the facility and provides information of the energy storage, generation, and loads.

Figure 41: Chemehuevi Indian Tribe Energy Management System Display



Chemehuevi Indian Tribe Microgrid

Weather

Solar Irradiance : 145.25 W/m2

Instantaneous Wind Speed : 15.60 mi/h

Instantaneous Wind Direction : 234 °

Relative Humidity : 29 %

CIT Community Center Building

Total Net Load AC (kW)

200A Circuit (kW)

400A Circuit (kW)

Power Factor : -0.60

Solar Energy Generation

Total Solar Power Generation DC: 61.40 kW

PV Drawer 1 DC: 21.40 kW

PV Drawer 2 DC: 20.80 kW

PV Drawer 3 DC: 19.20 kW

Solar Irradiance: 145.25 W/m2

Battery

Battery Power DC: 0

State of Charge: 0 %

2/19/2019 1:58:45 AM

2/19/2019 9:58:45 AM

Source: University of California, Riverside

Production Readiness Plan Components

Production and Manufacturing Requirements – Sponsored California Energy Commission (CEC) programs promote development of commercial technologies to make energy-enhancing products available to industrial markets. The microgrid architecture and EMS technology developed and tested in this project have been integrated within the Chemehuevi Indian Tribe facilities. This technology integration identifies the processes and operations suitable for the adoption of the EMS technology developed and tested for this project. The team also identified market sectors for further exploration. An advantage is that the technology does not require extensive production or manufacturing for industry adoption. It does require the dissemination of approaches, strategies, and methods for integration within the energy sector.

Production and Manufacturing Costs – Adoption of the microgrid architecture and EMS effectively met the specific energy demands of the tribe’s community center. The team collaborated with the tribe and electric utilities to identify the energy-use profiles and DR scenarios that would most benefit from this technology integration. Production and manufacturing costs were integrated within the industry that produced the EMS and microgrid components. The need for EMS integration needs to be more fully realized by EMS end users, operators, and microgrid technology providers.

Intellectual Property Considerations – This project helped eliminate barriers associated with intellectual property restrictions. The implementation of EMS strategies within a microgrid architecture can be simply adopted by referencing this and similar projects. The team has developed presentations, website reference materials, procedures, and reports to assist agencies in identifying which processes or facilities would benefit the most from adopting this technology. This information has been shared at a CEC-sponsored workshop focusing on the demonstration and deployment of energy storage, energy generation, and energy management strategies that improve resiliency and reliability while reducing electricity costs.

Production and Manufacturing Requirements

Existing software for EMS technologies allows the integration of microgrid architecture in behind-the-meter applications. As microgrid integrators and system operators realize the benefits of DERs, EMS software manufacturers will provide streamlined methods for EMS integration. The future production and manufacturing of EMS-adaptable microgrid systems will proceed smoothly. Ongoing efforts by the energy industry to promote energy management will also continue to push non-energy industries to adopt and integrate EMS strategies.

California Energy Commission-sponsored programs foster the development of commercial technologies to make energy-enhancing products available to industry. The EMS technology developed in this project was integrated within a microgrid at a critical facility to promote and demonstrate energy resiliency and reliability. This technology integration also identified the processes and operations most suitable for adoption. The team utilized this deployment to identify market sectors to be further explored. The technology does not require extensive production or manufacturing for further industry adoption.

Continued technology adoption requires dissemination of approaches, strategies, and methods for integration within microgrid deployments at critical facilities. Educational facilities, utilities, and EMS system providers should continue to collaborate on transitioning the energy sector to integration of EMS strategies within critical facility operations. Continued fiscal incentives for reducing energy costs should continue to incentivize adoption of EMS and DER integration. EMS software providers will promote and develop EMS and microgrid capabilities as energy sector DER implementation expands.

Production and Manufacturing Costs

Adoption of microgrid EMS architectures is effective in supporting critical facilities with unreliable or inconsistent energy supplies. The project team collaborated with both the tribe and the local electric utility to identify energy-use profiles that would best benefit from this technology integration. Production and manufacturing costs are integrated within the industry producing the EMS and microgrid components, so microgrid end users, operators, and technology providers need only realize the technology’s benefits to proceed.

EMS software is a mature industry that continues to evolve apace with market conditions and customer demand. As microgrid- and DER-implementing agencies increase their adoption of EMS and DER architectures, software development will also evolve with more tools and interfaces. Industry would also benefit from specialized training and tutorials to further advance this integration.

CHAPTER 7: Conclusions/Recommendations

The energy challenges that many Native American tribal communities face due to their remote locations are often related to frequent and prolonged grid power outages, primarily driven by extreme weather conditions, lack of redundancy in the electric-grid system, and remote access for repair crews. These grid power interruptions are often remedied by local energy generation via diesel backup generators. Despite their ubiquity, diesel generators are a major source of criteria air pollutants and greenhouse gas (GHG) emissions; the energy they generate is also relatively high cost due to the cost of operation and maintenance (O&M).

The goal of this project was to assess energy needs and challenges faced by the Chemehuevi Indian Tribe and demonstrate and evaluate the effectiveness of several pre-commercial distributed energy technology solutions. The project featured deployment of renewable high-efficiency solar PV modules from SunPower, a novel Zn/Br FBESS from Primus Power, and an EMS and inverter from EnSync. Upon completion of the demonstration phase of the project the Primus Power and EnSync equipment were replaced with Li-ion energy storage and conventional inverter technologies to provide continued benefits to the Chemehuevi Indian Tribe beyond this project. The successful completion of the project would not have been possible without the tremendous support by the tribe members involved in the project. Several key project team members are shown in Figure 42.

Figure 42: Project Team Members on Project Site

Front row, from right to left: Lorrie Ellsworth (CIT), Alfredo Martinez-Morales (UCR), Miro Penchev (UCR). Back row, from right to left: Glenn Lodge (CIT), Emmanuel Evans (CIT), Nick Challis (CIT) Not present in this photo: Mike Todd (UCR), Henry Gomez (UCR), Sadrul Ula (UCR)

Source: University of California, Riverside

Some of main challenges encountered in this demonstration project were regulatory rather than technical. More specifically, special consideration needs to be given to equipment compliance with safety standards, local jurisdictional regulations, and utility interconnection rules. Even if selected equipment meets all regulatory requirements at the inception of a project, projects that span several years will likely be impacted by changes and updates to interconnection agreements and regulations, net-energy metering agreements and tariffs, and fire code and local safety guidelines. These frequently changing and evolving standards in the DER ecosystem, whose research and development (R&D) resources are already seriously strained, may vary significantly based on specific utility, state, and local regulations.

A specific hurdle for this project concerned advanced inverter functions (UL 1741 SA) established in CA Rule 21 Phase 1 for interconnection applications submitted to SCE after September 2017. The EnSync inverter was not equipped with required "smart inverter" functions; this caused delays in the interconnection application process, though SCE eventually granted an exemption since the inverter installation occurred prior to September 2017.

Another major issue was related to the SCE requirement of pairing the NEM agreement for energy storage with the solar PV generation system. To preserve the integrity of NEM, the energy storage system was not permitted to charge from the grid and export energy back to grid at a later time. Normally, for a separate AC-coupled solar PV system and AC-coupled energy storage system, this rule can be enforced by simply installing a non-export relay on the energy storage system or a net-generation output meter on the solar PV system. Unfortunately, neither one of those two options could be employed on a system where DERs (both PV and battery) are DC coupled (one of the main advantages and highlights of the existing project due to higher efficiency achieved by direct DC battery charging from solar PV energy and utilization of a single DC-AC inverter system. The solution employed to satisfy this NEM requirement was to restrict the energy storage system from charging from grid power at all times through a software modification to the controls module of the EnSync's Matrix system. This feature required demonstration to both SCE and a nationally recognized technical laboratory (NRTL) representative, followed by a witness report prepared by the NRTL and submitted to SCE before granting an operating permit for the project. This particular obstacle resulted in a significant project delay and additional costs.

Another major consideration for this kind of demonstration project must be its long-term O&M beyond the demonstration period. Often the novelty and complexity of these pre-commercial technologies mean that only the original equipment manufacturer (OEM) is able to provide proper technical support. This lack of competition and specialized O&M needs may result in higher operational costs, or worse, an inability to maintain and operate the system if the OEM goes out of business. After EnSync exited the energy market, the project team was unable to locate an alternate source for spare parts, technical support, or long-term maintenance of the EnSync system. A choice was made to utilize remaining project funds to replace the EnSync matrix and inverter with standard solar-string PV inverters to continue to provide benefits from the solar PV system to the Chemehuevi Community Center.

Another major technical challenge was the integration of multiple DERs developed by different vendors with a single third-party EMS. Although most DER vendors do provide application program interfaces for third-party EMS control, documentation and actual used cases were limited and scarce. One reason for this could be the fact that most vendors develop their own exclusive EMS applications capable of basic EMS functions that are, however, tailored to the specific operational constraints and requirements of their equipment. This was the case with managing the EnSync matrix and inverter and the Primus Power battery system. The UCR team held multiple meetings with applications engineers from both EnSync and Primus Power. As a result of these meetings and a series of field tests, multiple software changes were implemented by both the vendors and the University of California, Riverside (UCR) team to integrate the controls of the two systems. This proved to be especially difficult with the Primus Power flow battery-control strategy due to various operational constraints and requirements, which were neither well documented nor intuitive due to the unique needs of the Primus Power flow battery.

These constraints in operating the Primus Power battery ultimately proved too prohibitive in meeting all the intended uses for the energy storage system, black-start and islanded operation in particular (which were both essential for providing resiliency to the microgrid). The main limitation of the Primus Power flow battery was its inability to remain idle in charged state for prolonged periods of time in order to provide back-up power during grid-power outages. The system required continuous charging and discharging, while long-term idling (longer than 12 hours) could only be performed with the system fully discharged. Another major drawback of the storage system was its inability to perform a black start since it was not equipped with a UPS system. An external 3-phase UPS system was not available in the required capacity range, and larger-capacity UPS systems were cost prohibitive and required additional space. Even though the Primus Power energy storage system proved was effective for energy shifting and peak-shaving, a subsequent reduction in the battery energy-storage capacity to 30 percent of the nominal state of charge (SOC) led to the decision to replace the Primus Power energy storage system near the end of the project. The replacement energy storage system was a conventional lithium-ion battery system capable of black start and islanded operation, described in greater detail in Chapter 4.

One aspect of the project for consideration was the project site location. The Chemehuevi Indian Reservation is located in a relatively remote part of California. Traveling to the project site was not always convenient for most of the project team members and shipments to the site were sometimes delayed. Despite the many visits to the project site by the UCR team, the local support by the Chemehuevi personnel was indispensable and critical to the successful completion of the project. The UCR team is grateful for the support and local accommodations provided by the Chemehuevi Indian Tribe.

CHAPTER 8: Benefits to Ratepayers

Project Objectives

The main objectives of this project were to improve the energy independence and resilience of the Chemehuevi Indian Tribe by providing local renewable energy generation, energy storage, and an energy-management system. The direct outcomes of these objectives are reduced electricity bills, reduced peak electricity demand, reduced GHG emissions, increased resiliency, and improved grid reliability. The following sections identify and quantify specific project outcomes.

Tangible Project Benefits

Electrical Energy Savings

During the demonstration phase of the project, the solar PV system generated 143,368 kWh AC renewable energy, over 12 months of operation, despite a few interruptions to system operations. The avoided utility energy use and reduced peak demand resulted in an annual electricity bill reduction of $11,042 for the community center when compared to the average electricity bills for the previous three years. An additional credit of $491 was issued by SCE for participation in critical peak pricing DR program in 2019.

Electrical Demand Reduction

The use of a combined solar PV system and energy storage system reduced peak electricity demand, shown in Figure 23, compares building data during the demonstration period with the average of the previous three years. Overall, there was a 69-kW peak reduction over one year.

Greenhouse Gas Emissions Reduction

The generated renewable energy of 143,368 kWh AC in the first year of operation resulted in displacement of 47,455 kg of CO_2e GHG emissions from grid electricity, assuming a GHG factor for grid electricity of 0.331 kg CO_2e per kWh.

Additional Project Benefits

Technology De-Risking

One of the objectives of this project was establishing the technical and practical feasibility of the proposed approach and technologies, proving the reliability and effectiveness of technologies developed and distributed by California companies, and ultimately reducing the risk in future investment in these technologies. Proven and widely adopted technologies benefit everyone by lowering costs for subsequent installations. A key benefit from this project for utility ratepayers will therefore be lower electricity bills and wider adoption of this technology. The de-risking of this technology and approach could potentially provide wider benefits for ratepayers. On the other hand, lack of deployment and demonstration and evaluation of novel pre-commercial technologies could alternatively lead to costly delays in developing paths to market for these much-needed technologies.

Increased Grid Reliability

The overall demand peak reduction associated with the solar PV system, energy storage system, HVAC management strategies, and participation in the DR program, together have a positive impact on electric-grid system operations in California's "duck curve." The duck curve is a day-by-day graph of power output that depicts the time imbalance between peak demand and renewable energy generation. The duck curve has come to represent the challenges faced by power system operators when incorporating variable renewables into the grid. During peak periods, the electricity generation, transmission, and distribution systems in California face maximum stress from high demand. Peak-demand reductions could therefore lead to increased grid reliability without the need for additional generation.

Awareness of Energy and Demand Use

This project provided an opportunity to review electricity bills from past years, not only for the community center building studied but for the other large community buildings as well. Through this project key members of the tribe have become more aware and better informed about the technologies, their benefits, and billing components and charges for specific electricity tariffs.

LIST OF ACRONYMS

Term	Definition
AC	Alternating Current
ATS	Automatic Transfer Switch
BESS	Battery Energy Storage System
BMS	Battery Management System
CCC	Chemehuevi Community Center
CE-CERT	University of California, Riverside Center for Environmental Research and Technology
CEC	California Energy Commission
CIT	Chemehuevi Indian Tribe
DER	Distributed Energy Resource
DC	Direct Current
DG	Distributed Generation
DR	Demand Response
EMS	Energy Management System
EPIC	Electric Program Investment Charge
FBESS	Flow Battery Energy Storage System
GHG	Greenhouse Gas
GID	Grid Isolation Disconnect
HMI	Human-Machine Interface
HVAC	Heating Ventilation and Air Conditioning
IOU	Investor-Owned Utility
Isc	Short Circuit Current
I-V	Current-Voltage
kW	Kilo Watt
kWh	Kilo Watt Hour
NEM	Net Energy Metering
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
PCS	Power Conditioning System (Socomec BESS Inverter)
PMS	Power Management System (Socomec BESS Controller)
PQ	Constant Power
PV	Photovoltaic

Term	Definition
R&D	Research and Development
SCE	Southern California Edison
SOC	State of Charge
TOU	Time-of-Use
UCR	University of California, Riverside
UPS	Uninterrupted Power Supply
VPN	Virtual Private Network
Zn/Br	Zinc-Bromine

REFERENCES

Gao, D. W. (2015). Energy Storage For Sustainable Microgrid. London, U.K: Elsevier.