Energy Research and Development Division

**FINAL PROJECT REPORT**

# Making a Microgrid From Legacy Systems

## Las Positas College Microgrid

**California Energy Commission**

Gavin Newsom, Governor

**July 2019 | CEC-500-2019-052**

**PREPARED BY:**

**Primary Author:**
Bruce Rich, PE, CCM, LEED[AP]

WSP USA
2150 River Plaza Drive, Suite 200
Sacramento, CA 95833
Phone: 916-849-1920
http://www.wsp.com

**Contract Number:** EPC-14-055

**PREPARED FOR:**
California Energy Commission

Jamie Patterson
**Project Manager**

Fernando Piña
**Office Manager**
**ENERGY SYSTEMS RESEARCH OFFICE**

Laurie ten Hope
**Deputy Director**
**ENERGY RESEARCH AND DEVELOPMENT DIVISION**

Drew Bohan
**Executive Director**

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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 solution, 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.

*Making a Microgrid From Legacy Systems—Las Positas College Microgrid* is the final report for the Las Positas College Microgrid project, grant number EPC-14-055, conducted by the Chabot-Las Positas Community College District. 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 Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

# ABSTRACT

Grid stability issues were introduced by the wide distribution of 1-2 megawatt solar photovoltaic systems on educational and commercial campuses and the use of the utility grid to store energy produced by these systems in excess of campus needs. To address these issues, the Las Positas Microgrid Project provides a model for campus grids to include on-site storage with upgraded smart grid control systems. The Las Positas Microgrid project installed a 200 kilowatt, 1,000 kilowatt-hour battery energy storage system to the 21.7 kilovolt grid at Las Positas College. The new storage system included predictive energy management applications to reduce peak utility power demands and reduce energy use in response to demand response signals. The new control systems integrate with the existing campus energy control systems to manage existing energy storage, generation, and consumption assets (including a 3,200 ton/hour thermal ice storage system); 100 kilowatts of light-emitting diode lighting; 2,350 kilowatts of photovoltaic solar generation; and heating, ventilation, and air conditioning systems across the campus. The project included installation of a UniEnergy Technologies ReFlex™ vanadium redox flow battery, an energy storage system that pumps electrolyte through stacks of electrochemical cells. The system showed it could reduce multiple power peaks during a four-hour evening period of maximum energy demand and store excess solar generation during the day. The $1.8 million project is projected to reduce the college's energy cost by $120,000 a year with potential for an additional $10,000 annually from demand response participation.

Keywords: microgrid, Vanadium redox flow, battery, smart grid, energy storage, educational campus

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## Introduction

California leads the nation in the shift from central plant fossil-based energy generation to distributed renewable generation, such as rooftop solar photovoltaic (PV) cells and fuel cells, as a way to reduce greenhouse gas emissions. The rapid development of PV and wind turbine generation (combined with hydroelectric and geothermal generation) has demonstrated that maintaining a reliable electrical grid with a high penetration of renewable energy introduces considerable grid management issues. These issues include frequent, rapid variations in renewable electricity generation due to weather conditions, widely dispersed and uncoordinated generation sources, and periodic mismatch between renewable energy generation and system energy consumption. Energy storage can solve these issues.

The rapid development of PV systems relied on the local utility grid acting as an energy storage battery, smoothing fluctuations and distributing locally generated excess energy. As renewable energy approaches 40 percent of the total energy source, the statewide system cannot absorb or redistribute energy to support excess PV generation between 10 a.m. and 4 p.m. Large amounts of energy storage are needed to manage the variations in renewable energy generation. This storage capacity could be added at the grid level or placed with the distributed local PV generation.

Over the past 15 years, the educational community led the development of new PV systems on its campuses. Three factors stimulated growth: (1) grant funding that provided a major share of capital expenses, (2) net metering that allowed market rate payment for any excess generation, and (3) immediate reduction in utility bills. For kindergarten through 12th grade campuses, much of the school day energy was provided by the PV system; during the summer, the excess energy was a welcome source of income. Larger systems on colleges and universities allowed some export year-round during the day and on weekends. Educational communities accepted the 12- to 15-year payback on PV systems as a long-term investment.

The addition of microgrids at educational institutions that incorporate energy storage and energy management software can be a low-cost enhancement to existing PV systems. The new microgrids can provide an economic benefit through lower energy costs and have similar payback times as PV investments. Just as important, microgrids can support use of schools as emergency shelters during natural disasters. Finally, the new microgrids can improve grid stability for local utilities.

Las Positas College was an opportunity to demonstrate the technical and financial feasibility of adding storage and controls to existing systems. The Las Positas campus electrical characteristics were similar to those of the statewide California grid. The college grid operates at a medium voltage of 21.7 kilovolts and includes 2.3 megawatts of PV arrays that produced more than 50 percent of the college's annual electrical needs. The utility power demand curve is similar to the statewide net demand curve, referred to as the “duck curve” because of the distinctive shape that reflects a deep midday drop in electric load due to large amounts of solar on the grid (the duck's "belly"). The drop is followed by a steep ramp in demand in late afternoon and evening (the duck's "neck") as solar fades and people returning from work begin using more electricity.

Before the addition of the energy storage system, Las Positas College exported energy daily, relying on the utility grid to manage fluctuations in PV generation. The college had invested in sustainability technologies, adding a central heating and cooling energy plant with thermal ice storage and a campuswide energy management system that provided tools to manage energy use.

## Project Purpose

The Las Positas College Microgrid project sought to design and install energy storage and microgrid controls that incorporated existing legacy PV and energy management systems to form a microgrid. From an economic perspective, the goal was to demonstrate achievable and repeatable energy cost reductions. Potential cost reduction strategies included reducing demand peaks during multiple periods each month, shifting energy use to lower-cost periods, participating in energy-reducing incentive programs such as demand response, and reducing energy use.

From a technical perspective, the project goal was to design and install equipment and systems with a long operating horizon that provided flexibility to adjust to changing market conditions and campus operations over time. As an educational institution, the college was interested in testing emerging technologies and systems funded by grants. The project also had the goal of providing additional benefits such as emergency power for an operations center and athletic field lights in the event of a grid loss during an evening event. The microgrid project was the stimulus for the college to evaluate the entire campus energy system and begin planning and implementing smart grid systems—controls, computers, automation, and new technologies that allow for two-way communication between a utility and its customers—to control energy purchases and use energy to operate campus buildings. The project is also a model for other educational and commercial institutions that may be evaluating ways to manage electrical energy systems within a microgrid.

## Project Process

The project consisted of four major elements: (1) a new battery energy storage system, (2) new microgrid controls, (3) an existing thermal storage system, and (4) existing PV integration. The project team included emerging firms with new technologies as well as firms experienced in designing and constructing microgrid systems. Project planning and design development used a cooperative team approach involving designers, contractors, systems and application programmers, equipment vendors, and college operations staff. This collaborative team developed an equipment design that integrated the new battery energy storage system into the campus' buildings and electrical grid. The team also developed a control strategy that minimized effects on the ongoing campus operations while allowing extensive testing and adjustments.

The most critical (and most disruptive) element was the battery energy storage system equipment. The college decided to use vanadium redox flow battery technology for the energy storage system based on factors including a promised 20-year life with minimal degradation, low initial cost, lowest life-cycle cost compared to other technologies, and safer operating conditions. Typical flow batteries pump electrolyte through stacks of electrochemical cells and use two different electrolytes; vanadium redox fuel batteries are able to maintain different states of charge using a standalone element, which is more efficient.

The lessons learned from the ongoing project provided an opportunity for the college and operations construction managers, project manager, and system integrator, to advance flow battery technology. The operations construction managers worked with Imergy, the initial battery supplier, and EPC Power Corporation, an established PV inverter manufacturer, to develop a new inverter designed to accommodate the unique voltage and power characteristics of a flow battery. Although Imergy left the project after 14 months, the college was committed to using a flow battery system and selected UniEnergy Technologies to provide two 100 kilowatt/500 kilowatt-hour ReFlex™ vanadium redox flow battery units. This change in vendors added a fair amount of time to the project. The UniEnergy Technologies equipment was delivered in 14 months, including a two-month delay for final UL certification of the EPC Power Corporation inverter units and four months of shop testing of the combined UniEnergy Technologies and EPC Power Corporation equipment.

The units were then installed and tested over four months by PDE, the design/build contractor. Commissioning (the process to assure that all components of the system are designed, installed, tested, operated, and maintained according to requirements) occurred over six weeks. The commissioning incorporated the battery energy storage system and the demand charge management software developed by Growing Energy Labs, Inc. Testing. Commissioning of the microgrid control software developed by Schweitzer Engineering Laboratories required another two months. The flow batteries experienced mechanical issues during operations and required replacement of major components. While these issues did not require wholesale replacement of the battery energy storage system equipment, they highlighted the need for maintenance agreements with key systems vendors and adequate training for on-site maintenance staff.

The project also presented an opportunity to reassess the use of the existing campus thermal energy storage system. When the thermal system was installed in 2008, the idea was to operate the campus on energy stored in the ice storage units during daylight peak energy rate periods and operate the chillers only during evening hours when energy costs were lower. With the addition of on-site PV, the college was able to export excess PV during daylight hours. This energy could be used instead to operate the chillers, and the energy stored in the ice units could be used to reduce peak demands that occur between 7 and 9 p.m. The project team worked with Syserco, a building energy management service, to develop a new control strategy for the chillers that started the chillers in the morning then shifted to ice mid-day, which provided an opportunity to integrate peak reduction planning into the campus energy management system to reduce total operating costs.

## Project Results

The Las Positas College Microgrid project successfully demonstrated the technical and financial benefits of adding energy storage and microgrid controls to existing PV systems to form a microgrid. The project demonstrated a potential 10- to 12-year financial payback, illustrated nonfinancial operational benefits to the college, and provided a social environmental benefit. Also important was the paradigm shift in the college's maintenance and operations department's perspective of the campus electrical systems. The maintenance and operations department now views the campus as a microgrid with energy generation, consumption, and storage interacting with data and control signals to allow greater control over when energy is consumed and from what source. The microgrid system provides new tools to adjust energy use as utility programs and campus usage changes and can demonstrate the college's efforts to reduce energy costs.

The project also provided a valuable testbed for the key project technology and equipment vendors who have developed their next generation of equipment and system using the test data and lessons learned from the Las Positas project.

As an educational institution, Las Positas College and the Chabot-Las Positas Community College District management supported opportunities to learn from failures and mistakes inherent in developing and implementing new systems, especially when integrating legacy systems. This high-level support allowed the project to take the time needed to identify issues, evaluate causes, develop options, and restart after implementing solutions. The result is an operational system that provides immediate benefits to the project participants and long-term benefits to the college as well as California ratepayers. The $1.9 million project was also completed 5 percent under budget.

This project addressed multiple challenges. A major challenge was maintaining communication among the technical vendors. A lesson learned was that a system integrator is necessary to ensure all vendors are involved in discussing how their system will interact with all the other systems on the project. Another challenge was the utility's interconnection process. The interconnection was delayed by misunderstandings about project design intent and purpose, response delays, and communication blocks. The commitment of the college and district administration to work through these problems was critical to the success of the project.

## Technology/Knowledge Transfer

The details of the project were widely disseminated to the educational community through presentations at campus facility manager conferences, local educational agencies, and technical seminars. The project gained recognition from several national microgrid-specific conferences as an early testbed for institutional-size battery energy storage systems and microgrid controls.

## Benefits to California

The project created benefits for the college, project participants, other educational institutions, and California ratepayers.

The college benefits from long-term energy cost savings projected to be $100,000 to $150,000 per year from the demand charge management, thermal energy storage reprogramming, and demand response applications, providing an acceptable payback of its investment. The college also benefits from the backup power provided to the emergency operations center and the emergency lighting for the outdoor athletic fields. The campus now has new tools to manage energy use as new on-site generation and site loads are added and can adjust to changing utility rate structures.

Project vendors and participants benefit from the lessons learned and testing performed during the project, and are building on this knowledge to develop new and improved products and systems that will in turn benefit other users.

The California educational community benefited from the project outreach efforts and technology transfer to convey lessons learned and provide evaluation tools they can use when planning and implementing storage and smart grid solutions.

California ratepayers will benefit through future development of microgrids for similar customers that seek to reduce demand charges, participate in demand response activities, and seek clean and safe energy solutions.

# CHAPTER 1: Introduction

The Las Positas College Microgrid project was undertaken to investigate the technical and financial benefits of adding energy storage and microgrid controls to existing legacy photovoltaic (PV) systems to form a microgrid. The project was intended to evaluate emerging technologies and model the financial characteristics of the proposed system. This report describes the planning and implementation of the microgrid and the smart grid, provides operational information, discusses project outcomes and lessons learned, and provides some recommendations and comments.

## Project Sponsor and Host

Las Positas College is located on a 143-acre campus in Livermore, California, with a student population of more than 8,000 (Figure 1 below shows an aerial view of the campus.) Las Positas College offers associate degrees, technical certification programs, and lifelong learning opportunities for residents in the Tri-Valley area of eastern Alameda County. Along with Chabot College in Hayward California, Las Positas College is part of the Chabot-Las Positas Community College District.

**Figure 1: Las Positas College Campus Aerial View**

Source: Google Earth

The college and the district strive toward sustainability in all aspects of the planning, development and operation of the campus facilities. In 2010, the district prepared the Las Positas Carbon Action Plan 2010, which identified baselines and set long-term goals to reduce the college's carbon footprint. As part of the action plan, the college has invested in energy savings and energy management technologies, including:

- Installation of 2.3 megawatts (MW) of solar PV arrays on the campus that generate more than 50 percent of the campus' total electrical energy needs.

- Installation of a central plant providing chilled and heated water to campus buildings, replacing individual building mechanical compressors and gas-fired rooftop units.
- Installation of a 3,200-ton/hour ice storage system as part of the central plant, providing options on central plant chiller equipment time of use.
- A mandate that all new construction meet Leadership in Energy and Environmental Design (LEED©) Silver certification or better.
- An Alerton Compass energy management system (EMS) to control all mechanical heating and cooling systems across the campus.
- Replacement of exterior and interior lighting with high-efficiency light-emitting diode (LED) lighting and controls connecting to the EMS.

# Project Team

The Las Positas College Microgrid project organization included new technology firms with experienced planning along with design and construction firms. The project was managed by WSP, an international professional services firm providing planning, design, and project management services to a wide range of public and private clients. WSP brought extensive experience with the Las Positas College campus to the project, having provided design and project management services in conjunction with the district's multiyear capital improvement program at the college. WSP provided overall project and construction management and was the system integrator.

The project team (Figure 2) included firms with new and developing technologies and services focused on the growing energy storage and microgrid market.

**Figure 2: Team Organizational Chart**


Source: WSP

## Team Members

- Growing Energy Labs, Inc. (GELI): Established in 2012, GELI is a leader in developing energy management applications using an "Internet of Things" concept, and managing multiple energy sources with energy applications in an overall GELI energy operating system. GELI provided the demand charge management (DCM) application.

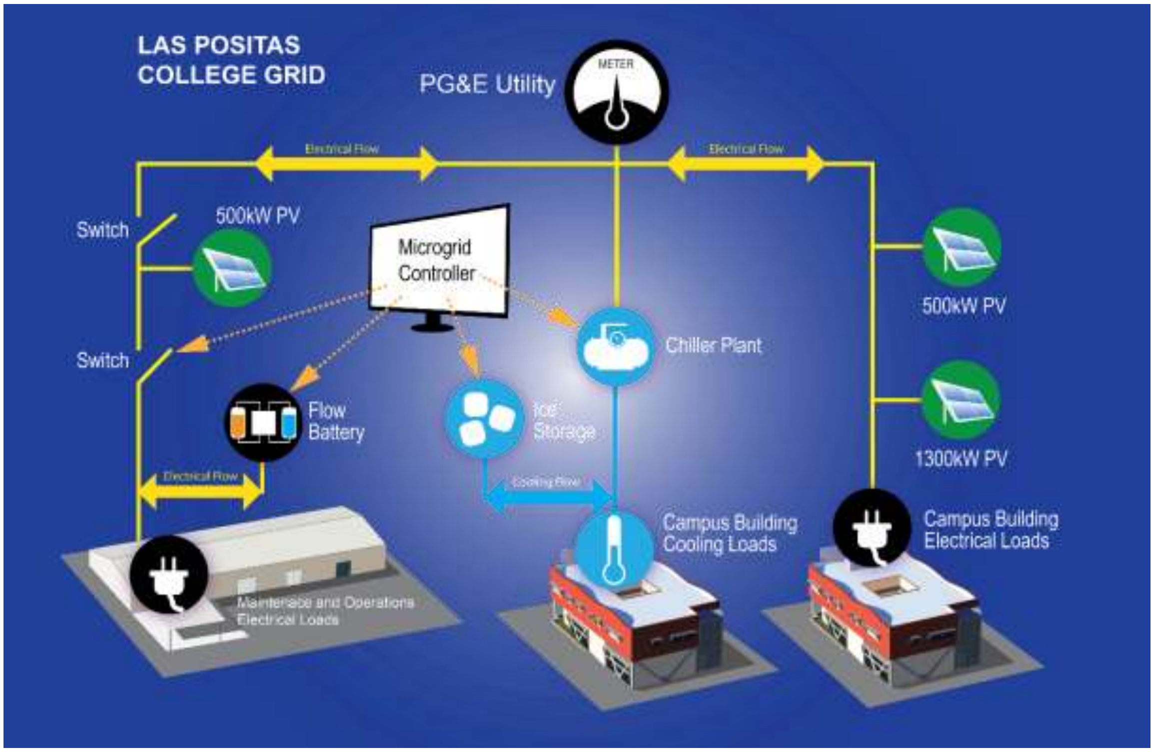
- UniEnergy Technologies (UET): UET was founded in 2012 and improved the performance of a vanadium flow battery based on research and development by the Pacific Northwest National Laboratories (PNNL). UET has supplied more than 60 megawatt hours (MWh) of its 600 kilowatt (kW)/2,200 kilowatt-hour (kWh) units to utility customers and has developed the ReFlex 100 kW/500 kWh units for commercial customers. UET replaced Imergy Energy as the battery system vendor and provided two of its ReFlex battery units for the Las Positas College Microgrid project.
- EPC Power Corporation (EPC): Established in 2010, EPC Power designs and manufactures grid forming bidirectional inverters and DC/DC converters for solar, wind, flywheel, and automotive areas. EPC developed a new inverter unit incorporating both a DC/DC converter and a DC/AC inverter to meet the special voltage characteristics of flow batteries used in the microgrid
- PDE Total Energy Solutions (PDE): PDE was established in 1990 and provided design/build and electrical contracting services. PDE brought experience in microgrid technology and installation. PDE acquired experience working with GELI and Imergy on the Point Hueneme Naval Base flow battery demonstration project and was familiar with the equipment and systems required.
- Olivine: Established in 2010, Olivine provides infrastructure and services that enable distributed and aggregated energy resources to offer services to the grid. Olivine brought experience on programs at Pacific Gas and Electric Company (PG&E) and the wholesale energy market to develop options for payments for grid services.
- Schweitzer Engineering Laboratories: Schweitzer was established in 1984 and invents, designs, and builds digital products and systems that protect power grids around the world. Schweitzer developed the microgrid control system for this project. .
- Syserco: Syserco provided design, installation, and programming for the Alerton building EMS. Syserco worked with Las Positas College to install and upgrade the Alerton campus-wide building energy management control system.
- Two initial project team members had limited involvement in the project. Imergy Energy Systems, the initial flow battery provider, went out of business and was replaced by UET.  PG&E, the local utility, was proposed as an active member providing input and guidance on services to the grid but its only participation was during the interconnection process.

# Project Description

The Las Positas College Microgrid consists of a new 200 kW/1,000 kWh battery energy storage system (BESS) integrated into the existing Las Positas College electrical grid. The system is designed to form a microgrid combining an existing 500 kW PV array and supply the maintenance and operations (M&O) complex building load with uninterrupted power. The project also upgraded the campus-wide EMS to strategically deploy the existing 3,200 ton/hour thermal storage system and to activate energy reduction schemes from a remote demand response signal.

As illustrated in Figure 3, the Las Positas College grid operates at 21.7 kilovolts (kV), the PG&E distribution voltage at the campus point of connection. The microgrid is connected to the campus grid at the main switchboard (MSB) near the M&O complex. The panel MSB contains the M&O complex and athletic field lighting and the BESS. The 2400A main breaker in the MSB is retrofitted with components for remote operation to form a microgrid. The 500 kW PV array can be manually isolated from the campus grid to supply only MSB loads. The microgrid controls can automatically disconnect the BESS and M&O from the campus grid and grid form[1] upon loss of campus grid power, as well as automatically transfer the BESS and M&O building back to the grid upon return of the campus grid power. In the event of a major area-wide disruption of the PG&E distribution system, the 500 kW PV array and the MSB panel can be islanded from the campus grid.

**Figure 3: Las Positas College Grid Diagram**




**This is a simplified diagram of the Las Positas College energy grid emphasizing the key elements of the microgrid project.**

Source: WSP

In addition to the microgrid, the project introduced smart grid features to control when energy is purchased from the PG&E grid. The existing 3,200 ton/hour thermal storage system is programmed to allow the campus M&O staff to select multiple energy use modes depending on

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1 Grid-forming refers to setting the frequency and voltage of equipment to a fixed value for supplying power. Doing so provides a reference grid for grid following equipment that supplies power at the frequency and voltage that it detects.

seasonal cooling loads. New energy-saving LED lighting systems include building-wide control systems that are programmed to accept demand response signals from the EMS to automatically reduce lighting levels. The microgrid controls and the EMS systems are interconnected to allow wider energy use decisions.

## Project Objectives

The objectives of this project were to:

- Develop applications for and evaluate performance from implementing smart grid systems and processes.
- Install microgrid controls and demonstrate the ability to island, grid form, and return to normal operations.
- Distribute information on the project to educational institutions throughout California.
- Develop and improve energy management applications, microgrid systems and equipment, and BESS equipment.
- Evaluate the performance of a vanadium flow battery.
- Collect and distribute information about lessons learned, benefits, and barriers to microgrid implementation.

# CHAPTER 2: Planning and Design

This chapter discusses the development of the project design from the initial definition of goals and objectives through concept of operations, design development, sequence of operations, and final design. In concert with the broad objectives of the Electric Program Investment Charge (EPIC) grant, the Las Positas College Microgrid project proposed to demonstrate means and methods for the district and the college to actively manage when and how energy was used across the entire campus grid using an integrated “smart grid” rather than single system controls. Expanding the district’s perspective from project-level energy projects to consider the campus as a microgrid created a paradigm shift, leading to an understanding of the value of integrating energy control systems across the entire campus. The microgrid project created energy cost savings by introducing new energy management equipment and systems and integrating those systems with existing EMS to create additional savings. The increased energy savings provided cost benefits to the both the district and the utility grid by reducing demand charges.

In addition to the objectives outlined in Chapter 1, the project had the following broad goals:

- Use the new BESS to reduce demand peaks.
- Integrate the new BESS microgrid controls with existing campus systems to increase the control of energy use.
- Study additional options to monetize the new energy assets.
- Collect data on new technologies, specifically the BESS, microgrid controller and energy control applications.

## Defining Project Needs

With the passage of a $490 million bond issue in 2004,[2] the Chabot-Las Positas Community College District embarked on a multiyear building program that would almost double the building square footage at Las Positas College. This large increase in building footprint resulted in a corresponding increase in energy use and cost. The EPIC grant award in 2015 provided the district the opportunity to implement a campus-wide approach to managing the rising cost of energy.

As part of the bond program over the past 10 years, the district had invested in systems and technology to reduce energy use, including:

2 On March 2, 2004, Alameda County voters and those Contra Costa County voters within the district’s boundaries approved Measure B, the $498 million dollar Chabot-Las Positas Community College District capital improvement (construction) bond. http://www.laspositascollege.edu/accreditation/assets/docs/LPC_Report_Final_30July09.pdf, page 6.

- 2.3 MW of PV arrays that generated more than 50 percent of the annual energy use of the campus.
- Development of new facilities to LEED energy conservation standards.
- A central energy plant to provide cooling and heating energy to new and existing buildings.
- Incorporation of a 3,200 ton/hour thermal energy ice storage system to shift energy used for building cooling.
- Conversion of exterior and interior lighting to LED fixtures.

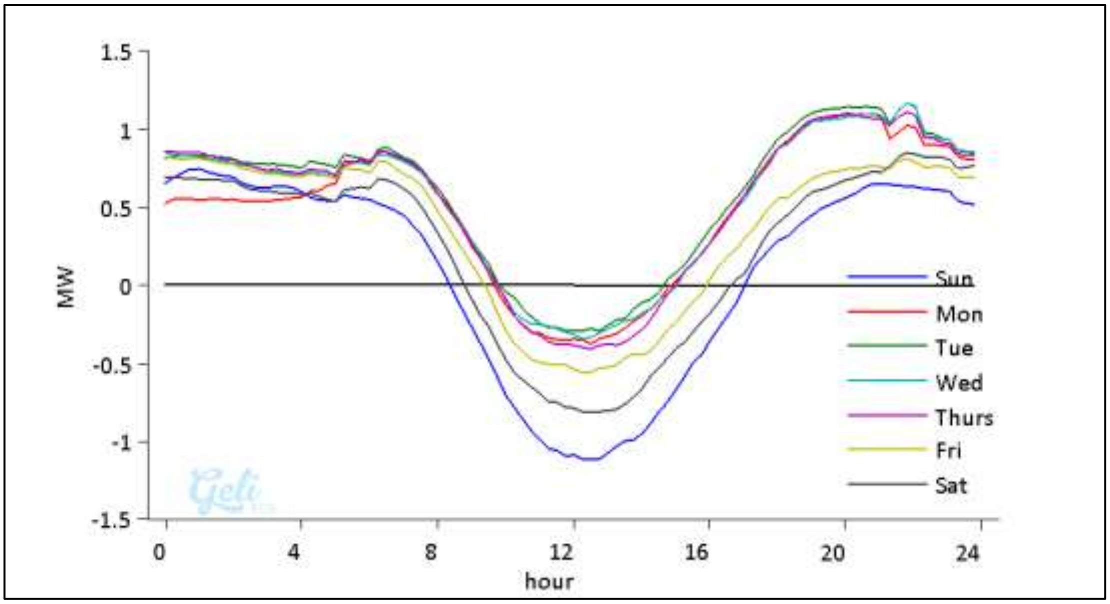
These technologies formed the legacy systems that needed to be included in the microgrid.

While per-square-foot energy use was reduced, energy costs continued to rise due to changing utility billing policies. The district needed to develop the ability to manage when energy was purchased and explore opportunities for revenue from utility energy reduction programs.

The Las Positas College Microgrid project was the vehicle to address energy use management. The project provided the stimulus to study how much and when energy was used over multiyear study periods. The addition of a BESS to the Las Positas College grid incorporating predictive analytic control systems was the key to creating the ability to manage energy purchases.

GELI produced a study during the project development of the campus energy use and utility demand characteristics at the college using 12 months of data from 2014. Figure 4 displays the impact of significant PV renewable generation on the college's net energy demand profile.

**Figure 4: Las Positas College 2014 Net Power Demand Profile**



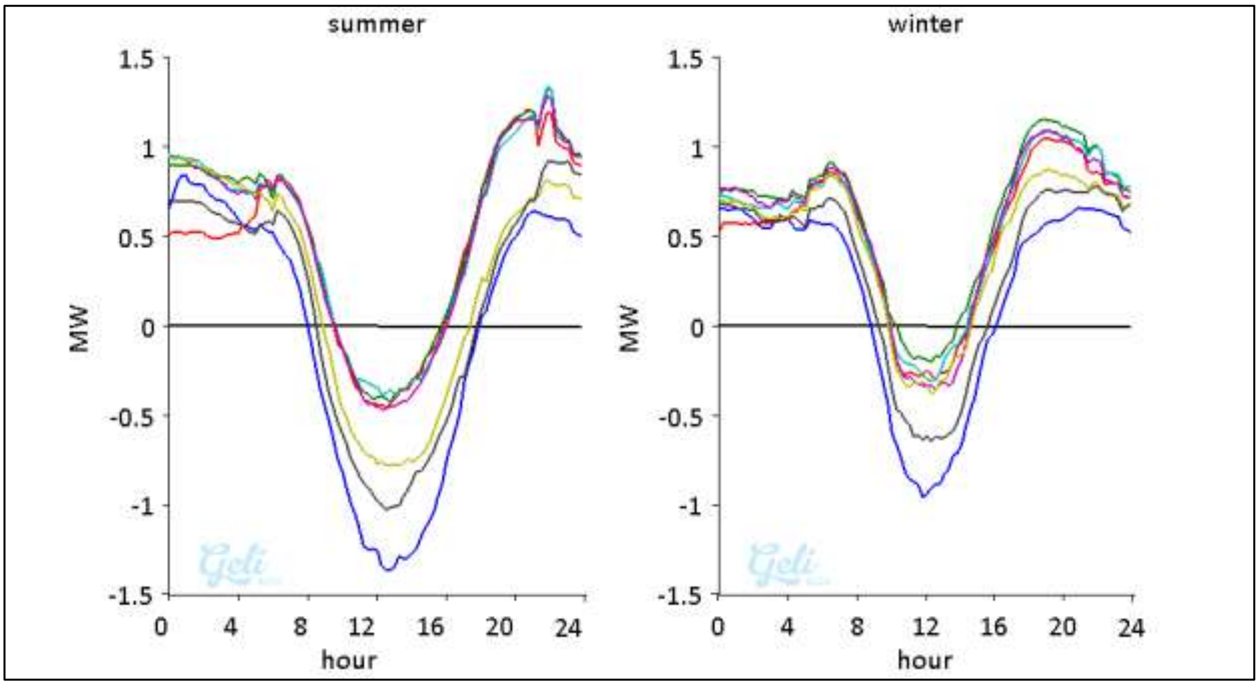

**The figure above summarizes the net power demand for each day of the week over 12 months in 2014. The blue profile, for example, is generated by averaging all Sundays.**

Source: GELI

The net utility power demand profile in Figure 4 illustrates the “duck curve” shape comprising the morning load, midday drop, and evening rapid increase to late night peaks. As the sun rose, power purchase dropped to zero and the college began exporting the excess energy generated. As the sun set, power purchases rose rapidly to high evening levels with late night peaks. This profile mirrored predictions for net statewide energy demand as the percentage of renewable energy generation increased past 40 percent.

Figure 5 separates the Las Positas College utility power demand data into the utility-defined summer period (May through October) and winter period (November through April). This figure illustrates the increased power demand due to cooling equipment loads in the summer months. The late-night peaks in the summer period arise from starting chiller equipment at 10 p.m. to recharge the ice storage system.

**Figure 5: Las Positas College Power Demand Data by Season**

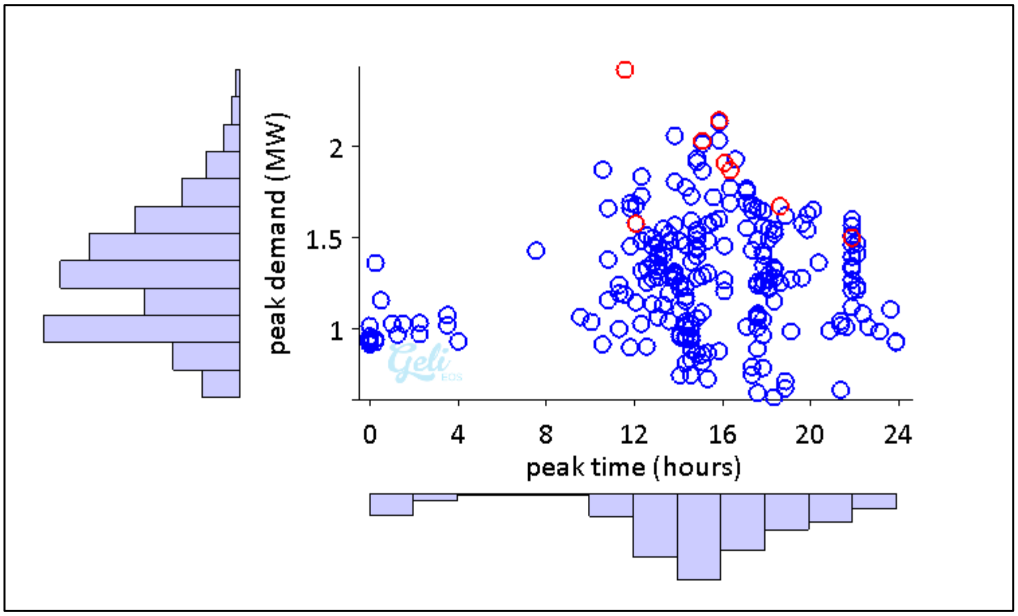



**Power demand pattern for each day of the week separated by Summer and Winter periods. Day of week profile colors match those in Figure 4.**

Source: GELI

GELI developed histograms to analyze peak power demand and peak energy purchase. Figure 6 and Figure 7 show 12 months of daily maximum power demand versus the time of day when it occurred. Figure 6 plots the actual campus consumption and Figure 7 plots the energy purchased, which incorporates the on-site energy generation. Figure 6 shows campus energy use peaks between noon and 6 p.m. and Figure 7 shows energy purchases peak between 6 p.m. and 10 p.m.

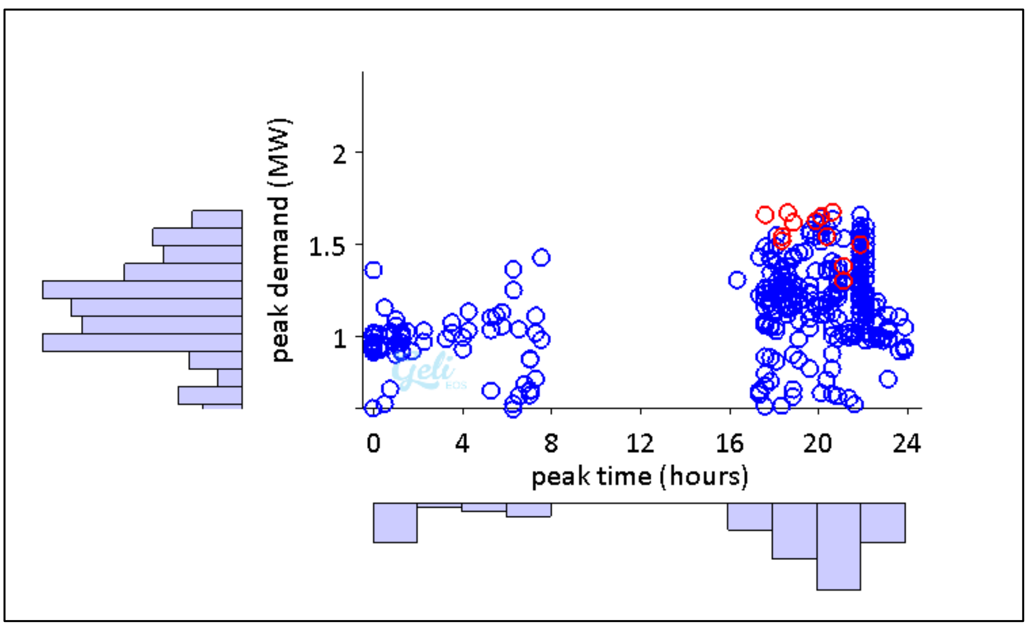
**Figure 6: Daily Maximum Campus Power Demand versus Time of Occurrence (Baseline)**




**Scatter plot of daily maximum power demand versus the time-of-day-at which it occurred. Maximum demand for each month is highlighted in red.**

Source: GELI

**Figure 7: Daily Maximum Utility Power Demand versus Time of Occurrence (with Photovoltaic Generation)**




**Scatter plot of daily maximum power demand versus the time of day at which it occurred Maximum demand for each month is highlighted in red. The histograms reveal the time-density (bottom) and power-density (left) of the daily peak demand events).**

Source: GELI

The addition of PV was effective in reducing reduce energy costs during daylight hours. The PV system eliminated energy purchases during many of the daylight hours, reducing peak demands during the noon to 6 pm. peak charge period. In addition, the energy that was exported during that period generated an energy credit, further reducing the total cost of energy.

Figure 6 and Figure 7 clearly show the value provided to the PG&E distribution grid by reducing peak power demands. As campus buildings were added, the energy use and peak power demands increased. As illustrated in Figure 6, without considering the on-site PV, campus use peaked at more than 2 MW. Considering the PV supply as shown in Figure 7, maximum utility peak demands are reduced to approximately 1.6 MW.

Analyzing energy use and cost, the project team identified opportunities to reduce energy peaks and valleys using 200 kW of battery storage, 200-400 kW of chiller equipment loads, and 3,200 ton/hour of thermal storage, including:

- Increasing consumption of on-site renewable energy in the morning hours between 7 a.m. and noon, when rates are lower and net metering is less rewarding.
- Evaluating the cost trade-off between less export between noon and 6 p.m. at peak rate times with increased on-site PV energy consumption.
- Evaluating opportunities to reduce excess export when the exports exceeded 1 MW.
- Implementing means to predict and automatically reduce demand peaks.

A method to increase the consumption of on-site renewable energy was to reprogram the sequence of operation of the chilled water system, consisting of mechanical/electrical chillers and the thermal storage system. The thermal storage system was designed and installed prior to the installation of the PV arrays. The design intent was to use the stored thermal energy in the morning and afternoon hours to reduce power purchased at peak rates, and then use the chillers to recharge the thermal storage units during the lower-rate evening hours (used overnight at the lowest rates).

The installation of the PV system changed the calculations. The peak demands now occurred between 8 p.m. and 9 p.m. rather than 2 p.m. to 5 p.m.. The morning use of ice storage increased the amount of energy exported and the evening use of chillers further increased the peak power demand. Starting the chillers after 10 p.m. created short-term peaks that became monthly demand peaks. The microgrid project defined four steps to improve chiller/thermal storage energy management effectiveness:

- Stage the chiller operation over one hour during the thermal storage recharge cycle to reduce short demand peaks.
- Change the control logic to operate the chillers during daylight hours and thermal storage in the evening hours.
- Develop a program to automatically switch from chiller to thermal storage, evaluating multiple variables.

- Evaluate other opportunities use the chillers to absorb excess energy from the PV system.

The first step was completed by reprogramming the chiller controls to stage chiller start-up for thermal storage regeneration by 30 minutes and delay regeneration until 10:30 p.m. to allow time to shut down all other campus buildings at the end of evening classes.

The next step involved reprogramming the chiller controls to provide the flexibility of using the chillers or the thermal storage for daylight cooling. During the winter months, the thermal storage could provide cooling energy for multiple days with occasional chiller overnight recharging. A summer/winter logic switch was programmed to provide thermal storage during winter daylight hours and chiller daylight operation during summer months. The programming included an operator-adjustable time selection to switch from chiller operation to thermal storage when operating in the summer mode. The programming maintained the automatic switch from thermal storage to chiller when the thermal storage capacity was exhausted.

The next step was dynamically determining the best time of the day to shift from chiller to thermal storage. The goal was to operate on thermal storage from late afternoon to 9:30 p.m. as classes ended. The challenge was evaluating the variables, including outdoor temperature, day of week, student loads, and amount of thermal storage available. The switch-over time was programmed to occur at 11:30 a.m. to preserve the net metering energy export earnings. The project planned to use the GELI controller for those evaluations, leveraging the predictive capabilities that were part of the GELI demand charge management program. Unfortunately, GELI was unable to have the application provide the signal to the chiller control system.

The last step was evaluating continuing the operation of the chiller equipment into the noon to 6 p.m. period, which would reduce export energy earnings but would also provide a benefit to the utility by reducing the excess PV energy exported during peak generation periods as well as ensure the thermal storage would be adequate for evening operation. Absent any utility incentive, the district did not pursue control strategies to further absorb on-site PV energy during the noon to 6 p.m. peak period.

Another consideration for future control development was to program the BESS to absorb excess PV energy. The original net metering tariff regulations contained in California Public Utilities Commission Rule 21, as implemented by PG&E, allowed net metering payments for energy that was generated by a maximum of a 1 MW PV array. (New tariff regulations have increased the maximum export amounts.) With 2.3 MW of PV arrays at Las Positas College, the campus exported energy every day, many times exceeding the 1 MW limit, especially on weekends when campus energy demands were low. The GELI study estimated more than $30,000 annually in unpaid energy exports to the grid. This represents an opportunity to reduce export and capture excess exports during the weekdays by using a combination of BESS charging and chiller operation that could be investigated further in future work.

# Basis of Design

The study of the campus grid and energy use profiles defined many of the economic benefits of the project. Adding the BESS and microgrid controls also had the potential to create non-economic benefits, primarily increased emergency operations capability.

The basis of design became:

- Integrate a BESS into the college campus electrical grid and add microgrid controls that will reduce peak utility power demands during multiple utility time of use periods.
- Leverage the BESS microgrid control system with other campus systems that control energy using equipment and devices to optimize time of energy purchases.
- Develop communication and control systems to respond to outside signals to enable the district to use the new energy storage assets to earn income by providing services to the grid.
- Develop automated systems to create emergency backup power to key facilities and functions using the non-polluting energy stored in the BESS with the opportunity to recharge the battery from on-site PV arrays.
- Evaluate the performance of new technologies introduced in the project.

## Concept of Operations

The basis of design was further defined with the concept of operations:

- The GELI DCM application would control the BESS system to reduce peak energy charges.
- The GELI system would interface with Olivine to accept signals from outside sources to control the BESS to respond to demand response and other grid services signals.
- GELI would develop an application to identify the time to shift between thermal storage to chillers for cooling.
- Syserco would reprogram the Alerton EMS to shift use of chiller and thermal storage and use the GELI signal to shift from chiller to thermal storage during summer season.
- Integration of the PV with the islanded microgrid would be a manual operation.
- The transition to and from islanded microgrid to and from the campus grid would not be seamless and would include a 3–10 second transition period
- Since the PG&E grid had been reliable, full-time automatic islanding was not necessary and a manual control option would be included.
- Meters would be installed at key points and the GELI system would collect, display, and store metering data.
- A revenue-grade meter would be installed at the output of the BESS for potential participation in demand response programs.

# Design Development

## Battery Energy Storage System Site Selection

The location of the BESS equipment and point of connection to the campus grid was an early design evaluation. The campus grid is connected to the PG&E Cayetano 2117 circuit. The college grid operates at the PG&E distribution voltage of 21.7 kV that is transformed to 480 V for building power.

The BESS was designed to operate at 480V three-phase power and could be connected at many points within the college grid. The college established the following criteria for the connection point:

- Only non-academic buildings could be islanded as part of the microgrid.
- The PV array must have the capability to be disconnected from the campus grid without changes to the electrical grid.
- The BESS equipment should be isolated from students and staff for safety.
- The BESS equipment must be protected from vehicle damage and fenced to prevent unauthorized access.

The only two non-academic buildings were the central plant (Building 1100) and the M&O complex (Buildings 3000 and 3100), as shown on Figure 8. The M&O complex was the preferred selection as it was separated from the main campus with minimal student traffic and the building electrical load of about 120 kW matched the BESS capacity of 200 kW.

**Figure 8: Las Positas College Campus Microgrid Locations**

**Upper highlighted area is the Maintenance and Operations complex and lower highlighted area is the central plant area.**

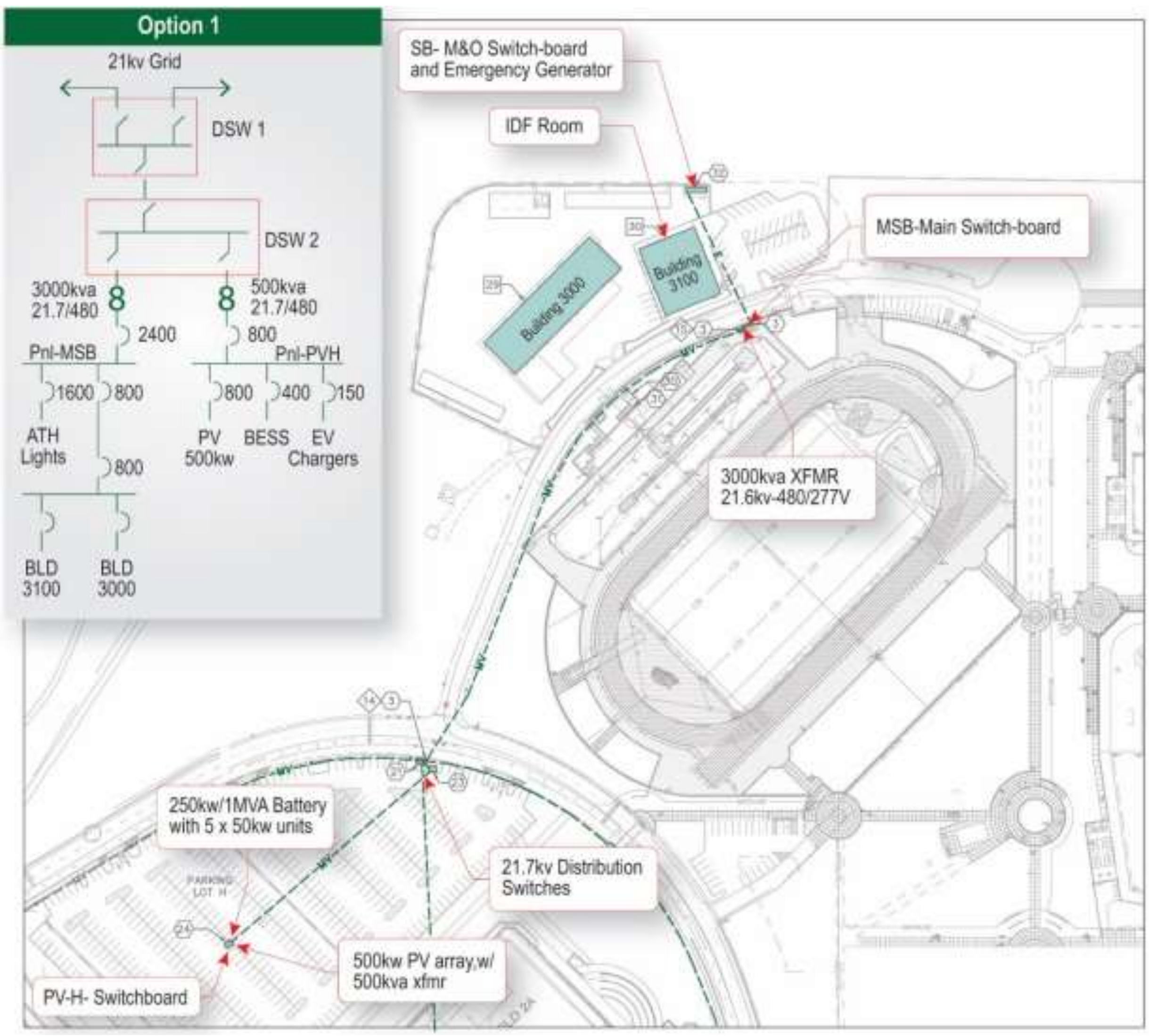
Source: Google Earth and WSP

Once the M&O complex was selected, the 500 kW PV array in Lot H was the only option to supply PV energy to the microgrid. There were existing switches to isolate the PV from the grid and connect to the M&O complex.

From the evaluations, the team developed three options to connect the battery systems into the grid, described in Figure 9, Figure 10, and Figure 11.

- Option 1: Install the BESS adjacent to the Lot H PV inverter and connect to the Lot H switchboard PV-H
- Option 2: Install adjacent to the M&O Complex electrical distribution equipment and connect to the M&O SB switchboard
- Option 3: Install near the upper campus electrical distribution equipment and connect to the MSB switchboard.

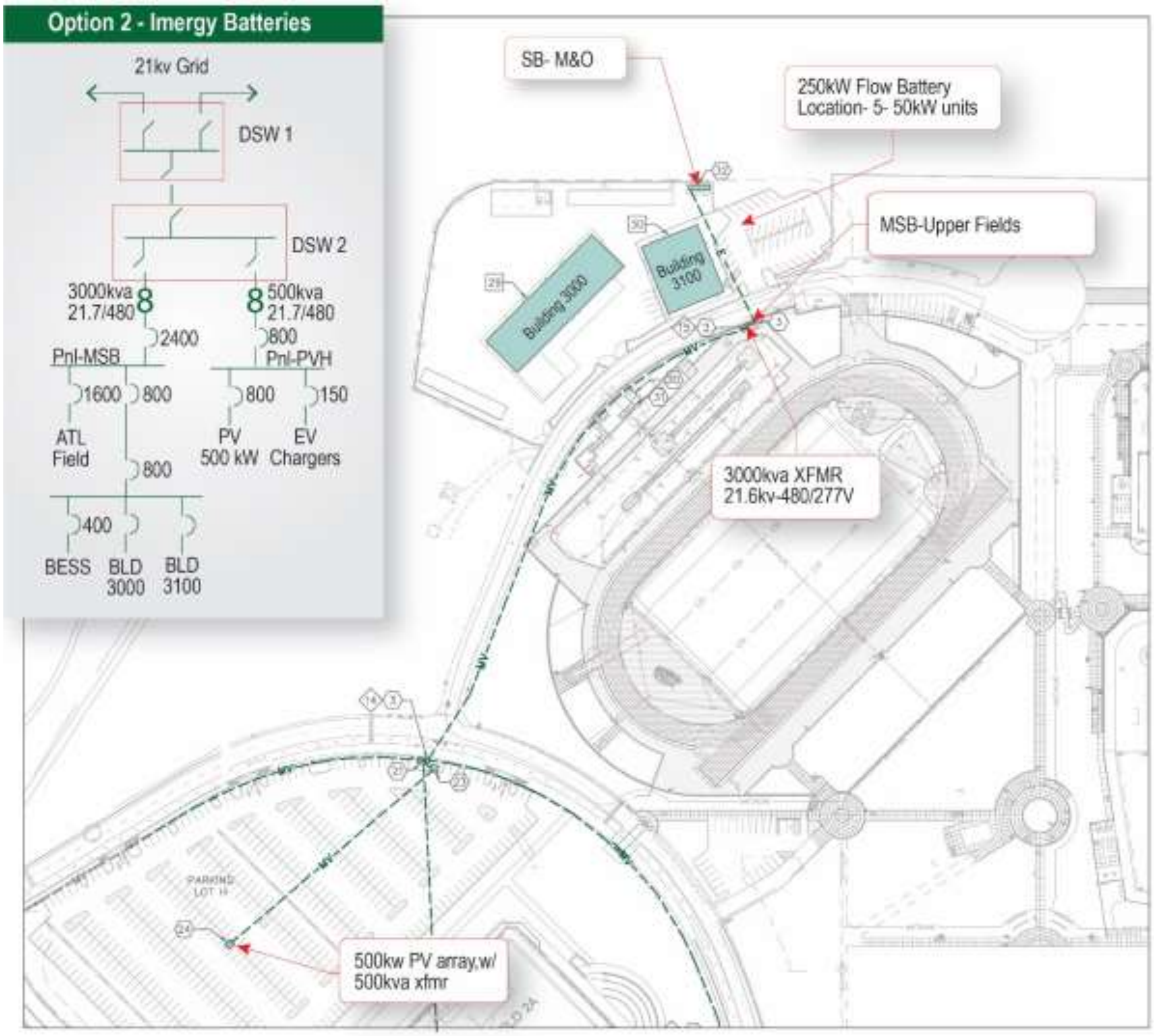
**Figure 9: Option 1- Connection at the Lot H Photovoltaic Inverter**




Source: WSP

Option 1 provided direct connection with the PV inverter, but was separated from the M&O by two 21.7 kV to 480 V transformers. However, the college quickly removed Option 1 from consideration because of the loss of 12 parking spaces, the effect of construction on adjacent parking spaces, and the proximity to students and vehicles.

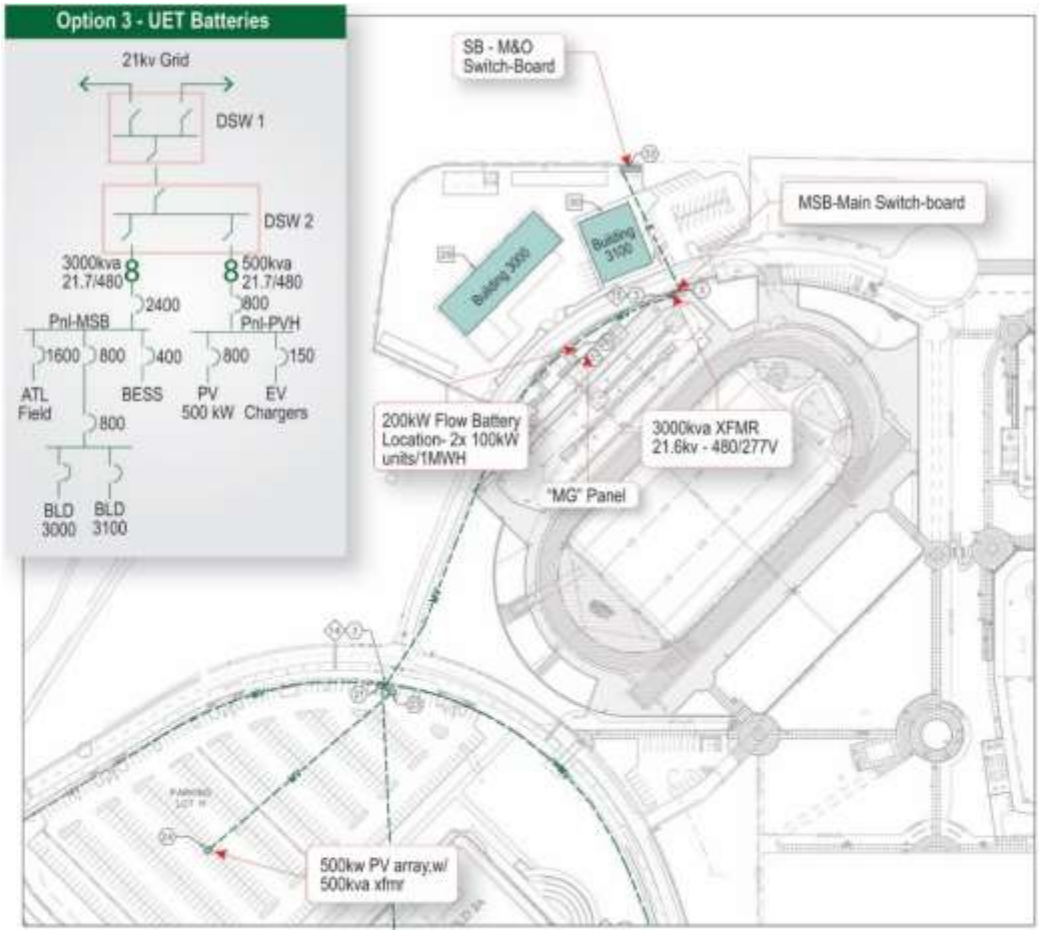
**Figure 10: Option 2 – Connection at Maintenance and Operations Complex**




Source: WSP

Option 2 provided a direct connection with the M&O complex, but the PV was separated by two 21.7 kV to 480 V transformers. There was adequate space adjacent to the M&O electrical distribution equipment for the five Imergy batteries. The site work would be more extensive than Option 1 and Option 3 due an undeveloped area with poor soils. The BESS equipment would be isolated from student traffic, but exposed to vehicle traffic in the parking lot. Option 2 was selected for the installation of the Imergy system.

**Figure 11: Option 3 – Connection at Upper Campus Switchgear**




Source: WSP

Option 3 provided close connection to the M&O complex, but still separated from the PV by two 21.7 kV to 480 V transformers. By connecting at the MSB switchboard, the BESS system could be used as emergency power for the adjacent athletic field lights supplied from the MSB switchboard. The site had been developed so that civil construction would be less costly than Option 2 but more than Option 1. The site was isolated from student traffic, but exposed to some roadway traffic. Option 3 was initially rejected due to battery placement limitations. However, with the replacement of the five Imergy units with two UET units, Option 3 was the final selected site.

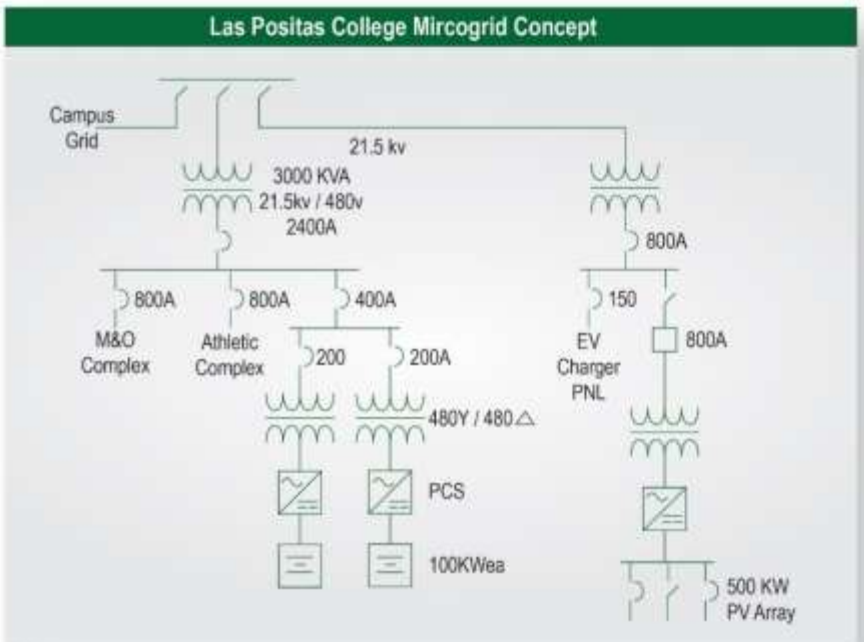
## Civil Design

The civil design consisted of some storm water relocations, and the addition of an equipment pad and fencing around the battery equipment. An existing storm water area drain was relocated to accommodate the new pad. The site was regraded to allow any runoff from the battery pad to be retained and filtered before entering the storm water system. Ninyo & Moore provided a geotechnical evaluation of the soils condition and recommended over-excavation of expansive material and backfill with select material. The pad was designed as a 6-inch-thick reinforced slab on grade concrete pad.

## Electrical Design

Figure 12 displays the single line electrical system. A new 400A breaker in the MSB switchboard provided the connection for the BESS. The new 400A switchboard SB-A located on the battery pad contained a 400A main breaker and 2-200A breakers for the battery feeders. A 400A visible-blade fused bolt switch was installed in the circuit to meet PG&E requirements.

**Figure 12: Battery Energy Storage System Electrical Single Line**




Source: WSP

The connection of the BESS at the MSB allowed islanding the BESS and M&O complex from the campus grid through the control of the 2400A main circuit breaker rather than a new separate transfer switch. In addition, by connecting at the MSB panel, the batteries could provide emergency power to the athletic field lights supplied from the MSB panel.

The 2400A Eaton main breaker was modified by adding a motorized spring charger, remote open and close coils, and breaker open and close position switches. A two-position switch was added to the islanding control circuit to allow manual or automatic control of the 2400A breaker by microgrid control system. In addition to the breaker modifications, a Schweitzer Engineering Laboratories (Schweitzer) SEL-351 programmable control relay was added to the MSB panel. The SEL-351 provided the following functions:

- Monitoring of the line side of the 2400A breaker at the MSB to signal when the campus grid was within voltage or frequency specifications.
- Monitoring of the load side of the 2400A breaker at the MSB to signal when the MSB bus was within voltage or frequency specifications.

- Monitoring of the breaker open/closed position switches.
- Programmable timing to reconnect the BESS to the campus grid.
- Interface with the microgrid controllers.
- Metering power and energy data to the microgrid controls.

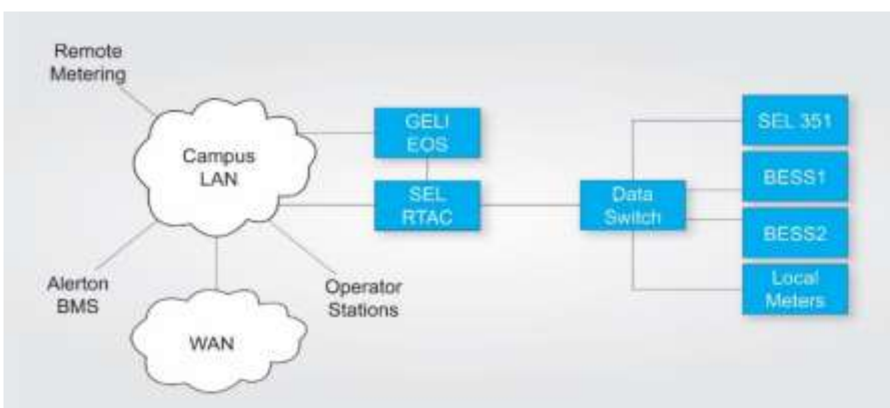
## Data and Communications

The campus IT department was closely involved with the design of the BESS communications network. The college required the BESS equipment to reside on a local network isolated from the campus network to maintain the security and performance of the campus network. The IT group established a virtual private network (VPN) to the microgrid controllers for external internet communications.

In the initial project design, the GELI server and program was the master site controller and provided multiple applications to manage the BESS system. When GELI opted to focus only on demand charge management, the district added a Schweitzer Engineering Laboratories Axion Real-Time Automation Controller (RTAC) as the master site controller and to manage the microgrid islanding operation.

Both the Schweitzer and GELI servers were delivered with two network interface card (NIC) ports, one for the local battery network and one to the campus network. This second port allowed the servers access to the Alerton EMS and other campus metering data points, and a means to establish a secure VPN to home offices for control and monitoring. They established secure internet communication protocol to allow transmission of battery information and signals from the on-site controllers to home office servers. Figure 13 illustrates the communications architecture.

**Figure 13: Microgrid Master Control Communications Architecture**




Source: WSP

The local GELI server and the Schweitzer Axion servers were installed in the building distribution frame room in the M&O office building (Building 3100) and connected to the BESS through parallel fiber optic cables. The field devices were interconnected through switches installed in each of the inverter units. Uninterruptible power supply (UPS) units were installed in the building distribution frame room for the GELI server and Schweitzer Axion (120 V AC) and the Schweitzer 351 relay (48 V DC).

## Microgrid Controls

The initial microgrid control was based on a GELI energy operating system (EOS) that provided master control of the BESS and incorporated demand charge management (DCM), demand response coordination, islanding, and coordination of the use of the thermal storage system. As the project developed, GELI reduced its scope to just the DCM application and coordination of demand response signals. The other planned functions were distributed to other firms. Schweitzer was contracted to provide master control of the BESS and islanding, and Syserco updated the thermal storage control logic to improve the use of the thermal storage.

The development of the islanding sequence of operations evaluated the complexity and cost investment against the need and probability of automated islanding. Since the Las Positas College campus had few PG&E service disruptions, and the M&O complex had an emergency generator for important loads, the district decided that the islanding control systems could be simplified and use manual control actions rather than completely automatic operations.

The sequence of operation was based on the following considerations:

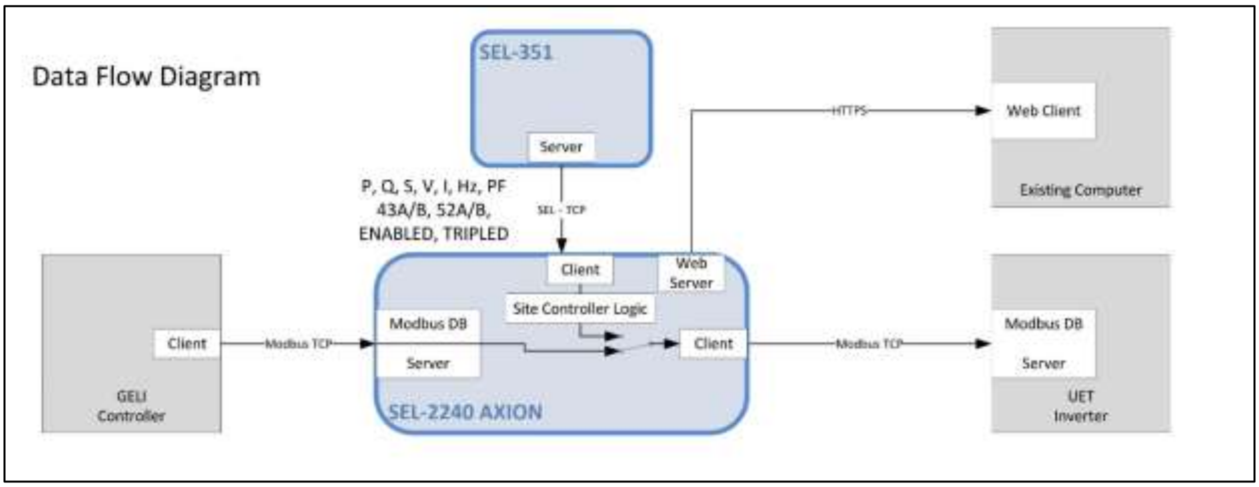
- Provide local control to switch between manual and automatic operation to prevent islanding during short-term utility outages.
- Accept a time gap during transition to and from islanding; and synchronization was not required.
- Integrate the PV system into the islanded microgrid as a second phase.

Each year, the college typically only experienced one or two grid outages that exceeded a few minutes and power was quickly restored by the utility switching equipment. The district did not want to transfer into islanding during these short outages. Therefore, the microgrid control system included a selector switch at the MSB switchboard to select manual or automatic islanding and a 30-second delay was included in the automatic sequence to allow utility system resets.

Since the M&O complex has an emergency generator, the district accepts that the M&O complex will de-energize during the transition. The transfer to and from islanding is designed like an emergency generator operation rather than as an uninterruptable power supply operation. This simplifies the control logic and islanding control devices and reduced project cost and complexity. While UET has testing data that indicates transfer to microgrid forming can occur within two cycles, the physical transfer of the 2400A breaker is longer and somewhat variable. The signal used to microgrid form is triggered by confirmation that the 2400A breaker in the MSB has opened, rather than immediately upon loss of grid power. Similarly, after a five-minute confirmation of resumption of stable grid power, the BESS is stopped and the transfer of the 2400A breaker in the MSB is not initiated until the SEL-351 relay senses less than 10 V on the load side of the breaker. Only after receiving confirmation of the breaker closure is the BESS signaled to grid-following mode.

The division of control responsibilities between GELI and SEL Schweitzer Engineering Laboratories requires Schweitzer, as the master microgrid controller, to manage multiple control signals from multiple vendor applications to ensure the BESS received signals from one application at a time. The UET system was designed to accept only one control signal source at a time, and the UET system also requires continuous communication with the controller or it will shut down within 1–2 seconds. Schweitzer's solution (Figure 14) was to create a new interface that mimicked the UET control interface and routed the GELI communication to that interface rather than directly to the UET. When the SEL-351 relay senses grid power failure, the control commands from GELI are blocked and replaced by the SEL program commands. When grid power returns and SEL has commanded the BESS to grid following mode, the SEL switches back to GELI control. Throughout the SEL control period, the UET status information continues to flow to GELI and is recorded in its data logging program.

**Figure 14: Schweitzer Control Data Flow**




Source: SEL Schweitzer Engineering Laboratories

## Microgrid Islanding Operational Considerations

The EPC inverter is a new design developed for the flow battery market to accommodate the lower input voltage of the original Imergy and later UET batteries. As shown in Figure 15, EPC added a DC-to-DC converter to expand the input voltage range and boost the flow battery output voltage of 150-250VDC to 750VDC needed for the EPC DC to AC inverter output of 480 V AC.

With the addition of the DC to DC converter and due to firmware capabilities at the time of product certification (July 2017), the BESS inverter did not include the ability for the units to parallel in grid-forming mode. The current EPC flow battery inverter with paralleling capability is currently undergoing UL testing and certification. When the BESS is signaled to grid form from a loss of grid power, Schweitzer's Axion unit signals one inverter to microgrid-forming mode, allows a delay for the microgrid to stabilize, then signals the second inverter to connect in grid-following mode. The Schweitzer Axion then sends load information to the second unit to allow the BESS units to balance the load. Both units are then shut off with the return of grid power and signaled to connect in grid-following mode.

**Figure 15: Photo of Internal EPC Power Corporation Inverter Cabinet**


Source: WSP

## Integration of Photovoltaics in Islanded Mode

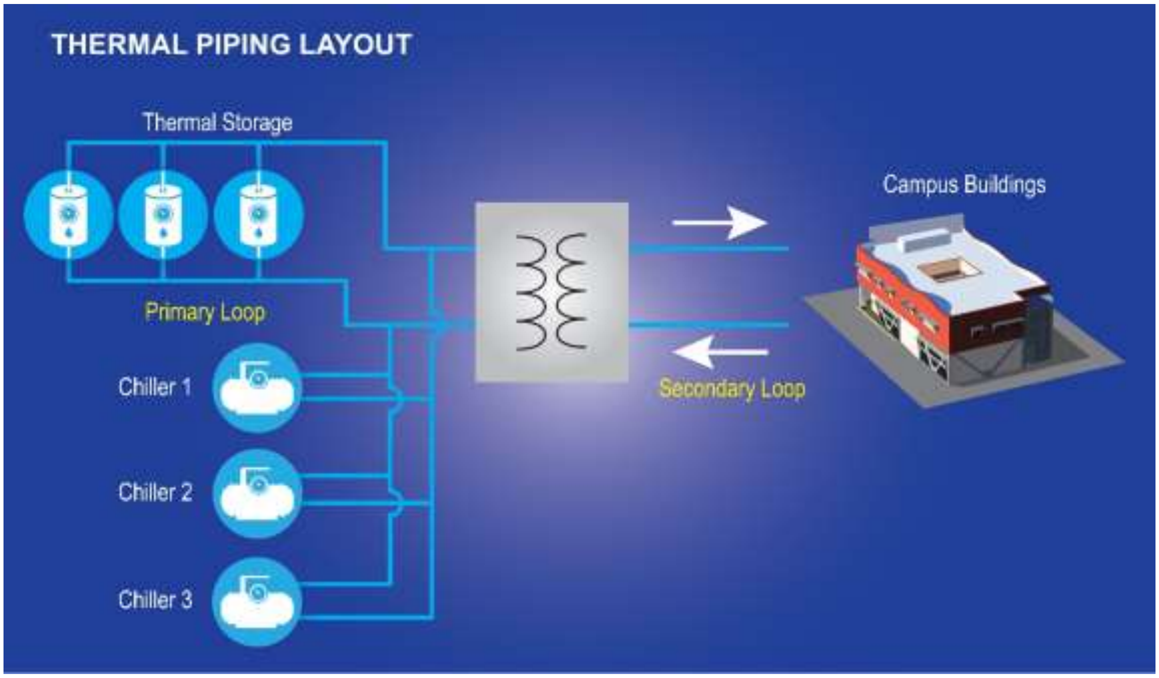
Due to delays in battery operation, the project did not pursue connecting the 500 kW PV array in the islanded microgrid. There are a few issues that need to be resolved to integrate the PV:

- Determine the right PV output to avoid overpowering and destabilizing the BESS microgrid. Estimates ranged from 25–50 percent of the BESS total power capacity.
- Develop a means to the control the 10-year-old Satcon PV inverters to respond to remote commands to adjust their output.
- Develop a strategy for the BESS to energize the 3,000-kilovolt-ampere (kVA) and 500 kVA 480 V to 21.7 kV transformers between the BESS and the PV array, avoiding inrush currents which will destabilize the BESS grid.

## Thermal Storage Controls

The chiller and thermal storage system are designed to provide cooling either independently or jointly. Figure 16 shows a simplified diagram of the central plant chilled water generation and storage system.

**Figure 16: System Diagram**




Source: WSP

When the thermal storage system was installed, the emphasis was to move chiller operation from peak daylight hours to evening hours for reduced energy rates. With the addition of the large solar PV system at Las Positas, the college is exporting energy most days between 7 a.m. and 6 p.m.. In addition, as the campus has increased in size, the peak energy use now is between 7 p.m. and 9 p.m., when the chillers are programmed to operate.

The project concept of operations was to start the chillers in the morning, make ice, and then switch to using ice for cooling later in the day,. This uses the excess solar energy during the day and reduces the 7:00–9 p.m. chiller equipment energy load. There were two considerations to the simplified plan:

- First, review of the operating loads of the chilled water system showed cooling energy peaked from 6 a.m. to 7 a.m. as the buildings were cooled down to prepare for classes. The cooling energy peaks were up to two times the capacity of the chillers. The cooling peak load was met by rapidly increasing the flow through the ice storage units.
- Second, the stored thermal energy should match the anticipated cooling load from the change over from chiller to ice storage until the classroom buildings closed at 10 p.m..

To address the cooling peaks upon morning building cool-down, the college used two approaches. The standard approach was to start the rooftop air handlers earlier in the morning to use the cooler early morning air to cool the building over a longer period. If the overnight temperatures remained high, the college started the thermal storage system for 30 minutes to provide initial cool-down, then switched to chiller operation.

To address the variability in cooling load and ice cooling capacity, GELI was expected to develop an application that would consider thermal storage capacity, projected outdoor maximum temperature, day of week, and historical cooling energy use on similar conditions. The GELI program would send a signal to the cooling system controller to establish the time of changeover from the chiller to ice cooling. The chilled water system is programmed to maintain temperature in the campus buildings, so if the ice cooling energy is not sufficient, the chillers will start and pick up the load.

Unfortunately, GELI was not able to provide the measured control program for the chiller/ice switchover. The chilled water control system was reprogrammed to accomplish most of the objective. Since there is significantly less need for cooling in the winter months, a summer/winter selector switch was installed to allow ice operation start-up and operation throughout the day. Typically, the chillers would not be needed at any time during the school day. During the summer months, the selector switch started the chillers in the morning and provided more hours of outside air cooling. The switch-over time was an adjustable variable that could be modified by the college staff considering the same variables that GELI would evaluate. The initial setting was 11:30 a.m. for the changeover.

# CHAPTER 3: Equipment

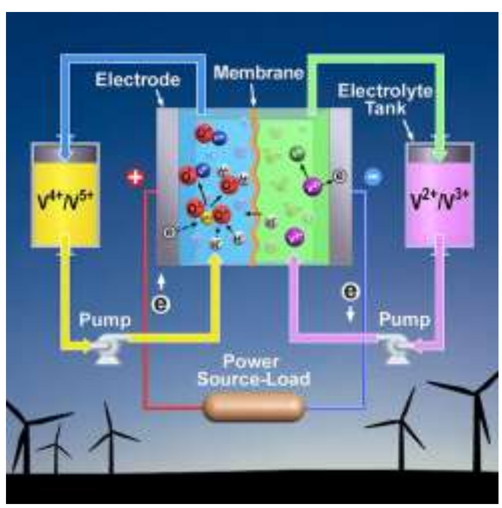
## Equipment Selection

The key element of the Las Positas College Microgrid is the BESS that combines the battery and inverter systems. The Energy Commission grant application was submitted in November 2014, with a vanadium redox flow battery (VRFB) used as the BESS equipment as provided by Imergy Energy Systems. At that time, the Imergy equipment was included in another Energy Commission EPIC grant to demonstrate performance on a small-scale project at the Port Hueneme Naval Base. There was a presumption that lessons learned from that project would shorten the development time for the Las Positas College Microgrid project.

When the Chabot-Las Positas Community College District submitted the Energy Commission grant application in 2014, VRFB units showed the promise for providing reduced-cost long-term storage, lower life-cycle costs, and increased safe operating conditions compared to similarly sized lithium ion solutions. Imergy was one of three flow battery vendors that had licensed the vanadium chemistry from research performed by Pacific Northwest National Laboratory (PNNL). Imergy's Energy Storage Platform 30 kW/120 kWh (ESP-30) had improved the PNNL formulation to increase energy density and Imergy had developed a refining process to use recycled vanadium, both innovations to reduce the cost of large-scale VRFB equipment.

Figure 17 illustrates the chemistry and construction of the VRFB flow battery. One of the important benefits of a flow battery is the separation of power (kW) capabilities from energy storage (kWh) capability. The power rating is defined by the size of the power module(s) combining electrodes and membranes with the capacity of the electrolyte pumps. The energy storage is established by the volume of the electrolyte tanks.

**Figure 17:Vanadium Redox Flow Battery**




Source: UET -Technology http://www.uetechnologies.com/technology

The proposed Imergy system consisted of five ESP-30 units designated to deliver 250 kW and 1 MWh. The ESP-30 was a scaled-up product based on Imergy's then-current 5 kW/25 kWh units. However, the firm was unable to complete the development of the ESP-30 to support the Las Positas College Microgrid project and the district subsequently contracted with UET for similar VRFB units.

# Project Development

The following timeline describes the activities relating to the BESS equipment over a three-year period to obtain an operating flow battery system. This is a cautionary story about including new technology and start-up companies in key elements of any project. It is essential to allow plenty of time for companies to get their technologies to perform and to mitigate any problems that may occur.

**June – December 2015**

During this period, the Las Positas College Microgrid project team was developing the project framework, including defining project goals, exploring design options, developing the concept of operations, and issuing the basis of design. Concurrently, Imergy was working to resolve operational issues with the ESP-30 units installed at the Port Hueneme Naval Base site. A major issue was the performance of the inverter units and communication with the South Africa manufacturer. Due to these issues, Imergy was exploring new inverter manufacturers for the Las Positas equipment. Imergy selected a 17 kW/70 kWh unit manufactured by Trumpf-Huttingen based in Huttingen, Germany. This solution required three of the Trumpf units per ESP-30 unit, or 15 for the system. The complexity of the control strategy caused concern among the project team. Imergy was forced to continue the search for an inverter vendor when Trumpf-Huttingen would not commit to obtaining UL 1741 certification as required by the utility interconnection agreement.

While Imergy was evaluating replacement inverter vendors, the microgrid control development was on hold, along with the electrical design. During this period, the district and Imergy were negotiating the terms of the equipment purchase order. Two key negotiation points were system performance and payments. The district wanted assurance that the Imergy units would perform to an agreed-upon standard and would not make partial payments prior to delivery and installation. The district and Imergy agreed that Imergy would submit general performance standards with detailed testing results to be submitted as the project developed and the district agreed to make partial payments to an escrow account to be released upon delivery and testing of the units.

**January – July 2016**

Imergy finally selected inverters supplied by EPC, based in San Diego, EPC would adapt its MG-LC 12/6-5 inverter for flow battery service, adding a DC/DC converter to boost the flow battery output voltage to the nominal DC input range MG-LC 12/6-5. The EPC MG LC 12/6-5 was completing the UL certification process and awaiting final certification documentation. However, the combination DC/DC converter and MG-LC12/6-5 unit, as a new product, would have to obtain UL certification to be accepted by PG&E for interconnection. The selection of the EPC unit also required Imergy and GELI to develop new drivers and control systems. With the inverter selected, preliminary design restarted.

The district required defined performance standards backed with test results prior to the first partial payment to escrow. Imergy delayed providing adequate documentation and the district delayed the payment. Unfortunately, on July 18, 2016, Imergy entered an Assignment for the Benefit of Creditors, a form of insolvency under California law.

**August – December 2016**

In consultation with the project team and the Energy Commission project manager, Jamie Patterson, the district decided to replace Imergy with another flow battery vendor to retain the opportunity to test the flow battery technology. The project team investigated eight flow battery manufacturers with various technologies, including:

- UniEnergy Technologies (UET) – VRFB
- Primus – Iron chromium redox flow battery
- Vionx – VRFB
- EOS – Zinc hybrid cathode battery
- RedFlow – Zinc bromine flow battery
- ViZn – Zinc iron flow battery
- Aquion – Saltwater electrolyte
- Gildermeister (now CellCube) – VRFB

After evaluation, the district requested proposals from UET, Primus, and Vionx for equipment that would provide at least 200 kW of power and 1 megawatt hour (MWh) of energy. A key requirement was that the vendors would use the EPC inverters, which were being developed for flow batteries, were in the UL testing phase, and for which the project team had invested engineering time to develop the software controls.

The district received proposals from UET and Primus. Vionx declined, stating it could not meet the specifications as its units' capacities were too large. The district selected UET based on the considerations shown in Table 1.

UET had also licensed advanced vanadium flow battery technology from PNNL. Starting in 2012, UET commercialized that technology into grid-scale containerized flow battery products, with 60 MWh of systems deployed, contracted, and awarded in three countries and six U.S. states. UET's technology promised no degradation of power or energy, unrestricted cycles, and 20+-year life.

The district and UET negotiated the terms of the purchase contract. UET requested an initial payment and progress payments through manufacturing, as had Imergy. UET agreed to establish an escrow account and the district agreed to the payment timing with the provision that the funds would not be released until delivery and initial operation. UET provided technical performance standards with test results.

**Table 1: Replacement Battery Evaluation Factors**

| Consideration Factor | UET | Primus |
|---|---|---|
| Technology/Chemistry | VRFB developed technology based on PNNL research | Zinc Bromide newer chemistry |
| Unit Sizing | 100 kW/500 kWH -two units required | 25 kW/12 kWH require more units, larger footprint, more units to control |
| Product Development | 60 MWH deployed, 6-year business history, major investors | New product, Beta Version available for this project |
| Pricing | $680,000 for two units | $1,000,000+ |

Source: WSP

UET offered options for the purchase of one or two of the 100 kW/500 kW ReFlex units. The proposal for two units providing 200 kW of power and 1 MWh of energy storage was 30 percent more than the project budget and Energy Commission funding from the Imergy pricing. The district issued a purchase agreement for one UET ReFlex unit to allow the project to proceed. After some evaluation, the district decided to commit to the capacity defined in the Energy Commission grant and increased its financial contribution by $150,000.

**January – October 2017**

UET initially estimated a mid-April 2017 delivery date for the single unit. When the second unit was added, the delivery date was moved to mid-June 2017. These dates were based on delivery of the inverter units from EPC. EPC would not release the units until the final UL inspection, acceptance of the completed unit, and receipt of formal documentation of UL acceptance. If the units were shipped prior to formal documentation, UL would need to retest the units at the project site. Consequently, the inverter units were not ready for shipment until late June 2017.

Since this project was the first between UET and EPC, the two entities had to coordinate their communication protocols and data registers. Once they had completed the coordination effort, GELI developed new drivers to communicate with the UET equipment and EPC inverters. Figure 18 shows the test set-up in the UET factory combining the UET battery unit and the EPC inverter.

Since UET had not used EPC inverters previously, the EPC equipment was shipped to the UET factory and connected for testing. In addition to the UET/EPC testing, GELI could test its programming at UET with the combined UET/EPC assembly. When the UET and EPC units were connected, UET and EPC still had to resolve communication and operational issues. The UET testing and coordination with the EPC equipment occurred from mid-July to mid-October. The GELI testing and coordination with the UET/EPC equipment was performed over a two-week period until November 5, when the units were disassembled and shipped to the project site.

**Figure 18: Initial Testing in UniEnergy Technologies Factory**


**Test bed set up in UET factory during initial testing of combined EPC inverter and UET Batteries, July 2017.**

Source: WSP

### November 2017 – January 2018

The UET and EPC equipment was delivered to Las Positas College on November 11, 2017. The units were set on the equipment pad on November 13 and 14 by the electrical contractor, PDE, along with the electrical switchgear. Figure 19 shows the installation of the UET units.

**Figure 19: Setting UniEnergy Technologies Battery Units**


Source: WSP

After UET's thorough inspection of the units after placement on the equipment pad and anchorage, UET placed the electrolyte in both units. The electrolyte installation occurred between November 29 and December 2. The electrolyte was delivered in totes, with 30 totes needed for each battery unit. UET established containment areas for the tote handling and empty tote staging areas. Figure 20 shows the electrolyte filling operation. The totes were moved from the staging area to the filling station and then to the empty staging area with a 5-ton rated forklift. The empty totes were reloaded on the delivery trailers and shipped back to the UET factory on December 3, 2017.

**Figure 20: Electrolyte Filling Operation**

Source: WSP

After the filling operation was completed and the piping system inspected, PDE was approved to complete the electrical work. Figure 21 shows the electrical work connecting the battery, inverter and electrical equipment.

**Figure 21: Electrical Installation**

Source: WSP

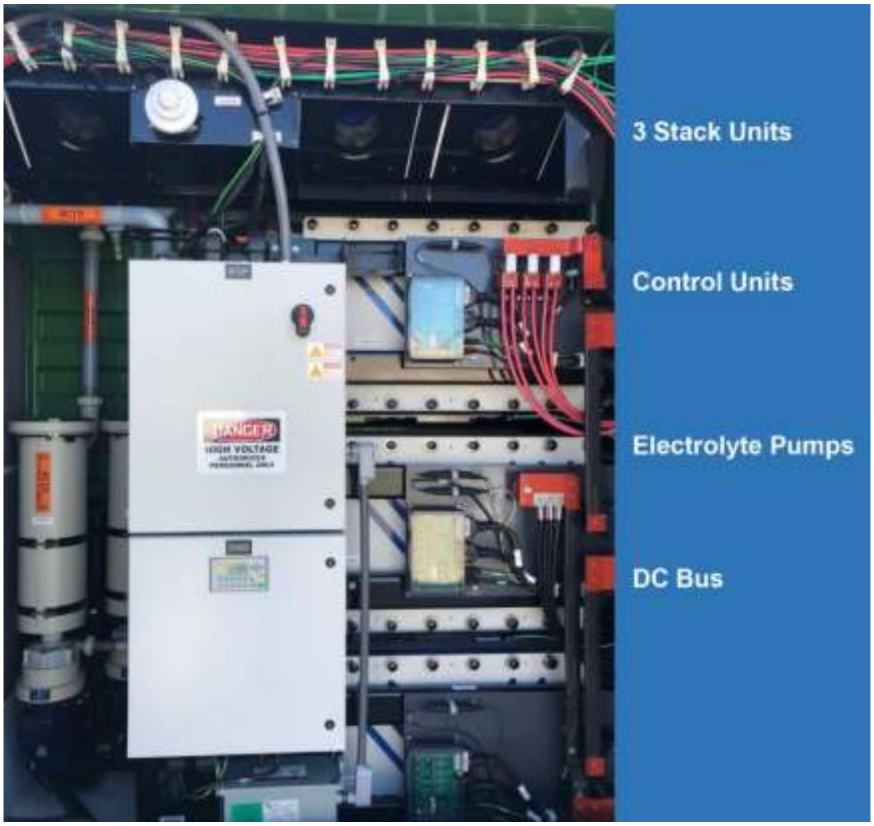
PDE installed conduit and wiring between the battery units and inverter units and connected the inverters to the pad-mounted switchgear. The pad-mounted switchgear was connected to the MSB switchboard. Data and control wiring was installed and connected. The electrical work was complete and tested by the end of January 2018.

As the electrical work was proceeding, WSP continued to communicate with the PG&E interconnection department to allow energization of the system to begin testing and commissioning. After many conversations and the involvement of the district's PG&E account manager, the interconnection department allowed energization for testing on January 18, 2018. The batteries were first energized the week of February 2, 2018.

### February – November 2018

The UET testing and commissioning process occurred from February 10 through the end of March 2018 and is described in Chapter 6. When the UET testing concluded, GELI began testing the performance of the system in response to the GELI controls. As the testing neared completion, UET's liquid sensors indicated a leak of electrolyte in both battery units and the systems were shut down. When UET opened the battery units, it was clear that at least three of the combined six stacks had leaked small amounts of electrolyte. Figure 24 shows the interior of the UET units. Each unit has three stacks on the right side of the container, containing alternate layers of electrodes and membrane.

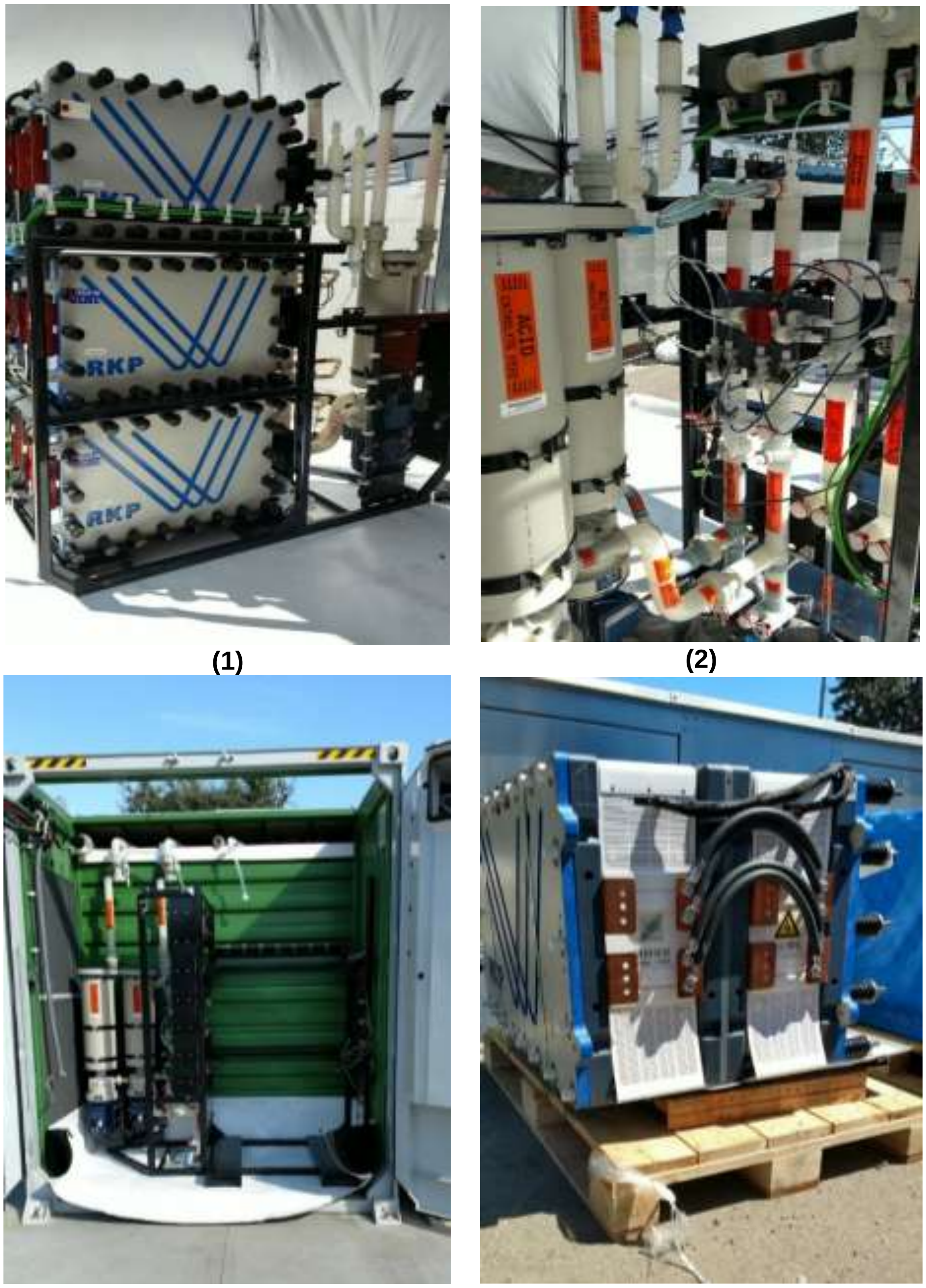
**Figure 22: Interior of  UniEnergy Technologies Unit**




Source: WSP

The battery units were shut down and UET ordered six new stack units to replace all the stacks in the two batteries. The replacement units were delivered on July 6. Figure 23 shows the progression of the stack replacement. UET completely disassembled the stack assembly, cleaned the framework and installed the new stacks over two weeks.

**Figure 23: Progression of Stack Replacement**




**(1)** **(2)**

**(4)** **(3)**

**Clockwise from top left: 1) Stack assembly frame removed; 2) Stack assembly, piping and electrolyte pumps; 3) Stack assembly frame; and 4) New stack assembly.**

Source: WSP

UET retested and commissioned both battery systems and readied them for service. After UET certified the batteries were fully operational, GELI finished its final communication tests and energized its DCM application. The DCM program operated successfully for the month of August until UET's monitoring system indicated excessive electrolyte filter debris and cross-contamination of the anolyte and catholyte liquids. This indicated a leakage across or around the electrolyte membrane(s) in at least three of the six stacks.

UET studied its monitoring data and determined that three of the stacks were performing and three stacks indicated problems. In mid-October, UET removed the three questionable stack units and placed the three functioning stack units in one battery to allow continued testing of the GELI application. The single unit was placed in service on November 1, 2018.

**November 2018 – March 2019**

The situation with only one of the two batteries operational exposed a gap in the GELI program. GELI had to modify its application to function with only one of the two units operational. Once that change was complete, GELI restarted its DCM application in mid-November. However, during the months of December and January, GELI discovered multiple programming issues with the DCM application resulting in limited performance data. The DCM application was finally restarted on February 3, 2019.

Between March 18–22, UET installed three new stack units in Unit 2 and completed testing on March 30.

# CHAPTER 4: Construction and Commissioning

This chapter provides an overview of the construction process and the major elements of the installation.

## Organization

The construction organization was led by PDE, the design/build contactor for the project. The firm subcontracted design work, civil work, and data work and self-performed the electrical work. PDE's subcontractors included:

- Gausman and Moore: Electrical engineering
- Bushra Tsai Engineering: Structural engineering
- SimonGlover Design: Architectural design
- Magnum Construction: Site and civil work, including trenching, storm water systems, and concrete slab on grade for the battery equipment
- CalCoast: Data cabling and termination
- King Crane: Crane service and rigging
- Power Systems: Switchgear testing and calibration
- Tyco Electrical: Medium-voltage switchgear work
- Chain Link Fencing: Perimeter fencing around the battery equipment
- One Line Systems: Electrical equipment
- Schweitzer Engineering Laboratories: Electronic relay equipment

## Project Schedule

The project schedule was driven by the battery delivery. The initial schedule anticipated battery system delivery in May 2016. The financial failure of Imergy caused a 14-month delay at the beginning of the project. The procurement and longer-than-promised battery delivery by UET resulted in battery delivery in November 2018.

The construction was performed in two phases with a three-month gap awaiting delivery of the batteries. The first phase included installing underground conduit runs, the concrete pad for the battery and electrical components, and miscellaneous site work. This work occurred between June and October 2017. The second phase was installing the equipment, and connecting power, control and data cabling between December 2017 and February 2018 as shown in Figure 24.

**Figure 24: Electrical Systems Installation**

Source: WSP:

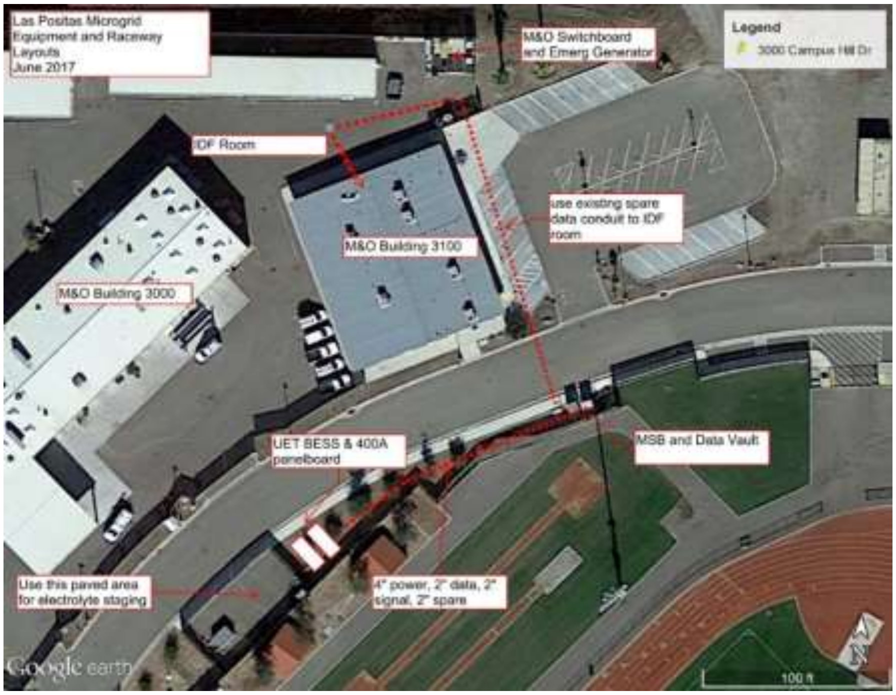
## Permitting and Inspection

Construction work on community college campuses and all kindergarten through 12th grade facilities is under the jurisdiction of the California Division of the State Architect (DSA). The district employed a DSA-certified inspector, ABC Inspection Services, to oversee the installation along with state-approved geotechnical engineers, Ninyo and Moore, for geotechnical investigation and inspection. The project was also subject to review by the local fire marshal and technical review and testing by PG&E.

## Construction Planning

The vendor change from Imergy to UET meant a change in physical equipment from five 20-foot shipping containers to two 20-foot shipping containers. The reduced footprint of the UET equipment allowed placement of the BESS system closer to the MSB switchboard and data raceway. The selected site was located approximately 300 feet from the point of connection to the campus electrical system, as illustrated in Figure 25.

**Figure 25: Battery System Conduit and Equipment Layout**




**Site plan showing proposed equipment locations, conduit routing and building information.**

Source: WSP

A 30-foot x 30-foot 6-inch reinforced concrete pad (shown in Figure 26) was constructed for the battery and associated electrical components. The site for pad was over-excavated and 18 inches of select backfill was placed and compacted to mitigate the expansive clay soils at the site.

**Figure 26: Battery Energy Storage System Equipment Pad**

Source: WSP

Power, control and data conduits were extended from the point of power connection and the adjacent data vault to the battery pad. Figure 27 shows the completed equipment installation. Perimeter fencing was installed after completion of all battery improvements and upgrades.

**Figure 27: Completed Equipment Installation**


Source: WSP

## Testing and Commissioning

The testing program for the project included the civil works as well as electrical and electronic systems. The civil work included soils and concrete tasks. The district hired Ninyo & Moore to provide foundation recommendations for the structural slab to support the batteries and electrical equipment. Ninyo & Moore tested the subgrade for compaction to meet design requirements. The firm also collected concrete samples and confirmed the 28-day break strength. All the civil work was inspected by a state-licensed inspector.

The electrical wiring and equipment was inspected and tested by Power Systems. A megger test to check insulation conformance was performed on the power wiring. The new panels were inspected and tested for insulation and assembly. The new breakers were tested and trip rating set.

Schweitzer tested the SEL-351 power relay and confirmed all programming and settings. The relay was energized and the control of the 2400A main breaker in the MSB switchboard was tested and the breaker position contacts were proven to be wired correctly.

UET begin testing after the electrical and electronic testing was completed. The first phase was mechanical testing of all the pumps and electrolyte piping and instrumentation. The next phase was testing of all sensing and safety devices. The control PLC logic was confirmed and tested. The next phase was conditioning the electrolyte.

The functional tests and commissioning are detailed in Table 2.

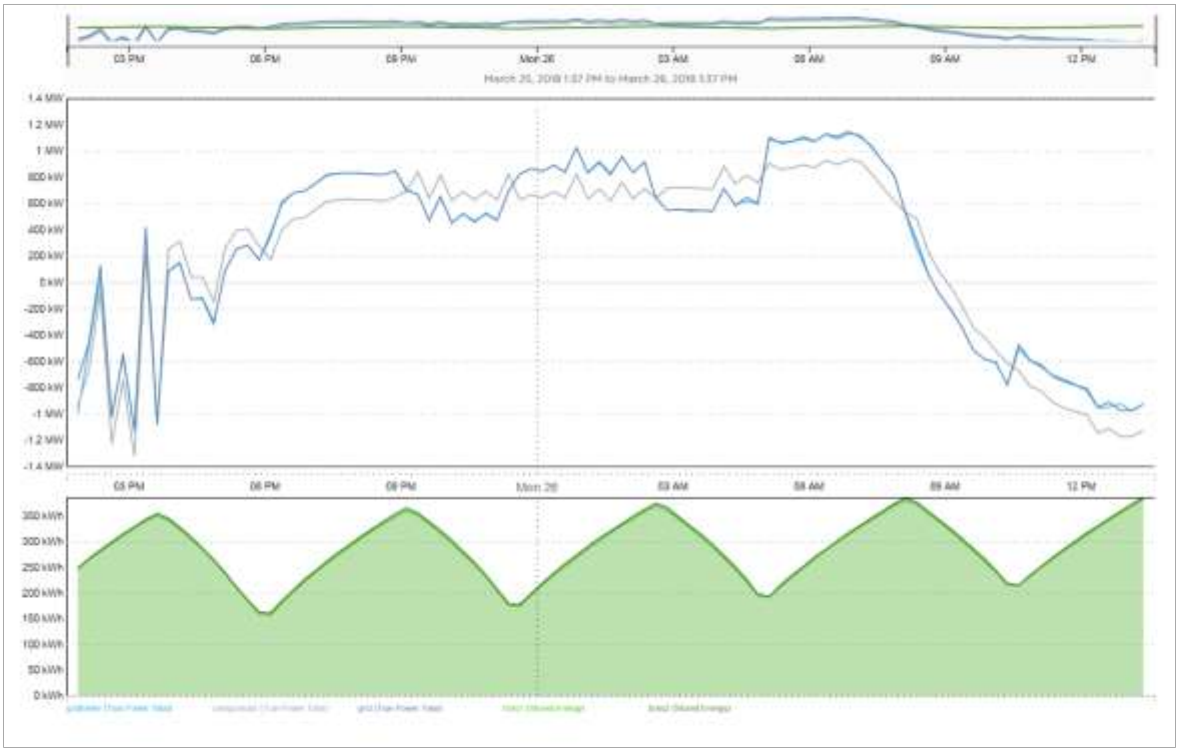
**Table 2: UniEnergy Technologies Testing Plan**

| Task Name | Duration | Start | Finish |
|---|---|---|---|
| **Conditioning** | 3 days | Sun 8 a.m. | Tue 5 p.m. |
| **Pre-Commissioning Service** | 1 day | Wed 8 a.m. | Wed 5 p.m. |
| **Filter Change / Service** | 1 day | Wed 8 a.m. | Wed 5 p.m. |
| **Performance Validation / "Show"** | 1.03 days | Thu 8 a.m. | Fri 8:15 a.m. |
| Control limit verification | 10 mins | Thu 8 a.m. | Thu 8:10 a.m. |
| Confirmation of emergency signals | 20 mins | Thu 8:10 a.m. | Thu 8:30 a.m. |
| Section 6.4 - Response time | 15 mins | Thu 8:30 a.m. | Thu 8:45 a.m. |
| Section 6.5 - Ramp rate test | 15 mins | Thu 8:45 a.m. | Thu 9 a.m. |
| Section 6.6.4 - Startup current test | 15 mins | Thu 9 a.m. | Thu 9:15 a.m. |
| Black start demonstration | 30 mins | Thu 9:15 a.m. | Thu 9:45 a.m. |
| Grid forming demonstration | 2 hrs. | Thu 9:45 a.m. | Thu 11:45 a.m. |
| Section 6.7 - Reconnection after abnormal condition (loss of utility power) | 20 mins | Thu 11:45 a.m. | Thu 1:05 p.m. |
| Peak power demonstration | 15 mins | Fri 8 a.m. | Fri 8:15 a.m. |
| **Remote Validation** | 8.02 days | Fri 8 a.m. | Tue 8:10 a.m. |
| Stand-by personnel | 2.25 days | Fri 8 a.m. | Mon 10 a.m. |
| Section 6.3.2 - Conversion Efficiency Test of ESS - (May required additional test equipment) | 20 mins | Fri 8:15 a.m. | Fri 8:35 a.m. |
| Max energy demonstration | 48 hrs. | Fri 8:35 a.m. | Fri 8:35 a.m. |
| Rated power demonstration | 33 hrs. | Fri 8:35 a.m. | Sat 5:36 p.m. |
| Section 6.2 - SOC test cycles | 50 hrs. | Sat 5:36 p.m. | Mon 7:38 p.m. |
| End test/reset | 10 mins | Tue 8 a.m. | Tue 8:10 A.M. |

Source: WSP

In Figure 28 below, the final state of charge test results indicated all systems functioning correctly. The blue line is the PG&E main meter and the grey line is the campus load.

**Figure 28: State of Charge Test Cycles Graph**




Source: GELI

## Interconnection Agreement

The interconnection agreement process took much longer than anticipated due to multiple factors, including:

- Equipment vendor changes, most significantly the replacement of Imergy with UET battery systems.
- Changes to the PG&E interconnection documentation process from paper filings to electronic
- Significant workloads in the PG&E Distribution group resulting in delays between submission and response.
- Communication by email between PG&E and the district’s project managers rather than meetings between technical and engineering staff of the two groups
- The unusual configuration of the Las Positas College campus grid with 2.3MW of solar PV, the Net Energy Metering Multiple Tariff (NEMMT), and the potential for the new battery system to switch to islanding mode.

The initial request for interconnection was submitted in November 2015. Before detailed reviews could be completed, Imergy changed inverter vendors, and, subsequently, went into bankruptcy. An updated request for interconnection was submitted in November 2016 with UET as the battery vendor. The submittal passed the initial technical review and the district executed the Interconnection Agreement in February 2017. For the next 10 months, emails passed between the PG&E and WSP project managers requesting information or documents and responding with answers. Finally, in December 2017, PG&E agreed that all engineering and design issues were resolved. In January 2018, PG&E allowed the project permission to connect for testing purposes. For the next six months, the district revised testing documentation and pre-paralleling inspection forms to address PG&E comments. In June 2018, PG&E notified the district that this type of installation did not require pre-paralleling inspection since it was not directly connected to the PG&E grid, but still required inspection for safety reasons. The pre-paralleling inspection was performed in early July, and after adjustments, the system passed. After more conversations explaining the roles of the electronic control relay and the inverter flow through timing and safety settings, the interconnection permit was issued by PG&E on August 15, 2018.

# CHAPTER 5: Achievement of Goals and Objectives

This chapter discusses the degree to which the general Las Positas College Microgrid goals for the project were achieved through the direct project activities. Because the project testing was restricted due to limited BESS availability, achievement of goals and objectives by project members concurrent with the project time frame are included in this discussion.

- Goal: Collect, evaluate, and publish performance data from an operating institutional-sized smart microgrid combining high-density renewable energy assets, multiple energy storage mediums, and islanding with modeling of automated demand response and other energy services to the grid.

  Achieved: The project successfully demonstrated the insertion of a BESS and a microgrid into an existing campus grid. The grant project was the impetus for the college to develop "smart grid" elements in the campus grid though data and control integration from multiple energy control systems. These actions have improved energy use efficiency and reduced energy costs. Studies by Olivine evaluated opportunities to participate in services to the grid.

- Goal: Develop and publish a microgrid blueprint that can be used by educational institutions statewide to evaluate, plan, and install a smart microgrid that will manage and coordinate the output of their existing renewable energy assets using energy storage systems, with the ability to provide benefits to the local grid though automating demand response and other energy services.

  Achieved: Throughout the project, team members actively presented project details and results to the primary target constituency; educational intuitions. Presentations to the facilities directors of the K-12, community college, and university systems illustrated the means to add storage to a college campus grid and discussed lessons learned. The GELI ESYST website (https://esyst.geli.net) provided the wider public with information on system selection and cost to assist with planning for new solar and storage applications.

- Goal: Demonstrate the benefits to customers, utility companies, and California independent system operators of an "Internet of Energy" concept using IEEE/ANSI-standards-based EOS and standardized energy management applications to control and coordinate local energy assets and enable coordination with utility programs and controls.

  Achieved: The development of the project design demonstrated that the "Internet of Energy" with "plug-and-play" interoperability has not yet arrived. Connecting the equipment controls and sensors required development of specialized applications and interface programs.

# CHAPTER 6: System Observations

This chapter presents system observations of the major equipment and systems of the Las Positas College Microgrid project. The equipment and systems were tested and operated in phases over the project duration. The major equipment and systems are:

- BESS, including the batteries and inverters performance, efficiency, and response time.
- Islanding system, including transfer timing, sequence of operations, and load characteristics during transfers.
- DCM, including peak demand reductions, BESS state of charge, and timing.
- Thermal storage system, including time of operation, energy use shift, and operational performance.

The project baseline data consists of four years of 15-minute power and energy data from the campus main PG&E meter. The data is logged in the PG&E InterAct site. The project collected data from existing metering at solar PV systems, and the central plant. New metering was installed at key points in the new microgrid. Table 3 lists the data collection points, equipment, type and data log locations.

**Table 3: Data Collection Points and Types**

| Sensor Point | Equipment | Data Type | Log Location |
|---|---|---|---|
| Incoming Campus Main Service | PG&E Revenue meter | KYX Pulse, 15-minute kW and kWh | PG&E InterAct site |
| Incoming Campus Main Service | Nexus 1262 | Modbus/IT, kW, kWh, 1 minute | GELI |
| 500 kW PV Arrays | Revenue Grade meters | Modbus, kW, kWh, kVAR 15-minute | PG&E InterAct site, Avonics data monitoring |
| 1.3MW PV Array | Revenue Grade meter | Modbus, KW, kWh, 15-minute | Avanoic data |
| | Sensors | Isolation, Wind Speed, Temperature | Avanoic data |
| Central Plant- Switchgear | Shark 250 | BACNET MS/TP, kW, kWh, 5-minute | Alerton Compass EMS |
| Central Plant- Chiller | Trane | BACNET MS/TP, run time, | Alerton Compass EMS |
| Central Plant- Thermal Storage | Various | BACNET MS/TP, BTU flow, operation state, 5-minute | Alerton Compass EMS |
| Central Plant- Chilled Water | Various | BACNET MS/TP, BTU flow, 5-minute | Alerton Compass EMS |

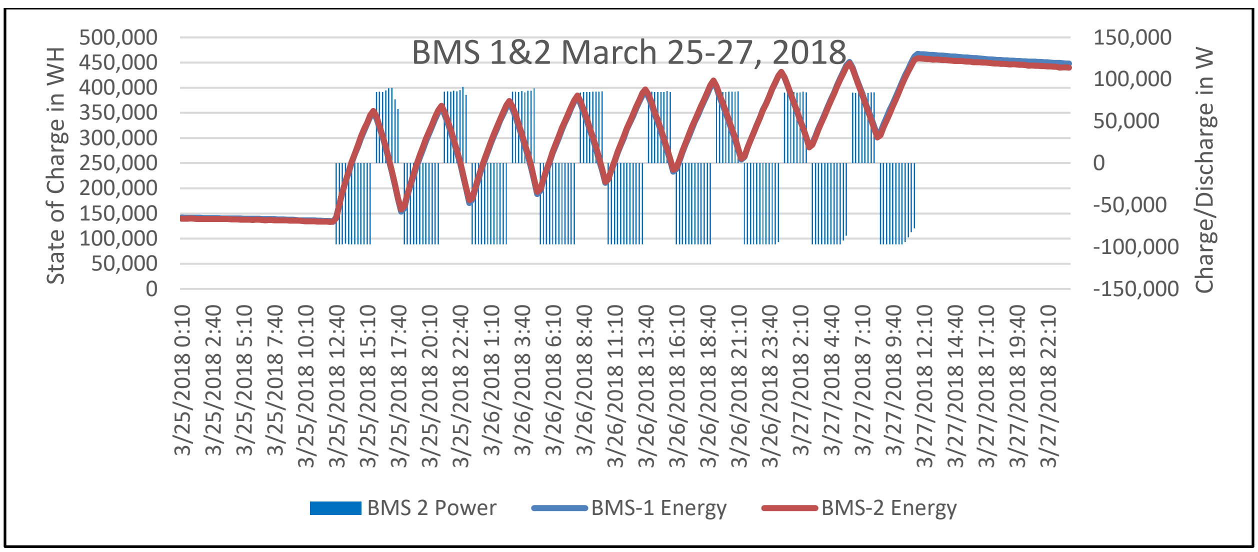
| Sensor Point | Equipment | Data Type | Log Location |
|---|---|---|---|
| MSB | SEL-351 | MODBUS/IT, event timing, device status | Schweitzer RTAC |
| | SEL-351 | MODBUS/IT, voltage, frequency, Kw, | Schweitzer RTAC |
| UET Battery | UET | MODBUS/IT, DC voltage, frequency, State of Charge, register status | UET Pi data |
| EPC Inverters | EPC | MODBUS/IT, AC & DC Voltage, Current, kW | UET Pi data, GELI |
| 400 A Switchboard | Shark 250 | MODBUS/IT AC voltage, current, kW, kWh | GELI |

Source: WSP

# Battery Systems

As part of the commissioning process during March 2018, UET cycled the BESS units over two days, charging and discharging Unit 1and Unit 2 in approximately five-hour cycles. Figure 29 displays the state of charge (SOC) in watt/hours and charge/discharge power in watts.

**Figure 29: Charge/Discharge Cycle Testing – March 2019**




Source: WSP

Since the cycle was timed charge/discharge rather than return to the initial SOC, each charge cycle increased the SOC by approximately 20 kW. Appendix A contains the calculated round trip efficiency for the eight cycles including an adjustment for the increase in SOC for each cycle. The average of the eight cycles is listed in Table 4.

**Table 4: Round Trip Efficiency Testing March 25-26, 2018**

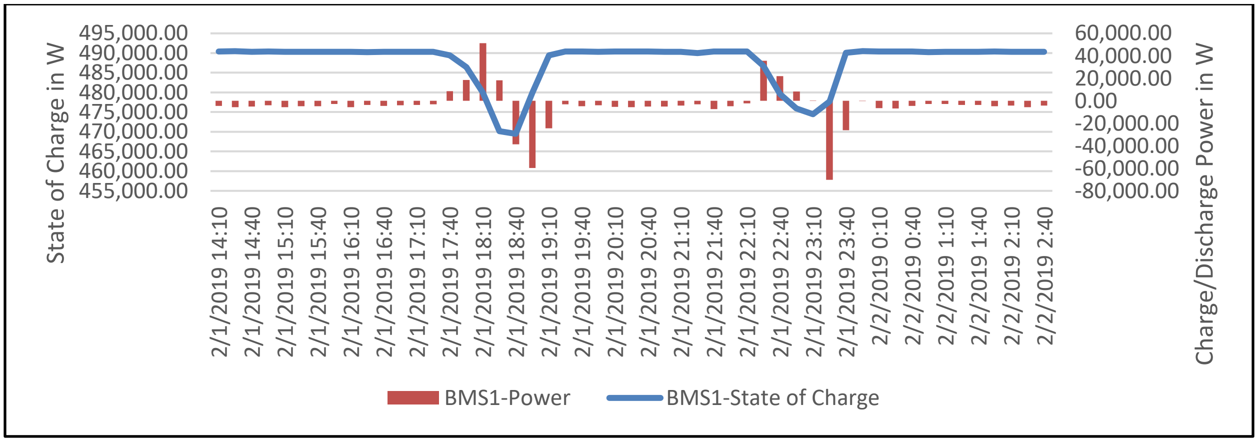
| Description | BESS Unit 1 | BESS Unit 2 |
|---|---|---|
| Charge (watts) | (1,161,575) | (1,157,574) |
| Discharge (watts) | 678,330 | 692,504 |
| SOC Change (watts) | 85,925 | 83,650 |
| Average Efficiency | 65.8% | 67.1% |

Source: WSP

The average efficiencies compared favorably with the performance of similar UET units documented from extensive testing by Schweitzer and UET as reported by Sandia Laboratories report entitled “Sandia Third-Party Witness Test of UniEnergy Technologies 1 MW/ 3.2MWH Uni.System” published June 2015.

Figure 30 and Figure 31 display the characteristics of the UET Unit 1 during operation by GELI’s DCM application in February 2019. These snapshots cover a 12- to 14-hour time period with multiple charge/discharge cycles to implement peak reduction strategies. The round trip efficiency calculated during the DCM operation listed in Table 5 and Table 6 compare to the testing results shown in Table 4 above. As indicated in the tables, the overall efficiency of the unit significantly decreases when the energy to maintain ready state is included.

**Figure 30: Demand Charge Management Operation – February 1-2, 2019**



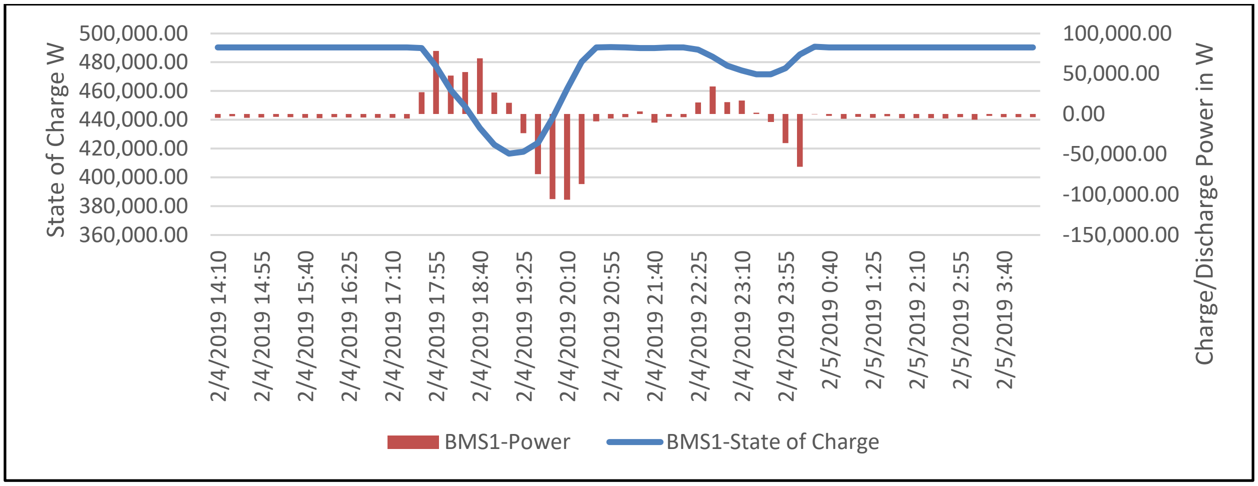

Source: WSP

**Table 5: Round Trip Efficiency Demand Charge Management Operation – February 1-2, 2019**

| | Charge | Discharge | % |
|---|---|---|---|
| Cycle 1 | (149,976.2) | 96,754.6 | 64.5% |
| Cycle 2 | (110,639.1) | 66,451.1 | 60.1% |
| Total Period | (383,761.6) | 163,205.8 | 42.5% |

Source:  WSP

**Figure 31: Demand Charge Management Operation – February 4-5, 2019**




Source: WSP

**Table 6: Round Trip Efficiency – February 4-5, 2019**

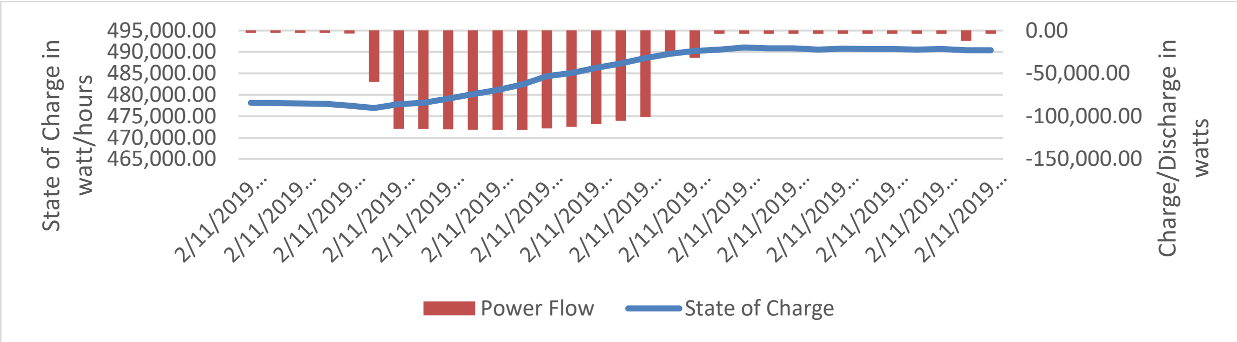
| | Charge | Discharge | Efficiency |
|---|---|---|---|
| Cycle 1 | (426,509) | 315,471 | 74.0% |
| Cycle 2 | (117,586) | 81,894 | 69.6% |
| Total Period | (667,946) | 400,730 | 60.0% |

Source: WSP

Calculating round-trip efficiency between similar SOC values confirms the testing performed in March 2018 as shown in Table 6 and Appendix A. However, as shown in both Figure 31and Figure 32, there is a continuous 4 to 4.5 kW charge required to maintain the SOC and provide near-instantaneous response time. This continuous charge significantly reduces the overall long-term efficiency of the BESS system.

The UET units have three modes; off, standby, and ready. To improve the long-term efficiency, control applications must consider use of the standby and the ready mode. In standby mode, the electrolyte pumps operate at minimum flow through the system sufficient maintain a minimum charge and temperature of the system, but not maintain a set SOC. In ready mode, the flow rate is increased to maintain a set SOC. The continuous power draw is 1.5 kW in standby mode compared to 4.5 kW in ready mode. Transition from standby to ready mode requires one to two seconds, which is acceptable for most applications. In standby mode, the BESS units lose charge at approximately 2 kWh/h as shown in Figure 32. When the SOC falls below an established percentage, the system changes to ready state and restores the SOC to set point.

**Figure 32: UniEnergy Technologies System Ready Mode Example**

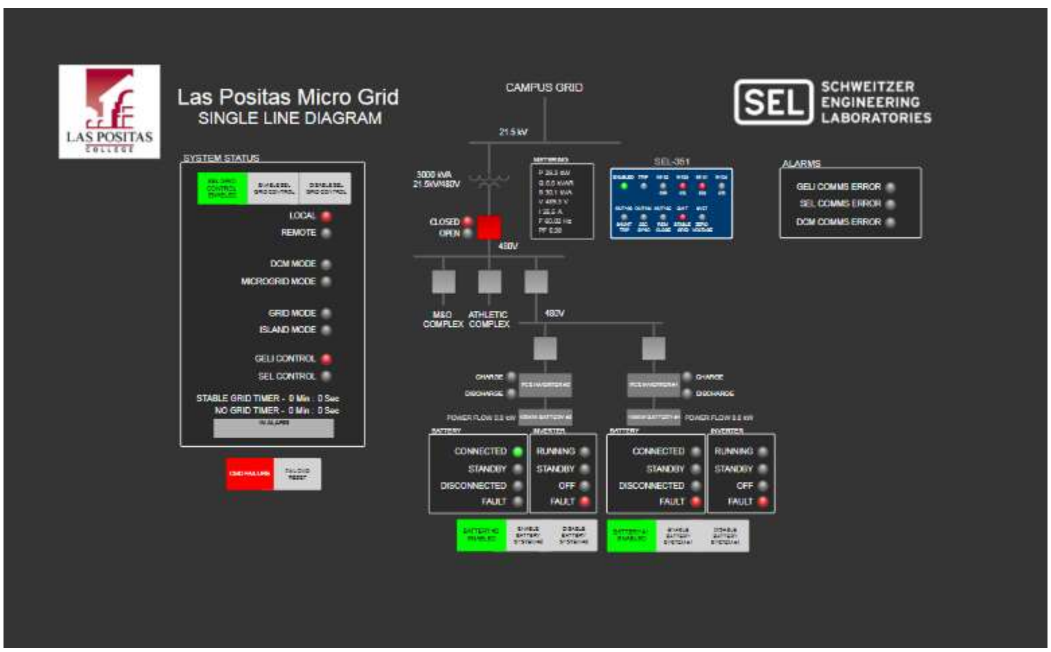



Source: WSP

# Islanding

The islanding function was developed by Schweitzer using the Schweitzer RTAC programmable controller. Figure 33 shows the human-machine interface (HMI) for the Schweitzer controls.

**Figure 33: Schweitzer Master Control Human-Machine Interface Screen**




Source: Schweitzer Engineering Laboratory

Both the UET battery and the EPC inverter units required internal programming changes to allow islanding mode. The UET system was adjusted to allow “Black Start” operation, where the electrolyte pumps and controls operate from the stored battery charge rather than wait for grid power. The EPC system was adjusted to reduce the reconnect timer from 300 seconds to zero.

With the control changes to allow islanding, the BESS systems required external signals to disconnect, reset faults and connect to a grid. Also, since the EPC systems operated independently, the Schweitzer controller had to start each system and set the discharge rate of the second system which was in the grid following mode.

BESS Unit 1 was established as the grid forming unit and BESS Unit 2 as the grid following unit to simplify the control logic. BESS Unit 1 formed a stable grid and adjusted to load changes. BESS Unit 2 was given a connect signal after a 20-second delay to allow grid stabilization. BESS Unit 2 was then commanded to discharge at a rate calculated as 60 percent of the then-current load. The discharge rate was recalculated and adjusted every five minutes.

The mechanical pumping systems inherent in a flow battery make the system unsuitable for a seamless transition to islanding operation. If the UET battery is not in the ready state with the pumps at operating speed, there will be a 20-second to 60-second delay as the pumps reach operating speed.

## Demand Charge Management

The DCM application provides the majority of direct energy cost savings to the district. The research team projected annual savings of more than $100,000 using electrical energy storage (battery) and thermal energy storage (ice plant). The tariff schedule is SE-20P/Net Energy Metering Multiple Tariff (NEMMT). The E-20 rate is based on Las Positas College connection at medium voltage distribution level, (21.7 kV). The NEMMT is determined by the 2.35 MW of solar PV arrays, which exceeds the 1 MW Net Energy Metering (NEM) Rule 21. The output from the first 1 MW of PV equipment is net metered; excess exported energy is not.

The DCM application is designed to predict peak energy use and discharge the energy storage units to replace utility energy draw with release of stored energy. The release of energy from the BESS is instantaneous and can respond to immediate changes in demand. The release of energy from the thermal storage requires pumping equipment changes and must be programmed at least an hour prior to release.

There are three peak demand evaluations during the summer months (April–October) and two demand evaluations during the winter months (November–March). The evaluations during the summer are peak period maximum between noon and 6 p.m.; part peak maximum between 6 p.m. and 9:30 p.m. and between 9 a.m. and noon; and monthly maximum, the maximum any time during the month. Las Positas College's monthly maximums and part peak maximums typically occur between 7:00 p.m.–9:00 p.m. when most of the campus buildings are in use for classes and the solar PV is not contributing energy. The peak period maximum typically occurs between 5:30 p.m. and 6 p.m. as the solar PV contribution is decreasing. Table 7 lists the demand charge rates for each period in cents per kW.

**Table 7: Demand Rates, 2018, E20, Cost per kilowatt**

| Period | Months | Monthly Max | Peak Max | Part Peak Max |
|---|---|---|---|---|
| Summer | April-Oct | $15.09 | $19.29 | $5.13 |
| Winter | Nov-Mar | $15.09 | N/A | $5.13 |

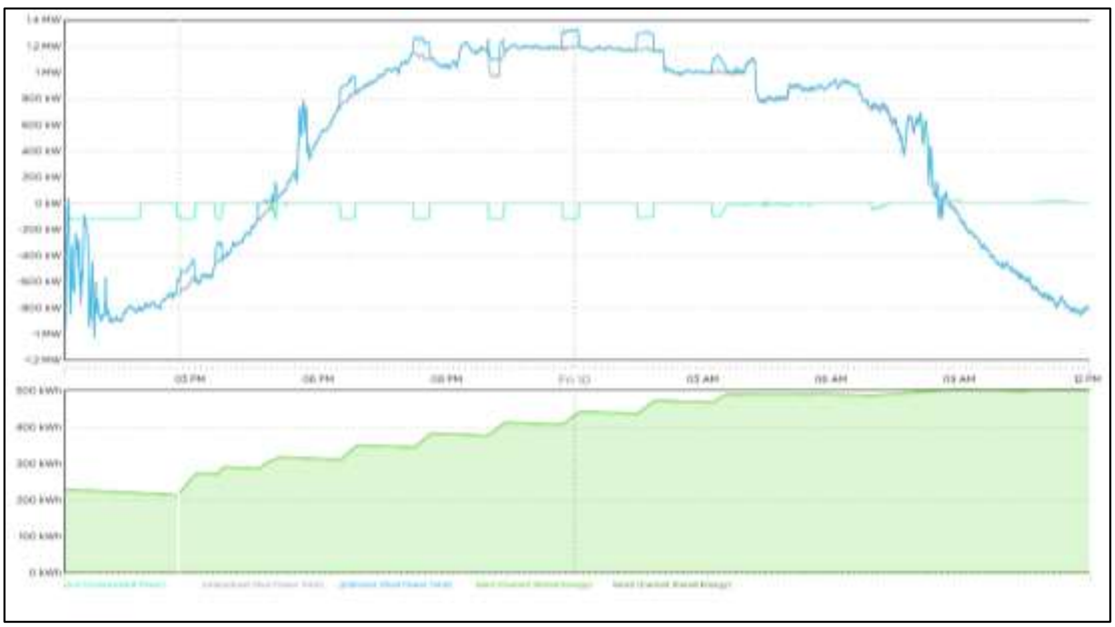
Source: LPC Monthly Billings

WSP estimated DCM cost savings using the actual 2018 15-minute data from the PG&E primary meter at the Las Positas College main switchgear and the billed demand charges. Appendix B provides the information from the PG&E billing, including demand peaks and charges. The project team prepared the simulation using the known maximum in each time-of-use period and simulating a full power battery discharge rate of 180 kW when the demand was within 180 kW of the known maximum for the period. This simplified method could be used prospectively by setting the maximum for each month and period based on the prior year's maximum. The simulation results are presented in Appendix B, and indicate a savings of $61,837 or 13 percent of the 2018 demand charges over 12 months.

The GELI DCM application improves on this simplified method by learning the energy pattern of the college and refining the predicted monthly maximum for the month over multiple years. The GELI application also reduces the amount of energy used for DCM by applying only enough energy reduce the energy to the anticipated peak less the maximum battery power of 180 kW.

Figure 34 shows the GELI DCM application performance during operation in one minute increments. The blue line is the campus load and the gray line is the PG&E supplied power. The light green negative lines show the battery discharge to reduce demand. The dark green shaded area shows the battery State of Charge.

**Figure 34: GELI Demand Charge Management Performance**

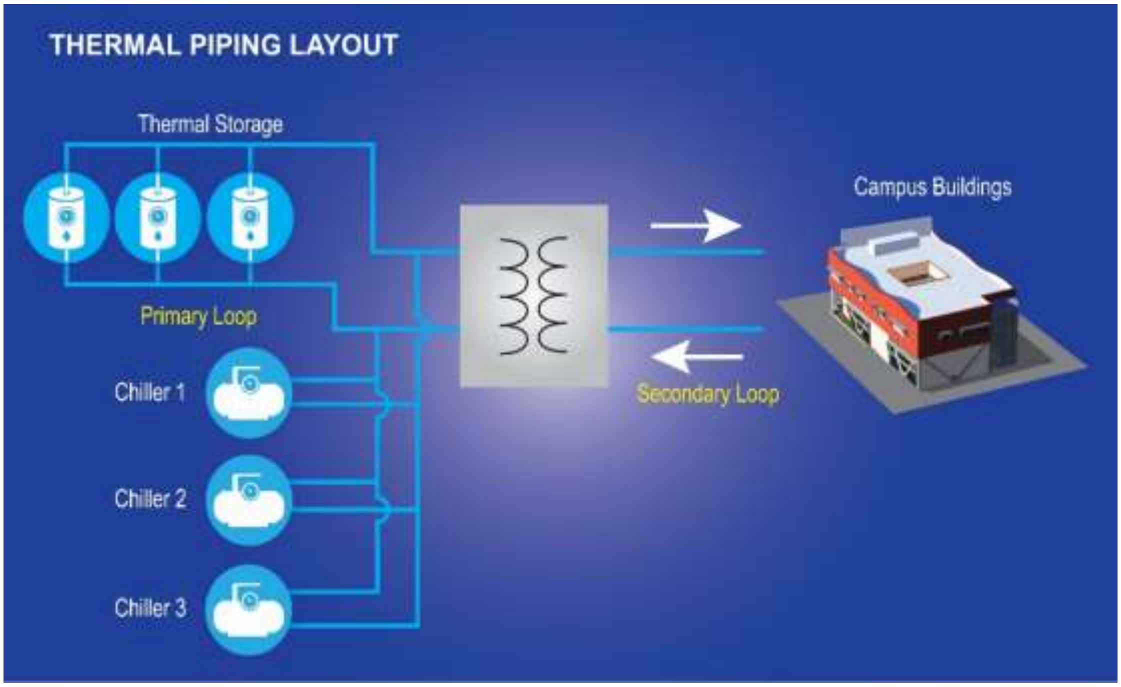


Source: GELI

## Thermal Storage System

The thermal storage system consists of 21 ice storage tanks connected in parallel with two 300-ton electromechanical chillers. The thermal storage-chiller primary loop is connected to the secondary loop that supplies the chilled water to the campus builds though heat exchangers, as shown in Figure 35 below.

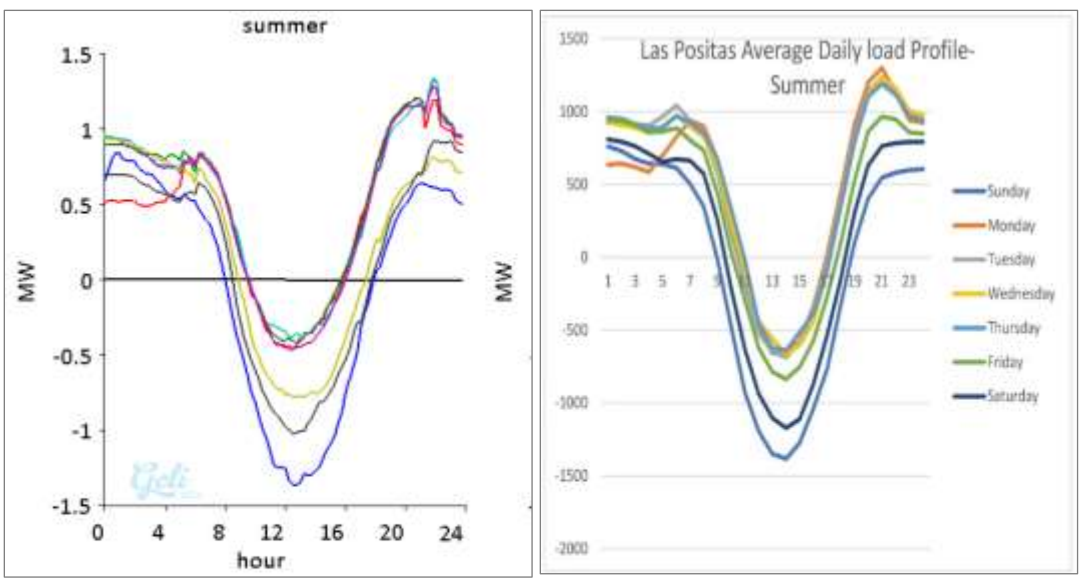
**Figure 35: Las Positas College Simplified Chilled Water System**




Source: WSP

The summer months create the largest cooling load and generate the most energy from the PV arrays. The control logic for the thermal storage-chiller system was modified to start the chillers in the morning rather than start cooling with the thermal storage. Figure 36 shows the impact of starting with thermal storage in the morning.

**Figure 36: Comparison of Summer Load Profiles**




**The graph on the left shows the average load profile from July 2014–June 2015. The graph on the right shows the load profile from July 2017–June 2018.**

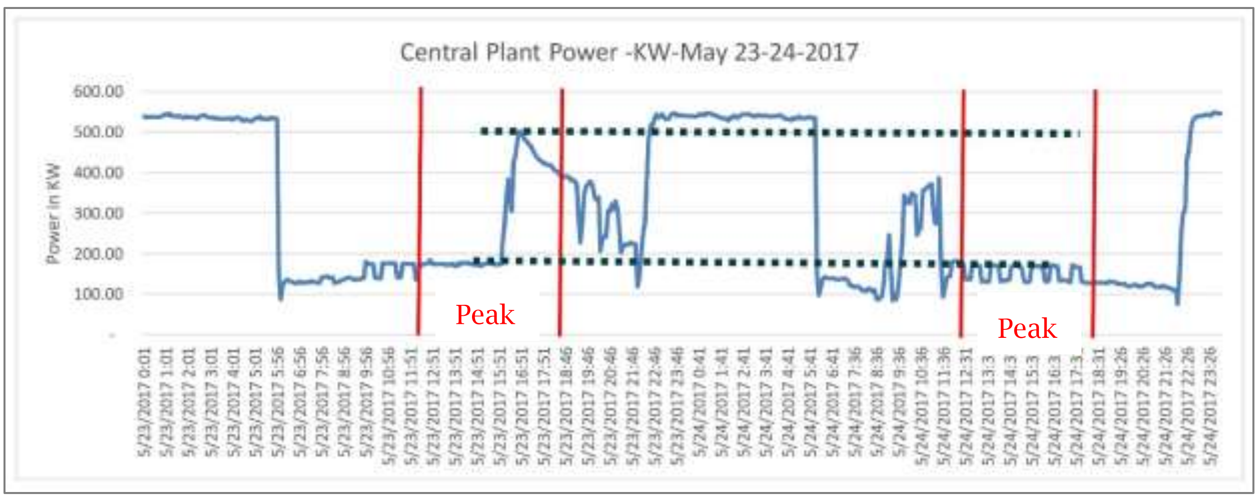
Source: GELI and WSP

In the morning, the time at which power purchases cross into export has moved almost two hours later. This indicates increased energy usage during the morning hours. Similarly, the time when power purchases cross back to positive in the afternoon has shifted later, indicating reduced energy use in the early afternoon.

Figure 37 and Figure 38 show the impact of switching chiller and thermal storage morning cooling. On May 23, 2017, the cooling began using thermal storage, but exhausted the storage supply by 3 p.m. and so the chillers were used to provide cooling. The chillers operated until 9:30 p.m. when both chillers were run at full capacity to recharge the thermal storage. On May 24, 2017, the cooling began using the chillers, and at noon, cooling was switched to using the thermal storage. The resulting impact was a reduction of the peak demand by more than 300 kW during the peak noon to 6 p.m. billing period. The use of the chillers in the morning hours prior to noon also absorbed the excess energy generated from the PV system reducing energy export to the grid.

As shown in Figure 38, the cooling loads for May 23 and 24 were similar and either energy source, thermal storage or chiller, could support the actual secondary loop cooling load.

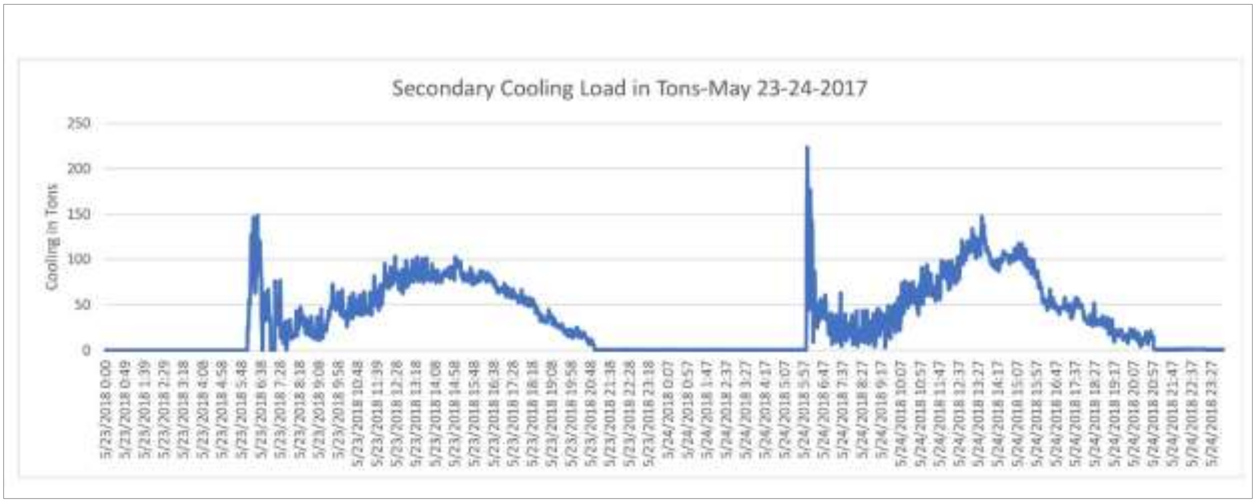
**Figure 37: Las Positas College Central Plant Power - May 23-24, 2017**




**The graph shows the reduction of 300 kW during similar time periods on consecutive days by switching chiller with ice for cooling source in the morning.**

Source: WSP

**Figure 38: Central Plant Secondary Loop Cooling Load in Tons, May 23-24,2017**




Source: WSP

# CHAPTER 7: Energy Market Participation Evaluation

This chapter summarizes studies performed by Olivine to evaluate programs that provide services to the grid and the accompanying incentive payments. Olivine is a registered demand response provider and scheduling coordinator in California and its distributed energy resource (DER) management platform is fully integrated with the California Independent System Operator (California ISO).

Olivine evaluated five types of incentivized grid services:

- DCM – Peak demand reduction using predictive algorithms such as the GELI DCM application at Las Positas College.
- Demand response – Electrical load reduction upon a signal from an outside source based on agreements to provide demand response services
- Resource adequacy (RA) – Agreements to provide an agreed capacity of energy available for demand response services.
- Spinning reserves – agreements to provide an agreed capacity of energy delivered into the grid upon a signal from an outside source.
- Time-of-use (TOU) shifting – The process of shifting when energy is consumed from grid peak periods to off-peak periods. TOU arbitrage is the financial benefit from reducing use or exporting energy at high cost during peak periods and importing a similar amount during off-peak periods at a lower cost.

Olivine analyzed energy data from Las Positas College, including 12 months of 15-minute energy consumption data, Las Positas College's energy profile, characteristics of the BESS, and other load shedding potential. Olivine also evaluated current PG&E E-20 commercial tariffs, changes in TOU periods, and wholesale market prices for demand response and other services.

## Valuation Approach

Modeling for the market participation evaluation used Olivine's Distributed Energy Resource Valuation Model (DER-VM). Olivine developed this model using the DER Valuation Framework developed for the Energy Commission's EPIC grant GFO-15-312 as part of an advanced energy community project in the City of Lancaster, California. The model compares 15-minute load data from the facility with hourly wholesale market prices and utility rate tariffs to model the effects of curtailing or shifting facility load at different times of the day. The model includes a behind-the-meter battery storage model that accounts for charge/discharge efficiency, usable capacity, and battery degradation. The model outputs a number of value streams for the customer including DCM, TOU utility rate price arbitrage, revenues from wholesale market demand response participation, and various other valuation methods for power capacity and other grid services. The model is also capable of determining value from the perspective of the load serving entity (LSE) or customer (Las Positas in this study) and an aggregator, but for this valuation only the customer perspective was considered and 100 percent of all appropriate value was attributed to the customer. All values are indicated at first-year value.

The Las Positas College meter data was run through the model twice. The first run modeled the DCM savings from the primary use of the battery. The analysis determined an independent assessment of the DCM savings described in Chapter 6. This confirmed the functionality of the model in estimating demand savings and was used to develop a post-DCM facility load curve for use in assessing market participation revenues. The second model estimated the revenue potential of wholesale market demand response participation using load data and battery energy and capacity available after DCM.

Key assumptions in the development of the valuation included:

- To provide a more conservative estimate of the remaining battery capacity for demand response, the full 200 kW power rating of the batteries was used for the DCM analysis.
- To provide a more future looking analysis, the most recent PG&E E-20 utility rates were used (effective March 1, 2019). These rates were applied to the new PG&E Commercial TOU periods, which will become effective in November of 2020. These TOU periods shift the peak period from noon-6 p.m. to 4 p.m.-9 p.m. to coincide with the shifting system peak load.
- The modeled battery characteristics for demand response were: 200 kW output power, 1,000 kWh energy capacity, 70-percent round-trip charge/discharge efficiency, 90-percent usable energy capacity, 20-year useful life, and no battery degradation for the flow battery.
- The model analyzed wholesale demand response revenue based on publicly available 2018 wholesale prices from the California ISO OASIS system.
- Both models assumed that the battery would cycle only once per day. In other words, the daily load on the battery could not exceed the maximum usable capacity of 900 kWh. It was assumed that all charging of the battery occurred during solar export hours during the future off-peak TOU period. This creates a conservative estimate as additional value could possibly be created by charging and discharging the battery for more than one cycle per day.

Olivine reviewed information on using the facility ice storage system for added capacity for wholesale market participation. However, it was determined that given the level of available information, the current strategy of using this resource to reduce energy consumption during peak pricing periods would likely remain the best strategy for using this resource. Further analysis on trade-offs between TOU arbitrage value and market participation value could be undertaken, but would require detailed information on the system's run time and power consumption.

# Results

## Demand Charge Management

The analysis of demand charge savings produced a value of $60,694 in DCM savings and a loss of $63 in TOU retail price arbitrage as a result of shifting load from peak periods to off-peak. The DCM savings are slightly different compared to the WSP estimates due to the different TOU rates and some different assumptions, but the values are generally in line with those estimated by WSP. The TOU arbitrage net loss is the total of the arbitrage savings from load shifting minus the increased energy consumption from the 70-percent round-trip BESS efficiency. In all months besides December, a full 200 kW reduction was achieved in maximum demand charges. December was not able to meet this maximum because to do so would exceed the available energy capacity of the battery on that day. Therefore, December was only able to achieve 135 kW peak demand reduction.

The analysis also showed that DCM load was only needed for 131 DCM "events," where an event is a single discharge duration of the battery of at least 15-minutes. These events covered only 132 hours in the year, for an average event duration of about 1 hour. DCM over the year resulted in 7,943 kWh of shifted load, averaging just 60.6 kWh per event. The maximum usable battery capacity of 900 kWh was only completely used for DCM on one occasion in December as described above.

## Demand Response Programs

Demand response programs consist of two elements, payment for energy reduced or delivered and payment to maintain the capacity and capability to actually deliver the energy reduction when signaled per agreement.

Las Positas College can participate in two demand response markets, the California ISO wholesale market or the PG&E Capacity Bidding Program (CPB). Services in the wholesale market are distributed across the state by the California ISO. Services in the PG&E program are first used by PG&E and any excess capacity is sold to the wholesale market. The price paid in the wholesale market is determined by submitted bids to dispatch an agreed amount of power over a specified length of time during a specified time period. The price paid in the PG&E program is established by PG&E as is the duration and time period.

### Wholesale Market

The wholesale market energy delivery was modeled as Las Positas College bidding in the California ISO wholesale market at 2018 prices in the electrical grid sub-market specific to the college. To take advantage of the 4.5-hour capacity of the battery, bidding occurred from 4 p.m. to 9 p.m. to coincide with high market prices. The bidding price was held constant over the year and scenarios were run with bid prices ranging from $50/MWh to $950/MWh to show a range of value options and the trade-offs between the number of dispatches and revenue generation. Table 8 shows the results.

**Table 8: Yearly Dispatches and First-Year Savings from California Independent System Operator Energy Delivery**

| Bid Price ($/MWh) | Yearly Dispatches | Energy Delivery Payments ($) | TOU Arbitrage Net Value ($) | Total ($) |
|---|---|---|---|---|
| $50 | 318 | $13,048 | $174 | $13,222 |
| $75 | 124 | $7,360 | $667 | $8,027 |
| $100 | 48 | $3,970 | $374 | $4,344 |
| $200 | 12 | $2,106 | $218 | $2,324 |
| $950 | 0 | $ - | $ - | $ - |

Source: G&E Market

PG&E Capacity Bidding Program (CBP) participants also get energy delivery revenue when dispatched, but the value of this is likely less than the potential listed in **Error! Reference source not found.** because there will likely be fewer and shorter dispatches in a year. CBP energy delivery revenue was modeled on a $95/MWh bid price, which is the current trigger price listed in the PG&E CBP tariff. However, it is important to note that this is just one of the possible criteria for PG&E to trigger a CBP event, so the actual value based on PG&E events in a given year will vary. More information on the CBP can be found in the PG&E CBP tariff. Table 9 provides the energy delivery value from CBP.

**Table 9: Yearly Dispatches and First-Year Savings from Capacity Bidding Program Energy Payments**

| Bid Price ($/MWh) | Yearly Dispatches | Energy Delivery Payments ($) | TOU Arbitrage Net Value ($) | Total ($) |
|---|---|---|---|---|
| $95 | 47 | $3,445 | $365 | $3,810 |

Source: WSP

## Capacity/Resource Adequacy Value

Capacity value was analyzed for both the wholesale market and the PG&E market. Capacity payments are made regardless of the number of yearly dispatches. To ensure adequate energy supply, California LSEs must demonstrate they have adequate resource contracts to cover their peak demand plus a 15 percent reserve margin. Conventional generation resources providing RA are expected to be dispatchable 24/7, but demand response resources are generally understood to have more limited availability. The estimated capacity value was based on average availability during California ISO's defined availability assessment hours of 4 p.m.–9 p.m. on weekdays, corresponding to the time of day with the greatest reliability need.

### Wholesale Market

RA is typically secured through proprietary bilateral contracts between the LSEs and RA providers so prices are usually confidential. Because RA pricing is not publicly available, the rough system average of $3/MW-month was used, as indicated in the California Public Utilities Commission's *2017 Resource Adequacy Report*.[3] The capacity value for RA using this approach was $4,529 per year.

### Pacific Gas and Electric Company

RA is secured through a third-party aggregator who contracts with resources and sells that capacity to PG&E during the PG&E summer months of May to October. The capacity prices vary from month to month with the minimum of $2.27/MW in October and a maximum of $22.54/MW in August. A number of scenarios were run, and it was determined that the best CBP program option is Elect+ with one- to four-hour events from 1:00 p.m. to 9 p.m.. The capacity value for CBP capacity using this approach was $11,141 per year.

## Spinning Reserves

Spinning reserves is an hourly capacity market through the California ISO and not available through PG&E. To participate in the market, a resource must have at least 500 kW of capacity available when bidding in the market. In addition, all spinning reserves must have additional telemetry installed with visibility by the California ISO. Spin capacity rewards also are co-optimized with energy awards. To model spin, all capacity between 4 p.m. and 9 p.m. was bid for spin capacity, but any hour given an energy dispatch award was not credited for spin capacity. As a result, spinning reserve capacity value increases as the energy bid price is increased which results in a lower number of energy dispatches, and therefore a greater number of hours earning spin capacity value. Table 10 summarizes spinning reserves capacity by bid price.

**Table 10: Capacity Value by Program and Bid Price**

| Bid Price ($/MWh) | Spinning Reserves Capacity Value ($) |
|---|---|
| $50 | $415 |
| $75 | $2,457 |
| $100 | $3,547 |
| $200 | $4,332 |
| $950 | $6,581 |

Source: WSP

As noted above, spinning reserves need a minimum capacity of 500 kW to be bid into the market. Because this resource has a maximum output of 200 kW, it would need an additional 300 kW of capacity to place a spinning reserve bid when all 200 kW are available. However, when the facility's solar is exporting or the battery is being used for DCM, additional resources would have to be available for as much as the whole 500 kW. Therefore, this resource would

3 Available at https://www.cpuc.ca.gov/ra/.

also have to be aggregated with another resource to be able to bid into the market. Spinning reserves would also require telemetry, which would add greater implementation costs.

## Considerations

The battery storage system is sometimes being used for DCM during the peak capacity hours of 4 p.m.–9 p.m.. As a result, there are times when the maximum power capacity of 200 kW will be used for DCM and not available for wholesale market participation. This analysis used a simplified model that did not account for this to get indicative value potential for capacity, since overall DCM usage is small. This issue would need to be considered to fully capture this value stream.

To get RA value, a resource must be available with at least 100 kW and bidding in the market every weekday from 4 p.m.–9 p.m.. However, as a behind-the-meter demand response resource, Las Positas College's capacity is limited to positive (import) load on the facility. Because of the substantial solar on the Las Positas site, the facility is often exporting between the hours of 4 p.m. and 6 p.m. in the summer when RA value is typically highest. Because there is not consistent availability of the resource in the assessment window, this resource would need to be aggregated with other facilities that could provide load when this facility is not available. RA would also most likely require the development of a bilateral contract with an LSE, since there is not currently a public market for RA.

Spinning reserves need a minimum capacity of 500 kW to be bid into the market. Because the Las Positas College BESS has a maximum output of 200 kW, it would need an additional 300 kW of capacity to place a spinning reserve bid when all 200 kW are available. However, when the facility's solar is exporting or the battery is being used for demand charge management, additional resources would have to be available. Therefore, this resource would also have to be aggregated with other resources to be able to bid into the market. Spinning reserves would also require telemetry which would add additional implementation costs.

## Summary of Results

Table 11 summarizes results for market participation value for Las Positas College bidding directly in the wholesale market. If Las Positas could get both spinning reserve capacity and RA credit, then the potential value ranges from $11,110 with no energy delivery (capacity only) to $18,165 for 318 dispatches a year. If neither RA or spin is pursued, the facility could earn up to $13,048 for energy only.

**Table 11: Summary of Wholesale Market Results**

| Bid Price ($/MWh) | Yearly Dispatches | Energy Delivery Value | TOU Arbitrage Value | RA Capacity Value | Ancillary Services Spin Value | Total Value |
|---|---|---|---|---|---|---|
| $50 | 318 | $13,048 | $174 | $4,529 | $415 | **$18,165** |
| $75 | 124 | $7,360 | $667 | $4,529 | $2,457 | **$15,013** |
| $100 | 48 | $3,970 | $374 | $4,529 | $3,547 | **$12,420** |
| $200 | 12 | $2,106 | $218 | $4,529 | $4,332 | **$11,186** |
| $950 | 0 | $0 | $0 | $4,529 | $6,581 | **$11,110** |

Source: Olivine

Table 12 provides a breakdown of values for the participation in the PG&E CBP program.

**Table 12: Summary of CBP Results**

| Bid Price ($/MWh) | Yearly Events | Energy Delivery Value | TOU Arbitrage Value | RA Capacity Value | Ancillary Services Spin Value | Total Value |
|---|---|---|---|---|---|---|
| $95 | 47 | $3,445 | $365 | $11,141 | $0 | **$14,943** |

Source: Olivine

# Recommendation

The initial study indicates the potential value from services to the grid is only 15–20 percent of the value of the current DCM program. In addition, providing services to the grid may have impacts on the ability to use the BESS for DCM. Given the uncertainty around achieving significant capacity value due to the facility export and times when the battery is needed for DCM, the recommendation was to start with simply bidding extra battery capacity into the wholesale market on a campus basis on days when the battery is not needed for demand charge management. Using this strategy, the facility can determine the optimal tradeoff between the number of dispatches and the value produced, as well as set up the operational infrastructure for wholesale market participation. Following this, the facility could explore opportunities to gain capacity or ancillary service value by joining a larger aggregation of resources.

# CHAPTER 8: Technology and Knowledge Transfer

## Project Fact Sheet

As part of the technology and knowledge transfer plan, the project team developed a project fact sheet that was updated as the project proceeded. The final project fact sheet is provided in Appendix C.

## Technology and Knowledge Transfer Plan

The project team actively disseminated information about the project through conferences, publications, press releases, and intra-company communications. The educational community was the focus of the outreach effort in California. Most educational institutions in California have installed PV either through direct purchase of systems or through developer-owned power-purchase agreements. With the shift in utility rate structures, the addition of BESS and microgrids will become an essential element of educational institutions' energy management programs.

Nationwide, microgrids are a rapidly developing technology that has attracted significant attention from owners, utilities, and controls and equipment vendors. The project team attended multiple technical conferences to share ideas, concepts, and lessons learned as well as gather experience to improve the Las Positas College Microgrid project. In addition to external events, the project team members shared project information within their organizations as new opportunities arose to implement similar systems for new clients. For example, the Las Positas College Microgrid was one of the first multi-storage microgrids managed and developed by WSP. The newly formed microgrid working group within WSP has studied the Las Positas project to gather lessons learned and understand the economic and operational benefits.

One of the proposed products from the EPIC grant was a microgrid blueprint to provide educational institutions information for evaluating and planning the addition of microgrids and storage assets to their campus grids. While WSP and the project team ultimately did not publish such a blueprint, they have presented the information at conferences and seminars attended by educational facilities managers and energy managers. Presentations at the California Community College Facilities Coalition and Coalition for Adequate School Facilities and California Higher Educational Sustainability Conference detailed the ideas, concepts, and lessons learned that were to be incorporated in the blueprint to the community college, K-12 and university facilities directors, respectively.

In addition, GELI developed GELI-ESYST, a web-based online tool for analyzing and designing investment-grade energy storage projects. The tool allows firms combine tariff information, historic electricity consumption data, and solar PV performance projections to determine the true energy needs of a customer facility. Once the system sizing is estimated, users can select from multiple system options according to client needs, financial parameters, and supplier preferences. After system components are selected, users can download full financial pro forma and a detailed breakdown of how the system will generate value at the client site.

During the Las Positas College grant period, other microgrid evaluation reports and studies have been issued, including:

- *The Economics of Battery Energy Storage, How Multi-Use Customer Sited Batteries Deliver the Most Services and Value to Customers and the Grid*, Rocky Mountain Institute, October 2015.[4]
- *The Financial Decision-Makers Guide to Energy-as-a-Service Microgrids*, Energy Efficiency Markets LLC, 2018.[5]

# Outreach Activities

The project team attended and made presentations at conferences, workshops, and informal gatherings to share the project details and lessons learned. The project team also developed and disseminated project information through publications, webinars, and press releases. Types of outreach included:

- Participation in seminars and conferences.
- Presentations at K-12, community college and university facilities managers' statewide conferences.
- Presentations at national microgrid and energy conferences.
- Presentations to educational sustainability conferences.
- Participation in industry forums.
- Publications.
- Distribution of project fact sheets.
- Project press releases.
- Publication in educational industry publications.
- Corporate news letters.
- Outreach to interested parties.
- Site tours.
- Integration into Las Positas College educational course work, including chemistry (flow battery); ecology (energy management); and engineering (design and operation).
- International engineering group tours.

4 Available at https://rmi.org/insight/economics-battery-energy-storage/.

5 Available at https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/MGK_Special_Report_on_Energy_as_a_Service.pdf.

Table 13 lists key technology and knowledge transfer activities.

**Table 13: Key Technology and Knowledge Transfer Activities**

| Date | Event and Activities |
|---|---|
| Dec. 3, 2015 | Las Positas College Microgrid Project Presentation; 2015 EPIC Innovation Symposium, Folsom, California<br>Presenters: Bruce Rich, WSP; Ryan Wartena GELI |
| June 28, 2016 | "Las Positas College Microgrid Energy Storage Project, Integrating Campus Distributed Energy Resources Renewables, Storage and Microgrids"; California Higher Education Sustainability Conference, Fullerton, California<br>Presenters: Bruce Rich, WSP; Doug Horner, Chabot-Las Positas CCD |
| Oct. 2016 | "Las Positas Microgrid Project," *School Construction News,*<br>Author: Richard Reitz, WSP |
| Oct. 28, 2016 | "Las Positas Microgrid", Energy Educators Forum, San Mateo County Office of Education, San Mateo, California<br>Presenter: Bruce Rich |
| Nov. 16, 2016 | "How large scale on-site energy storage complements renewable energy generation"; Community College Facilities Coalition Annual Conference, Sacramento, California<br>Presenters: Bruce Rich, WSP; Doug Horner, Chabot-Las Positas Community College District (CCD) |
| Jan. 2017 | "UET to Deliver ReFlex Energy Storage System to Las Positas College Microgrid," Press Release, UET |
| Jan. 18, 2017 | Presentation on use of large battery storage and microgrid to reduce energy charges and provide other benefits to schools; Santa Clara County Office of Education, K-12 Facilities Officers Meeting, San Jose, California<br>Presenter: Bruce Rich, WSP |
| Apr. 5, 2017 | "Internet of Energy at Las Positas College; Technology, Financing and Operations"; ACI's 6$^{th}$ National Conference on Microgrids, Boston, Massachusetts<br>Presenters: Bruce Rich, WSP; Ryan Wartena, GELI |
| June 13, 2017 | "Community Microgrid Update"; Microgrid Markets Summary Conference, Washington DC<br>Presenter: Philip Jonat, WSP |
| June 26, 2017 | "Microgrids and Long Duration Energy Storage, Maximizing Value and Resiliency"; International District Energy Association 2017, Scottsdale, Arizona<br>Presenter: Michael Carr, UET |
| Oct. 2, 2017 | "Using P3 to Transform Energy Management on Campus"; P3 Higher Education Summit, San Diego, California<br>Presenters: Bruce Rich and Terry Marcellus, WSP |
| Feb. 27, 2018 | "The State of Solar and Storage 2018" Coalition for Adequate School Housing (CASH) Sacramento, California<br>Presenters: Bruce Rich WSP, Kevin Flanagan School Project for Utility Rate Reduction (SPURR) |
| Apr. 3, 2018 | Las Positas College Microgrid Project Presentation; Microgrids-Basic Applications, Technologies, Values and Economics, Napa, California<br>Presenter: Bruce Rich, WSP |
| Sep. 2018 | Lawrence Livermore National Laboratory and the U.S.-China Climate Change Working Group (CCWG) Smart Grids Workshop, site tour and system presentation |

Source: WSP

# CHAPTER 9: Project Benefits

## Summary

The project demonstrated both economic and non-economic benefits to the Las Positas College, the Chabot-Las Positas Community College District, and California electricity ratepayers and residents.

## Energy-Related Benefits

### Cost Benefits

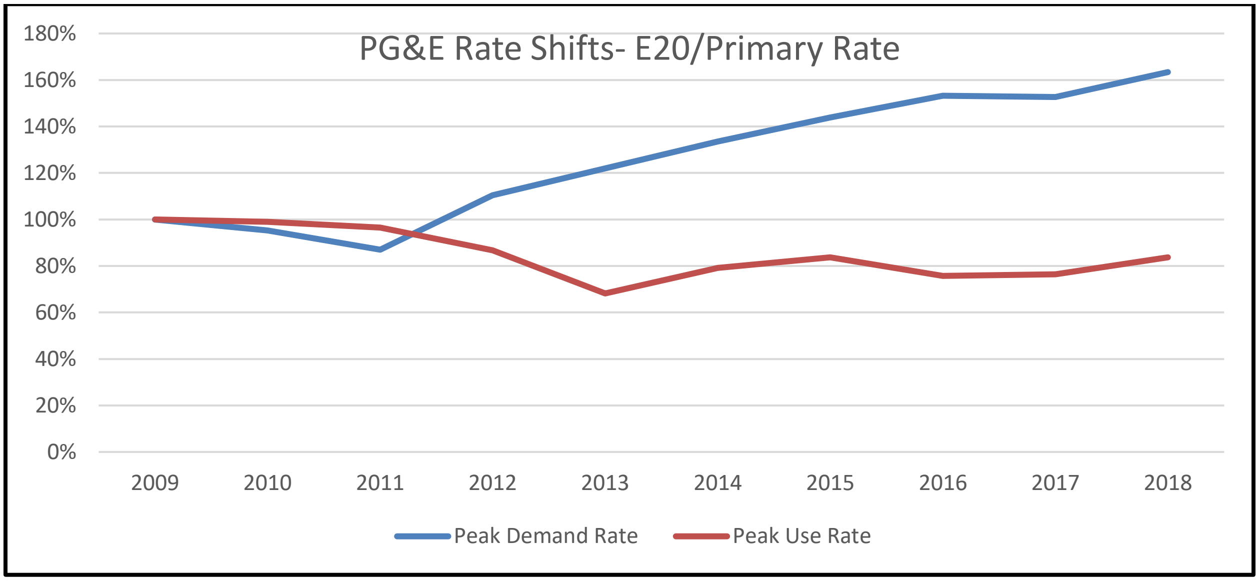
The project demonstrated the potential to reduce the college's energy cost, primarily through the reduction of peak demand charges. This was accomplished by using the BESS tactically for instantaneous response to reduce peaks and employing thermal storage strategically to use excess on-site generated renewable energy when available and avoid energy use during evening hours when the campus load peaked.

The cost benefits will change as utilities modify their rate structures to address the increasing development of distributed energy resources that they do not control. Conversely, customers are developing renewable energy generation and microgrids to address rising electrical utility costs.

Recent rate structure changes over the last years illustrate how the investor-owned utilities are responding to changes in the DER market. Utilities have increased peak demand rates and are shifting the peak time of use periods, moving from a usage-based billing system to a demand-based billing. This change began with the nationwide separation of generation and distribution ownership. It accelerated with the development of independent development of local renewable generation and energy conservation measures, reducing the utilities' usage revenue.

Figure 39 shows the divergent movement of peak demand rates and usage rates extracted from the utility billings at Las Positas College from 2009 to 2018. Demand charge rates have increased by 60 percent over 10 years while usage charges have decreased by 20 percent. The ratio of demand charges to usage charges had changed from 30/70 in 2009 to 50/50 in 2018.

**Figure 39: Pacific Gas and Electric Company Change in Demand and Usage Rates**

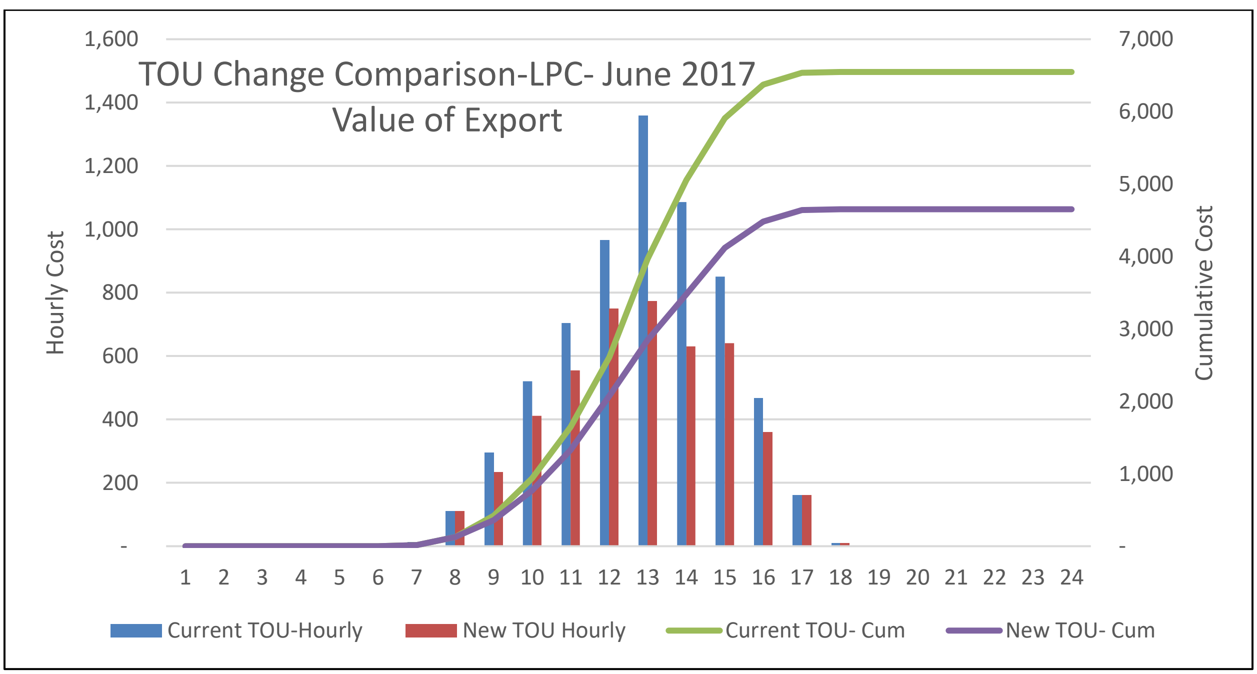



**The percentage change in PG&E Peak Demand Rate and Peak Use Rate from 2009-2018, Las Positas College**

Source: WSP

The upcoming shift in the TOU periods will have significant impacts on the college's cost of energy. On one hand, the value of the solar PV produced during the noon to 6 p.m. period will be reduced by more than 30 percent, as shown in Figure 40.

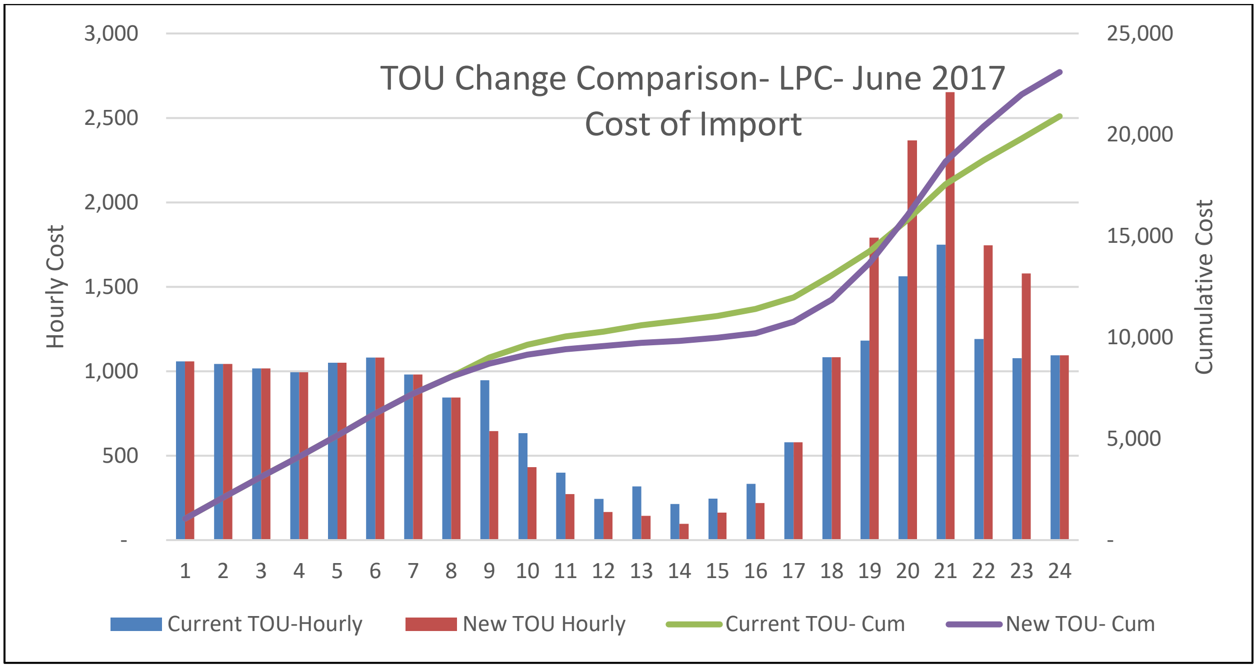
**Figure 40: Impact of Time of Use Changes on Value of Solar Exports**




Source: WSP

On the other hand, the college's energy purchased in the evening hours between 4 p.m. and 9 p.m. will increase, as shown in Figure 41.

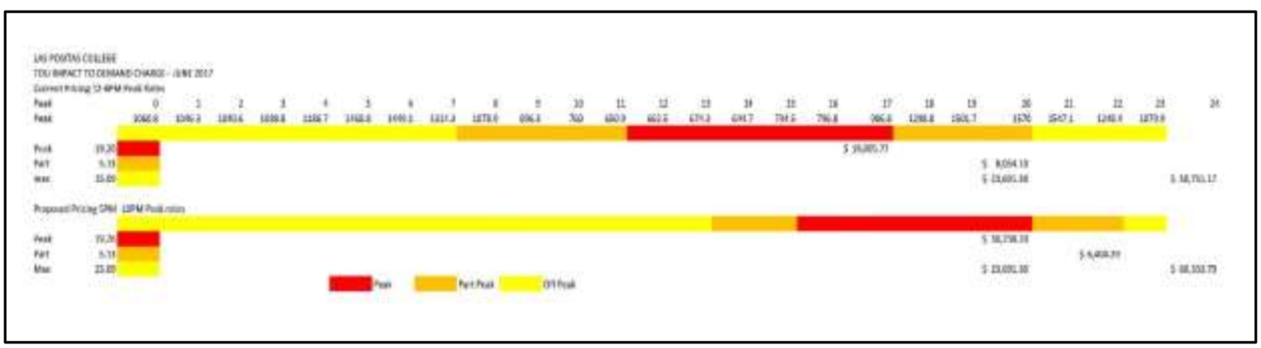
**Figure 41: Time-of-Use Changes Impact on Cost of Purchased Energy**




Source: WSP

Also, the peak period demand charges will be moved to the evening hours when the maximum campus energy purchased occur. Figure 42 illustrates the impact of the TOU changes for Las Positas College.

**Figure 42: Time-of-Use Changes Impact on Demand Charges**



Source: WSP

Table 14 summarizes the impact of TOU changes to Las Positas College.

**Table 14: Summary Total Cost Impact of Time-of-Use Change from June 2017 Data for Las Positas College**

| TOU Changes | Base | New | Delta |
| --- | --- | --- | --- |
| Increased cost of Energy | $ 20,915.2 | $ 23,094.2 | $ 2,179 |
| Decreased value of Exports | $ (6,547.7) | $ (4,652.5) | $ 1,895 |
| Increased Demand Charges | $ 50,751.2 | $ 60,333.8 | $ 9,583 |
| Total Impact | $ 65,118.7 | $ 78,775.5 | $ 13,657 |
| | | Impact Percentage | 21% |

Source: WSP

The development of energy storage systems and corresponding microgrid controls are necessary for the college to maintain the ability to manage its electrical energy costs. The development of the Las Positas College Microgrid demonstrates to the college and district the value of additional energy storage and, more importantly, the need for the district to consider the campus distribution system as a microgrid used to manage when to purchase energy and how that energy is used across the campus.

# Non-Energy-Related Benefits

## Public Safety

The Las Positas College microgrid has the potential to provide long-term renewable energy to power the M&O complex as an emergency operations center in the event of an area-wide disaster affecting the electrical grid. The combination of the 200 kW/1,000 kWh BESS and the 500 kW solar PV system with backup emergency generator could conceivably operate indefinitely. In addition, the BESS can provide emergency power to restart the stadium lights on the adjacent athletic field in the event of a power failure during an evening sporting event.

## Technology Improvements

The Las Positas College Microgrid project has stimulated research and investment by the firms involved in the project. The development of new and improved equipment and systems are benefiting new microgrid projects and equipment currently being researched and tested.

The most significant technical advancement is the new inverter developed by EPC for the flow batteries used at Las Positas College. Imergy turned to EPC in early 2016 when three other inverter vendors declined to develop inverters that would function with the output of its flow battery. A flow battery differs from metal-based systems in that the output DC voltage is lower with wider variations.

The inverter EPC perfected for the Las Positas project was based on its model LC-6/12, a 125 kW model developed for solar PV systems. To address the voltage issues, EPC coupled the LC 6/12 with new DC/DC converter to increase the variable battery input voltage of 150-225 volts DC (vdc) to 750 vdc. The 750 vdc is required to achieve 480 V three-phase AC output from the LC 6/12. The combination converter/inverter in the outdoor enclosure required a newly designed liquid cooling system and control system. Building on the UL approval of the LC-6/12, EPC obtained UL 1741 approval of the new integrated inverter system for the UET batteries at Las Positas College. The new EPC inverter is being deployed on all new UET ReFlex flow battery systems. EPC has developed and marketed an updated design that integrates the DC/DC converter and DC/AC inverter in a single module. The DG Wide range power units are available for other flow battery BESS systems.

The project also created advancements from other project team members:

- UET – The UET ReFlex 100 kW/500 kWh battery was a relatively new product for the firm. The ReFlex is a derivative of the UET 500 kW/2,000 kWh system that has been in operation for 8 years. The ReFlex used a new stack design providing higher energy density allowing all the stacks, electronics and electrolyte contained within a 20-foot shipping container. The ReFlex unit underwent several improvements derived from operational testing at Las Positas College. UET has installed four similar systems subsequent to the Las Positas College system implementing improvements and lessons learned from the Las Positas College system.
- GELI – The GELI operating system and multiple applications were relatively new when the Las Positas College Microgrid project began. This project was the first where GELI was tasked to control multiple energy sources and exercise microgrid control. GELI's flagship DCM application was modified throughout the Las Positas project after feedback from operations. GELI developed its GELI-ESYST website to provide planning and cost data to assist organizations with the planning of solar and storage systems.
- Schweitzer Engineering Laboratories – Schweitzer provided its real-time automation controller (RTAC), SC2200, in conjunction with the SEL-351 power control relay as the Las Positas College Microgrid project system controller. The unique feature of the Las Positas microgrid was the requirement that the BESS be controlled by the GELI application when the grid was stable and the Schweitzer RTAC when the grid was offline. Schweitzer developed a solution that routed the GELI communication through its RTAC unit. When the grid was normal, the RTAC mirrored the UET battery interface to GELI. When the grid failed, the RTAC switched communication from the GELI input to the RTAC programming. The switch occurred within a second without any interruption in battery operation. With RTAC control, the UET system moved from grid forming and returned to grid following after return of a stable grid and switched back to the GELI application.

# CHAPTER 10: Lessons Learned and Recommendations

The development of the Las Positas College microgrid encountered many obstacles that were ultimately resolved. The following narrative offers a combination of lessons learned, recommendations, and comments for developing similar projects.

## Project Development

Energy storage systems, equipment, and controls are emerging technologies. New technologies are being marketed by start-ups and established companies. Whether new or established companies, implementation of new technologies will be uneven and involve higher-than-normal project risk, as demonstrated by the Las Positas College project. Some thoughts and comments:

- Communication between systems and devices: Each interface between a control system and an energy device required a specially programmed interface application. A few interface applications had been developed from previous projects, but most were new or updated. The Internet of Things is not “plug-and-play,” like peripherals on a computer. Creating the interface applications added cost and time to the development process and added time to the commissioning process. As control systems and energy devices become standardized, this issue will decrease.
- Degree of automation: The greater the degree of automation, the more complex the solution. Increasing the time gap from loss of grid to grid forming from three seconds to three cycles increases the project cost, programming and commissioning periods, and installation and operational risk. The Las Positas College Microgrid project did not require seamless transition; therefore, the system controller could wait for physical switches and position indicators before transiting to grid forming. It is important to determine the project owner’s tolerance for all of these elements before beginning the project design.
- System complexity: The more complex the system and controls, the more support and maintenance staff training is required. If the M&O staff is not trained and supported adequately, the system will not function as designed. In lieu of in-house staff, contracting with third-party firms with experience with these systems should be considered.
- Flow battery operational considerations: The mechanical pumping system introduces operational considerations. The UET flow battery pumps should be continuously operated to provide charge maintenance and temperate control in the stacks. If there are long periods between charge/discharge cycles, the continuous pump operation significantly decreases the battery efficiency. If the battery is in a low energy or standby pumping mode, the delay to the ready mode means a delay in transition to islanding rather than seamless.

- Local support: These complex systems require computer programming to perform the applications and manage the systems. Computers and automation work well until they do not. The project design should include a fault or failure analysis of each system with mitigation actions defined. One element is the provision of a degree of local control to allow a means to manually place the system in a safe or planned state in the event of a system component failure. If a third party is providing M&O services, it should provide on-site trained staff or train key owner staff in emergency manual control actions.
- Project team experience: New products and technologies require more experience than testing proven systems. Firms with experience with energy management equipment bring lessons learned and a range of successful solutions. Firms that have worked together bring an understanding of the capabilities, communication protocols, and performance of their partners' equipment and systems.
- Utility interconnection process: This interconnection process should recognize behind-the-meter installations and establish simplified processes similar to the streamlined processes for addition of PV systems.
- Percentage of new technologies: Consideration is needed of how much of the system will be developed with new or emerging technology and with new start-up companies. The two key vendors of the Las Positas College Microgrid project were start-up companies with a new technology. The Imergy battery was a first-generation scale-up of a much smaller unit. Many of GELI's energy operating system applications were being developed for this project. While EPC is an established company with experience with inverter technology, the Las Positas inverter was a new development.
- Project and technical management: Every project requires experienced project management. These are team projects that require communication and project-level planning and coordination. The system integrator needs to be a key part of the team. Many of the elements are new systems that have different communication protocols and unknown operational characteristics. A system integrator needs to understand the elements, lead the discussions between vendors, and oversee testing and commissioning plans and implementation to ensure a successful project.
- Project funding: New technologies require higher-than-normal funding contingencies. Grant funding is fixed. Therefore, the project owner needs to establish a contingency fund for increased project cost due to delays, equipment, or vendor failures, and other unanticipated occurrences.
- Communication with project owner's facility organization: A new microgrid inserted into a functioning campus or business facility will make an impact on their operation. Involve the operations staff with connection points and control strategies, work with the IT group to coordinate with the existing data network structure and operational philosophy, and work with senior management to provide project status with a true picture of issues.

## Paradigm Shift

The Las Positas College Microgrid project caused the district M&O group to view the campus utility control systems differently. While a part of the project focused on the microgrid and the ability to island a segment of the campus, other project elements considered the entire campus electrical system as a microgrid with integrated systems to control energy generation, usage, and storage assets. As the M&O staff became engaged with the project, they saw examples of methods to link elements of one control system with others to better control energy use and when to purchase energy. One example was the opportunity for the DCM system using predictive analysis to assist with timing the switch between chiller and thermal storage for campus cooling. The specification for conversion to LED lighting contained a requirement that a building-wide control system have the capability to communicate with the campus-wide EMS and adjust building-wide lighting levels in response to a signal from the EMS or an outside demand response signal.

# GLOSSARY AND ACRONYMS

| Term | Definition |
|---|---|
| BESS | Battery energy storage system |
| CB | Circuit breaker |
| CBP | Capacity Bidding Program |
| DCM | Demand charge management- reduce peak power demands by using energy storage |
| DG | Distributed generator |
| DSW | Distribution switch, at LPC a 25kv rated switch on the campus grid |
| EMS | Energy management system |
| EOS | Energy Operating System, developed by GELI to control the DCM program |
| EPIC | Electric Program Investment Charge |
| EPIC | The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company. |
| GELI | Growing Energy Labs, Inc. DCM software provider |
| HMI | Human-machine interface |
| Islanding | Separating a portion of grid from the primary energy source and operating independently |
| IT | Information technology |
| K-12 | Elementary to high school educational institutions |
| kW | Kilowatt, measure of electrical power in watts |
| kWh | Kilowatt-hour, measure of electrical energy in watt/hours |
| LED | Light emitting diode, used as a lighting source |

| Term | Definition |
|---|---|
| LEED | Leadership in Energy Efficiency Development |
| LPC | Las Positas College located in Livermore, California |
| LSE | Local Service Entity, for this project PG&E |
| M&O | Maintenance and Operations, both the physical complex and the operations staff at LPC |
| MSB | Main switchboard |
| MW | Megawatt-hour, measure of electrical power in watts |
| MWh | Megawatt-hour, measure of electrical energy in watt/hours |
| PCC | Point of common coupling; the point at which a microgrid is connected to the wider utility grid. |
| PDE | Pacific Data Electric, Inc |
| PG&E | Pacific Gas and Electric, electrical utility serving LPC |
| PLC | Programmable Logic Controller |
| POC | Permission to operate |
| PPI | Pre-parallel inspection |
| PV | Photovoltaic |
| RTAC | Real Time Automation Controller, part of the microgrid system wide control system |
| SEL, Schweitzer | Schweitzer Engineering Laboratories, Inc.; project vendor. |
| SEL-351 | Specific model of protection relay device, manufactured by SEL, Inc., used to monitor and control the point of common coupling breaker and for foundational control. |
| Smart Grid | Smart grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities. |
| SOC | State of charge; the amount of energy stored in the battery system. |
| UL | Underwriters Laboratory, a testing agency |

| Term | Definition |
| --- | --- |
| PS | Uninterruptable power supply; device capable of powering attached loads from stored energy (usually batteries) for a short period of time after normal input power is interrupted, and of transferring quickly enough that connected loads are not affected by the transfer. |
| WSP | WSP USA, Inc., program manager and integrator |

# APPENDIX A:
# Round Trip Efficiency Calculations

| | | BMS1 | BMS2 |
|---|---|---|---|
| Cycle 1 | Charge - watts | (1,163,030) | (1,164,000) |
| | Discharge - watts | 661,456 | 662,395 |
| | SOC Change | 80,400 | 96,600 |
| | Ratio | -63.8% | -65.2% |
| Cycle 2 | Charge - watts | (1,164,000) | (1,164,000) |
| | Discharge - watts | 687,581 | 695,653 |
| | SOC Change | 69,600 | 73,400 |
| | Ratio | -65.0% | -66.1% |
| Cycle 3 | Charge - watts | (1,164,000.00) | (1,164,000.00) |
| | Discharge - watts | 687,904.00 | 702,233.00 |
| | SOC Change | 70,000 | 66,600 |
| | Ratio | -65.1% | -66.1% |
| Cycle 4 | Charge - watts | (1,164,000) | (1,164,000) |
| | Discharge - watts | 680,301 | 697,600 |
| | SOC Change | 89,400 | 78,400 |
| | Ratio | -66.1% | -66.7% |
| Cycle 5 | Charge - watts | (1,164,000) | (1,164,000) |
| | Discharge - watts | 679,736 | 699,258 |
| | SOC Change | 89,200 | 97,200 |
| | Ratio | -66.1% | -68.4% |
| Cycle 6 | Charge - watts | (1,164,000) | (1,160,120) |
| | Discharge - watts | 680,778 | 695,428 |
| | SOC Change | 96,800 | 88,600 |
| | Ratio | -66.8% | -67.6% |
| Cycle 7 | Charge - watts | (1,161,090) | (1,149,450) |
| | Discharge - watts | 675,808 | 692,814 |
| | SOC Change | 99,400 | 90,400 |
| | Ratio | -66.8% | -68.1% |
| Cycle 8 | Charge - watts | (1,148,480) | (1,131,020) |
| | Discharge - watts | 673,074 | 694,650 |
| | SOC Change | 92,600 | 78,000 |
| | Ratio | -66.7% | -68.3% |
| | Average Efficiency | -65.8% | -67.1% |

# APPENDIX B:
# Las Positas College Demand Charge Calculations

**Actual 2018 Demand Charges**

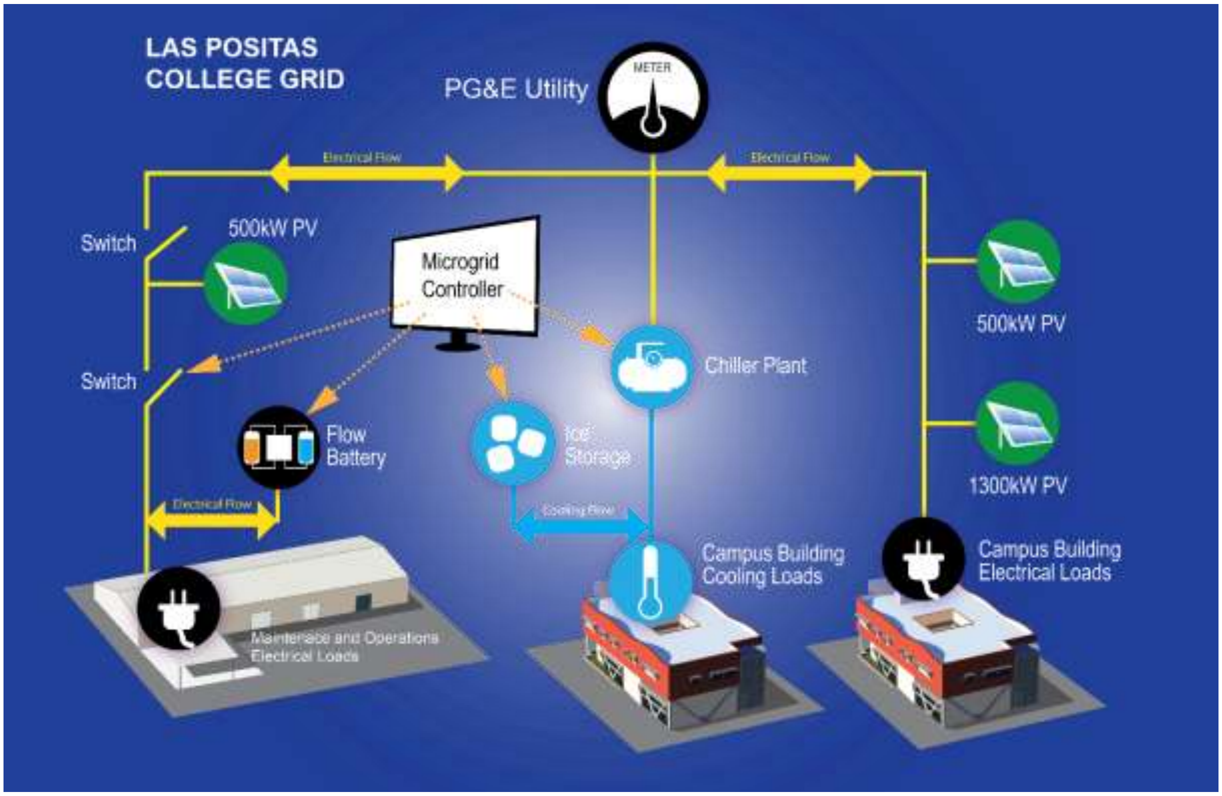
| | Demand in kW | | | Demand Charges | | |
|---|---|---|---|---|---|---|
| **Month** | **Max** | **Peak** | **Part** | **Max** | **Peak** | **Part** |
| January | 1422 | | 1422 | $21,472.20 | $0.00 | $170.64 |
| February | 1519 | | 1519 | $22,936.90 | $0.00 | $182.28 |
| March | 1506 | | 1506 | $23,508.66 | $0.00 | $180.72 |
| April | 1512 | | 1270 | $23,602.32 | $0.00 | $152.40 |
| May | 1441 | 803 | 1441 | $22,494.01 | $16,333.02 | $7,723.76 |
| June | 1463 | 1045 | 1463 | $22,837.43 | $21,255.30 | $7,841.68 |
| July | 1641 | 1031 | 1524 | $25,616.01 | $20,970.54 | $8,168.64 |
| August | 1571 | 1055 | 1571 | $24,523.31 | $21,458.70 | $8,420.56 |
| September | 1667 | 1593 | 1667 | $26,521.97 | $32,847.66 | $9,085.15 |
| October | 1680 | 1441 | 1680 | $26,728.80 | $29,699.01 | $9,156.00 |
| November | 1526 | | 1526 | $24,278.66 | $0.00 | $198.38 |
| December | 1210 | | 1198 | $19,251.10 | $0.00 | $155.74 |
| | | | | **$283,771.37** | **$142,564.23** | **$51,435.95** |
| | | | | **TOTAL** | | **$477,771.55** |

**Calculated 2018 Demand Charges with DCM**

| | Demand in kW | | | Demand Charges | | |
|---|---|---|---|---|---|---|
| **Month** | **Max** | **Peak** | **Part** | **Max** | **Peak** | **Part** |
| January | 1242 | | 1242 | $18,754.20 | $0.00 | $149.04 |
| February | 1338 | | 1338 | $20,203.80 | $0.00 | $160.56 |
| March | 1325 | | 1325 | $20,683.25 | $0.00 | $159.00 |
| April | 1337 | | 1337 | $20,870.57 | $0.00 | $160.44 |
| May | 1261 | 622 | 1261 | $19,684.21 | $12,651.48 | $6,758.96 |
| June | 1283 | 865 | 1283 | $20,027.63 | $17,594.10 | $6,876.88 |
| July | 1460 | 851 | 1343 | $22,790.60 | $17,309.34 | $7,198.48 |
| August | 1390 | 874 | 1390 | $21,697.90 | $17,777.16 | $7,450.40 |
| September | 1486 | 1413 | 1486 | $23,642.26 | $29,136.06 | $8,098.70 |
| October | 1499 | 1261 | 1499 | $23,849.09 | $25,989.21 | $8,169.55 |
| November | 1346 | | 1346 | $21,414.86 | $0.00 | $174.98 |
| December | 1029 | | 1001 | $16,371.39 | $0.00 | $130.13 |
| | | | | **$249,989.76** | **$120,457.35** | **$45,487.12** |
| | | | | **TOTAL** | | **$415,934.23** |

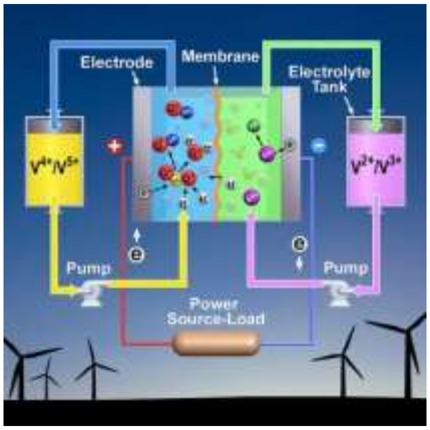
# APPENDIX C:
# Final Project Fact Sheet

## Las Positas College Final Fact Sheet




### The Project

The Las Positas Microgrid project is a demonstration of the next generation campus smart grid; combining multiple energy storage mediums, on-site generation and building systems controls with a campus-wide integrated energy management system that can determine when and how energy is used and from which sources. In addition, the energy management network is connected to outside energy coordinators to enable Las Positas to provide services to the grid for fair compensation. New Battery Energy Storage Systems provide and microgrid controls provide energy cost reductions and backup power for emergency operations center and athletic field lighting. Two UniEnergy Technologies 100 kW/500 kWH ReFlex are Vanadium Redox Flow Battery systems providing long term energy storage with unlimited battery cycles. The microgrid controller was developed by Schweitzer Engineering Laboratories. The Schweitzer system controls the islanding process and is capable of integrating solar PV when in islanding mode. GELI developed the Demand Charge Management application and provides the interface to outside energy services for demand response actions. The GELI controller is designed to interface with the campus-wide Alerton energy management system to manage the deployment of the 3200 ton/hour ice thermal storage unit during summer evening hours.




Each 100 kW vanadium redox flow battery is contained in a 20 foot long shipping container with two containment layers. The anolyte and catholyte tanks each contain xx gallons of electrolyte solution. There are three stack units consisting of xx electrode/membrane assemblies. The stack units each generate 75VDC and are connected in parallel for an output of 200-225VDC. Each flow battery is connected to the external power conversion system manufactured by EPC. The EPC units contain a DC/DC converter in increase in input 200VDC to 750VDC then an inverter to convert the DC to 480V three phase AC power.

**Highlights**

- Projected $60k annual saving from BESS from Demand Charge Management application and additional $60K annual savings from coordination of thermal storage with DCM signals
- Islanding mode supports the emergency operations center and can provide emergency power to athletic field lights.
- Development of web based solar and storage sizing and pricing application

| | |
|---|---|
| Project Sponsor | Las Positas College, Livermore and Chabot-Las Positas Community College District, Dublin, California |
| Project Manager/ Systems Integrator | WSP |
| Team Members | UniEnergy Technologies, EPC, GELI, Schweitzer Engineering Laboratories, PDE, Olivine |
| Funding | $1,551,200 - California Energy Commission-<br>$450,000 - Match Funding from Project Team |
| Time Line | March 2015-March 2019 |
| California Energy Commission Agreement Number EPC-14-055 | |
| Contact: Bruce Rich, PE email Bruce.Rich@wsp.com | |