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ENERGY COMMISSION



ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

**Marine Corps Air Station Miramar
Battery Energy Storage System**

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PREFACE

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

In 2011, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned electric 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 CEC is committed to ensuring public participation in its research and development programs to promote greater reliability, affordability, and safety for California electric ratepayers. EPIC investments advance these values by:

- Providing societal benefits.
- Reducing greenhouse gas emissions 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 projects), and finally with a clean electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Marine Corps Air Station Miramar Battery Energy Storage System is the final report for EPC-17-032 conducted by National Laboratory of the Rockies and University of California San Diego. The information from this project contributes to the CEC Energy Research and Development Division's EPIC Program.

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

ABSTRACT

The Miramar Battery Energy Storage System (BESS) project was designed to enhance the microgrid at Marine Corps Air Station Miramar, which is about 14 miles north of San Diego, California. This project aimed to reduce energy costs and improve reliability while integrating renewable resources into the existing microgrid.

Previously, the microgrid at Marine Corps Air Station Miramar was designed to optimize energy costs by managing various generation assets, including landfill gas generators, natural gas, and diesel fuel sources. The project installed a 1.5-megawatt, 3.3-megawatt-hour lithium-ion BESS that supported the microgrid's unique operational requirements and served as a critical new resource, allowing the microgrid to significantly reduce peak electrical demand at lower cost, compared with traditional fossil fuel sources. The microgrid's existing landfill gas generators faced reliability challenges due to intermittent outages caused by poor gas quality. These outages can lead to instantaneous drops in power output, risking demand charge events and power quality issues. The BESS mitigated these risks by providing backup power during outages, enhancing overall system reliability, and reducing reliance on diesel and natural gas generators.

The BESS was successfully tested and commissioned during a base-wide blackstart exercise. The exercise demonstrated the capability of the BESS to support islanding operations and stabilize generation outputs during unexpected-loss events. The battery has been operational for a year and has successfully demonstrated the ability to consistently reduce demand charges by an average of 962 kilowatts per month.

Overall, the Miramar BESS project represents a significant step toward enhancing energy resilience, economics, and sustainability at Marine Corps Air Station Miramar. It also provides valuable insights and lessons learned for future microgrid implementations.

Keywords: microgrid, battery energy storage system

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EXECUTIVE SUMMARY

Background

The California Energy Commission is leading the state to a 100% clean energy future. However, extreme weather events and wildfires are straining California's grid and increasing the frequency and duration of power outages, displaying the need for better power reliability and resilience.

Conventional microgrids often target high-reliability applications for critical infrastructure such as hospitals, university campuses, waste management infrastructure, and military bases. Renewable generation is not yet reliable enough for use in these applications, causing microgrid owners to often resort to natural gas generators and diesel gensets, abandoning existing renewable generation assets during islanded operations. Natural gas generators are often powered by nonrenewable natural gas. For the investment to return a profit, these natural gas generators must run constantly, which prevents the owners from decarbonizing their microgrid energy mix.

The Miramar Battery Energy Storage System (BESS) was designed and installed by Schneider Electric. This research project's goal was to enhance the U.S. Department of Defense-funded microgrid demonstration at Marine Corps Air Station (MCAS) Miramar, located about 14 miles north of San Diego, California, by installing a lithium-ion battery to both optimize the dispatch of energy resources and increase reliability while integrating renewable resources into the existing microgrid.

The microgrid at MCAS Miramar was previously designed to optimize energy costs by managing various generation assets, including landfill gas generators, natural gas, and diesel fuel sources. The introduction of the BESS as a critical new resource allowed the microgrid to significantly reduce peak electrical demand at lower cost when compared with traditional fossil fuel sources.

Project Purpose and Approach

The microgrid's existing landfill gas generators faced reliability challenges from intermittent outages caused by poor landfill gas quality. These outages could lead to instantaneous drops in power output of 1.6 megawatts (MW) to 3.2 MW, risking both demand charge events and power quality issues. The BESS mitigated these risks by nearly simultaneous, instantaneous power supply to the base when production from the landfill gas generators was curtailed. This enhanced the reliability of electric service on the base, reduced large peak loads that would otherwise be supplied by the utility grid, and reduced reliance on diesel and natural gas generators.

Key benefits of the BESS included:

- Displacing fossil fuel generators as the primary source of backup power for landfill gas.
- Reducing peak demand charges as backup power for landfill gas when grid connected.

- Providing ride-through capabilities in the event of a local San Diego Gas & Electric Company outage.
- Improving power reliability and quality when operating in islanded mode by allowing an additional 1.6 MW of landfill gas integration into the microgrid.
- Increasing the overall share of MCAS Miramar’s electric demand with renewable resources.

Key Results

This research project assessed optimal sizing for the BESS to support the microgrid’s unique operational requirements, resulting in the selection of a 1.5-MW/3.3-megawatt-hour (MWh) system. The BESS, consisting of lithium-ion batteries, was successfully tested and commissioned on November 16, 2024, during a base-wide blackstart exercise. This exercise demonstrated the capability of the BESS to support islanding operations and stabilize generation outputs during unexpected-loss events.

BESS economic performance data were analyzed for the 2025 calendar year and they showed an average of 917 kilowatts in monthly peak shaving, which in turn resulted in major demand charge savings of over \$21,000 per month for MCAS Miramar. The reductions in peak load were primarily a result of the BESS quickly responding to landfill gas generation outages. Benefits to grid operators included reduced peak demand and reduced power fluctuations, which in turn reduced wear and tear on distribution equipment, allowing for deferment of distribution system upgrades.

Knowledge Transfer and Next Steps

Overall, this BESS project represents a significant step toward enhancing energy resilience, economics, and sustainability at MCAS Miramar. It also provides valuable insights and lessons learned for future microgrid implementations, including the ability of the BESS to provide firm and responsive power to back up other generators in grid-connected and islanded scenarios. Project knowledge was shared broadly through several press releases describing this microgrid. Within the federal government, MCAS Miramar shared lessons learned through Marine Corps and Navy energy meetings and workshops. The National Laboratory of the Rockies shared information with other federal agencies through its participation in the Federal Energy Management Program, including training webinars, the Federal Utility Energy Partnership Working Group, and direct support of other U.S. Department of Defense installations.

Benefits to California Ratepayers

California ratepayer benefits included:

Lower Costs: A carefully orchestrated BESS dispatched through the microgrid controller decreased customer costs by \$258,000 through demand charge savings.

Greater Reliability: Although it was not tested during the evaluation period due to a lack of demand response opportunities, ratepayer reliability benefits will accrue as more BESS technology reduces grid peak demand during demand response events. Reduced peak demand and reduced power fluctuations, in turn, reduced wear and tear on distribution equipment, allowing for deferment of costly distribution system upgrades.

Public Health and Environmental Benefits: Local emissions were avoided by not operating the 1.8-MW diesel generator during short landfill gas outages.

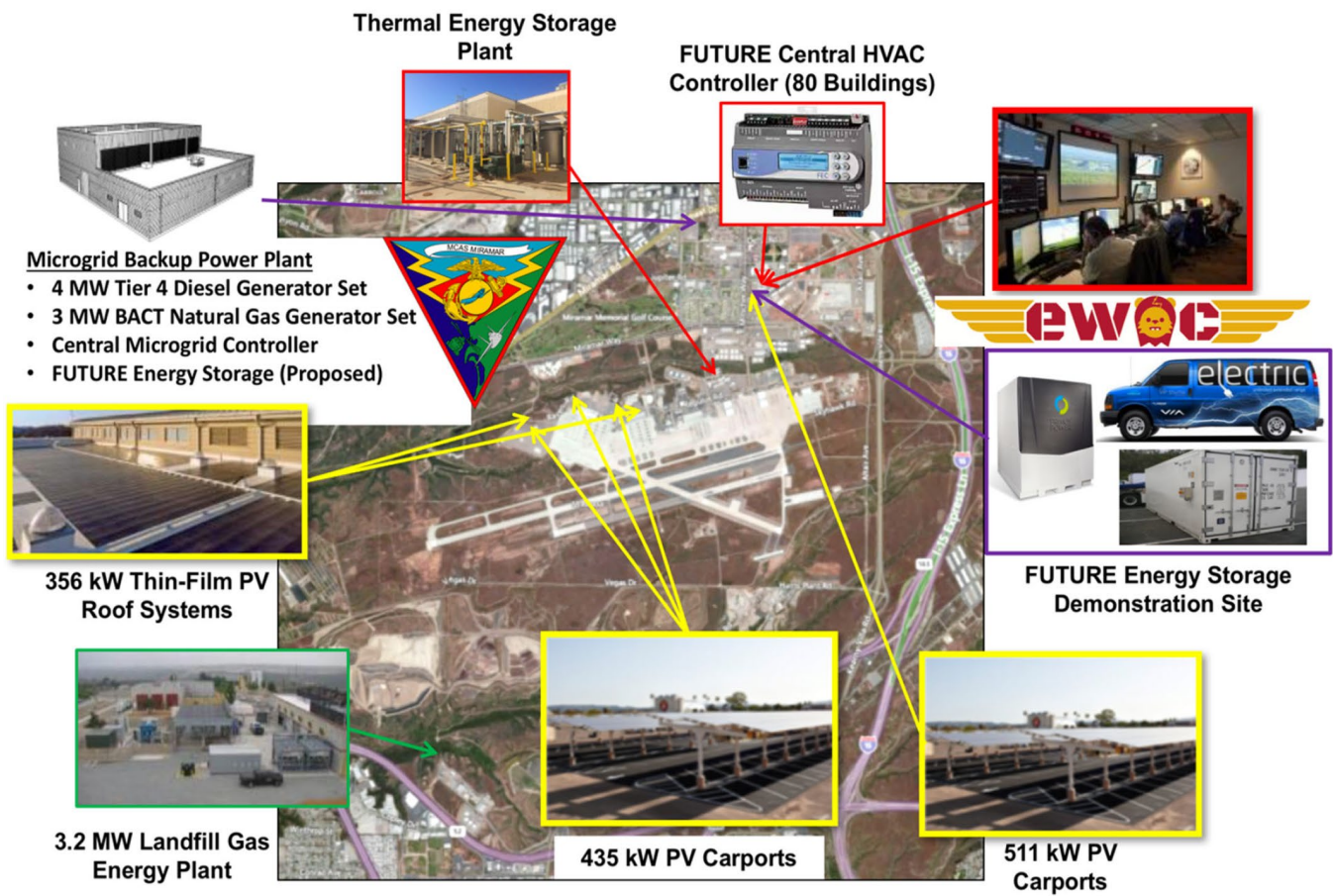
Conclusions

Through 12 months of continuous BESS operation, MCAS Miramar has demonstrated that it can leverage this advanced technology to enhance its energy management capabilities and contribute to a more resilient and sustainable energy infrastructure. The BESS and microgrid system are fully operational, enhancing energy efficiency and reliability while supporting MCAS Miramar's economic and sustainability goals.

CHAPTER 1: Introduction

The University of California, San Diego (UCSD) was awarded a project by the California Energy Commission (CEC) to install a lithium-ion battery energy storage system (BESS) at U.S. Marine Corps Air Station (MCAS) Miramar, located about 14 miles north of San Diego, California. MCAS Miramar was chosen because it commissioned one of the nation’s largest renewable microgrids with funding from the U.S. Department of Defense (DoD), as shown in Figure 1. The DoD-funded microgrid integrates 3.2 megawatts (MW) of existing landfill gas (LFG) generators, 1.3 MW of existing solar photovoltaic (PV) generation, 3.6 MW of new Tier 4 prime permitted diesel generation, and 2.8 MW of new best-available control technology prime permitted natural gas generation. The DoD-funded microgrid is designed to ensure power to 100 percent of MCAS Miramar’s flight line and support facilities (more than 100 buildings, representing approximately 60 percent of the total military base) in islanded mode. The DoD-funded microgrid is controlled in the new Energy and Water Operations Center, a 3,000-square-foot energy control room that houses the microgrid controller. Through the CEC project, a BESS was added to the DoD-funded microgrid.

Figure 1: Map of the DOD-Funded Portion of the MCAS Miramar Microgrid



Source: MCAS Miramar

MCAS Miramar's peak net load is 15 MW, and its median load is 4.2 MW. Landfill gas and PV provide approximately 52 percent of MCAS Miramar's energy needs. While the LFG is a baseload generating resource, outages occur on a frequent but unpredictable basis due to poor gas quality from the landfill. During these outages, one or both of the 1.6 MW sources of landfill gas shut down, resulting in an instantaneous drop in power output.

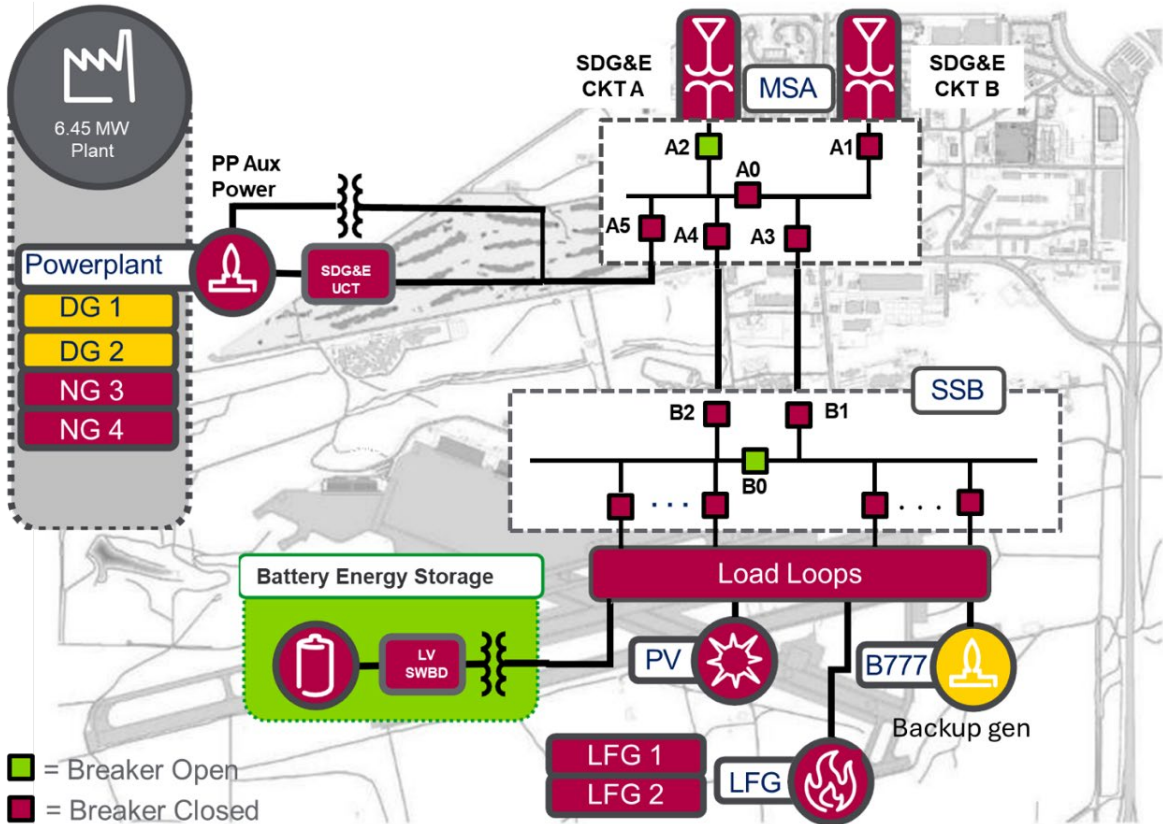
When the MCAS microgrid is in grid-connected mode, this instantaneous loss of power is met by the San Diego Gas & Electric Company (SDG&E) grid, resulting in significant risks for high-demand charges and creating large peaks on the SDG&E distribution grid. When the MCAS microgrid is in islanded mode, the instantaneous loss of power causes poor power quality and dramatically increases the risk of catastrophic microgrid failure. For this reason, the DoD-funded microgrid controller allows only one 1.6-MW landfill gas facility to operate in islanded configuration, while the balance of the load is met by other generation sources including natural gas and diesel generators.

The CEC-funded BESS was designed to enhance the DoD-funded microgrid with the addition of significant new microgrid components, controls, and capabilities. The new equipment and controls expanded the permanent microgrid to coordinate the following distributed energy resources (DERs): LFG, solar PV, BESS, two diesel and two natural gas generators, and a diesel backup generator with parallel capability. The CEC-funded enhancements to the DoD-funded microgrid demonstrated a standards-based and scalable solution that can be replicated at other military bases, ports, waste-handling facilities, and wastewater-treatment facilities world-wide. Figure 2 shows an overall high-level representative single-line diagram of the MCAS Miramar microgrid system showing all the various generating resources and BESS. Figure 3 shows the high-level representative communication architecture, where the microgrid control system communicates with key protection and control systems associated with all the DERs and key protection and metering points.

The project goals were for the addition of the BESS and associated controls to provide significant operational and environmental benefits to the MCAS Miramar microgrid, including:

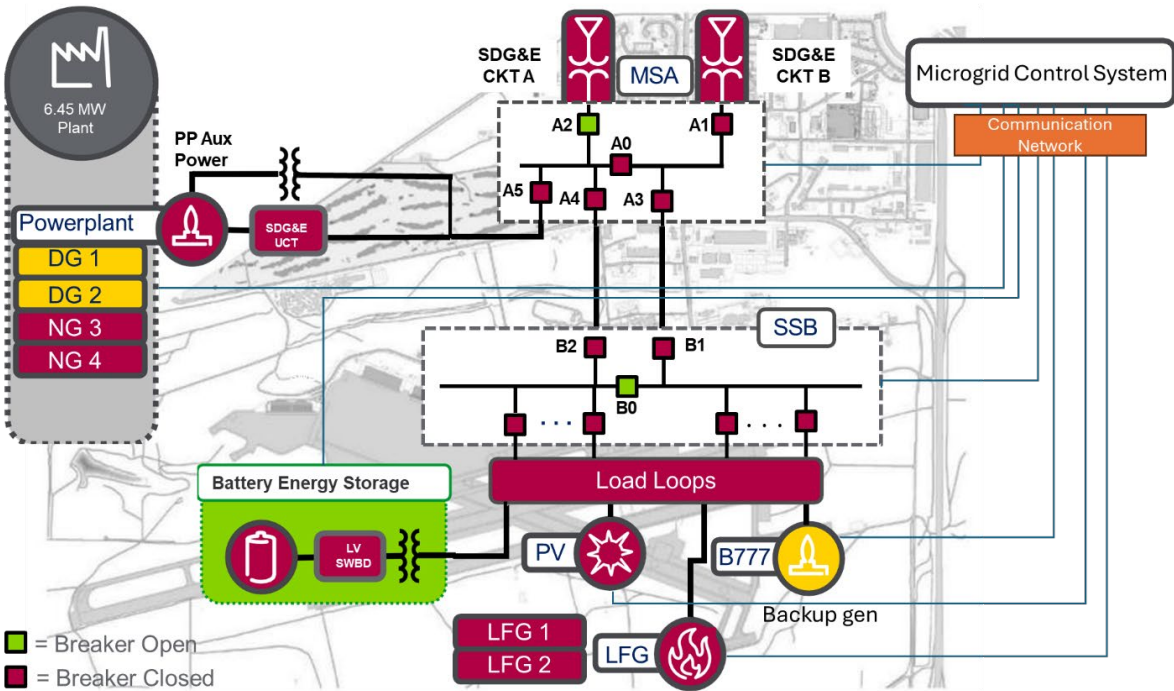
- Displacing diesel generators as the primary source of backup power for the LFG.
- Reducing demand charges when SDG&E is utilized as backup power for the LFG.
- Allowing for increased renewable resource penetration.
- Providing ride-through capabilities in the event of an SDG&E outage.
- Improving power reliability and quality to allow 3.2 MW of LFG to be integrated into the DoD-funded microgrid when it is operating in islanded mode.

Figure 2: High-Level Single-Line Diagram of MCAS Miramar



Source: Schneider Electric

Figure 3: High-Level Communication Architecture of MCAS Miramar



Source: Schneider Electric

CHAPTER 2:

Project Approach

Pre-Existing Generating Resources

Power Plant

A 6.45-MW power plant served as the anchor resource for the microgrid. The power plant was built adjacent to the utility substation, where the main utility feeders power the base. It houses four prime generator units with the emissions equipment required to meet California air quality standards, the capability to store fuel for extended operations, and the electrical distribution equipment required for connection to the electrical utility distribution system. The building also contains an operator control center.

The natural gas generators are operated mainly to minimize peak consumption from the grid, but also when the utility energy tariff is higher than the fuel cost. The diesel generators are faster acting when compared with natural gas generators. The diesel generators can ramp up at 182 kilowatts (kW) per second to reach full load in around 10 seconds, while the natural gas generators ramp at 7 kW per second to reach full load in around 3 minutes. Thus, the diesel generators are designed for immediate action to either reduce peak consumption from the grid or to maintain the power supply when LFG generation drops off. The diesel generators are started and operate continuously until natural gas generators ramp up to full generating capacity. For the islanding mode of operation, these four generators form the grid and regulate the voltage and frequency by balancing supply and demand.

Emergency Diesel Generator

The emergency diesel generator has a 2-MW capacity with paralleling switchgear and enhanced generator controller. This generator is normally in standby mode but can be paralleled with both the normal and the emergency breakers in the closed position with a controllable setpoint. This allows fuel preservation of the anchor resource while adding additional spinning reserves.

Landfill Gas Generator

Two 1.6-MW LFG turbine generators were operated by a third party under a power purchase agreement. This offsite renewable resource utilizes a dedicated 12-kilovolt (kV) line connected to MCAS Miramar's electrical distribution system.

New Battery Energy Storage System

CEC funding, combined with a cooperative research and development agreement between UCSD and the Naval Information Warfare Center, funded the addition of a large BESS to the MCAS Miramar microgrid. The BESS consists of three paralleled ELM MG500 units, each rated at 500 kW peak and 1,100 kilowatt-hours (kWh) of storage capacity, for a system total of 1,500 kW/3,300 kWh. The BESS and BESS inverters comply with various standards, outlined in the references.

The BESS control system features microgrid capabilities for grid-tied and islanded operation, blackstart, optimized operation in response to time-of-use (TOU) tariffs, peak shaving, and demand response conditions. The BESS will minimize the use of diesel generators for grid-connected operations, as it can ramp up or down at 1 MW/sec (full load in 1.5 seconds), which is faster than diesel generators. Immediate action from the BESS both reduces peak consumption from the grid and maintains the power supply when LFG generation drops off. The BESS can operate until natural gas generators ramp up to full generating capacity. Each BESS container consists of an inverter, the battery modules, a battery management system, a fire alarm and control panel, and the BESS controller. One of the BESS works as a master system while the other two work as slaves. The master BESS controller communicates with both the other two controllers and the microgrid control system. The microgrid control system monitors and controls the BESS. Figure 4 shows the installed BESS switchgear (left), consisting of switchgear and protection systems, including ground fault detection, and the three installed BESS containers (right). Figure 5 depicts the full site where the BESS is installed.

Figure 4: The BESS Switchboard (left) and Containers (right)



Source: Schneider Electric

Figure 5: The Completed BESS Installation Site



Source: Schneider Electric

Construction and Installation Lessons Learned

The project resulted in several lessons learned during the construction and installation.

BESS suppliers are slow to meet new Underwriters Laboratories (UL) updates and requirements; fire safety requirements may change throughout the course of a project lifecycle. It is therefore critical that customer specifications are created early in the project and provided to suppliers during the bidding stage. It is important to communicate requirements clearly to suppliers during the bidding stage, including potential changes throughout the project's lifecycle.

Multiple changes to the switchboard design occurred because of base requirements for future BESS expansion and site relocation. The requested design was not standard (according to SDG&E), causing additional design changes to the switchboard. It is therefore important to work closely with utility providers and site hosts to align the switchboard design with their respective standards. Involving experienced design consultants will minimize design changes.

The project suffered from supply chain delays and cost increases. It is therefore important to use suppliers with strong supply chains and leverage to establish clear communication channels to proactively address lead-time risks. It is additionally important to maintain transparency with suppliers regarding material cost increases. Establishing a mechanism for reviewing and approving change orders, with adequate backup documents, will manage cost increases effectively.

BESS Operating Modes

The BESS was designed to operate differently when either the microgrid is grid connected or the microgrid is in islanded configuration. When grid connected, the BESS can operate in the following modes.

- Grid PQ mode, in which the BESS can receive active ("P") and reactive power ("Q") setpoint commands. In grid PQ mode, the BESS can receive any P and Q setpoint commands from the microgrid controller to support a variety of services, including energy arbitrage, peak shaving, voltage control, and energy-loss reductions.
- Grid power factor mode, in which the BESS can receive active power and power factor setpoint commands. In grid power factor mode, the BESS receives setpoint commands from the microgrid controller to support voltage control and reduce energy losses.
- Grid autonomous mode, in which the BESS can be in either charge or discharge mode. In grid autonomous mode, the BESS focuses solely on managing its active power output for peak shaving and energy arbitrage.

When the microgrid is in an islanded configuration, the BESS can operate in the following modes.

- Generator following PQ mode, in which the BESS can receive active and reactive power setpoint commands.
- Generator following Hertz (Hz)-Watts mode, in which the BESS can charge and discharge active power based on real-time frequency sensed by the inverters.

- Grid forming voltage frequency mode, in which the BESS and inverter can form the grid and act as the microgrid master generating asset in response to voltage and frequency commands.
- Grid forming uninterruptible power supply mode, in which the BESS and inverter form the grid and act as the microgrid master generating asset, setting voltage and frequency to the default values of 480 volts (V) and 60 Hz, respectively.

Microgrid Controller and SCADA

Microgrid Control and Optimization Functions

MCAS Miramar's microgrid control system runs using Schneider Electric's EcoStruxure OASys SCADA (supervisory control and data acquisition) software with its integrated power control system (PCS) package. The PCS is UL3141 compliant. This comprehensive solution enables automated energy resource monitoring and control. The PCS, with modular applications, maximizes benefits from both new and legacy generation assets and renewable energy resource integration to provide an advanced microgrid solution. The PCS suite includes the following real-time control and optimization functions.

- Automatic generation control balances power generation with load demand in real time. Automatic generation control maintains system frequency and interchange transactions, with the utility using feedback from proportional integral derivative controls on individual generating units. It minimizes operating costs by recognizing all system and unit operation constraints, including energy reserves, economic cost factors, and generator emission calculations.
- Economic dispatch and unit commitment applications, which form the advanced microgrid controller and provide economic generation and load balance. The PCS calculates dispatch commands for all DERs, considering load and renewable forecasting, utility tariffs, and thresholds for importing and exporting power from and to the utility. The SCADA system mainly creates a communication interface between the PCS and the DERs.
- Islanded operation, during which the system utilizes PV, LFG generation, BESS, and both diesel and natural gas generators in the power plant. The microgrid control system can perform planned and unplanned islanding operations and perform seamless reconnection with the grid. The power plant's generators are grid forming generators that regulate frequency and voltage while islanding sequences are completed, and they additionally consider available spinning reserve capacity of the grid forming generators. Due to limited spinning reserve capacity without the BESS, only one LFG generator was allowed to operate during islanding mode.

Use Cases

The microgrid controller operates the BESS in grid-connected and islanded modes to meet the following use cases.

1. **Manual Scheduling:** Start time, end time, and power level can be manually entered into the PCS.
2. **Landfill Gas or Other Generator Backup in Island Mode:** An LFG trip while in islanding mode can create a load-shedding event, resulting in an outage. The PCS can regulate the BESS to provide additional base energy when any generator (especially LFG) trips.
3. **Peak Shaving and Loss of LFG in Grid-Connected Mode:** The BESS will provide a better and cleaner alternative than diesel generators, considering cost and reaction time of the BESS.
4. **Charging the BESS in Low-Load Scenario in Grid-Connected Mode:** When the PCS is in grid-connected mode and economic mode (not in either peak shaving or demand response modes), the BESS will be charged when low load is detected.
5. **Charging the BESS in a Low-Load Condition in Island Operation:** In islanded operation, the PCS will charge the BESS in low-load conditions as part of remedial actions for overgeneration.
6. **Frequency Response:** The BESS will be activated when there is a sudden load change on the microgrid in islanding mode. Through frequency, watt control of the BESS will react to maintain system frequency through the BESS controller.
7. **Voltage Support via Reactive Power Through the BESS Controller:** The BESS controller will sense the grid voltage and either inject or absorb reactive power to improve the voltage.

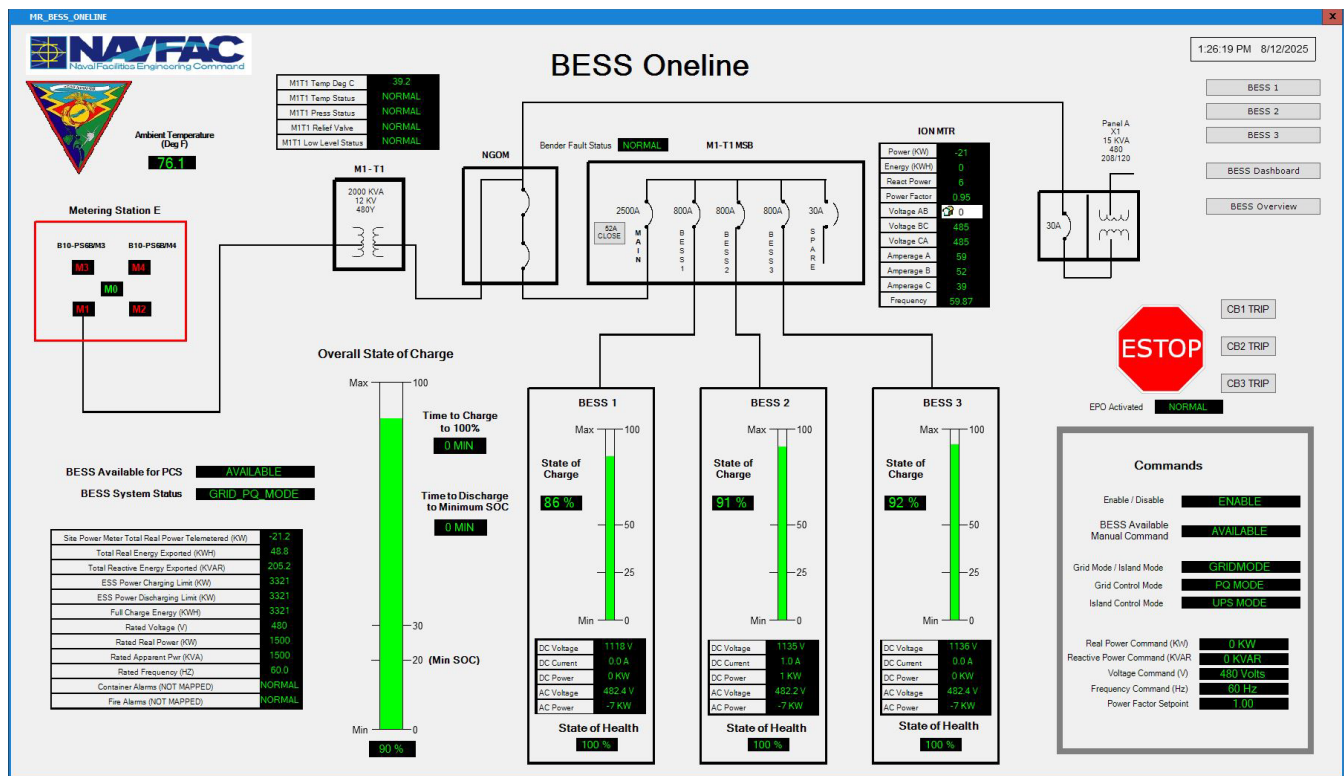
CHAPTER 3: Results

PCS and SCADA BESS Operation

BESS SCADA Operation

Figure 6 shows the SCADA screen for BESS manual operation. The left bottom side "Commands" section in the screen shows all the buttons that can be used for dispatching and operating the BESS in various functional and operating modes. All key information, including measurements, indications, and switch/breaker statuses, can also be monitored using this screen. Individual BESS system screens can additionally be navigated by clicking buttons on the left top corner of the screen.

Figure 6: SCADA BESS Control and Monitoring Screen



Source: NAVFAC

BESS PCS Operation

The BESS has three thresholds for state of charge (SOC) that govern its operation. The minimum permitted SOC is 20 percent, at which point the BESS stops discharging. The BESS will recharge if the SOC is below the charging SOC of 80 percent if the conditions for charging mode operation are met. The BESS stops charging at the maximum SOC of 100 percent.

Grid-Connected BESS Operation

Overview

When the microgrid operates in economic mode, the PCS monitors utility imports and dispatches diesel and natural gas generators and/or the BESS to perform economic operations, based on which optimization is enabled. In economic operation mode (see PCS screen in Figure 7) the PCS can be selected to operate in functional modes. While several functional modes can be activated at the same time, the PCS operates in the respective modes based on assigned priority and functional criteria settings. The priorities are in the following order, with peak shaving as the highest priority.

1. Peak Shaving (15-minute resolution, calculated every 1 minute)
2. Demand Response (1-hour resolution)
3. Energy Optimization (1-hour resolution)
4. Charging

More detail of the functional modes follows.

Figure 7: PCS Microgrid Monitoring and Control Screen



Source: Schneider Electric

Peak Shaving/LFG Backup

The PCS runs both load and renewable forecasts. When a new peak is forecast, or when a new peak is identified in real-time – from a situation like an LFG outage or increased consumption on the base – the PCS dispatches generators and/or the BESS to mitigate the peak. This will achieve cost savings and level the grid import that MCAS Miramar receives from the utility grid.

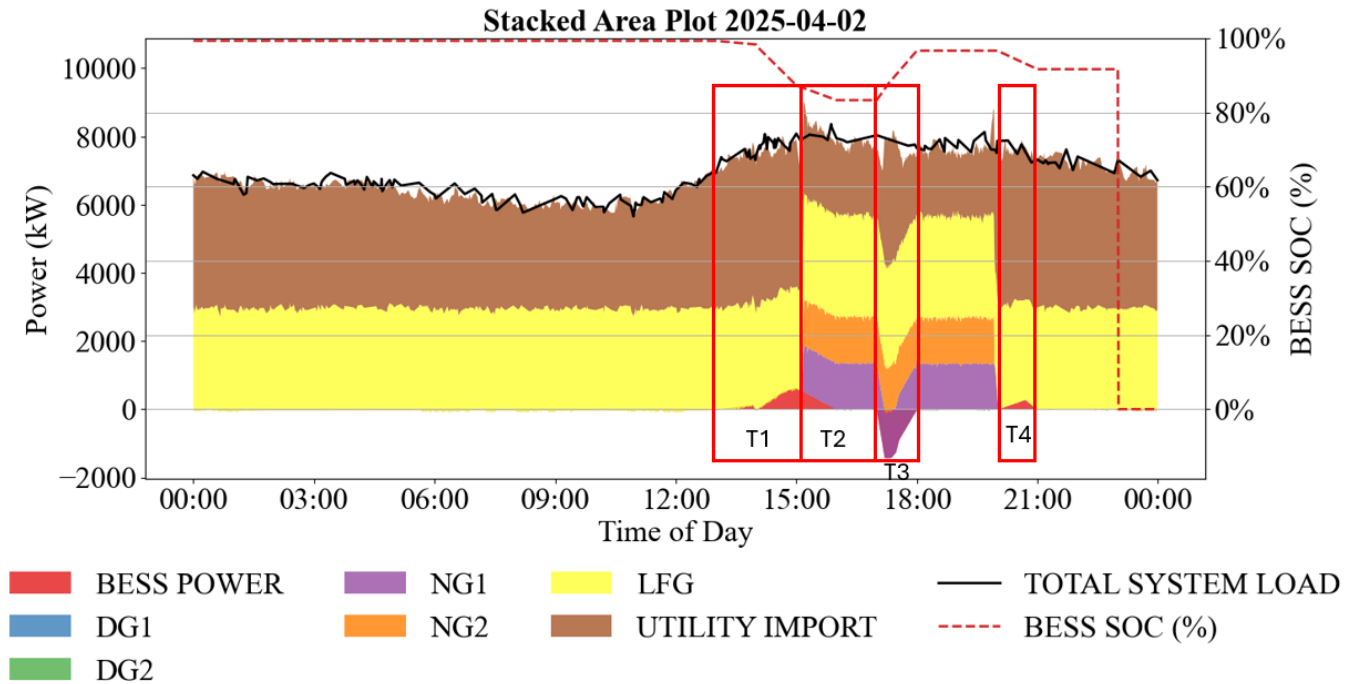
The PCS calculates the 15-minute average electricity import from the utility and stores the highest 15-minute average import for the current billing period as a coincident peak or a non-coincident peak. If the power import from the utility exceeds the coincident or non-coincident peak for more than 3 minutes, the PCS activates the peak shaving function mode.

Once peak shaving is activated by the PCS, it dispatches selected DERs, based on their assigned priorities, to achieve a calculated real time peak of 100 kW less than either the recorded coincident or the non-coincident peak demand. If the BESS is selected, it will be dispatched first with the highest discharge capacity. If the PCS detects that the BESS SOC will reach 20 percent in the next 5 minutes with current dispatch, it will start the natural gas generator if selected. This 5-minute delay considers the natural gas generator startup duration. Generally, when the LFG drops off, it can potentially cause a new peak, and this peak shaving functionally activates and mitigates that potential peak.

Figure 8 shows the stacked area plot for microgrid operation on April 2, 2024, where the positive stacked area shows all generation; the black line shows the overall net load of the system. The secondary y-axis on the right side shows the SOC in percent, and the red dotted line shows the BESS SOC. The negative area shows the BESS charging. Notable behaviors and time periods are marked in the red boxes and discussed here.

For the time period T1, the PCS predicted potential peak consumption, with utility import exceeding the set threshold of around 4 MW. The PCS commanded the BESS to discharge and commanded the natural gas generators to start. Once the natural gas generators ramped up, the BESS discharge reduced, shown in time period T2. To maintain both a minimum utility import and a minimum power output of the natural gas generators, the BESS was commanded to charge for time period T3. As shown in time period T4, the BESS was again commanded to discharge to reduce consumption from the grid and avoid a new peak occurrence.

Figure 8: Microgrid Operation on April 2, 2025, Demonstrating Peak Shaving Mode



Source: NLR

Demand Response

When commanded, the PCS will either start required DERs or make future load reductions to fulfill demand response requests. Demand response is a manually activated, functional mode. The microgrid operator must define energy or power values, energy tariffs, and the durations of demand response events. The PCS will then dispatch the selected DERs, based on both their assigned priorities and operating costs. The BESS will be dispatched first if its SOC is above the minimum SOC of 20 percent. The BESS will be dispatched at the maximum power if it can sustain the entire demand response duration. If not, the constant discharge power will be calculated so that it will be at the minimum SOC at the end of a demand response period.

Since the BESS is the least-cost DER, it will be dispatched with the first priority, while natural gas generators will be dispatched as the next most-cost-effective DERs. The BESS will not be charged during the demand response period.

Energy Cost Optimization

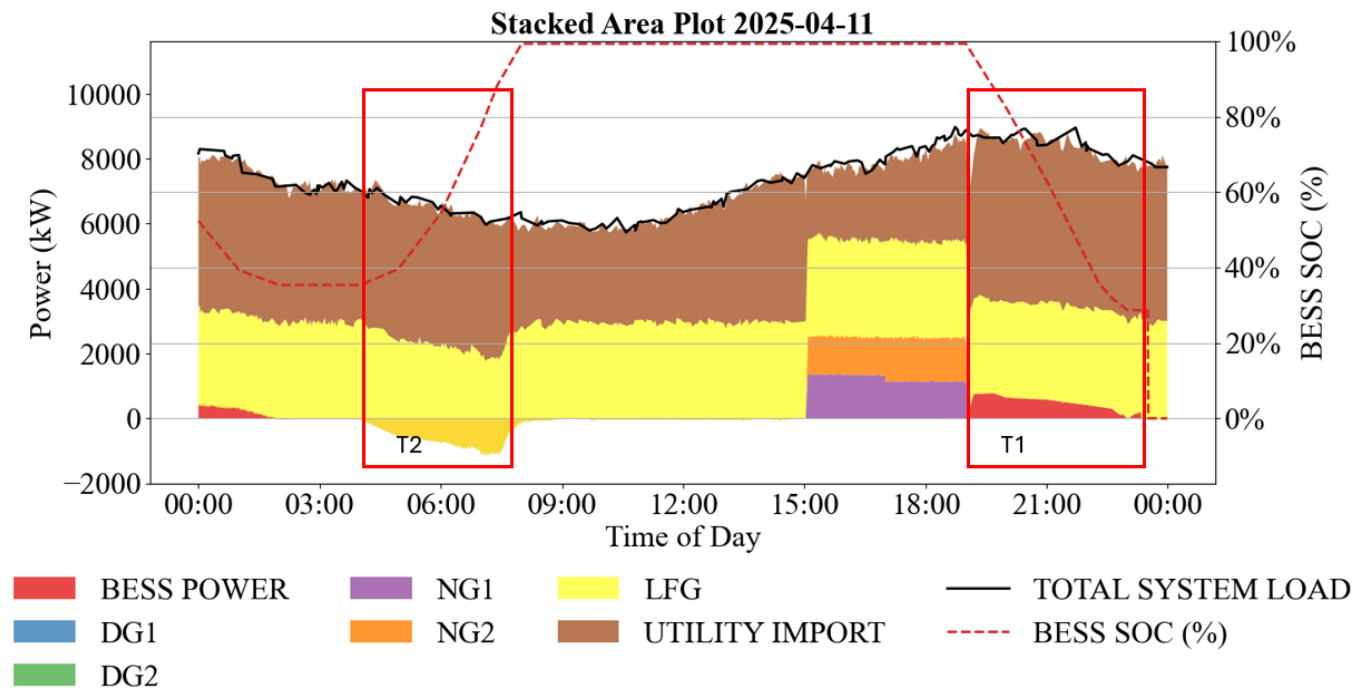
For energy cost optimization, the PCS optimizes the economic dispatch of generators based on their operating costs, to ensure that MCAS Miramar produces or imports the cheapest available electricity. For this energy optimization, the BESS needs to be selected for this functional mode, using the PCS screen.

If the BESS is selected, it will be dispatched to discharge for the next hour at full capacity, considering current SOC values. If it cannot discharge at full capacity, the dispatch power will be reduced so that the SOC at the end of the hour will be at the minimum SOC (20 percent). Since the BESS is the least-cost DER, it will be dispatched with the first priority, while natural

gas generators will be used as the next most-cost-effective DERs if they are selected. The BESS will not be charged during energy optimization.

Figure 9 shows a stacked area plot for the microgrid operation on April 11, 2025. The highlighted red box with time period T1 shows BESS operation for energy optimization, discharging until the SOC reaches the minimum SOC to reduce both overall microgrid operational costs and the use of natural gas generators.

Figure 9: Microgrid Operation on April 11, 2025, for Energy Optimization



Source: NLR

Charging

The BESS will charge only if either the calculated real time peak or the import power from the utility is at least 1,000 kW less than the coincident or non-coincident peaks and the BESS SOC is below 80 percent (L2). Once the BESS starts charging, it will continue to charge to 100 percent if neither demand response nor peak shaving functionality is triggered, as shown in Figure 9 for time period T2. The PCS will dispatch BESS charging power based on the existing utility import and coincident/non-coincident peak values.

Islanded BESS Operation

PCS Islanding Steps

Once a loss of power is detected on the connected utility circuit, there is an automatic throw-over scheme, which will open the transition to the alternate utility circuit if available. If the alternate circuit is unavailable, the configurable timer starts. After that timer expires, the utility breaker is opened to isolate, and it commands blackstart of the microgrid system. The timer is set to expire in 5 minutes; if the grid returns within 5 minutes, the system will be restored to the available utility circuit. Once a blackstart command is triggered, the PCS system initiates a

series of events to create a microgrid island configuration. The timeframe for islanding is configurable, since the time duration between the individual steps is also configurable, allowing time to detect the successful completion of each step. The PCS automatically configures the operation sequences for islanded operation through the following steps.

- Configure the load distribution system at the distribution substation pad mount switches.
- Start up the power plant generators and connect the power plant with distribution.
- Sequentially close the distribution substation breakers to restore power in accordance with both load restoration priorities and system capacity calculations.
- Coordinate the addition of LFG generation.
- Maintain system stability and prioritize critical loads with automated load shed priorities.

BESS Islanding Hz-Watts Mode Operation

While in islanding mode, the PCS operates the BESS in generator-following, Hz-watts mode. Since the BESS provides support only for an instantaneous change in load or generation, it is important to check whether other generators will be able to meet the load in steady state. If the generators cannot meet either the load or small changes in generation, this can cause fluctuations in frequency in a wider range (59.9 Hz to 60.1 Hz).

In Hz-watts mode, the BESS functions as grid/generator, supporting mode and charges or discharges, depending on the frequency of the system.

- If the frequency decreases from 59.97 Hz, the BESS will start discharging according to the ratio percent BESS power output/Hz and, if the frequency decreases below 59.91 Hz, the BESS will discharge at its maximum output.
- If the frequency rises from 59.92 Hz, the BESS will decrease discharging below maximum output and will stop discharging when frequency reaches 59.98 Hz. The BESS discharge rate decreases as the frequency increases.
- If frequency keeps increasing from 60.03 Hz, the BESS will start charging based on the slope of the curve in percent power output/Hz and will charge at maximum output if frequency increases above 60.09 Hz. If the frequency starts decreasing from 60.08 Hz, the BESS will reduce charging power and, if the frequency reaches 60.02 Hz, the BESS will stop charging.

PCS Blackstart Operating Sequences With BESS

The PCS blackstart operating sequence starts the BESS in islanding mode/generator after the main power plant generators have started and warmed up and the main power plant generators have been closed. The blackstart operating sequence is further described in time period T1 in Figure 10.

PCS Reconnecting to Grid Operating Sequences With BESS

Following is the PCS grid reconnection operating sequence with BESS.

1. Start available generators
2. LFG offline
3. BESS switches to generation, follows PQ mode
4. Synchronize to utility
5. Restore remaining load
6. LFG start
7. BESS switches to grid-connected PQ mode

The sequence is based on the fact that the LFG generator is unreliable and should not be active when re-synchronizing with the utility. Therefore, during synchronization, the PCS relies on available generators and the BESS to seamlessly reconnect with the grid. The BESS will be in generation-follow PQ mode to support the generators. After connecting to the grid and restoring the load, the LFG generator can be started safely since there are now ample resources to balance a loss of LFG generation. After the LFG generator is operating reliably, the BESS switches to grid-connected PQ mode to enable all of its use cases.

BESS Site Acceptance Test Results for Islanded Mode Testing

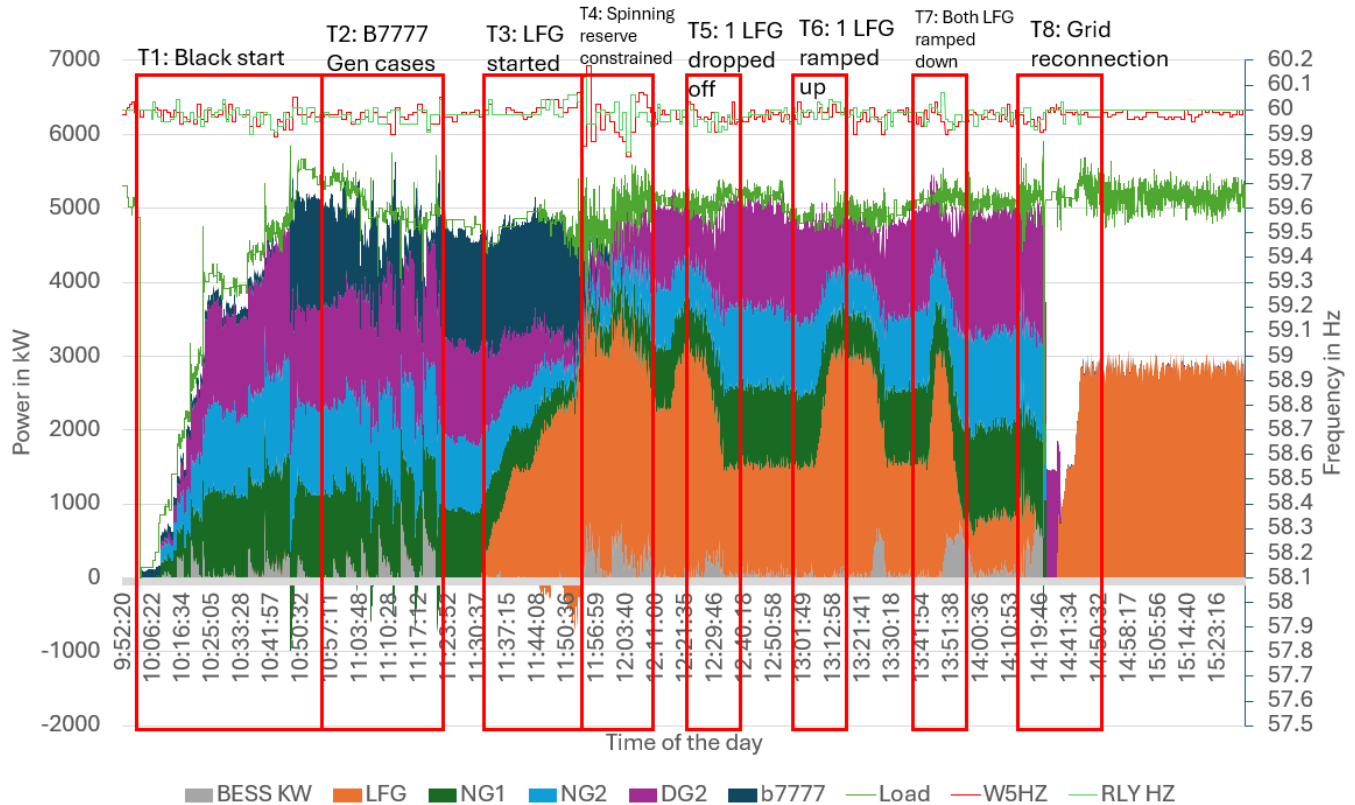
Final commissioning of the BESS took place on November 16, 2024, when the BESS was the primary focus during a 5.5-hour base-wide blackstart exercise. The main purpose of conducting the blackstart exercise was to ensure that the microgrid controls could manage the process of restarting an electrical system after a total or partial shutdown, without relying on external utility power.

The exercise served a dual purpose: to verify that both the microgrid control software and the BESS were fully integrated, and that they could be operated correctly. The tests conducted using the BESS were a culmination of the functional, use case, and performance tests performed in the weeks leading up to the exercise.

The exercise consisted of two blackstarts and began with the recovery and restoration of the microgrid island through application of the microgrid control software in manual mode. Once the island restoration was successfully completed, the microgrid was returned to the utility grid. The system was then adjusted to run the microgrid control software in full-auto mode to verify the capability of conducting island restoration without operator intervention. Island restoration was successfully completed during the second blackstart, proving that the microgrid control software could fully operate the microgrid and the BESS in both manual and automatic modes.

Figure 10 presents a stacked area power plot with frequency line profiles from various metering points, with W5Hz in the legend representing the frequency at the BESS.

Figure 10: Microgrid Operation in Islanding Mode on November 16, 2024



Source: NLR

T1 represents blackstarting the microgrid with both natural gas generators, one diesel generator, the emergency diesel generator, and the BESS. The loads were added in steps, ensuring that the frequency stayed within the allowable range. The gray area shows BESS discharging, because once load was added it caused the frequency to drop. In Hz-watt mode, the BESS discharges if the frequency drops. Once the frequency is back within a normal range, the BESS stops discharging. Note that there are multiple occurrences of BESS discharging for every load increase step. This validates the BESS Hz-watt setting operation and shows that the BESS supports the generators to regulate frequency in a fast and reliable manner.

T2 represents testing the BESS with various emergency diesel generator setpoints to validate BESS settings for LFG drop-off scenarios. The power output of the emergency diesel generator (dark blue) was set to drop in varying steps from 150 kW to 1,350 kW. Each time the generator output dropped, the BESS started discharging to make up the reduction in generator power. Similarly, the BESS started charging once the generator ramped up to full power output. This test scenario validated the BESS operation in Hz-watt mode for the emergency generator drop-off and ramp-up cases.

T3 and T4 represent both LFGs ramping up to keep the emergency diesel generator at full capacity. Once LFGs were ramped up to their full capacity, this caused a condition of more generation than load and an increase in frequency. The BESS started charging close to its maximum power capacity to support the generators in achieving demand and supply balance. However, the addition of LFG caused reduced spinning reserve situations, as the grid forming

generators were operating close to their minimum generating points. This caused the emergency diesel generator to stop and caused a drop in frequency. This, in turn, initiated the BESS to start discharging to regulate the frequency. The frequency stabilized at the end of period T4. This is one of the extreme scenarios for microgrid operation when there is not sufficient negative spinning reserve available, also validating the BESS operation to support the grid forming generators under extreme operating conditions.

T5, T6, and T7 represent LFG drop-off and ramp-up. In period T5, to test BESS performance in Hz-watt mode during LFG drop, both LFGs were commanded to reduce their power output to 50 percent. As the LFGs were ramping down quickly, the BESS started discharging as the frequency dropped. Once the grid forming generators ramped up, the BESS stopped discharging. In time period T6, both LFGs ramped up to 100 percent power from 50 percent. The power plant generators were able to ramp down fast enough to not require the BESS to either charge or discharge. In time period T7, both LFGs were commanded to reduce their power output to 25 percent. The BESS started discharging to support the grid forming generators in maintaining demand supply balance and regulating frequency. The frequency was stable in this time period, validating the BESS operations for the LFG drop-off and ramp-up operating scenarios.

T8 represents a case where LFG generators were stopped and grid reconnection sequences were performed. Successful grid reconnection was achieved during the test.

Economic Performance Analysis

Background

Following its commissioning in November 2024, the BESS was put into regular operation in December 2024. The data collection period began on January 1, 2025, and covered a contiguous 12 months until December 31, 2025. The analysis presented in this section focuses on the economic performance of the BESS, which was measured by its ability to reduce non-coincident demand peaks and associated demand charges. Demand charges are utility charges that penalize high demand peaks with a dollar-per-kW charge based on the highest energy demand during any 15-minute period of the month.

At MCAS Miramar, demand peaks can be caused by load peaks such as high air conditioning usage and by drop-outs of one or both LFG generators, which need to be offset by grid imports. The peak shaving/LFG backup mode on the BESS was designed to reduce demand peaks.

To support this analysis, MCAS Miramar provided SCADA data on a weekly basis that contained high resolution energy time series data of the total load on the base and all major generators on the base (including diesel generators 1 and 2, natural gas generators 1 and 2, landfill gas generation [the sum of both LFG generators], BESS SOC, and BESS energy). The grid import data are the difference between the total load on the base and the sum of all generators. The grid import data correspond to the data that are read by SDG&E's utility meter and are used for billing.

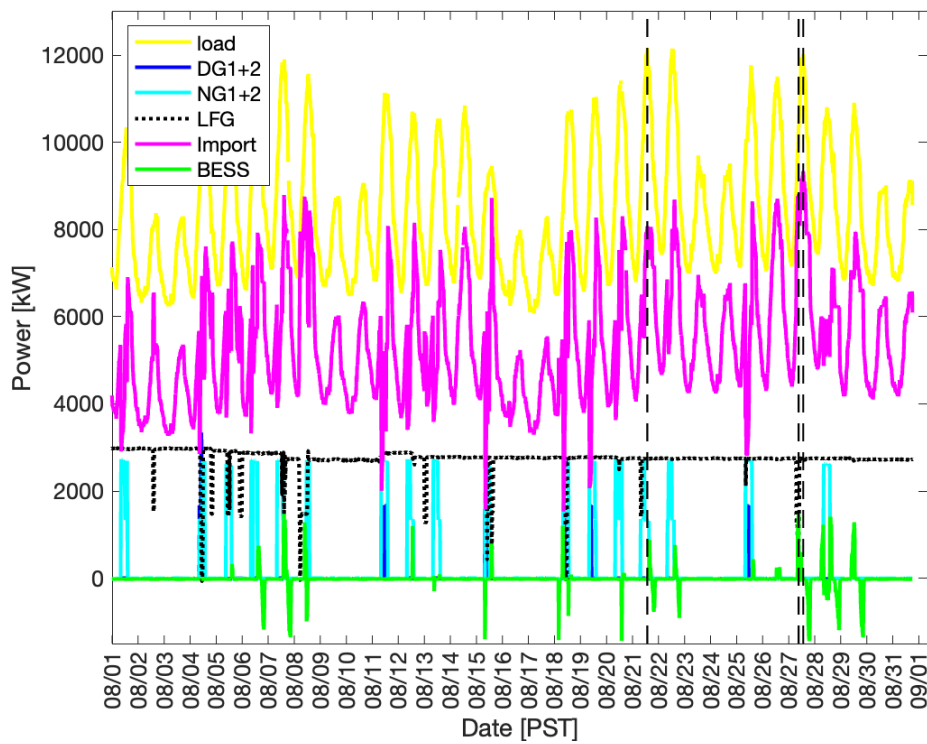
The data were imported, averaged over 15-minute periods, and analyzed over calendar months. The non-coincident demand peak was obtained as the maximum grid import. The following two scenarios compared:

1. The actual situation with all DERs, which formed the basis for the SDG&E billing in 2025.
2. A counterfactual that assumed that the BESS did not exist. For the counterfactual, the BESS energy was subtracted from the grid imports. The difference between (1) and (2) quantifies the contribution by the BESS to reducing the monthly non-coincident demand peak.

Peak Shaving Performance Results

Figure 11 shows an example of the monthly energy time series data. The total load on the base (yellow) and grid import (purple) shows the expected weekly patterns, with lower loads during the weekends. The natural gas generators (turquoise) are frequently run during weekday afternoons or evenings, contributing about 3 MW of power to offset the peak load. The LFG generators (black dashed lines) drop out during 12 time periods of the month; during 3 of those time periods, both LFG generators are offline, resulting in a drop in generation of 3.2 MW. The diesel generators (dark blue) run only occasionally. The BESS (green) is discharged (positive) and charged (negative) on most weekdays. Vertical dashed lines mark times of the peak load (August 21), and peak import with BESS and peak import without BESS (both on August 27).

Figure 11: Monthly Timeseries of Load and Generators for August 2025

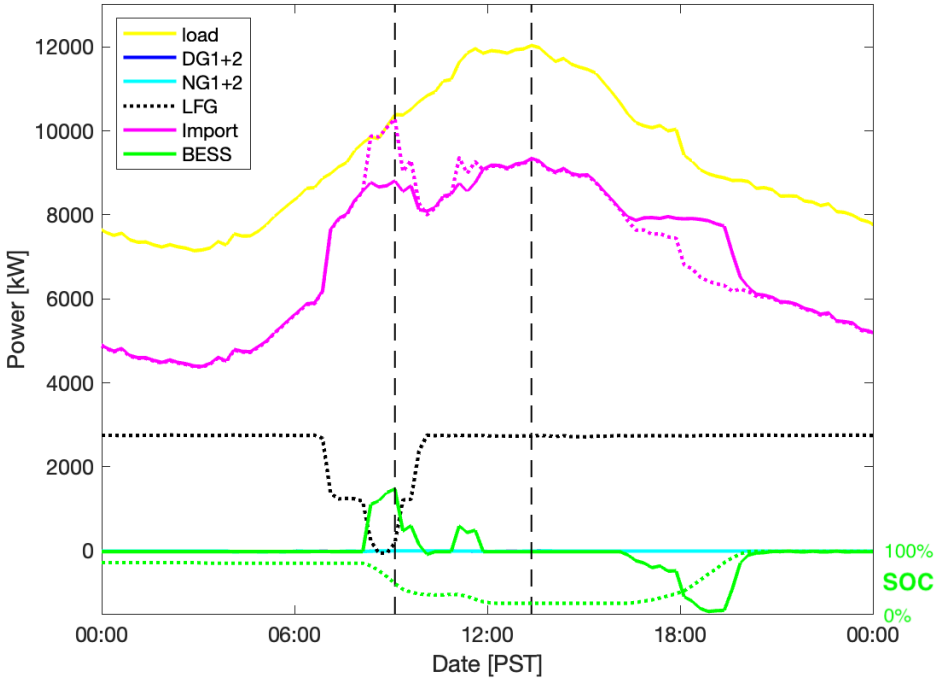


Legend: DG: Diesel Generator; NG: Natural Gas Generator

Source: UCSD

Figure 12 shows the same time series data but only for the day when the peak grid import occurred. The left vertical dashed line shows the time of the monthly peak load without the BESS, and the right vertical dashed line shows the monthly peak with the BESS. On August 27 the diesel and natural gas generators were not dispatched. The load peak (yellow) occurred from about 9 a.m. to 4 p.m. However, the grid import peak started earlier as one LFG dropped off at 7 a.m. As the second LFG dropped off, a new grid import peak of 10,284 kW would have occurred if the BESS had not discharged immediately to balance the loss of the second LFG. The BESS replaced the second LFG for the 1-hour outage by discharging at approximately 1,400 kW; it then reduced the discharge to approximately 500 kW as the second LFG came back online but one LFG was still out. Once LFG was online, the BESS stopped discharging, but its SOC had decreased to 32 percent. When the load of the base increased to 12,000 kW around 11 a.m., a new grid import peak occurred, even though both LFG generators were generating. The BESS responded by discharging again but reached its minimum SOC by 12 p.m. Therefore, when the grid import peaked between 1:15 p.m. and 1:30 p.m. at 9,344 kW, the BESS was no longer able to shave the peak. However, without the BESS the grid import would have been even higher at 10,284 kW from 9 a.m. to 9:15 a.m. while both LFG generators were out. Therefore, the BESS reduced the monthly peak by 939 kW.

Figure 12: Daily Timeseries of Load and Generators on August 27, 2025, when the Monthly Peak Import Occurred



Source: UCSD

Using this approach, the project team quantified the load peak, grid import peaks, and the peak shaving benefit of the BESS for every month of 2025, as shown in Table 1. The BESS reduced monthly peaks by between 33 kW and 1,495 kW, with an average of 962 kW. Detailed descriptions for each month are provided in the Microgrid Performance Report project deliverable. Given that the BESS power capacity is 1,500 kW, this represents the highest

possible peak shaving result and, in fact, the maximum was nearly achieved in January, April, September, and November. During other months the peaks were shaved less, by between 760 kW and 952 kW. The peak shaving was less because of premature complete discharge during a net load peak, leaving the BESS unable to react to new net load peaks (as shown in Figure 12), and insufficiently aggressive discharge during net load peaks (the BESS should have discharged at a higher power). Generally, since future net load peaks are unknown, the BESS dispatch needs to strike a balance between discharging overly aggressively to achieve a lower peak and the expense of risking a premature complete discharge. Given the net load forecast uncertainty and the uncertainty in LFG generator outages, the BESS delivered strong peak shaving results.

The only month with poor performance was March, when the BESS responded too slowly to an outage of both LFG generators. The reasons for this failure were addressed in the PCS and the BESS responded quickly to LFG generator outages throughout the rest of the year.

Table 1: Peak Shaving Results for the BESS for Each Month in 2025

Month	Load Peak (kW)	Import Peak Without BESS (kW)	Import Peak With BESS (kW)	BESS Peak Shaving (kW)
January	8,793	8,170	6,839	1,331
February	9,344	8,637	7,815	822
March	8,963	8,131	8,098	33
April	8,963	6,385	5,102	1,283
May	11,013	8,358	7,516	842
June	10,851	8,653	7,893	760
July	11,130	8,612	7,825	787
August	12,164	10,284	9,344	939
September	12,065	12,027	10,572	1,454
October	10,390	8,185	7,344	841
November	9,280	8,017	6,522	1,495
December	9,474	8,173	7,221	952
Average	10,203	8,636	7,674	962

Source: UCSD

Economic Results

The demand charge rates for MCAS Miramar in 2024 were \$21.05/kW for non-coincident demand and \$3.87/kW for peak demand, and the same rates were assumed for 2025. Therefore, the average non-coincident peak load reduction of 962 kW resulted in \$243,001 in demand charge savings. The peak load reductions that occurred during the on-peak period from 4 p.m. to 9 p.m. (February, July, October, and November) resulted in an additional \$15,267 in savings. The total demand charge savings from the BESS were \$258,268.

The business case analysis considered the capital and installation costs and demand charge savings to analyze key economic metrics. The savings associated with dispatching the microgrid assets came from the avoided cost of utility purchases. Given the capital expenses of \$3,249,933 for the BESS, the BESS transformer, and the microgrid controls software, the year-1 savings of \$258,268 resulted in a simple payback time of 13 years. The simple payback time is defined as the ratio of capital cost divided by the utility bill savings in year 1.

The net present value (NPV) discounted all future costs and revenues to arrive at the net value at the present time. Given the lifecycle savings of \$3,572,384 after 20 years, the NPV of the BESS is \$322,451.

CHAPTER 4:

Knowledge Transfer

The key technologies validated in this project are related to microgrid controls and applications for BESS in microgrids for energy cost optimization and facility resilience. The research team's industry partners Schneider Electric and Dynalectric San Diego leveraged their respective experiences through the deployment of these cutting-edge technologies at MCAS Miramar to build in-house professional expertise, understand and reduce costs, and demonstrate the benefits of microgrid technologies to other customers.

The National Laboratory of the Rockies (NLR) provided direct transfer of information to other federal agencies through its participation in the Federal Energy Management Program, including training webinars, the Federal Utility Energy Partnership Working Group, and its direct support of other DoD installations.

MCAS Miramar provided knowledge transfer through Marine Corps and Navy energy meetings and workshops.

- MCAS Miramar microgrid subject matter experts contributed to writing codes and standards for the unified facilities criteria (UFC). The meetings, review, and final review occurred in 2022-2023 for the UFC code, implemented in 2024.
- MCAS Miramar microgrid subject matter experts also engaged with the U.S. Marine Corps Naval Postgraduate School in Monterey, California, in August 2025 to create master's program classes where MCAS Miramar is showcased as one of its functional and successful microgrid systems and case studies.

MCAS Miramar also hosted tours for key stakeholders, particularly colleagues from other military bases, to showcase the microgrid. Tours at MCAS Miramar usually occur several times a month. Notable tour guests include members of Congress, the Secretary of Defense, CEC members, utilities' personnel, active-duty military, and energy managers from around the world. Tours have occurred since 2020. Some 2025 notable tours include the following.

- February 2025: Naval Facilities Engineering Systems Command (NAVFAC) Europe stakeholders building microgrids on foreign bases
- May 2025: Naval Facilities Engineering and Expeditionary Warfare Center (EXWC) and Army Prime power group personnel
- June 2025: CEC personnel
- July 2025: Southern California Edison personnel for its upcoming Catalina Island project
- July 2025: U.S. Marine Corps Marine Expeditionary Force headquarters personnel
- September 2025: NAVFAC Southwest Commanding Officer

The project team trained the MCAS Miramar workforce to operate and maintain the microgrid. Schneider Electric prepared a microgrid training plan for microgrid operators that included a

training schedule and training materials. Schneider Electric conducted the training according to the microgrid training plan.

Subcontractor GC Green conducted outreach to the veteran workforce and business community. GC Green prepared a Miramar workforce equity plan that includes recommendations on specific ways to successfully engage disadvantaged communities and veterans in workforce opportunities for similar microgrid projects. Recommendations include: more clearly defining microgrid construction and operation workforce needs; conducting further research on veteran workforce opportunities in the supply chain; and involving community colleges to support training, skills development, and microgrid certifications.

CHAPTER 5:

Conclusion

This research project demonstrated the successful integration of a BESS into an existing microgrid at MCAS Miramar. The construction process yielded several lessons learned related to compliance with evolving codes and standards, reconciliation of government and utility requirements early on, scheduling, and contractor management. An in-depth commissioning process validated the operational functionality of the BESS. The extensive 5.5-hour base-wide blackstart exercise effectively demonstrated the successful integration of the BESS controls into the existing microgrid control software, affirming the ability of the BESS to support restoration of electrical systems following a shutdown. Both manual and automatic modes were rigorously tested, confirming the system's reliability and performance under real-world-based outage conditions.

Extensive BESS health and performance metrics were collected through SCADA communications. The data demonstrate that the BESS aligned with design specifications, operational requirements, and use cases. This monitoring capability of the microgrid system enhanced the ability to conduct ongoing analysis and optimization.

Through 12 months of continuous BESS operation, MCAS Miramar demonstrated the ability to leverage this advanced technology to enhance energy management capabilities and contribute to a more resilient and sustainable energy infrastructure. Through the BESS, the monthly peak demand of MCAS Miramar was shaved by an average of 962 kW, providing annual demand charge savings of \$258,268. Given capital expenses of \$3,249,933 for the BESS, the BESS transformer, and the microgrid controls software, the year-1 savings of \$258,268 resulted in a simple payback time of 13 years. The system is fully operational, reducing energy costs and enhancing reliability while supporting MCAS Miramar's economic and sustainability goals.

Benefits to California Ratepayers

California ratepayer benefits are as follows.

Lower Costs: A carefully orchestrated BESS dispatch through the microgrid controller decreased customer costs by saving \$258,000 in demand charges.

Greater Reliability: Although it was not tested during the evaluation period due to a lack of demand response opportunities, ratepayer reliability benefits will accrue as more BESS technology reduces grid peak demand during demand response events. Reduced peak demand and reduced power fluctuations will further reduce wear and tear on distribution equipment and allow deferment of costly distribution system upgrades.

Public Health and Environmental Benefits: These benefits were achieved through local emission avoidance by not operating 1.8-MW diesel generator during short LFG outages.

List of Terms/Glossary

Term	Definition
AGC	automatic generation control
BESS	battery energy storage system
CEC	California Energy Commission
DER	distributed energy resource
DoD	Department of Defense
EPIC	Electric Program Investment Charge
Hz	hertz
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LFG	landfill gas
MCAS	Marine Corps Air Station
MW	megawatt
MWh	megawatt-hour
NAVFAC	Naval Facilities Engineering Systems Command
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NLR	National Laboratory of the Rockies
NPV	net present value
PCS	power control system
PQ	real power – reactive power
PV	photovoltaic
SCADA	supervisory control and data acquisition
SDG&E	San Diego Gas & Electric Company
SOC	state of charge
TOU	time-of-use
UL	Underwriters Laboratory
UCSD	University of California, San Diego
USMC	U.S. Marine Corps
V	volt

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Project Deliverables

- Microgrid Design Report
- Commissioning Plan
- Commission Report
- Measurement and Verification Plan
- Demand Limiting Demonstration and Verification Report
- Data Collection Plan
- Microgrid Performance Report
- Microgrid Training Plan
- Miramar Workforce Equity Plan
- Business Case Report
- Project Fact Sheet
- Technology/Knowledge Transfer Plan
- Technology/Knowledge Transfer Report
- CPR Report #1
- CPR Report #2

Project deliverables, including interim project reports, are available upon request by submitting an email to pubs@energy.ca.gov.