

Business & Technology Surveillance

Microgrids with Energy Storage: Benefits, Challenges of Two Microgrid Case Studies

(Summary of CEATI report: *Integration and Coordination of Energy Storage within Microgrids*—Part 2 of 3)

By Alice Clamp

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SUBJECT MATTER EXPERT ON THIS TOPIC

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ARTICLE SNAPSHOT

WHAT HAS CHANGED IN THE INDUSTRY?

Microgrids have the potential to help utilities and their customers by mitigating long-term outages from extreme weather events, providing grid services, and improving reliability. Improved performance and decreasing costs for distributed energy technologies have resulted in increased microgrid deployments, many of which are beginning to incorporate energy storage.

WHAT IS THE IMPACT ON ELECTRIC COOPERATIVES?

The processes and considerations for enabling resilient microgrids lack a list of best practices that can guide their practical implementation, particularly in reference to developing energy storage technologies.

WHAT DO COOPERATIVES NEED TO KNOW/DO ABOUT IT?

Rural electric cooperatives, as well as end-users and developers, need to understand how microgrids with energy storage are currently being used and how they may be most effectively used in the future. By learning how energy storage can be used in different microgrid applications, cooperatives can better plan current and future uses. They will also understand how communication between the battery management system and the power conversion system is critical in efficient operation of the battery, and in turn, overall microgrid operation. Cooperatives should also learn about best practices that can be applied to all microgrids that incorporate energy storage.

Introduction

Microgrids have the potential to help utilities and their customers by mitigating long-duration outages from extreme weather events, providing grid services and improving reliability. Improved performance and decreasing costs for distributed energy technologies have resulted in increased microgrid deployments, many of which are beginning to incorporate energy storage.

However, the processes and considerations for enabling resilient microgrids lack a list of best practices that can guide their practical implementation, particularly in reference to developing energy storage technologies.

This series of three *Surveillance* articles evaluates how energy storage is currently being used in microgrids and develops best practices for integrating energy storage technologies.

The articles are based on a report—*Integration and Coordination of Energy Storage within Microgrids*—that is the result of a collaboration between utilities, CEATI's Strategic Options for Integrating Emerging Technologies and Distribution Energy Interest Group, and ICF (a consulting and technology services firm).

The work—and the findings—are divided into four tasks:

- Task 1: Research and analyze current energy storage and microgrid operational structures
- Task 2: Conduct surveys of stakeholders involved in integrating energy storage systems with microgrids
- Task 3: Develop case studies based on stakeholder experiences with energy storage and microgrid integration
- Task 4: Identify best practices for the integration and coordination of energy storage with microgrids.

The **first article** discussed Tasks 1 and 2. This article, the second in the series, discusses two of the four use cases from Task 3. The third article will discuss the other two use cases, and provide best practices for implementing energy storage within microgrids.

Task 3: Case Studies for Microgrids with Energy Storage

For this task, different microgrids with energy storage were analyzed in order to:

- Summarize how energy storage technologies had been implemented within each microgrid
- Review the primary drivers and motivations for developing the microgrid and incorporating energy storage
- Highlight key design and operational features, including energy storage integration
- Review microgrid ownership structures and financing details
- Summarize the project benefits, challenges and potential best practices for incorporating energy storage in each microgrid.

CASE STUDY 1: UNIVERSITY OF CALIFORNIA, SAN DIEGO

Background

The University of California, San Diego (UCSD) is a public research institution and campus community of more than 45,000 people. The UCSD microgrid serves students, faculty and guests with resilient on-site power across 1,200 acres and 16 million square feet of building space, producing approximately 47 MW of peak capacity on an annual basis.

Project Drivers and Motivations

There are several key factors that prompted the original formation of the UCSD microgrid, as well as its many additions in recent years. The primary drivers and motivations for the UCSD microgrid include:

- Improving power quality and reliability for all campus operations and, in turn, increasing the survivability and safety of all critical operations
- Providing a means of self-sufficiency through on-site generation, and balancing campus energy supply and demand more efficiently by incorporating a variety of energy and storage resources
- Providing time-based energy cost savings for the UCSD campus compared with grid power

- Reducing the overall greenhouse gas emissions of the campus through renewable energy integration and use of a biogas-fueled fuel cell generator
- Promoting campus research and collaboration through the ongoing integration and testing of new technologies.

Microgrid Equipment and Technologies

The UCSD microgrid currently produces 92% of the entire campus' energy needs, with the remaining 8% coming from the California Independent System Operator (ISO), delivered through a San Diego Gas and Electric substation. The energy generation technologies, controls systems, and other resources included in the microgrid – together with a simple schematic of the UCSD microgrid – are shown in [Appendix A](#).

Microgrid Design and Operation

Key Operational Features

The UCSD microgrid is a complex and evolving mix of resources and technologies that provide a number of services to the UCSD campus. These resources and technologies have specific design features and characteristics that allow them to function within the microgrid. A number of key features for resources and the microgrid as a whole include:

- **Utility grid connection:** The campus is connected to the California ISO by a single 69 kV substation.
- **Microgrid control:** The Central Utilities Plant control room manages the campus' evolving microgrid, with real-time energy monitoring that ensures that the energy systems work in tandem with the utility grid and efficiently integrate all distributed energy resources.
- **Bypass stacks at the cogeneration plant:** steam bypass stacks enable rapid starting of the central utility plant turbines, if a power interruption occurs.
- **PMU monitoring system:** Phasor Measurement Units (PMU) or synchrophasors monitor the utility grid feed and notify the central utilities plant of potential power interruptions, giving the campus an opportunity to reduce or transfer loads to minimize the potential effects of power disruptions.
- **Resistive load bank on fuel cell:** The fuel cell requires roughly eight hours to restart if it goes offline. In the event of a power outage, the resistive load bank helps the fuel cell restart quickly by apportioning electrical output from the fuel cell and allowing a quick transition once grid power is restored.
- **Automatic substation control system:** An automatic substation control system allows the campus cogeneration plant to operate independently during an interruption or loss of San Diego Gas and Electric grid-supplied power.
- **Paralleling emergency automatic transfer switches:** If the campus experiences an interruption of power, the paralleling automatic transfer switches enable select campus emergency generators to work in parallel with either the utility grid or microgrid.

Energy Storage Integration and Deployment

The energy storage systems that provide direct service to the campus microgrid are the thermal energy storage system and the advanced energy storage system (92.5 MW battery). The most important function of these systems is to control and constantly balance campus supply and demand. They act as a shock-absorber to provide flexibility to the UCSD microgrid, allowing UCSD to charge the systems off-peak with onsite generation, and use the stored energy on-peak when utility prices are the highest.

In addition to the battery storage system, the thermal energy storage system (39,000 ton-hours of chilled water) is cooled at night during off-peak hours when electricity rates are lower, providing arbitrage opportunities for UCSD and also minimizing the use of electric-driven chillers. These key functions of the storage systems are made possible with the advanced control systems and microgrid platform. The energy storage systems are also a key factor in demand response market participation.

Controls and Communication Systems

The UCSD microgrid incorporates a high-end master controller, which provides optimization setpoints and constraints for all generation, storage and loads with hourly computing to optimize operating conditions. The controller receives hundreds of thousands of inputs per second, and is supported by software that processes market price signals, weather forecasts and the availability of microgrid resources. The UCSD campus has installed power meters throughout the main electrical lines and at the buildings' main circuit breakers to provide data inputs to the system.

In addition to microgrid optimization, SEL's POWERMAX utility microgrid control platform has been integrated with UCSD's on-site power generation, load balancing and energy storage systems. The platform uses more than 100 SEL devices, such as protective relays, automation control equipment and communications equipment in order to assist with continuous load balancing, distributed energy resource integration and unstable load detection and protection schemes.

The control system is used to detect, respond to and mitigate potential microgrid blackouts through synchrophasor-based monitoring that initiates a primary load shedding scheme and enables microgrid islanding.

Johnson Controls provides all building control systems through an energy management system that helps reduce energy consumption based on building occupancy. The system uses smart meters placed throughout campus, and assists in coordinating demand-response efforts. UCSD is the largest participant in the San Diego Gas and Electric demand response market, at times shedding between 6 MW and 10 MW when called upon.

Microgrid Ownership Structure and Financing

The ownership of microgrid assets and operations is split between UCSD and San Diego Gas and Electric. Given the diverse set of resources deployed to the microgrid, there are a number of financing structures and initiatives that have been used to reduce overall

system costs, including: power purchase agreements (PPAs); clean renewable energy bonds; and grants.

- **Power Purchase Agreements (PPAs):** UCSD has a PPA with Solar Power Partners for the 1.2 MW solar PV system. This has allowed UCSD to take advantage and incorporate solar PV without any upfront cash. The estimate average cost of the UCSD solar PPA is currently \$0.185/kWh. The 2.8 MW fuel cell project also uses a similar PPA arrangement. The molten carbonate fuel cell runs on waste methane that is supplied from the Point Loma wastewater treatment plant. BioFuels Energy supplied the upfront capital for the system and supplies biogas to SDG&E. The project used California's self-generation incentive program funds and takes advantage of a 30% federal investment tax credit.
- **Clean Renewable Energy Bonds (CREBs):** UCSD will receive a total of \$15 million for 15 projects from Clean Renewable Energy Bonds, which have interest rates lower than the market, through the Internal Revenue Service, which has allocated \$154 million for financing renewable energy projects for public facilities.
- **Grants:** For details on grants, see Section 4.1.3.3 in CEAT's *Coordination of Energy Storage within Microgrids*.

Key Takeaways from Interviews

Interviews were conducted with several individuals involved in the design and operation of the UCSD microgrid, including Byron Washom, director of strategic energy initiatives at UCSD. Washom emphasized the importance of an advanced, robust and dependable controller system, which can yield significant operational and economic efficiencies.

With an advanced control system and smart grid design, less storage is required for load balancing. The thermal storage and lithium ion battery system at UCSD represent a small fraction of the total microgrid loads, but have been effective at continuously balancing energy supply and demand in daily operations.

Washom attributed the UCSD microgrid success to significant planning efforts in identifying and pursuing various energy financing options, tax credits and funding options. UCSD employs financial mechanisms like PPAs for commercially established technologies, like CHP, while using funding opportunities for demonstration projects involving prototype technologies.

Washom also discussed the multiple measures that UCSD has undertaken to ensure the technologies used within the campus met sustainability goals of the organization, including aspects related to after-life disposal and electronic waste. Washom also stressed that with the advancement in monitoring and controlling systems, cybersecurity will pose a critical challenge, especially as these are billions of dollars of research and assets connected to the UCSD microgrid system.

Key staff from Schweitzer Engineering Laboratories were also interviewed to provide detail on control systems and control platforms. One takeaway from these interviews included precautions around programming microgrid and energy storage controllers for different use cases without considering the life cycle effects of changing operational characteristics.

Energy storage can strengthen the short-term value proposition of a microgrid, but significant attention also needs to be paid to the long-term value of energy storage, including the effects of different cycling patterns on equipment degradation. At lower operational efficiencies, energy storage may not provide the same value proposition. The cost and frequency of battery replacements also need to be considered when evaluating use cases that could shorten a battery's life span.

Project Benefits, Challenges and Best Practices

Project benefits

The UCSD microgrid has provided significant benefits to the campus community and UCSD's energy system as a whole. The use of multiple energy resources and technologies at UCSD has demonstrated the viability of advanced microgrids integrating energy storage and multiple distributed energy resources with advanced controls and optimization strategies.

A summary of the benefits includes:

- The microgrid has also improved energy security on campus through the advanced microgrid controls and load shedding schemes, which allow for autonomous islanding, increasing the reliability and resiliency for critical loads, such as university hospitals, student housing and fire/police stations.
- The microgrid has promoted forward thinking technology deployment, collaboration and innovation to students, researchers and other universities, and has positioned UCSD as a facilitator of innovative technology testing.
- The arbitrage opportunities from energy storage systems have provided economic benefits to the campus and allowed researchers to identify individual technology use cases (solar + storage) and the key considerations that make these cases most effective.
- The microgrid has allowed UCSD to significantly reduce peak demand and energy costs for the university; campus energy costs have been reduced by more than \$8 million per year.
- The advanced controls and communication systems allow for real-time modeling and optimization in order to maximize efficiency for all included technologies and resources.

Project Challenges

While the UCSD microgrid has provided many benefits to the campus and UCSD as a whole, there have been a number of challenges in incorporating the many different resources and new technologies. They are:

- Originally integrating and optimizing the diverse set of energy assets, and continually integrating new technologies, control and communication systems, and demand response energy savings measures on campus. In addition to the ongoing integration and optimization of resources, understanding how to coordinate new resources with existing infrastructure and the systems already in place.
- Capturing, storing and understanding how to use the vast amount of energy monitoring

data, given the variety of data protocols and output formats associated with the complex microgrid system. Roughly 200 power meters have been installed on campus power lines and at circuit breakers. OSIsoft's PI system has been used to capture, translate and store data from the meters and sensors to monitor data outputs and coordinate energy asset operations. UCSD continues to work with SDG&E and other stakeholders to understand the potential of this data and its use within the microgrid optimization framework.

- Planning for further renewables integration, because rooftop space for solar PV is limited and parking lots are temporary deployment locations and may not serve as permanent locations well into the future.
- There have been a number of environmental safety and health inspection permissions given for fire and chemical hazards with various energy storage technologies.
- Cybersecurity risks are increasingly important for a university with a number of tangible and intangible resources and research assets, and understanding the concerns in the context of the microgrid will be an important factor in future decision making.

Best practices

The UCSD microgrid has been successful in employing various distributed energy resource technologies by overcoming multiple challenges on the technical, operational, financial and environmental fronts. Some of the essential practices that have contributed to its success are:

- When selecting and engineering advanced microgrid controller systems, it is critical to thoroughly assess the robustness, operational warranty and commercial field-tested results of the controller technologies.
- The operational purpose and functionality of a microgrid should inform the energy storage requirements. For instance, the size and type of storage system will vary based on whether the microgrid is being used to provide grid-support services (wholesale power market participation, ancillary services) or being used internally for balancing energy system services in island mode.

- When evaluating the economic benefits of different use cases for energy storage, degradation and cycle life for batteries – and their associated effects on long-term project economics – should be considered and thoroughly analyzed.
- Identify and select the appropriate financing method (or combination of methods) for a new technology based on its market viability and available funding/incentives at the federal, state and local level.
- It is important to take appropriate physical safety measures while deploying energy storage technologies. For instance, fire safety and prevention measures are extremely important when using large battery systems with varying chemical combinations.
- Identifying vulnerabilities and taking measures to prevent cybersecurity threats, ranging from data and privacy issues to major operational failures of the microgrid monitoring and controller system, is of critical importance, and will only become more important as technologies advance.
- UCSD has realized the importance of employing novel methods to develop interest and encourage participation in programs that can support microgrid operations. For example, UCSD promotes “EV Happy Hours” (periods with low-cost EV charging) during periods of highly forecast solar output, to help balance the microgrid energy system.

CASE STUDY 2: KODIAK ISLAND, ALASKA

Background

Kodiak Electric Association (KEA), a rural cooperative utility, operates an isolated electrical grid system serving roughly 5,800 individual members on Kodiak Island, Alaska. In 2004, the KEA board voted to pursue an ambitious plan to generate 95% of its electricity from wind and hydroelectric resources by 2020. By 2014, the utility microgrid – which has peak demand of approximately 28 MW – had already surpassed that goal, producing more than 99% of its power from wind and hydropower, with support from flywheel and battery energy storage systems.

The Kodiak Island microgrid offers an excellent example of how different types of energy storage technologies can function within an islanded microgrid that supports a variety of loads and generation sources.

Project Drivers and Motivations

KEA has operated an islanded electric grid system or island microgrid since 1941. However, given the need to upgrade port infrastructure and move away from costly diesel generation, the integration of new energy resources and storage technologies has played a key role in developing the microgrid as it exists today. The main drives for pursuing these upgrades were:

- Wind turbines were installed in 2009 (4.5 MW) and 2012 (4.5 MW) in order to decrease the reliance on costly diesel fuel (estimated to save 20,000* gallons per year).
- In 2012, the City of Kodiak was planning to install a 2 MW electric crane at its Pier III to replace the older, less efficient diesel-powered crane. The new electric crane would create destabilizing power fluctuations and undesirable battery cycling, so a new flywheel energy storage system (FESS) was installed to effectively integrate the crane load onto the KEA grid and provide frequency and voltage regulation.
- The wind and FESS projects would play a key role in decreasing the dependency on diesel fuel that had been previously used to power the crane, and operated inefficiently as a spinning reserve on an as-needed basis.
- The project would also allow for the integration of a greater number of renewable resources (hydro and wind) and provide grid stabilization services given the variability of renewable energy generation.
- These technological upgrades and additions would also serve as a model for remote communities looking to integrate variable loads, renewables and /or energy storage onto their system.

Microgrid Equipment and Technologies

The Kodiak Island microgrid has historically relied on diesel and hydroelectric power generation, but new hydroelectric turbines, wind turbines and energy storage technologies have

been added in recent years. All equipment and technologies deployed within the microgrid are detailed below and the energy generation technologies, controls systems, and other resources included in the microgrid are shown in [Appendix B](#).

Microgrid Design and Operation

Key Operational Features

The Kodiak Island microgrid has undergone a significant number of changes in recent years. The integration of new resources and technologies has led to the need to continuously balance the overall system and respond to frequency fluctuations. The characteristics detailed below highlight some of the key operational features and considerations for the newly incorporated technologies:

- Terror Lake is the largest form of energy storage that is deployed within the microgrid, generating roughly 124,400 MWh of electricity annually, and providing long-term storage of excess wind energy as opposed to responding to intermittent loads on a second-to-minute (BESS) or microsecond basis (FESS).
- The BESS stabilizes variable wind generation on a second-to-minute basis and also provides frequency regulation. Both the BESS and FESS are able to inject both real and reactive power to the microgrid and provide spinning reserves for the large load fluctuations while the newly installed electric crane is in use.
- Large frequency changes or disturbances were the main driver when originally integrating the BESS with the wind and hydro generation, although the primary activity of the BESS has been in response to microsecond frequency fluctuations on the system. The integration of the FESS reduces stress and increases cycle life on the BESS by being able to respond to microsecond frequency changes on the system. This allows the BESS to function as originally designed.

Energy Storage Integration and Deployment

The Terror Lake hydro project has long served as the main source of energy storage within the microgrid. Water is stored in the form of potential energy and is released for hydroelec-

*correction: diesel fuel estimated savings of almost 2,000,000 gallons per year.

tric power generation as needed. Terror Lake provides long-term storage for the excess wind energy on an annual basis. The Terror Lake system is also able to respond to over-frequency disturbances caused by high penetration of wind energy onto the microgrid through an internal governor system that can rapidly limit hydro power output.

However, given the requirements for responding to over-frequency disturbances and the short-term storage required with variable wind power, the incorporation of the BESS was needed in order to stabilize the highly variable wind generation and provide additional services for under-frequency disturbances when wind output suddenly drops.

The incorporation of the BESS into the Kodiak Island microgrid has allowed all storage resources to operate more efficiently and effectively. The FESS stores short-term energy and responds to frequency fluctuations on a microsecond basis that are caused by the electric crane.

The FESS is also critical in responding to other over-frequency disturbances produced by the sudden increase in wind output that the Terror Lake system cannot address. It is designed to respond first to these microsecond frequency variations, and is also able to inject both real and reactive power onto the microgrid through the ABB inverters within the individual Power Store flywheel units.

This allows the BESS to serve its original purpose in essentially bridging the gap between intermittent wind generation and a ramp up of hydro generation. The PowerStore system operates under two different control modes discussed in the next section, Controls and Communication Systems.

Although the different storage systems within the Kodiak Island system essentially operate on different time scales, the combination of the Terror Lake storage, BESS and FESS is able to fulfill the technical needs of the microgrid, while also limiting stress on certain components. This combination of storage resources makes the microgrid more robust in its operational capabilities and more responsive when reacting to grid disturbances.

Controls and Communication Systems

The Kodiak Island microgrid uses a networked ABB Microgrid Plus control system to manage the various energy resources. ABB MGC600 Decentralized Microgrid Control system is also used, consisting of distributed control modules for all resources coordinated on a peer-to-peer basis, allowing communication among and between resources.

For details on these systems, see Section 4.2.2.3 of CEATI's *Coordination of Energy Storage within Microgrids*

Microgrid Ownership Structure and Financing

Kodiak Electrical Association (KEA) owns and operates the microgrid, which has been funded through a number of sources, including grant money created by the Alaska Energy Authority fund, Alaska Legislature, KEA and Clean Renewable Energy Bonds (CREBs), which were provided through Co-Bank, a cooperative bank that funds rural utilities. The recent FESS project was coordinated and funded through a public-private partnership, with KEA contributing a total of \$3.5 million to the project, and Matson (crane equipment provider) and the City of Kodiak contributing \$400,000 each.

Key Takeaways from Interviews

ICF interviewed Nathan Adams, director of microgrids and renewable automation at ABB and discussed his experience in using energy storage within microgrids, with a focus on the Kodiak Island microgrid. Adams emphasized the importance of correctly identifying the specific need for energy storage in the microgrid under consideration and selecting the most appropriate storage technology for meeting that need.

Until about 5 years ago, when the cost of energy storage was high, the primary role of storage in microgrids was to support the intermittent renewable power. However, with the decrease in the cost of energy storage, energy shifting and peak shaving applications of storage within microgrids are becoming more cost effective.

A range of storage technologies are now available, but are generally not well understood by the market that may be buying them.

Given the nascent nature of the energy storage market, there have been many cases in which those who have invested in deploying storage technology have not been able to achieve the desired results. In one of these instances, the storage system was not sized correctly for the application, while in another, the storage system did not meet the charging/discharging speed requirement for the applications.

The Kodiak Island microgrid took these concerns into consideration when ABB was approached to install a storage system to support the new crane. ABB's flywheel technology and MGC controller appropriately meet the site application, which requires the storage to maintain system frequency while supporting the crane's operation.

Adams also noted that financing for microgrid projects is challenging because they do not typically present the scale of investment that is attractive for large lending organizations. Therefore, capital grants and incentives are important for such deployments.

Project Benefits, Challenges and Best Practices

Project benefits

The incorporation of renewable energy resources and multiple energy storage systems into the Kodiak Island microgrid has not only provided multiple benefits to the technical operation of the Kodiak electrical system, but also to the surrounding community, including residential, commercial and industrial customers. These benefits are:

- The increased use and integration of cleaner generation sources like hydro and wind energy has allowed KEA to decrease its reliance on diesel fuel to generate power, providing benefits to the environment and also decreasing prices for end-use electric customers.
- The integration of a variety of forms of energy storage has allowed the microgrid to operate more efficiently, and made it possible to respond to different disturbance events produced by resources or loads.

- The BESS works to smooth renewable generation from wind output, and also provides under-frequency responses when wind output decreases, allowing the renewable resources to operate most efficiently and cost-effectively.
- The FESS has helped the BESS operate as originally designed and protected it from unintended operational processes that caused degradation of the BESS before the FESS was implemented.
- The FESS was instrumental in providing a variety of services for the integration of a new electric crane, which increases efficiency for the fish processing industry in Kodiak and does not use costly diesel for operation.
- The FESS is essential in protecting the existing BESS from providing rapid response to frequency fluctuations, and will allow the BESS to operate as originally designed.
- The FESS also provides a number of services to the microgrid, including backup power, excess energy storage (from the intermittent resources), frequency regulation in grid support mode and voltage regulation in crane support mode.

Project challenges

A number of challenges arose throughout the commissioning and initial operation of the Kodiak Island microgrid, many of which were due to the remote location and climate, and unique configuration of the isolated grid that KEA operates. These challenges were:

- KEA had limited knowledge on how to manage grid frequency and voltage issues inherent to intermittent wind resources due to the limited examples at the time. Thus, the integration of the electric crane with the new and existing energy storage systems was a primary engineering challenge.
- There were issues related to the timeline of funding, system design and turbine construction.

- Kodiak's remote location made wind turbine transport and installation difficult. Due to extreme weather variations, the installation had to take place in the summer.
- KEA faces additional and ongoing operational challenges because of Kodiak's wet and windy climate, which can cause excess water to collect inside the turbine hubs.
- There were additional challenges with the regulatory system related to how different agencies viewed the integration of different distributed energy resources and energy storage resources, and the potential functions that they could provide.

Best Practices

The Kodiak Island microgrid represents a unique situation where different forms of energy storage can be used to meet a variety of technical challenges and foster the incorporation of renewable energy within a remote microgrid. Some best practices that led to the successful deployment of this project are:

- The BESS was originally designed to provide storage and other services on a second-to-minute basis, but was largely used to respond to microsecond frequency fluctuations on the microgrid. This caused significant stress on the battery and significantly impacted its projected lifetime, which was determined by detailed performance data obtained for the BESS. Therefore, it is critical to identify both the current and future technical requirements for an energy storage system in the microgrid and select an appropriate energy storage system (or combination of systems) accordingly. One method would be to generate a simulation model to evaluate various system configurations and use cases, which could validate a microgrid design and significantly increase the success rate of physical deployments.
- The Kodiak Island microgrid demonstrates how incorporating various kinds of energy storage to provide different types of functionality can improve the overall flexibility of a microgrid. Ensuring that the various energy storage technologies accurately meet the site characteristics and resources is key to a successful deployment.
- Remote island communities with similar technical capabilities can use Kodiak Island as an example of how communities can decrease their reliance on costly fossil fuels (e.g., diesel) in order to achieve environmental and economic goals. The upfront costs of microgrid applications can be significant, but the savings over time should not be overlooked.
- A variety of funding options and resources can be used when pursuing this type of community microgrid project. Interested parties seeking financial assistance should consider state renewable energy funds, Clean Renewable Energy Bonds (CREBs), local programs and local financial institutions, among other options.

Conclusion

This article will give cooperatives insights—through the case studies—into how energy storage can be used in various configurations and for different types of microgrids. Cooperatives also will benefit from the best practices developed for incorporating energy storage in microgrids. ■

APPENDIX A: UCSD MICROGRID ENERGY TECHNOLOGIES

The energy generation technologies, control systems and other resources included in the microgrid are shown below:

EXCERPT A-1: Microgrid Energy Generation Technologies, Control Systems and Other Resources (Source: CEATI report: *Integration and Coordination of Energy Storage within Microgrids*, pp 30)

- **CHP** – The campus operates ~33 MW of CHP, consisting of two 13.5 MW natural gas combustion turbines, one 3 MW natural gas steam turbine, and one 2.8 MW biogas molten carbonate fuel cell. Additionally, there are three steam-driven chillers (~10,000 tons) and eight electric-driven chillers (~7,800 tons). The CHP system provides 85% of the electricity and 95% of the heating and cooling needs for the campus. The fuel cell utilizes waste methane gas from the nearby Point Loma Wastewater Treatment Plant [3], [5].
- **Energy Storage** – A variety of energy storage resources are utilized within the campus microgrid, but the main energy storage devices are a 3.8-million-gallon thermal storage tank and a 2.5 MW (5 MWh) Li-Ion Fe-P battery storage system. There are also a number of smaller storage systems primarily utilized as demonstration or test projects, consisting of 25 kW flywheel storage, 28 kW energy storage ultracapacitors, 35 kW (35 kWh) compact Li-Ion battery storage (integrated with solar PV), and 100 kWh Li-Ion Mn-Co battery storage (integrated with solar PV and EV DC Fast Charging) [6], [7], [8].
- **Solar PV** – The UCSD microgrid includes a total of 2.9 MW of solar PV that integrating conventional and solar-tracking systems.
- **Solar Thermal** – The solar thermal system within the UCSD microgrid is a 300 kW solar water heater, located at North Campus Housing.
- **Control Systems** – Schweitzer Engineering Laboratories (SEL) is the main control system provider for UCSD microgrid, integrating the POWERMAX Power Management and Control System to help with continuous balancing of load and DER generation, and detect and mitigate system blackouts [9]. The microgrid also uses a straight SCADA system for communication between all building controls and the energy supply. Johnson Controls also provides all building control systems to help incorporate energy efficiency and coordinate demand response [10].
- **Other Resources** – The UCSD microgrid has 4,000 smart thermostats throughout campus buildings under remote control, and 56 fast EV chargers that are combined with a solar PV and battery storage system [3], [4].

APPENDIX A: UCSD MICROGRID ENERGY TECHNOLOGIES (CONT.)

The figure below shows a simple schematic of the UCSD microgrid and how the energy storage and distributed energy resources components interact with the site loads.

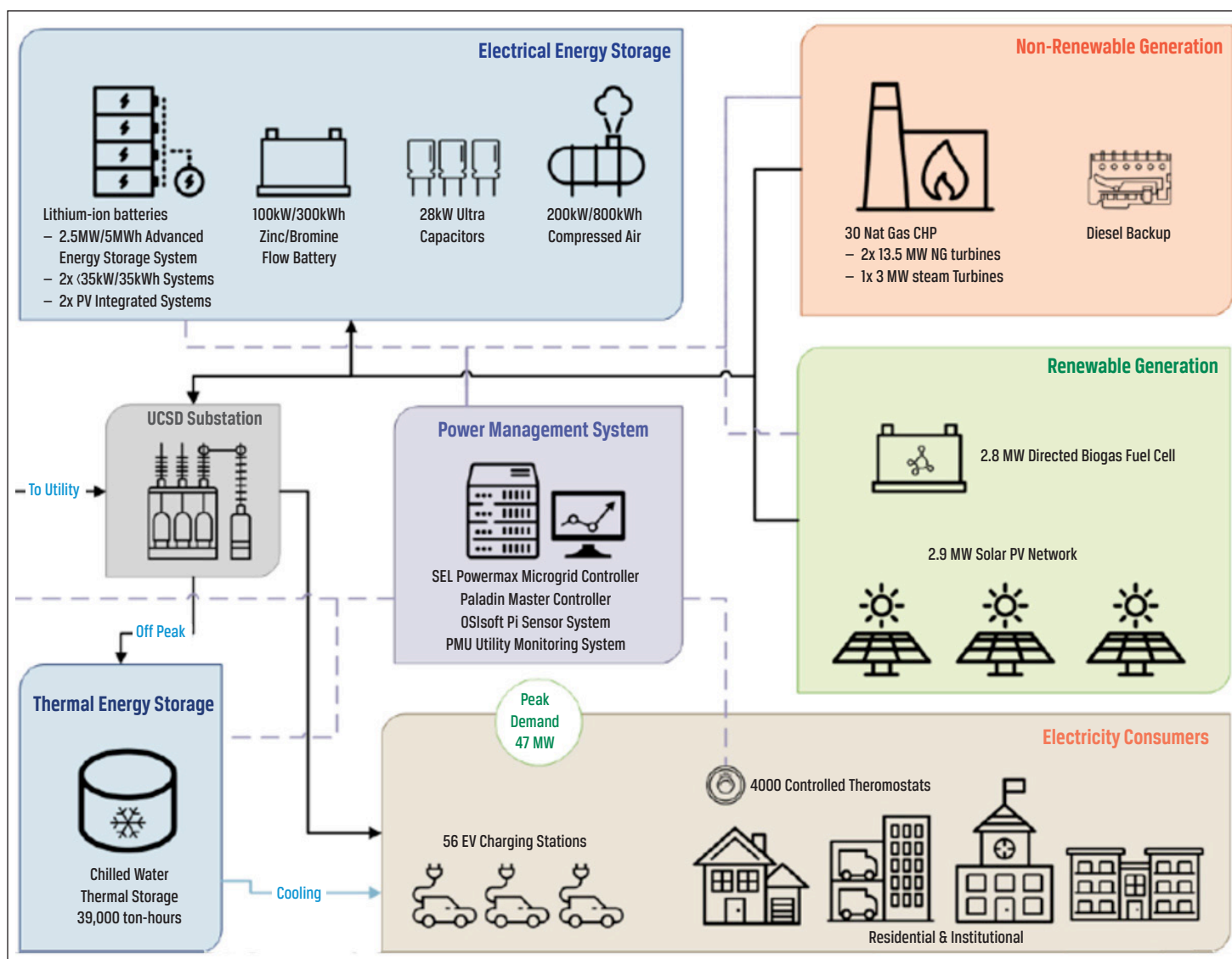


FIGURE A-1: UCSD Microgrid Schematic Showing Energy Storage and Distributed Energy Resources Interaction with Site Loads (Source: CEATI report: *Integration and Coordination of Energy Storage within Microgrids*—pp 31, Figure 4-2)

APPENDIX B: KODIAK ISLAND MICROGRID ENERGY TECHNOLOGIES

All equipment and technologies deployed within the Kodiak Island microgrid are show below:

EXCERPT B-1: Kodiak Island Microgrid's Equipment and Technologies (Source: CEATI report: *Integration and Coordination of Energy Storage within Microgrids*—pp 37-38, Section 4.2.1.3)

- Hydroelectric – The main power source for the microgrid is the Terror Lake Hydroelectric Facility, which has a peak total capacity of 31 MW. The hydro generation consists of three (3) 11.25 MW hydroelectric turbines, the most recent of which was installed in 2014 [16].
- Wind – The microgrid includes a total of 9 MW of wind energy generation from the Pillar Mountain Wind Project. The wind project was completed in two phases, both with the installation of (3) x 1.5 MW wind turbines in 2009 and 2012.
- Diesel – The diesel generators once generated more than 20 percent of the island's electricity, but now sit mostly idle and are only required for emergency backup power. The individual generator units and respective capacities are as follows: (1) x 17.6 MW, (1) x 9 MW, (1) x 3.6 MW, (1) x 0.76 MW.
- Battery Energy Storage – Two 1.5 MW (3 MW total, 2 MWh) advanced Lithium-Ion batteries were installed in 2012 in order to provide backup power and renewables smoothing capabilities for the intermittent wind generation. The battery energy storage system (BESS) is also used to conserve water for the hydro facility [13].
- Flywheel Energy Storage – The flywheel energy storage system (FESS) was installed specifically to manage the new electric crane's fluctuating load while also providing voltage and frequency regulation for the Kodiak Island grid. The FESS also helps to extend the BESS' lifespan and conserve water for the Terror Lake hydro facility. It consists of (2) x 1 MW ABB PowerStore Flywheel units (2 MW total) [13], [17].
- Controls Systems – The Kodiak Island microgrid utilizes a networked ABB Microgrid Plus control system to manage the different generation sources throughout the microgrid. The ABB MGC600 Decentralized Microgrid Control system is also used and consists of distributed control modules that are coordinated on a peer-to-peer basis, allowing communication among resources [17], [18].

APPENDIX B: KODIAK ISLAND MICROGRID ENERGY TECHNOLOGIES (CONT.)

The figure below shows a simple schematic of the Kodiak Island microgrid.

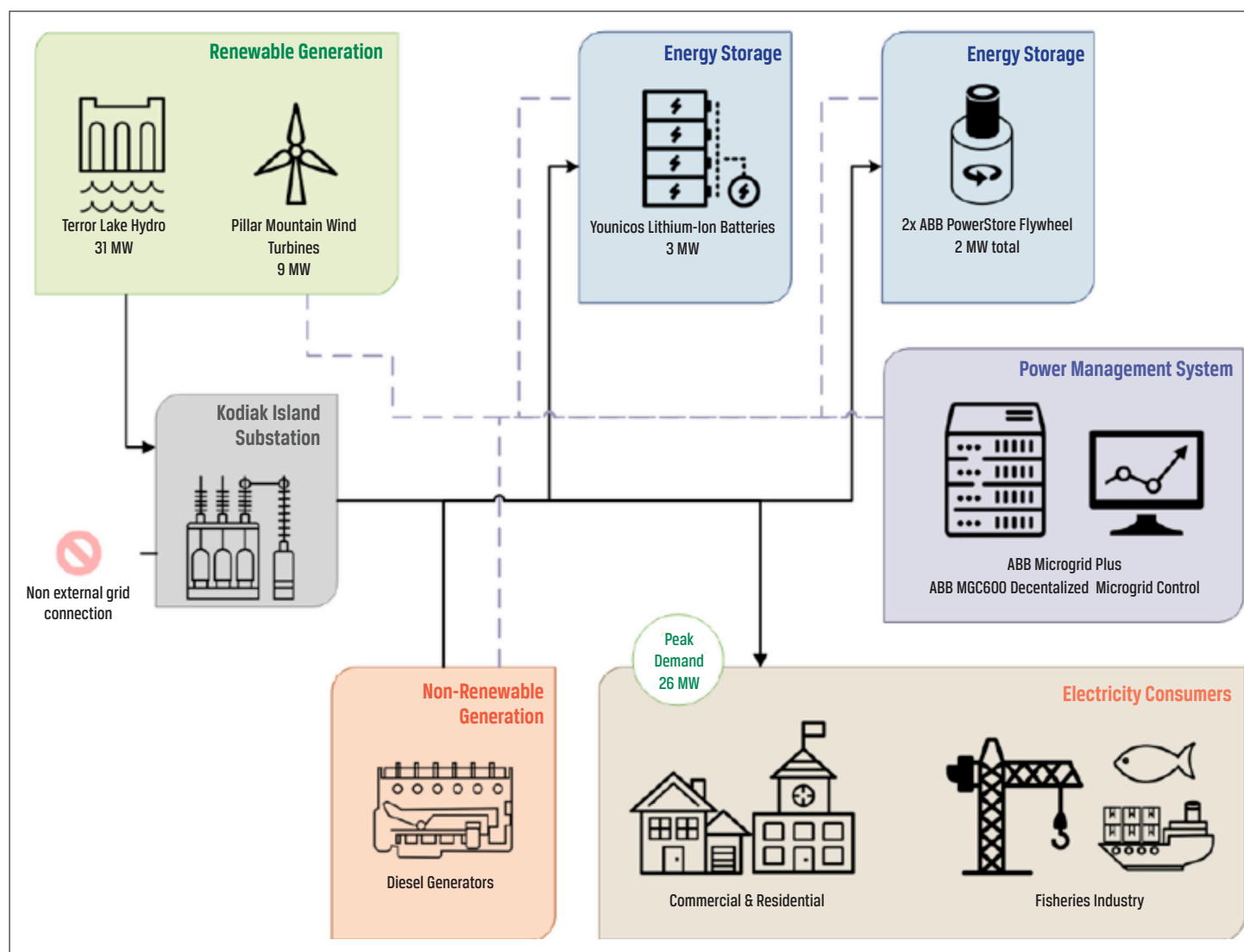


FIGURE B-1: Kodiak Island Microgrid Schematic (Source: CEATI report: *Integration and Coordination of Energy Storage within Microgrids*—pp 38, Figure 4-4.)

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