Energy Research and Development Division

FINAL PROJECT REPORT

A Novel, Renewable Energy Microgrid for a California Healthcare Facility

California Energy Commission

Edmund G. Brown Jr., Governor

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PREFACE

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

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solution, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities – Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company – were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

A Novel, Renewable Energy Microgrid for a California Healthcare Facility is the final report for Agreement Number EPC-14-080, conducted by Charge Bliss, Inc. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The California Energy Commission awarded a $4.78M grant to Charge Bliss, Inc. through PON-14-301 to design, engineer, build, and operate the first renewable energy microgrid for a hospital in California at the Kaiser Permanente facility in Richmond, California. The hospital is the only general hospital serving western Contra Costa County providing essential services to the surrounding community. Moreover, the region is affected by high levels of environmental pollution and the consequent health impacts. The project also developed a novel microgrid controller that can island the hospital's life safety emergency power branch, including emergency lighting and exit signs, and provide power services during emergencies. During non-emergency periods, the controller enabled the microgrid to achieve performance goals such as reducing utility energy consumption, site peak load, and utility costs with the capability to participate in demand response and electrical islanding.

Charge Bliss proposed to overcome a number of barriers to the development of renewable energy microgrids for hospitals. This included engagement with the Office of Statewide Health Planning and Development to identify relevant regulatory requirements for the build-out of the microgrid and methods to comply with them, define approaches to permitting and approvals, demonstrate interconnection with the investor-owned utility, and illustrate the feasibility and value of renewable energy microgrids to healthcare stakeholders. At the behest of the Office of Statewide Health Planning and Development, the system was allowed to have a discretionary second point of interconnection to the hospital's emergency power system. This allows for islanding of essential systems in the event of grid outages. The team demonstrated the ability to lower the gross facility utility cost by 15 percent through a combination of solar generation and time-shifting of use, energy arbitrage, and demand reduction. The team anticipates further value from grid services such as automated demand response.

Keywords: renewable energy, microgrid, demand management, power quality, energy storage.

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EXECUTIVE SUMMARY

Introduction

Healthcare facilities are vital to the safety, security, and wellness of communities and the unpredictable nature of health crises requires that these institutions stay operational at all times regardless of external disruptions such as a power supply outage. The recent wildfires in Northern California and hurricanes in New York City, New Orleans, and Puerto Rico disrupted the utility grids and almost disabled entire critical healthcare facilities in the areas.

In addition, hospitals are one of the most energy intensive commercial buildings due to significant air management requirements and equipment with heavy electrical load. Over time, hospitals have incorporated supplemental, onsite power generation to reduce energy costs. This onsite generation includes combined heat and power generators, fuel cell devices, solar generation, and even wind turbine generators. However, prior to this project, none of these resources was permitted to interconnect to and support emergency power systems during grid outages. Equally importantly, no data existed as to the value of coordinating multiple energy resources to achieve optimal technical and economic performance.

The majority of healthcare facilities in California face rapidly declining and even negative operating margins with increasingly burdensome energy cost. Microgrids, the aggregation and coordination of multiple resources to optimize power delivery to connected loads, offer the potential to significantly reduce current costs, constrain cost escalation over time, and allow hospitals to turn resulting savings towards clinical programs. Furthermore, the ability of renewable energy microgrids to support facility operations with diminished reliance on diesel generation offers greater resilience, reliability, and continuity of services, particularly for at risk communities such as Richmond, California. Lastly, as some of the most intensive consumers of utility energy, hospitals are an important target for the mitigation of greenhouse gas emissions through renewable generation. When these resources are housed within a microgrid, this allows for larger deployments without the potentially adverse impacts upon the utility grid.

Despite the predicted benefits of renewable energy microgrids, prior to this project, there were no renewable energy microgrids connected to a hospital in California. Indeed, there were only three other hospitals in the nation with such microgrids: Dell Children's Medical Center (Austin, Texas), Utica College/Faxton-St. Luke's Healthcare (Utica, New York), and Shands Cancer Hospital at the University of Florida. In collaboration with Office of Statewide Health Planning and Development (OSHPD), this project provides lessons learned, challenges encountered and overcome, and recommendations to help standardize future microgrid deployments for hospitals to support the resiliency and autonomy of critical healthcare facilities.

Project Purpose

The California Energy Commission sought to fund the investigation of renewable energy microgrids to support critical infrastructure. Charge Bliss, Inc. was awarded $4.78M to design, engineer, build, and operate an innovative renewable energy microgrid system at the Kaiser

Permanente Hospital in Richmond, California. This project was funded by the California Energy Commission to:

- Identify and overcome existing barriers to renewable energy microgrid implementation in healthcare facilities.
- Demonstrate the opportunity to reduce hospital energy consumption, peak load, fossil fuel usage, and costs.
- Demonstrate the capability to support continuous facility operation by "islanding" the microgrid during a utility power outage.
- Design and implement a novel, commercializable microgrid controller.

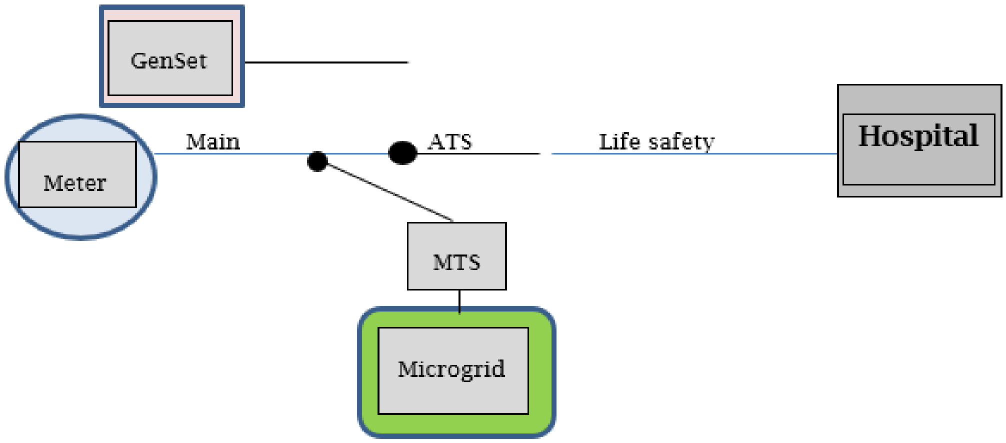
Project Process

Project Design and System Configuration

As the first effort of its type, this project required more extensive investigation, design, and engineering than will be required in future projects.

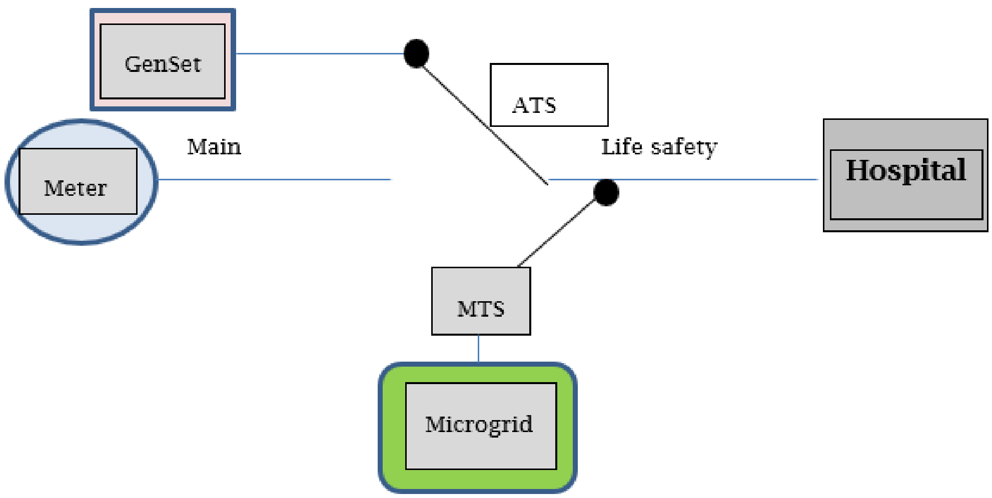
- Team formation: At the peak of the process, more than 35 different parties collaborated to develop safe, feasible, and effective designs. Parties included electrical, mechanical, civil, and structural engineers, communication systems designers, fire safety, architects, battery and inverter manufacturers, contractors (general, solar, electrical, concrete, mechanical systems, others), OSHPD specialists, and two distinct university teams to coordinate with the design team for monitoring, communication, and control.
- Site characterization: The team evaluated site energy loads, electrical architecture, operational objectives, physical space constraints, OSHPD and non-OSHPD governed spaces, possible points of interconnection, site geology, structural versus non-structural elements, relevant national, regional, and local ordinances and regulations, and the stipulations of the serving utility, Pacific Gas and Electric Company.
- Design meetings: In addition to several site meetings to evaluate physical systems, the project team held virtual meetings with all stakeholders to ensure project progress, strict adherence to regulatory requirements, and compliance with site tolerances and objectives. A Technical Advisory Committee composed of all technical stakeholders provided additional commentary and recommendations to achieve project success.
- Microgrid engineering: Engineering representatives from the suppliers, contractors, facility, and consultants collaborated to determine systems sizing, controls goals, point(s) of interconnection, monitoring and communications architecture, fire suppression, and other systems. Additionally, the participation of OSHPD representatives resulted in a novel dual interconnection methodology to both the "normal" and life/safety branch of the hospital electrical systems.

Figure ES-1: Normal Operation



Source: Charge Bliss

Figure ES-2: Utility Service Interrupted



Source: Charge Bliss

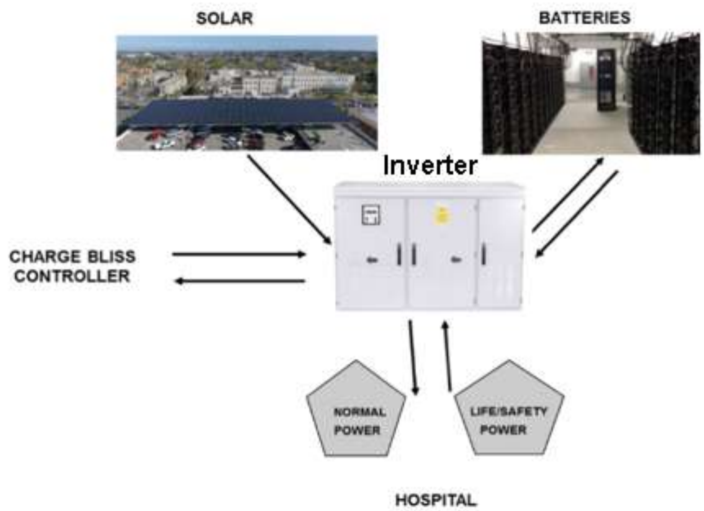
As shown in Figures ES-1 and ES-2, the addition of microgrid equipment allows for multiple power supply options. During normal operation, the diesel generator(s) ("GenSet") remain idle and disconnected while power is supplied from the utility across the main meter and the microgrid. When the utility energy supply is interrupted and power delivery is initiated from the generator(s), the manual transfer switch (shown as MTS in the figures) may be repositioned to allow the microgrid to supply the entire life/safety branch load ("islanding" mode).

System Installation and Commission

Once the project team received approvals from the City of Richmond, Pacific Gas and Electric Company, and OSHPD, project installation proceeded in a mostly linear fashion, including the following key steps:

- Solar canopy: The SunPower solar canopy panels were erected on a steel canopy superstructure atop the hospital parking structure. Solar panels (250 kilowatts) were joined electrically to meet the direct current port voltage requirements of the single, centralized inverter.
- Battery/inverter room: Concrete block wall battery and inverter rooms were constructed for heat isolation and long-term battery performance. The solar panels and Samsung® SDI® batteries (1 megawatt-hour) were coupled to a Princeton Power Systems® BIGI250™ inverter.
- Central utility plant: Approved penetrations into the OSHPD-governed central utility plant were made to allow the dual interconnection specified in the design phase. Simultaneously, six specialized data acquisition devices called phasor measurement units were installed at critical monitoring points and connected to a secure, independent communications network to monitor systems performances.
- Microgrid controller: Microgrid controller resides in the computers that are resistant to harsh conditions. These computers were located onsite and at a control design facility for the purpose of systems regulation, remote access, and redundancy.
- Ancillary systems: The team installed fully independent fire suppression, DSL internet service, security, and environmental controls.
- Testing and commissioning: Charge Bliss developed testing and commissioning processes to evaluate the individual systems within the microgrid as well as the microgrid as a whole. As the core item in the direct current-coupled microgrid, the most time was spent on inverter commissioning and tuning. First, internal inverter controls were tuned to maximize the amount of solar energy. Second, communications and controls between the battery system and the inverter were verified through serial charging and discharging. Third, standard inverter functions – including output of solar generation, charging and discharging batteries, shutdown, restart, and islanding – were verified. Finally, the supervisory Charge Bliss controller was over layered on the embedded inverter controller. A schematic of the power flows and controls is shown in Figure ES-3.

Figure ES-3: Microgrid Power Flows



Source: Charge Bliss

Microgrid Controller Design

The Charge Bliss microgrid controller was first remotely tested using real-time controller hardware in the loop simulation by the Nhu Energy, Inc. and Florida State University. Remote, specialized testing allowed the team to virtually eliminate risks inherent in new controller implementation in the real-world microgrid. The process also proved that control could be done locally but supervised and corrected from another location. The microgrid controller provides the external control capabilities for the inverter. The methodology is repeatable for other critical facilities.

Project Results

The Kaiser Permanente Richmond microgrid achieved several notable successes. As the first installation of its kind for a hospital in California, this project demonstrated the safety, feasibility, and performance of renewable energy microgrids for healthcare facilities. Successful interconnection to the life safety branch demonstrated a novel method for hospital resiliency and reliability as well as reduction in reliance upon diesel generation. This has resulted in the increased willingness by the OSHPD Hospital Building Safety Board to include renewable energy microgrid standards in its next code document and to consider routine use of these systems for new hospitals as they are built in the future. The ability to “island” the life safety branch supports the concept that diesel generation may not need to remain the dominant backup power resource not only in hospitals but in other critical facilities. When renewable resources such as solar generation are paired with energy storage technologies and interconnect to emergency power, the reservoir of renewable energy may be deployed to mitigate or even replace the need for fossil-fuel backup power generation. The ability to substantially reduce hospital utility costs has led to broader consideration by previously skeptical investors, hospital systems, and other stakeholders of microgrid applications in California and elsewhere.

The microgrid controller has been in use since system commissioning to perform automated functions including energy arbitrage, photovoltaic power quality regulation ("smoothing"), time-shifting of photovoltaic energy usage from lower value hours of production to times of higher utility cost, and reduction of peak facility loads ("demand management"). Ongoing development will add grid services functions such as automated demand response, graphical user interface, and other tools to help commercialize the microgrid controller.

With progressive tuning, the team has reached 140 kilowatts of demand reduction, approximately 20-25 percent of peak load. In turn, this can yield as much as $5,800 per month in savings (summer). Adding further resources, such as fuel cells, may allow hospitals to be negligible contributors to utility system demand. For example, Kaiser Permanente Richmond will soon be adding a 400 kW fuel cell system. When this device and the microgrid operate together, peak facility demand should be reduced from an original level approaching 800 kilowatts to as low as 150-200 kilowatts, or by 75 percent. When this is extrapolated to the more than 500 facilities in California, statewide demand reduction could reach 1.875 gigawatts. Using the Energy Commission formula of 0.4354 million tons of carbon dioxide per megawatt-hour, the averted greenhouse gas emissions could reach 7,151,445 million tons of carbon dioxide/year.

Project Challenges and Lessons Learned

The first significant project challenge was the venue. The original host hospital declined to participate so Charge Bliss had to identify another suitable host site. The Energy Commission approved substitution of the Kaiser Permanente facility in Richmond, California with the other design parameters remaining the same.

Interconnection is generally considered to be a major obstacle to microgrid development. In this case, well-engineered designs which sought to interconnect a system that was highly unlikely to export power, limited the requirements for utility investigation, systems upgrades, or other expensive or time-consuming processes.

While pre-engineered, containerized battery-plus-inverter-plus-control systems are increasingly desirable, there may be no reasonable location for their construction at many facilities. In the case of Kaiser Permanente Richmond, none of the open parking lots, spaces next to buildings, or other areas were available for use. Moreover, bringing electrical lines above- or below-ground to the main power plant would have required complex, expensive, and potentially dangerous crossing of transportation routes and utility easements.

Like many hospitals, the Kaiser Permanente facility has a multi-story parking structure which is owned by the facility and appeared to have adequate space for location of microgrid systems. However, the entry height of the main parking structure was too low to permit placing a shipping container within it. Therefore, the team had to design an entirely new block wall room for both the inverters and batteries as well as the fire suppression, heating, ventilation, and air conditioning, internet communications, and security systems that would otherwise have been included in a containerized system. Future deployments in the built environment will need to consider available space, height, depth, and weight allowances, and complexities of electrical connections to facility electrical systems.

The design with a canopy array on top of the parking structure required additional structural and civil engineering to ensure that weight, wind shear, anchoring points, and other elements could be rendered safe to build such an array. The same design also allowed the microgrid systems to be located in proximity to the central utility plant for the shortest distances for electrical lines, which help balance additional expenditure for unexpected structural requirements.

To meet OSHPD oversight requirements, penetrations through the central utility plant walls require structural engineering review for seismic safety and also must use one of a small number of allowable sealants around the conduit. Fire safety regulations require that there be no decrease in the fire-rating of the penetrated walls to protect key electrical systems. Suspension of conduit and ancillary systems must meet seismic code, and any system which could fall during an earthquake may require shake table testing. To date, no relevant microgrid hardware systems such as batteries, power conditioning, and control systems have been tested or approved for use in such spaces. As such, any attempt to locate microgrid systems within the central utility plant or other OSHPD-regulated spaces of a healthcare center would require extensive and expensive testing and certifications that would render an individual project both cost-ineffective and unable to be completed in a timely fashion. In this circumstance, Charge Bliss was fortunate to be able to locate all microgrid equipment and materials in the hospital-owned, City-governed parking structure that adjoins the central utility plant and, thus, avoid the need for OSHPD approval of said designs and construction. OSHPD oversight may variably be predicted to add 3-9 months of review and revision time to projects depending upon the significance of interplay with OSHPD-governed systems.

Commissioning, testing and validation of safety and basic performance of systems, systems tuning, and adjustment of performance over time to optimize outcomes, are integrally related. Tuning, in particular, considers factors such as: type of utility tariff, the balance of value of energy or demand cost mitigation, arbitrage of nighttime power (using inexpensive nighttime power stored in the battery during expensive daytime periods), Internal Revenue Service regulations for capture of tax equity, planning for low solar productivity intervals, site needs for backup power versus routine usage, long-term battery system health, and other variables. Charge Bliss discovered that tuning required upwards of six months for regular examination and refinements to achieve a stable outcome.

Technology Transfer and Dissemination

The project demonstrated the value of hospital microgrids as stated in the project results above. Since the public announcement of the microgrid performance, Charge Bliss has received numerous requests to evaluate options for these systems at clinics, hospitals, manufacturing facilities, and cities. The San Benito Healthcare Clinic in Santa Cruz, California has contracted to build a renewable energy microgrid with the ability to island the entire facility indefinitely.

Charge Bliss presented information on its microgrid system performance on its website, in postings on Linkedin®, Facebook®, and Twitter®, and has received media coverage from several digital media companies and local CBS news in the San Francisco Bay area. In addition, the team held an opening ceremony and separate technical "deep dive" workshops attended by representatives of the California Public Utilities Commission, the California Independent System Operator, electric utilities, Kaiser Permanente representatives, and hospital engineers, microgrid designers, the Energy Commission and other stakeholders. Charge Bliss has presented data at multiple Energy Commission events including the annual EPIC symposium and Dr. Bliss has shepherded the development of standards for renewable energy microgrids through his role on the Hospital Building Safety Board of the Office of Statewide Health Planning and Development (OSHPD). The team also presented at international conferences (SPI™ and Homer®). Two academic papers have been published and presented at national scientific meetings. Charge Bliss is preparing to unveil a multi-party campaign to develop microgrids for healthcare facilities throughout the Western United States.

Benefits to California

The benefits of the renewable healthcare microgrid include:

- Greenhouse gas emissions reductions: The project is on track to produce between 365,000 kilowatt-hours and 390,000 kilowatt-hours per year of clean energy and reduce consumption of fossil fuel generation by 292,000 kilowatt-hours per year through the arbitrage of clean nighttime power. The combined reduction of carbon dioxide production is more than 214 metric tons per year and as much as 6,400 metric tons over the 30-year projected project lifespan.
- Development of a novel microgrid controller: Using an innovative monitoring and data management strategy as well as novel control tools, the team developed a cutting-edge controller capable of safely, autonomously, and reliably administering all of the microgrid systems to optimize both technical and financial performance. This testing and implementation methodology will be disseminated to critical facilities throughout the State- creating greater resiliency of essential institutions for public service, decreased complexity and greater safety of operation to assist the grid, and ancillary services such as Automated Demand Response to mitigate peak system-wide demand and the deleterious impacts of peaker plant operation,
- Decreased strain on the utility and independent system operator: With documented daily demand reduction in the current project in the late afternoon and early evening of 100 kilowatts to 150 kilowatts and plans for as much as 200 kilowatts, the microgrid improves late day ramp rates and mitigates the need for discretionary utility fossil fuel generation.
- Safety and effectiveness: The renewable energy microgrid had no safety lapses and has demonstrated technical and financial success. Ongoing tuning of the microgrid has led to a 94 percent time of continuous operation ("uptime") with expectations of more than 98 percent once refinements are completed.

- Resilience of critical infrastructure: The Kaiser Permanente facility in Richmond, California now has added energy capacity to support emergency operations through microgrid-driven islanding of life safety power. As the sole full-service hospital in western Contra Costa county and the only hospital in the City of Richmond, Kaiser Permanente supplies critical emergency services. This success has initiated discussions between OSHPD and the Energy Commission to consider expanding the role of renewable energy systems in supporting hospitals statewide.
- Cost savings and program development: The project is projected to save the hospital nearly 20 percent of its baseline utility cost. These substantial savings can be shifted to patient care programs to sustain and grow healthcare services to an underserved community.
- Dissemination of knowledge: Through technical transfer activities, a broad range of stakeholders has become aware of the successes of the hospital microgrid. In turn, this awareness has generated discussions with new investors interested in supporting project development for hospital systems.

Recommended Future Research

Significant progress has been made in the arena of renewable energy microgrids for healthcare facilities, but continued research is needed. First, as California hospitals have partitioned systems, expansion of supplemental and back-up energy resources for emergency power are needed. This will require standards development through OSHPD, compliance with Energy Commission standards for commercial buildings, and funding to study the impacts. Most importantly, research directed at pathway development for the phase-out of diesel generator facility back-up is an essential step to minimize carbon-based fuel consumption for healthcare resiliency. Second, research is needed to expand healthcare microgrids to coordinate multiple resources such as continuous generation systems (fuel cell, combined heat and power), renewable generation (solar, wind, other), and energy storage. Third, expansion of control architectures to incorporate utility services will increase the value and applicability of renewable energy microgrids for healthcare facilities.

CHAPTER 1: Introduction

California environmental statutes and policies are directed towards reducing greenhouse gas emissions, promoting the adoption of renewable energy generation, and ensuring reliable, affordable and safe energy supply for the citizens of the state. Specifically, these require that California reduce relevant emissions by 40 percent below 1990 levels by 2030, reach 33 percent renewable energy generation by 2020 and 50 percent by 2030. In the process of achieving these goals, however, several unanticipated obstacles have arisen that require innovative solutions to permit further progress. Renewable resources are limited by temporal and geographic constraints. Solar photovoltaics only produce energy during daylight and are intermittent and unpredictable during natural weather events. Wind resources are only available in specific physical locations where air flow is rapid and unimpeded by the natural or built environment. Moreover, because these resources lack an inherent reservoir of power, they cannot be dispatched when demand increases, meaning they are not available on demand at the request of power grid operators according to market needs. Finally, the unconstrained export of power to the utility grid system has the potential to create power quality instability, rapid swings in system wide demand, and increased need for discretionary fossil-fuel based generation.

Renewable energy microgrids are potential solutions to many of the problems inherent in distributed renewable energy generation. Microgrids may be defined as an aggregation of distributed energy resources that are coordinated to serve the co-located electrical loads as well as act as power nodes to contribute to the utility grid. While the composition of microgrids may vary, they may generally be defined as power generation (solar, wind, fuel cell, wave, geothermal, and others), energy storage (chemical, thermal, mechanical, hydrologic batteries), and the loads they serve. By juxtaposing these resources and directing them with intelligent controls, microgrids may mitigate the intermittency of renewable generation, regulate power quality, decrease peak loads for the target location(s), and convert renewable energy generation into dispatchable resources. Moving forward, microgrids are potential resources to collaborate with grid systems to mitigate the need for centralized fossil-fuel energy generation, stabilize system power quality, regulate power export, and improve overall grid performance.

Microgrids not only serve the grid system as a whole, but have substantive local benefits. First, by allowing far more widespread penetration of renewable generation, microgrids may have significant impact on greenhouse gas emissions. Second, the ability to regulate when locally-generated energy is deployed can reduce ratepayer energy and demand costs. Third, microgrids that can operate in parallel to the utility when utility services are unavailable can maintain the operability of critical infrastructure including first responders, municipal services, and hospitals.

The purpose of this project was to design a renewable energy microgrid for a healthcare facility that would reduce utility energy consumption, especially during periods of peak electricity demand, provide significant energy cost savings, and be able to support critical infrastructure during electricity outages or other adverse utility supply events.

Specific objectives included:

- Identify and overcome obstacles for renewable energy microgrids at hospitals.
- Design, engineer, and build a renewable energy microgrid for a hospital.
- Demonstrate the value of hospital microgrids to utility ratepayers.
- Develop a supervisory microgrid controller and demonstrate it in various situations, including islanding.[1]

This final project report presents the results of the development, installation, and deployment of a microgrid system and controller at the Kaiser Permanente hospital in Richmond, California. The facility is in Pacific Gas and Electric Company's service territory and interconnected to both the "normal" and emergency power systems. The controller was installed in the onsite system as well as at a remote facility with the ability to make real time adjustments to system configuration and performance.

This chapter discusses potential environmental, economic, and electric system benefits of renewable energy microgrids, particularly in critical infrastructure such as hospitals, as well as obstacles to wider adoption of renewable microgrids that must be considered.

The remaining chapters discuss the project approach, findings, and results:

- Chapter 2: Renewable Energy Microgrid Design
- Chapter 3: Installation of a Hospital Microgrid
- Chapter 4: Data Acquisition Systems, Communication Tools, and Controller Development
- Chapter 5: Results and Lessons Learned
- Chapter 6: Evaluation of Project Benefits
- Chapter 7: Technology Transfer Activities
- Chapter 8: Production Readiness Plan

Renewable Energy Microgrids

Throughout the twentieth century, the United States electrical grid followed certain consistent principles: large, centralized, fossil-fuel generation, long-distance transmission and distribution, and interconnectedness. However, amid growing concerns about environmental impacts, energy security, cost, and reliability, that design has come into question. More specifically, diverse stakeholders have proposed that a more distributed, renewable, and

[1] Islanding refers to the ability to fully physically isolate from the utility grid during power emergencies, with back-up power provided from an onsite source of electricity such as solar panels or a diesel generator.

flexible architecture may address some of the perceived shortcomings of the current grid design. The advent of renewable energy generation, energy storage, and robust power conditioning and control systems has fostered creative solutions through which the United States may transition to this distributed energy architecture.

California has some of the most ambitious standards in the country for the adoption of renewable energy which have led to widespread adoption of solar photovoltaic (PV) and wind power throughout the state. California's Renewable Portfolio Standard (RPS) originally required utilities to reach 33 percent renewable generation by 2020 and 50 percent by 2030, and in 2017, 32 percent of the state's electricity came from renewable sources.[2] In September 2018, Governor Edmund G. Brown Jr. signed Senate Bill 100 (De León, Chapter 312, Statutes of 2018) into law which requires 50 percent renewables by 2025 and 60 percent by 2030, and calls for a path toward 100 percent zero-carbon electricity, including renewable sources, by 2045.[3]

However, efforts to increase renewable energy in California have led to unintended consequences that could threaten further gains. First, renewable resources depend on natural phenomena. Solar arrays produce only during daylight, and even under the best of circumstances demonstrate intermittency (stopping and starting) and variability (generating but at varying levels) that can have substantial impacts on the electricity grid as more solar is integrated into the system. Similarly, wind farms tend to produce more energy at night when electricity demand is low. Second, most renewable resources are not dispatchable, meaning they are not available on demand at the request of power grid operators according to market needs; they lack storage capacity and the ability to rapidly increase generation in response to fluctuations in electricity demand. Third, variability in the power quality of renewable resources requires substantial grid "inertia" to buffer their potentially negative impacts on the overall system.[4]

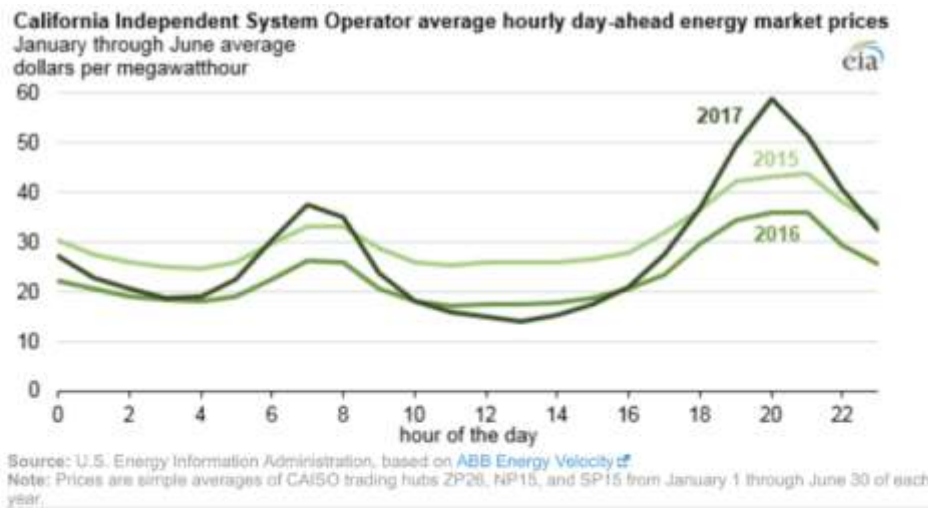
One of the more visible and increasingly impactful aspects of PV generation in California is the system load profile for the state's grid operator, the California Independent System Operator (CAISO). The load profile shows system electricity demand over time. As shown in Figure 5, the increase in solar generation has resulted in a phenomena known as the "Duck Curve," wherein large-scale solar generation in the middle of the day reduces system load (the duck's "belly") but drops off later in the day resulting in a rapid upswing in electricity demand that must be met with other resources.

[2] California Energy Commission, "Renewables Tracking Progress Highlights," October 2018, https://www.energy.ca.gov/renewables/tracking_progress/documents/renewable_highlights.pdf.

[3] Office of Governor Edmund G. Brown, Jr., "Governor Brown Signs 100 Percent Clean Electricity Bill, Issues Order Setting New Carbon Neutrality Goal," September 10, 2018, https://www.gov.ca.gov/2018/09/10/governor-brown-signs-100-percent-clean-electricity-bill-issues-order-setting-new-carbon-neutrality-goal/.

[4] Grid inertia is the ability of the electric grid to maintain a stable frequency when the grid is subjected to some type of fault. The inertia comes from the rotating elements of generators and turbines that continue to turn during a grid fault, helping keep the electricity frequency within a safe range which helps avoid blackouts.

Figure 1: California Independent System Operator Load Curve



California system loads showing the "Duck Curve" in the middle of the day. Further adoption of photovoltaic generation with unconstrained export to the utilities will further deepen the curve - potentially leading to negative pricing, curtailment, or other ineffective forms of management.

Source: United States Environmental Protection Agency

The rapid increase in energy demand late in the day is costly because it requires inefficient operation of large, discretionary, fossil-fuel systems and leads to wear-and-tear on generating equipment from the wide swings. In other venues, this can lead to considerable loss of renewable energy capacity through curtailment (reducing electricity generation for a period of time) or intentional "dumping" of power that cannot be curtailed, used, or stored. For example, the Maui Electric Company in Hawaii curtails up to 25 percent of wind generation due to the lack of simultaneous load and minimal on-grid energy storage.[5] One solution has been to deploy utility-scale energy storage systems including pumped hydroelectric, compressed gas, flywheel, chemical batteries, and others.[6] While each of these storage options has merits and applications, the renewable microgrid project explored whether storage could be used in a behind-the-meter customer application.[7] Moreover, in recognition of the unique vulnerabilities of critical infrastructure, the Energy Commission sought solutions that are applicable in those venues.

Renewable energy microgrids, defined as clean generation technologies co-located with energy storage, smart power conditioning, and controls system with local loads, have the promise to overcome some of the challenges discussed above while respecting grid performance requirements. Microgrids can regulate the local energy environment, constrain the use and export of power, and convert renewable generation into a dispatchable, distributed tool. In addition, microgrids can make the electric system more resilient through "islanding" of local

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[5] Utility Dive, "An embarrassment of riches? Maui shows why renewables curtailment isn't all bad," https://www.utilitydive.com/news/an-embarrassment-of-riches-maui-shows-why-renewables-curtailment-isnt-all/419023/, May 2016.

[6] For an explanation of storage technologies, see California Energy Commission, "Energy Storage Tracking Progress," August 2018, https://www.energy.ca.gov/renewables/tracking_progress/documents/energy_storage.pdf.

[7] "Behind the meter" refers to electricity generation on the owner's property on the owner's side of the utility meter.

systems even when utility energy supply is inadequate. Thus, the overall energy system can have greater flexibility and reliability, increased adoption of distributed, clean generation, and lower costs without disruption to the quality of power delivered and used.

Hospitals as Critical Infrastructure

Healthcare facilities are arguably some of the most essential public infrastructure in any community. Illness and injury frequently require immediate access to care and cannot be delayed due to disruptions in energy supply. This is one of the reasons the State of California first established the Office of Statewide Health Planning and Development (OSHPD). Recognizing that earthquakes could threaten hospital operations, OSPHD was formed to create and enforce standards to protect healthcare workers and patients alike.

While OSHPD governs all aspects of hospital design, construction, operation, and maintenance, one of the most relevant standards created by the agency was emergency power standards. In California, hospitals must be able to separate electrically from the utility grid during power emergencies and maintain all essential operations for up to 96 continuous hours using onsite diesel generation. When utility service returns, hospitals can resynchronize and once again rely on grid supply.

This standard, while safe and effective, creates several problems. First, diesel fuel must be stored on site, leading to health and safety concerns. Second, generating equipment must be regularly tested and operated to ensure adequate function, leading to emission of greenhouse gases and potentially toxic volatile organic compounds. Third, there is no mechanism to address more prolonged outages that have become increasingly common as illustrated during the recent California forest fires and hurricanes in New York, Florida, Louisiana, and Texas. These events caused widespread power outages and destroyed utility infrastructure, forcing evacuations of patients from some of the most critical healthcare facilities in the United States.

Hospitals not only face vulnerabilities from the availability of energy supply, but also from cost. As of 2013, fewer than half of California hospitals reported positive operating margins.[8] High operating costs are one of the more important reasons for hospital closures and bed shortages. California has one of the lowest supplies of available hospital beds per 1,000 person population (Table 1), and the shortage of beds has been growing due to facility closures, particularly in disadvantaged communities. According to the Los Angeles Times, 62 healthcare centers in California closed between 1998 and 2008.[9] Western Contra Costa County, for example, has only one general hospital providing full-service healthcare to the community at this time.

[8] California Health and Human Services Agency, https://data.chhs.ca.gov/dataset/hospital-profitability-2009-2013/resource/2a3d5e7f-f1cf-4fb1-a245-c64930cbdd40?filters=Year%3A2013.

[9] Los Angeles Times, http://projects.latimes.com/hospitals/emergency-rooms/no/closed/list/.

Table 1: Hospital Beds By Type and State

Location	State/Local Government	Non-Profit	For-Profit	Total
1. Oregon	0.2	1.4	0.0	1.6
2. Hawaii	0.3	1.4	N/A	1.7
2. Washington	0.4	1.1	0.1	1.7
4. California	0.3	1.2	0.3	1.8
4. New Mexico	0.3	0.7	0.8	1.8
4. Utah	0.3	0.9	0.6	1.8
7. Arizona	0.1	1.3	0.5	1.9
7. Colorado	0.4	1.2	0.4	1.9
7. Maryland	N/A	1.9	0.0	1.9
7. Nevada	0.2	0.6	1.1	1.9
11. Connecticut	0.0	2.0	0.0	2.0
11. Idaho	0.5	1.1	0.4	2.0
11. Vermont	N/A	2.0	N/A	2.0
14. New Hampshire	N/A	1.8	0.3	2.1
14. North Carolina	0.6	1.3	0.2	2.1
14. Rhode Island	N/A	2.0	0.1	2.1
14. Virginia	0.2	1.5	0.4	2.1
14. Wisconsin	0.0	2.0	0.1	2.1
19. Alaska	0.3	1.5	0.4	2.2
19. Delaware	N/A	2.1	0.0	2.2
19. Texas	0.4	1.0	0.9	2.2

Number of Hospital Beds per 1000 persons in 2013 by State and Hospital type beginning with lowest ratio.

Source: Henry J. Kaiser Foundation (https://www.kff.org/other/state-indicator/beds-by-ownership/)

One significant source of hospital operational cost is the cost of energy. According to the United States Energy Information Administration, "the 2003 Commercial Building Energy Consumption Survey data showed that large hospitals (greater than 200,000 square feet) accounted for fewer than 1 percent of all commercial buildings and 2 percent of commercial floor space, but consumed 4.3 percent of the total delivered energy used by the commercial sector in 2003."[10] Because they operate 24-hours per day, use high-intensity electrical

[10] United States Energy Information Administration, https://www.eia.gov/consumption/commercial/reports/2007/large-hospital.php#_ftnref1.

equipment, and cannot meaningfully curtail operations, already financially-strained institutions must simply bear the cost of energy.

Disadvantaged Communities

Renewable microgrids have the potential to address inequities in bringing clean energy to California's disadvantaged communities. The state has worked diligently over the past quarter century to address environmental quality issues and ensure that the benefits of energy efficiency, renewable energy, and clean energy technologies flow to all regions and citizens in the state. Despite these efforts, evaluations of air, water, and soil quality reveal that regional differences persist and that these may have negative effects on disadvantaged community populations.

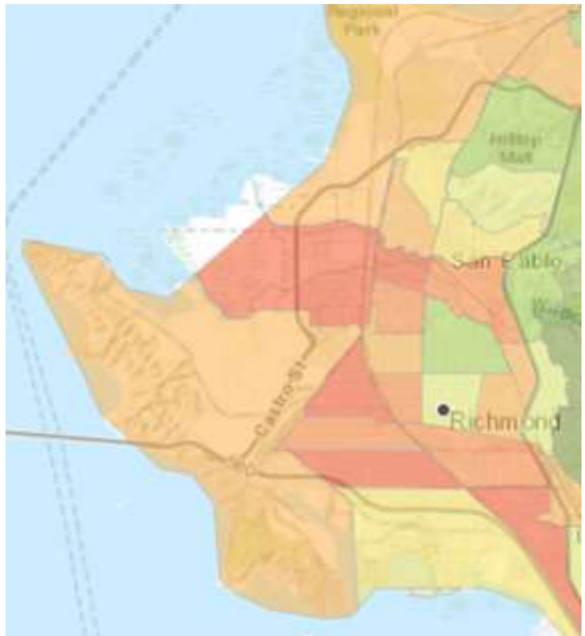
As shown in Figure 2 and Figure 3, the Kaiser Permanente Richmond facility project site has experienced progressively worsening air quality between the CalEnviroScreen2.0 (2014) and CalEnviroScreen3.0 results (2018).[11] Communities such as Richmond are historically underserved with respect to renewable and sustainable technologies. In particular, there is little solar energy generation and many obstacles to its development within the region. Lack of investment capital, diminished public resources, prioritization of other deferred maintenance and operational costs, and lack of environmental stewardship have led to an imbalance in environmental justice.

Regional Nature of Air-Quality

As demonstrated by the above map data, air quality is a regional phenomenon and can therefore have disproportionate impacts on certain communities. Though the reasons for this are complex, certain patterns seem to emerge. First, many of these communities are urban, have high density industries with particular emphasis on manufacturing, chemical processing, or transportation, and have higher poverty levels. If one expanded the CalEnviroScreen3.0 map to view the entire San Francisco Bay Area, only Richmond, Oakland, and South San Francisco have unacceptable air-quality while the remainder enjoy some of the best air-quality in the entire State of California.

[11] CalEnviroScreen is a mapping tool to help identify California communities most affected by pollution and uses environmental, health, and socioeconomic information to produce scores for every census tract in the state. Areas with with high scores experience a higher pollution burden than areas with low scores.

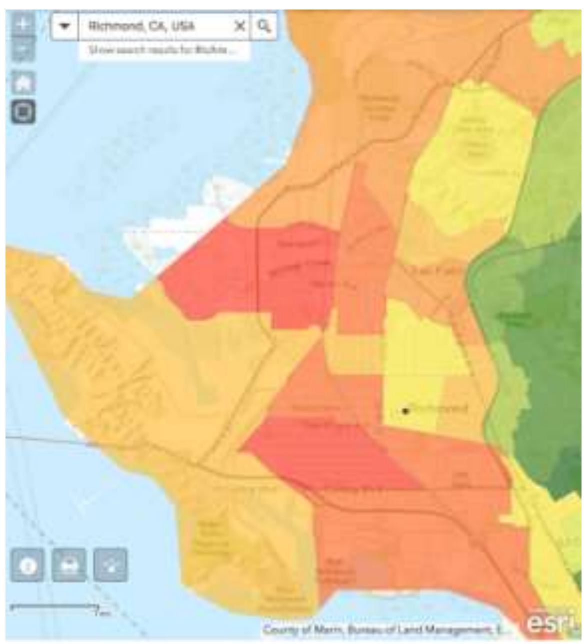
Figure 2: CalEnviroScreen2.0 of Richmond, California (2014)



Red hues represent poorest air quality while green represent good air quality.

Source: Office of Environmental Health Hazard Assessment, https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-version-20

Figure 3: CalEnvironScreen3.0 of Richmond, California (June 2018)



Note the conversion of prior areas such as central, north, and south Richmond to worse air quality ratings.

Source: Office of Environmental Health Hazard Assessment, https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

Health Effects

Environmental pollutants, including the volatile emissions and some greenhouse gases emitted by energy generation and vehicular transportation, are recognized to adversely impact human health, particularly in children.[12] Among the health effects are higher rates of premature birth, respiratory illness, developmental disorders, cancer, and heart disease. One of the principles underpinning the statutory and regulatory requirements for renewable energy in California is to mitigate these very effects.

Environmental Justice

Both legal and ethical principles suggest that all citizens are to be treated equally with respect to numerous factors including health and safety. Environmental quality in general and air quality in particular have direct impacts on human health, yet are experienced differently depending on where one lives. Applying renewable energy microgrids in disadvantaged communities that face air quality concerns may help address this disparity.

Economic and Technical Performance

Microgrid applications must also address economic and other performance imperatives. The transition to clean energy solutions must be cost-effective, safe, reliable, flexible, and scalable. Moreover, it is critical that the performance of existing systems is not adversely affected by installation of the microgrid, with the preference that it actually be improved.

To meet economic objectives, microgrids must provide multiple value streams for all parties involved, sometimes referred to as "value stacking." This could include the production of energy at a lower cost than fossil-fuel generation, decreased life-cycle costs of utility and host site electrical equipment, improved power quality and device efficiency, arbitrage of nighttime energy for daytime use, and time-shifting of solar to more expensive time-of-use periods or for peak demand mitigation. Tax equity, which can only be realized by for-profit entities, and directed incentives, such as the Self-Generation Incentive Program Advanced Energy Storage, can augment project value for third-party investors. Finally, emerging revenue streams from utility services such as automated demand response (see Glossary) may maximize financial performance.

Less apparent economic advantages from microgrids result from deferred utility costs. As distributed energy generation and storage become available at a large enough scale, less may be demanded from centralized systems. Specifically, late-day CAISO ramp rates could be mitigated through the time shifting of local generation. Renewable energy that is held in standing storage systems can be deployed through local or systematic control to decrease peak demand in the late afternoon and early evening hours. Furthermore, decreased demand for centralized generation may defer or eliminate the need to replace or enhance current generation systems. As markets grow for behind-the-meter storage to have interplay with utility and CAISO services, reserve power supply may be deployed in lieu of discretionary fossil fuel generation. Finally, conversion from dependence on the volatile, increasing costs of fossil fuels to predictable and declining renewable energy mitigates future utility expense and ratepayer impacts.

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[12] Frederica Perera. "Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist." Int J Environ Res Public Health. 2018 Jan; 15(1): 16. Published online 2017 Dec 23. doi: 10.3390/ijerph15010016.

Ratepayers are, in many senses, the most directly affected by investor-owned utility (IOU) cost mitigation. Although the IOUs are governed by the California Public Utilities Commission and must set their pricing accordingly, prices will still need to increase over time. As shown in Table 2, average total electrical industry and commercial energy prices have risen from $0.1215 per kilowatt-hour (kWh) in 2001 to $0.1507 per kWh in 2016, or 24 percent in 15 years. While price corrections have occurred, these have generally been short term and the rate of rise has been relatively consistent.

Table 2: California Electrical Prices over Time

Average Price (Cents/kilowatthour) by State by Provider, 1990-2016

Year	State	Industry Sector Category	Residential	Commercial	Industrial	Transportation	Other	Total
2016	CA	Total Electric Industry	17.39	16.07	11.92	9.80	NA	15.23
2016	CA	Full-Service Providers	17.32	15.50	12.70	11.91	NA	15.68
2015	CA	Total Electric Industry	16.99	16.73	12.17	8.98	NA	15.42
2015	CA	Full-Service Providers	16.97	16.25	12.90	11.20	NA	15.91
2014	CA	Total Electric Industry	16.25	15.62	12.34	8.90	NA	15.15
2014	CA	Full-Service Providers	16.24	16.04	12.81	10.75	NA	15.52
2013	CA	Total Electric Industry	16.23	14.20	11.44	8.54	NA	14.30
2013	CA	Full-Service Providers	16.21	14.54	11.85	9.89	NA	14.65
2012	CA	Total Electric Industry	15.34	13.41	10.49	7.17	NA	13.53
2012	CA	Full-Service Providers	15.32	13.82	10.72	7.96	NA	13.80
2011	CA	Total Electric Industry	14.78	13.05	10.11	8.14	NA	13.05
2011	CA	Full-Service Providers	14.75	13.16	10.14	8.82	NA	13.22
2010	CA	Total Electric Industry	14.75	13.09	9.80	8.27	NA	13.01
2010	CA	Full-Service Providers	14.74	13.22	9.79	8.87	NA	13.16
2009	CA	Total Electric Industry	14.74	13.27	10.42	8.35	NA	13.24
2009	CA	Full-Service Providers	14.74	13.35	10.39	9.05	NA	13.36
2008	CA	Total Electric Industry	13.81	12.54	10.09	8.16	NA	12.49
2008	CA	Full-Service Providers	13.79	12.41	9.77	8.58	NA	12.45
2007	CA	Total Electric Industry	14.42	12.82	9.98	8.37	NA	12.80
2007	CA	Full-Service Providers	14.41	12.82	9.88	8.28	NA	12.89
2006	CA	Total Electric Industry	14.33	12.90	10.09	8.29	NA	12.82
2006	CA	Full-Service Providers	14.32	12.93	9.95	7.66	NA	12.92
2005	CA	Total Electric Industry	12.51	11.92	9.55	6.55	NA	11.63
2005	CA	Full-Service Providers	12.49	11.97	9.39	8.11	NA	11.71
2004	CA	Total Electric Industry	12.20	11.64	9.27	6.42	NA	11.35
2004	CA	Full-Service Providers	12.20	11.81	9.33	8.03	NA	11.53
2003	CA	Total Electric Industry	12.23	12.48	9.59	5.80	NA	11.78
2003	CA	Full-Service Providers	12.23	12.83	9.79	7.38	NA	12.06
2002	CA	Total Electric Industry	12.84	13.36	9.81	NA	6.60	12.19
2002	CA	Full-Service Providers	12.83	13.84	10.23	NA	6.53	12.52
2001	CA	Total Electric Industry	12.09	12.15	9.23	NA	8.48	11.22
2001	CA	Full-Service Providers	12.06	12.41	9.54	NA	8.47	11.41

Average California Energy Prices years 2001-2016.

Source: EIA, https://www.eia.gov/electricity/data/state/

While the rate of rise is attributable to multiple operational cost factors, major variables include the costs of fuel, labor, materials, and equipment, and the impacts of inflation. In contrast, expenses for renewable resources are largely paid up front so energy production cost is constrained and predictable over time. By diminishing the need for IOUs and CAISO to increase and service centralized generation, ratepayers may experience lower electric rates over time.

Reliable technical performance is also important to demonstrate the overall value of renewable energy microgrids. In discussions with CAISO, prevailing concerns for microgrid performance include the consistency of energy supply, the timing to respond to utility or CAISO calls for energy or power, up and down ramp rates, and the quality of the power exported. Because of the tight tolerances required of both the IOUs and CAISO, there is little room for variation in performance. In addition, because the parameters for acceptable responses by renewable microgrids have not been thoroughly defined, additional developmental, testing, and validation will be required before these can be used as regular tools. Nevertheless, once such issues have been addressed, renewable energy microgrids could assume a significant role in power balancing, transmission and distribution, and even resilience when supply is limited regionally.

In turn, ratepayers could experience lower costs, lower greenhouse gas emissions, and improved system reliability.

Obstacles to Hospital Applications of Renewable Energy

While renewable energy systems and microgrids appear to be logical applications for California hospitals, they have not received widespread stakeholder support. Prior to this project, hospital and health system leaders believed that regulatory, technical, and cost hurdles would block renewable microgrid installations. For example, OSHPD regulations currently prohibit PV systems on hospital roofs. Some health facilities have used solar arrays in parking lots, but the majority have yet to deploy any renewable technologies.

Additional potential obstacles were recognized prior to the outset of the grant-funded project and are addressed in subsequent chapters on project execution. These may be categorized as constraints on available space, points of interconnection, and electrical isolation ("islanding").

Regulatory Barriers

In addition to complying with standard building codes (including the Energy Commission's building efficiency standards) and unlike non-medical commercial buildings in California, hospitals must also fully comply with all OSHPD standards. While an exhaustive review of these standards is beyond the scope of this document, there are several that are particularly relevant to this project. First, any systems that connect with, reside within, or are directly used by the hospital or its occupants must be earthquake certified. In many instances, this requires "shake table" testing which costs upwards of $100,000; thus, placement of systems such as batteries, inverters, or control systems within OSHPD-governed spaces could result in substantial cost as well as time expenditure. Second, points of electrical interconnection to hospital energy systems must meet higher standards for safety and performance and go through more exhaustive electrical, structural, mechanical, civil, and other engineering reviews. Third, interconnection of electrical, mechanical, and communications systems with the hospital requires a detailed OSHPD approval process prior to execution, including comprehensive contingency planning for resulting emergencies.

Technical Barriers

Interconnection of energy generation devices to hospitals is a well-established practice that can be readily replicated. Such devices include combined heat and power,[13] solar, fuel cells, and others. In general, interconnecting these devices requires brief shutdowns and reliance on backup diesel generation followed by continuous passive performance, regular maintenance, and only rarely significant malfunctions. However, the addition of smart inverters, controls, batteries, and other items that might be included in a microgrid design requires more space and complex design, engineering, construction, commissioning, testing and tuning and involves unknown risks and liabilities. For example, while battery fires are rare, even the suggestion of this event can deter interested parties. Moreover, bringing these systems into operation may

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[13] Combined heat and power refers to an integrated system that simultaneously generates electricity and useful thermal energy (such as steam) from a single fuel, representing a more efficient use of the fuel.

include additional and longer shutdown periods, testing and validation, and active management to achieve desired results. Finally, the need to construct key elements in public spaces such as on parking structures or lots introduces concerns about damage to public infrastructure.

Financial Barriers

Hospitals recognize the costly nature of power supply and are used to budgeting for it. The prevailing assumption is that energy is a fixed, escalating cost that cannot be avoided. Despite the overall fiscal strain facing hospitals as they consider gross operational budgets that, in some cases, are billions of dollars per year, savings of several hundred-thousand dollars may not appear attractive. Hospitals are also unable to capture the tax benefits and other incentives offered for renewable systems because virtually all healthcare facilities in California are non-profit entities and therefore cannot claim tax credits or depreciation or finance projects through the Property Assessed Clean Energy mechanism.[14] Therefore, they must rely on debt financing, cash expenditure, or third-party ownership and energy services agreements. The latter is a particular source of concern. While power purchase agreements are well understood by most stakeholders, neither hospitals nor prospective microgrid system investors have yet determined the best method to value renewable microgrid services. Numerous models are being tested, from power purchase agreements to shared savings and others, but there is inadequate long-term performance data for the relevant stakeholders to be comfortable with and support renewable microgrids.

Space Available

Because of regulatory constraints, renewable energy systems and related technologies cannot be placed on hospital roofs. Though discussions are underway at OSHPD to consider regulatory changes, the matter is largely moot due to the relatively small rooftop surface area available in proportion to energy use within the building. High-rise architecture combined with high-intensity power operations render the roof space insufficient for adequate amounts of PV panels. Similarly, hospitals frequently lack the space for parking lot solar or larger battery arrays. Existing lots may be shaded by the main hospital structure, may have easements or surface passageway requirements that restrict use, or may simply be too small to give up parking spaces. In many urban centers, ground-level parking lots have given way to high-rise parking structures with variable rooftop surface area and height restrictions that can limit the use of pre-configured shipping container battery/inverter combinations.

Public Safety

The proximity of energy systems to the general public can raise concerns for safety. Systems must be accessible for standard operation and maintenance but physically protected enough to minimize vandalism, unintentional damage or disruption, or harm to unsuspecting individuals.

[14] Property Assessed Clean Energy or PACE programs allow property owners to finance energy efficiency and renewable energy improvements to their property, with financing repaid through an assessment on the property tax bill with the loan attached to the property rather than the borrower.

This may require more hardened or redundant barriers, signage, added fire safety, and security systems.

Points of Interconnection and Islanding

At the outset of the project, the prevailing belief was that renewable energy systems could only be interconnected to the "normal" power of the host hospital. This was based on the belief that the emergency power systems, which are separated into different branches depending on the degree of criticality, would be considered non-modifiable by OSHPD. In turn, this presented challenges for demonstrating the capacity to "island" part or all of a medical center. Specifically, when the utility energy supply is insufficient and the hospital isolates itself through the opening of the automatic transfer switches, the California Public Utilities Commission's Rule 21 requires a microgrid that is solely connected to the "normal" power side to shut down. The alternative scenario would be to pioneer a "zero export" method wherein high speed detection devices are used to inform the microgrid of any grid export. During a utility outage, this could theoretically prevent energizing of utility equipment.

Hospital Operations and Shutdowns

Hospitals must operate continuously. In the California, there are structured points at which each hospital must test backup generation equipment. In addition, there are OSHPD processes to schedule elective construction, maintenance, and repair. All shutdowns must be coordinated between OSHPD, the hospital, administration, critical areas, clinicians, and patients to ensure the absolute minimum disruption to care delivery, patient safety and comfort, and hospital systems protection. Unlike other construction sites where nights, weekends, or holidays can be used, there is only marginal benefit to such scheduling within the healthcare environment.

Controller Development

One of the requirements of the Energy Commission's funding for this project was to design a microgrid controller that could improve on current generation technologies. The design intent was to use novel data monitoring, innovative data processing, and more complex decision algorithms to maximize systems performance. However, in the interest of the highest level of performance and safety, added levels of up-front empirical testing and validation are required. Moreover, integration into the hospital electrical environment required modeling of utility energy supply, hospital loads, and the function of the first layer controller supplied by the inverter manufacturer.

CHAPTER 2: Renewable Energy Microgrid Location and Design

Host Site, Obstacles, and Other Findings

In its initial proposal to the Energy Commission, Charge Bliss included a commitment letter from the John Muir Medical Center in Walnut Creek, California to host the project. However, after the Energy Commission issued its Notice of Proposed Award, the medical center withdrew from the project. After meeting with Energy Commission leadership, Charge Bliss agreed to identify other host site candidates with similar characteristics as the original host site for the Energy Commission's consideration. Using the OSHPD database for all hospitals in California,[15] cross-referenced by utility to select those within investor-owned utility territories, the project team members and external consultants communicated with nearly all relevant hospitals and health systems in California. Independent hospitals that declined to participate included Oakland Children's Hospital, Sonoma Valley Hospital, Cottage Hospital, Children's Hospital of Orange County, Loma Linda Medical Center, Catalina Island, Eisenhower Medical Center, Hemet Valley, Lucille-Packard Children's Hospital, Miller Children's Hospital, Palomar Medical Center, and Rady Children's Hospital. Sutter Health, Dignity, Adventist, Providence, Scripps, Veteran's Administration and similar systems elected to forego the grant. University hospitals including University of California, San Francisco and Stanford could not participate.

Ultimately the University of California, the home institution for the main members of the controls design team, offered the new Jacobs Medical Center for participation. The team gathered relevant site data and presented the site to the Energy Commission oversight committee for consideration. After discussion, the Energy Commission decided the site was unsuitable for this project and asked the team to present an alternative.

After working with the Director of Renewable Energy for the Kaiser Permanente National Facilities Services, the Charge Bliss team presented the Richmond, California facility to the Energy Commission for consideration. Based on the level of commitment provided both from the Kaiser Permanente system and the local leadership as well as site characteristics, the Energy Commission approved the site.

Notable characteristics of the new site include:

- Disadvantaged community: As shown in Figure 2 and Figure 3 in Chapter 2, Richmond, California is an air-quality disadvantaged community.

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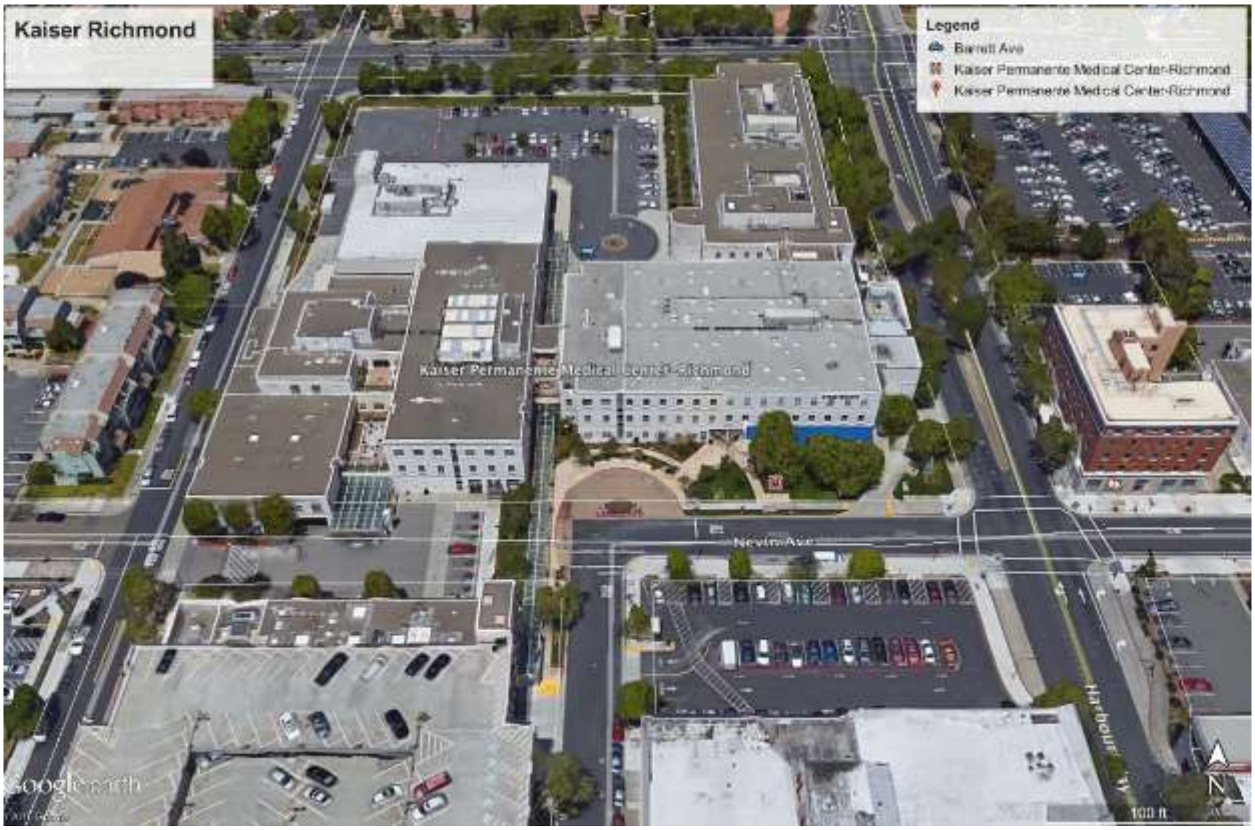
[15] Office of Statewide Health Planning and Development, https://oshpd.ca.gov/data-and-reports/healthcare-facility-attributes/.

- Healthcare shortage: The Kaiser Permanente facility is the only remaining general hospital operating in western Contra Costa County and the sole location for emergency care in the Richmond community.

Figure 4: Aerial Photograph of Kaiser Permanente, Richmond, CA



Satellite image of the Kaiser Permanente Healthcare Facility in Richmond California demonstrating the main hospital, detached parking structure, and city parking lot across the street.

Source: Google Earth 2017.

- Supplemental energy systems: The hospital has standard "normal" power and emergency power, plus combined heat and power. The hospital is also considering fuel cell technologies and has installed electric vehicle charging.

- Match funding: The Kaiser Permanente system committed, in writing, to provide match funding identical to that of the original proposed host site.

- Space available: The site committed to the space required for all systems design, installation and operation.

- OSHPD collaboration: Kaiser Permanente agreed to facilitate the participation of OSHPD in all relevant processes.

A leader in healthcare in the Western United States, Kaiser Permanente has also elected to take the lead in the realm of sustainability. Their enthusiasm about participating in the project stemmed from a system-wide commitment to sustainability, which includes "…ambitious environmental goals for the year 2025 that include becoming carbon positive, buying only sustainably produced food and sending zero waste to landfills."[16] Kaiser was particularly interested in the ability to use renewable energy, mitigate peak demand, and support hospital operations despite utility shortages.

The difficulty in identifying a suitable substitute site is notable for several reasons. At the time the project began, there was pervasive skepticism regarding the feasibility and value of renewable energy microgrids for hospitals. By their nature, healthcare organizations are conservative and look to other industries to pioneer technologies and financing mechanisms prior to instituting them in hospitals. In addition, the financial constraints of hospitals make healthcare organizations reluctant to accept any degree of perceived financial risk, and the lack of durable models of microgrid performance in "similar" environments has discouraged interest. Perhaps most importantly, there was a nearly uniform belief among hospital leadership, operations personnel, engineers, and electricians that this project would not receive OSHPD approval. The risk that a large capital project would languish for months or years in regulatory limbo while disrupting hospital operations led to aversion to participation in the project. Many of these objections were successfully addressed through this project, but potential developers and builders of future projects need to understand how healthcare organization concerns could affect real and perceived obstacles.

Optimal Sites

Design of a renewable energy microgrid for a hospital prior to completion of a new hospital design is arguably the best-case scenario. It allows teams to create the physical space, electrical system capacity, and options for interconnection to specific locations to best support hospital operations, and to maximize the potential impacts of the systems. Unfortunately, this is a relatively rare situation and retrofitting will be the norm until renewable microgrids become standard.

Based on the evaluation of not only Kaiser Richmond but multiple other hospitals across the California, certain specific characteristics stand out:

- Adequate ground-level space for lower-cost solar: Though it is unlikely to result in hospital net zero in terms of energy consumption, larger solar arrays could substantially decrease power drawn from the investor-owned utility and, perhaps more importantly, support larger battery arrays, more significant time shifting of usage, far better reduction of peak load, and more savings.
- Adequate space for large battery and power conditioning: In combination with large solar, large battery arrays can achieve far more profound impacts. Though cost of the batteries is somewhat linear, larger systems are less expensive to develop per unit of

[16] "Kaiser Permanente Pledges Bold 2025 Environmental Performance to Benefit People and Planet," https://share.kaiserpermanente.org/article/kaiser-permanente-pledges-bold-2025-environmental-performance-to-benefit-people-and-planet/ , May 2016.

storage capacity because engineering and other design elements are not necessarily incremental.

- Sufficient interconnection capacity: Having multiple options for possible points of interconnection, including on the emergency power panels, allows the design team flexibility to minimize construction costs, losses over distance, disruption of site operations, and violation of OSHPD principles. Options to connect on the main electrical supply of the facility could also be desirable and may be achievable if a hospital is undergoing a major electrical system upgrade for other reasons.
- Undersubscribed local solar and adequate utility equipment: To avoid utility interconnection difficulties and cost, it is potentially valuable to identify hospitals where the surrounding areas do not yet have significant interconnected solar as well has newer, higher performing transmission and distribution hardware that is more easily able to tolerate the thermal, voltage and other impacts.
- Collaborative site personnel: Given the need for substantial input from site operations personnel, electricians, engineers, and leadership, a site team that is fully committed to project excellence is more likely to have success.

Site Characterization

Though hospitals in California share basic characteristics, they may vary based on the scale of systems, operational intensity, ambient conditions, utility energy usage and demand, and tariff type. By statute, all designs, materials, equipment, and devices in California hospitals are regulated by OSHPD. The stringent standards and the expenses to meet them result in a far smaller number of device options within hospitals. In turn, there is a measure of predictability with respect to systems types and performances. Standards for lighting, air movement, temperature, humidity, life support, and many other systems are uniform and must be met by all facilities.

Nevertheless, building and systems ages and performances can vary widely. Newer institutions tend to have a tighter building envelopes with less heat loss, more efficient energy systems and devices, and better systems monitoring. There tends to be less variation in daily, monthly, or seasonal performance. In contrast, older institutions, particularly those that have been modified and expanded over decades, may have highly variable performance of systems, relatively wide swings in power quality due to more frequent and significant cycling of induction motors, and overall designs less conducive to efficiency and load management.

Perhaps most importantly, hospitals may have different physical layouts that affect not only the placement of microgrid systems but also the need for boring, trenching, or overhead transmission lines. While rural and lower population density cities frequently have low-rise hospital buildings with considerable ground-level parking lot space or even adjoining land, many hospitals in urban and high-density environments are built on small parcels, use vertical construction, and rely on parking structures. Each presents different options for the insertion of new systems and the physical layout may be one of the most significant factors in defining design parameters.

Therefore, expert electricians, engineers, architects, and construction tradespersons must evaluate major electrical panels and subpanels (age, quality, wiring, capacities, current loads, space, and relationship with OSHPD), possible locations for conduit, penetrations, monitoring systems, and ancillary support tools (heating, ventilation, and air conditioning [HVAC], internet, security, fire suppression), and confer with site electricians, engineers, operations and management personnel, and other advisors to comply with institutional policies and best practices. The teams also involved concerned parties such as the host site city (Richmond, California), utility (Pacific Gas and Electric Company [PG&E]), CAISO, and OSHPD to ensure compliance with oversight requirements.

Specific systems characterization is also essential as discussed below.

Solar Array, Battery, Power Conditioning, and Controls Systems

At the original site specified in the grant application, the developer, contractors, and relevant systems supplier specified a fully-integrated, pre-containerized and co-engineered Princeton Power Systems® BIGI250™ inverter, Princeton Power Systems® EMOS™ first-layer controller, and one megawatt hour/250 kilowatt (kW) discharge capacity Samsung® SDI™ batteries. There are several distinct advantages to this form of integration. By virtue of independent engineering, integration, and installation within a shipping container, this is a single solution that eliminates considerable non-recurring engineering. All sub-systems are anchored, wired, and connected in addition to including ancillary systems such as HVAC and fire suppression. Moreover, pre-installation performance validation can be performed to assure optimal system performance prior to shipping. Finally, considerable site disruption, labor time and cost, and coordination of relevant contractors may be avoided. However, as will be discussed in more detail in the Design Process section, this methodology was not applicable at the Richmond site.

When the Richmond site was substituted, the General Contractor (Charge Bliss Construction CA Inc.) had to repeat the detailed site inspection. In combination with site personnel, Charge Bliss discovered several impediments to this deployment that are relevant to other hospitals and commercial buildings. It requires considerable space to install the large solar and battery arrays needed for the microgrid. Unfortunately, space is frequently at a premium, particularly in urban hospitals. Furthermore, what may appear as usable surface area may be constrained by the type of ownership, under or above-ground easements, natural elements (underground rivers), and limitations on loss of usable space. As shown in Figure 4 above, there is a large parking lot across the street from the main building that would seem to have adequate surface area for both canopy solar and a shipping container for the batteries, inverter, and controls. However, the team of Charge Bliss Construction, Kaiser, City of Richmond, PG&E, and Mazzetti and Associates determined that this parking lot could not be used. First, the lot is leased from the City of Richmond and long-term modifications were considered unwise. Second, interconnection to hospital panels would have required boring under the street and penetrating the central utility plant in a fashion that would a) interfere with PG&E under-street easements and b) violate OSHPD principles. While a surface parking lot installation would have avoided other significant engineering and labor costs, these problems were insurmountable. The obstacles are noteworthy for other designers, engineers and builders as the team has since encountered remarkably similar constraints at other California hospitals.

Careful examination of the building envelope, access routes for both the public and shipping deliveries, and buffer zones required for safety is equally essential. As was evident through the onsite review of the Richmond facility, there is frequently no reasonable option to place the batteries in the immediate vicinity of the main hospital building or, in many cases, near the central utility plant. Indeed, to even consider such a placement, the team learned that additional, very expensive evaluations and documentation would be required (for example, shake-table testing) without any reasonable expectation of success or approval. Equally important, the mass and density of battery and power conditioning systems placed within a shipping container is such that they generally cannot be placed above ground floor level without significant engineering and structural redesigns that are cost prohibitive in other than new-build environments. Therefore, for all practical purposes, the battery and power conditioning systems must be as remote from the main building as possible but as near to the central utility plant as possible while also not triggering complexities due to space usage or how conduit is run to reach the point of interconnection. For hospitals, in particular, engagement with a representative of OSHPD, an engineer or firm with hospital regulatory experience, and the electrical contractor is essential to fully characterize options.

Once full site analysis was completed, it became apparent that the only reasonable and achievable location for the battery and inverter systems was the ground floor of the parking structure sharing a wall with the central utility plant. The general contractor and subcontractors obtained measurements of each entry point of the structure only to discover that the height would not permit the use of a shipping container. Thus, the design team would have to switch from a pre-designed, pre-integrated system that could be drop-shipped to the site for connection to a ground-up, site-engineered option. Specifically, a sub-team was needed to create a two-room, block wall structure that could house the batteries, monitoring, and controls in one room and the inverter in the other. In general, most energy projects avoid building structures because these add cost and time as well as permanently alter the built environment in a way that may be avoided with shipping containers or other more mobile solutions. Should such designs be required, however, either a comprehensive engineering firm or individual engineers with electrical, structural, mechanical, and civil training as well as a licensed architect may be needed to fully plan additional structures. In addition, it is critical to understand the temperature and humidity tolerances of equipment to be housed, the respective heat loads, and ventilation requirements as well as the requirements for access and egress for safety to meet fire marshal and city codes.

Similarly, the team faced challenges for installation of the solar array. While ground-mount and rooftop solar are far less expensive than other forms, these are largely unachievable at most hospitals due both to OSHPD restrictions and space constraints. Indeed, Charge Bliss discovered in earlier discussion with one interested hospital that they would have been interested in a ground-level parking lot solar array were it not for plans under consideration to build a new hospital tower on the same lot.

Spanning solar arrays on the roofs of parking structures may trigger the need for additional engineering and design costs, not to mention greater costs for more structural steel. In Richmond, the team had to consider the weight tolerances of the major structural elements of both the canopies and the parking structure, wind shear, and how to run conduit and systems from the top floor to the inverter room several floors below. As shown in the under-canopy view from the final product (Figure 5), considerable mass must be distributed on heavy columns which are anchored to the superstructure of the parking garage. This required structural and civil engineering effort by the canopy supplier and was regulated and inspected by City of Richmond personnel.

Figure 5: Under Canopy Images

Picture taken under the actual built canopy showing width and span of the solar structure, supports, and parking structure anchors.

Source: Charge Bliss

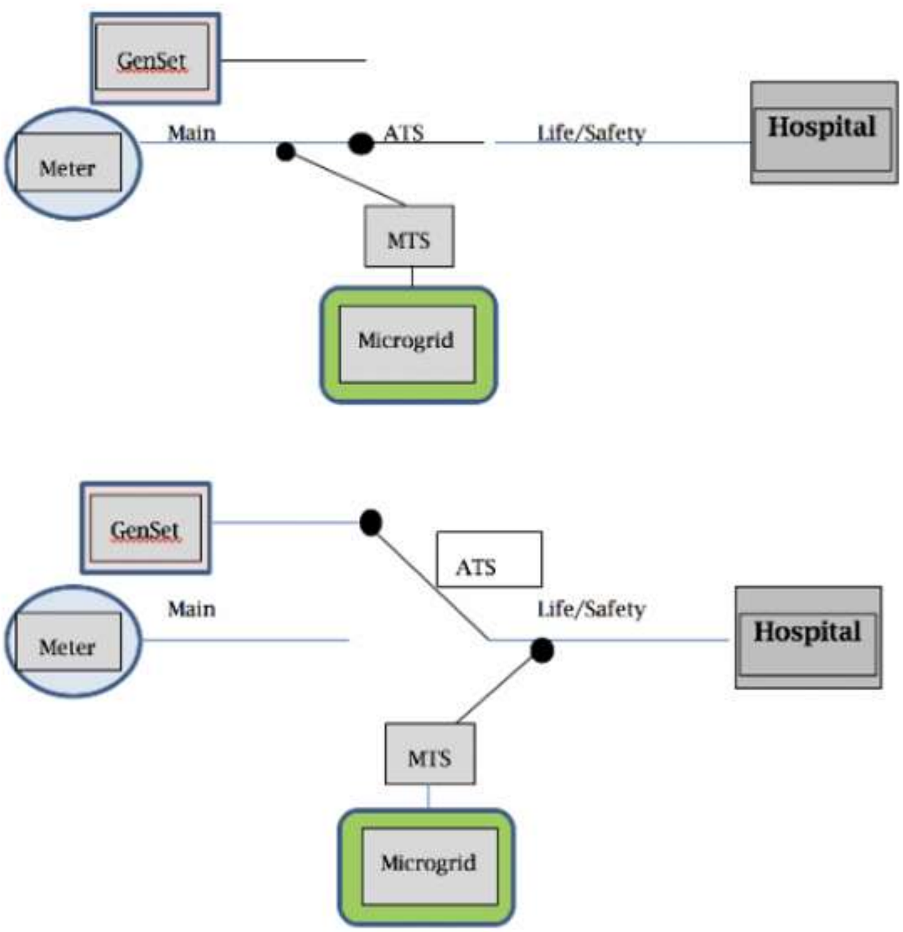
Although in this case the team could rely on the in-house team from SunPower® to perform the needed design and engineering work, the process impacted the duration and cost. It also required collaboration between the host site for traffic and safety planning. Future design teams should consider that the incremental cost of solar decreases with larger arrays. As design and engineering costs are relatively fixed and not incremental, larger arrays will have lower per-unit expense.

Electrical Systems

Detailed evaluation of site electrical systems is crucial to project design. Older facilities in particular may contain panels, wiring, and safety systems from different time periods that may no longer be available and must be fabricated specifically for the site in question. Most importantly, the project engineering, contracting, site, and OSHPD participants must agree on the points of interconnection. The choice depends not only on having adequate capacity to receive of deliver power, but also on what is allowable by code and regulation and is acceptable to the site. For example, during the course of the project it became clear that Kaiser Permanente was considering the installation of multiple fuel cell systems at other facilities. The fuel cell system manufacturer/installer informed the Richmond project team that its intent was to interconnect to the main hospital energy supply. The Charge Bliss project team met internally and with facility representatives and OSHPD, all of whom felt this would be too difficult, cause multiple, prolonged shutdowns of the hospital, and might trigger more difficult obstacles from regulations. In large measure, there is no practical value in exploring designs at the expense of considerable cost and time that might appear to have a poor chance of feasibility. This is best determined before formal design and engineering begins.

The Kaiser Permanente hospital facility in Richmond is one of the older sites in the Kaiser portfolio that includes many energy systems dating back 15-20 years. Because of building modifications, movement of site records, lack of detailed records at the city offices, and changes in personnel at both the site and city, it was challenging to find detailed electrical plans and specifications for relevant items. As a consequence, the general contracting team, electrical installers, and design engineers had to inventory and examine each electrical panel, visible wiring, and connected loads to determine possible points of interconnection. Ultimately, only one panel was considered adequate with respect to capacity for power flows. Equally important, this same panel was considered an acceptable target by the site, OSHPD, PG&E, and the City of Richmond as shown in Figure 6.

Figure 6: Points of Common Coupling



Single line drawing of the Point of Common Coupling for Normal Power and Emergency Power (Life Safety) at the Kaiser Permanente Richmond facility.

Source: Charge Bliss

This underscores the ease with which such systems may be incorporated prior to a new build or within an existing structure where adequate space and electrical capacity has been specified in advance. However, older facilities with limited information regarding existing systems, fewer options for repair or upgrade of these systems without prohibitive expense, but greater need for energy efficiency, sustainability, and resilience may often go overlooked. Renewable microgrids remain achievable in such environments but require collaboration among all stakeholders before design commences.

In an interesting and far-reaching development, the collaboration with OSHPD and joint systems evaluation led to a first-of-its-kind design breakthrough. Despite the prevailing belief that OSHPD would not allow interconnection to the emergency power, the agency in fact suggested a dual interconnection method with the second point being the life safety panel. Though OSHPD required that this optional point for interconnection and islanding lie behind a manual transfer switch that requires human initiation, this proved to be a significant step that has altered the dialogue both within OSHPD and with hospital systems designers and operators.

The opportunity to achieve this novel interconnection method is the direct result of a team approach that includes all relevant stakeholders. Had OSHPD not been engaged until later when designs were underway or ready for submission, there would not have been the opportunity to consider dual points of interconnection and support of emergency power through the renewable microgrid. Future design teams should consider early consultation with external experts on regulatory and interconnection processes and with the agencies and entities who ultimately render decisions including OSHPD, the utility and system operator, and the Energy Commission.

Utility Supply and Interconnection Considerations

Beyond the fact that interconnection of a microgrid to on-grid buildings requires going through the formal interconnection process, there are several variables to consider regarding utility energy suppliers, equipment, and regulations. Each utility has its own process to comply with the California Public Utility Commission's (CPUC) Rule 21,[17] though the basic principles remain similar. Non-export designs are, perhaps, the most straightforward approach. These designs either constrain solar array sizing to well below the contemporaneous site load or have "smart" systems to curtail or divert solar production into site-based storage. In contrast, designs which intend to export energy or are determined by the utility to have the possibility to export may be subject to interconnection studies. In a recently published study from the National Renewable Energy Laboratory, 57 percent of photovoltaic interconnections in the western United States required upgrades of utility equipment or other mitigation strategies.[18] The three most common issues are transformer thermal load, protection impacts, and voltage effects, with voltage issues being the most common. In addition, arrays between 100-500kW cost a median of

[17] California Public Utilities Commission, http://www.cpuc.ca.gov/Rule21/.

[18] Bird, Lori, Francisco Flores, Christina Volpi, Kristen Ardani, David Manning, and Richard McAllister. 2018. Review of Interconnection Practices and Costs in the Western States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71232.

$120,000/megawatt (MW). However, California does have provisions for a 25 percent cost envelope that constrain utility charges. The same study found that California is one of three Western states of the 11 examined that have specific interconnection processes for PV + battery installations.

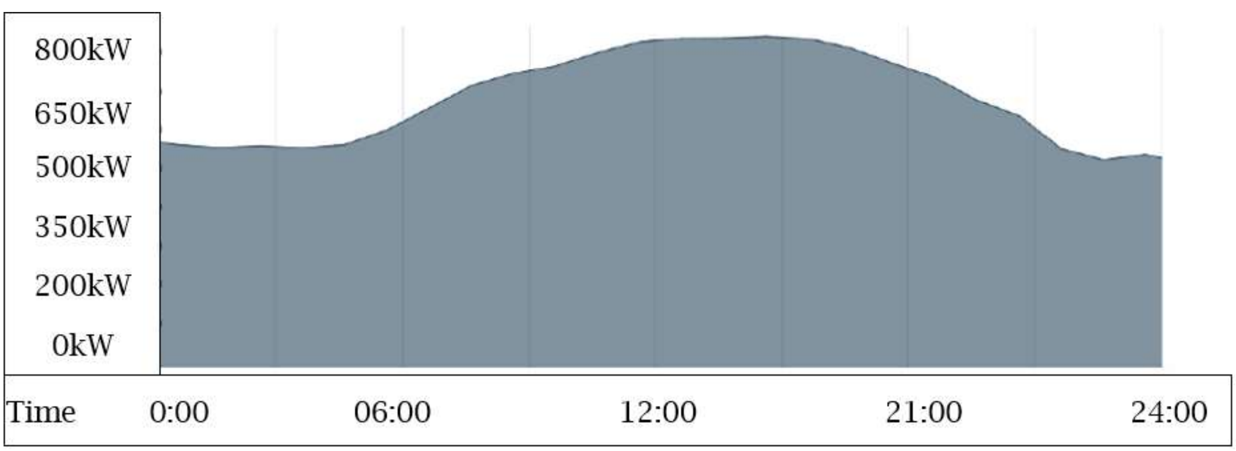
Notably, the density of interconnected solar in the immediate area and the degree of grid effect may affect a new project. While Southern California Edison provides an online distributed energy resource (DER) interconnection map,[19] other utilities are still preparing detailed versions. Nevertheless, the maps can provide valuable insight into the options and risks at a particular location. Early interaction with the utility, using electrical engineers and electrical contractors who are familiar with the commercial interconnection processes, and complying with the Rule 21 processes for the specific utility are essential.

Utility Load Profile, Tariffs, and Costs

While investigating candidate hospitals, the project team discovered several useful characteristics about healthcare facilities. Because they must operate continuously, even under circumstances where other commercial buildings will close temporarily, load profiles do not differ substantially across a typical week or, in many cases, a season. Seasonal variation does occur, especially if ambient conditions are variable. For example, a wider disparity of outside temperatures in the San Francisco Bay Area leads to more significant differences in heating, cooling, and ventilation compared to San Diego, where the temperatures less variable.

In addition, all hospitals appear to have high base loads which rise quickly in the early morning hours and have a broad, sustained arc until approximately 9pm. Based on data obtained by Charge Bliss, peak facility demand may be as low as 60-900kW or as high as 12MW or more. Examples of single-day load profiles are shown in Figure 7 and Figure 8.

Figure 7: Summer Load Profile



Single day summer load profile for the site demonstrating high base load (demand) with broad and sustained arc across the day.

Source: Charge Bliss

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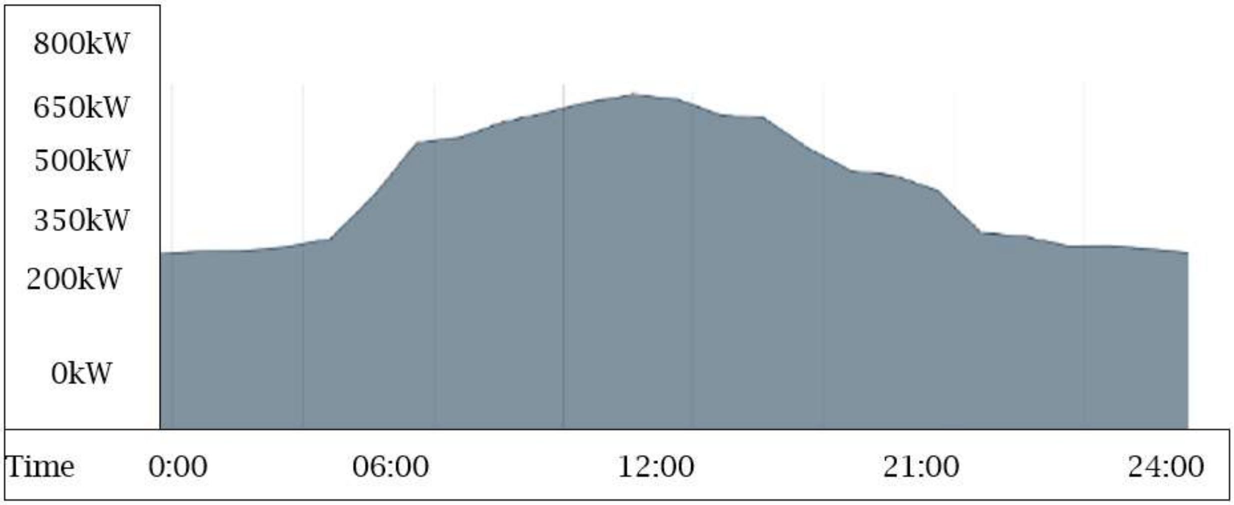
19 https://drpwg.org/sample-page/drp/ .

Figure 8: Winter Load Profile



Single day winter load profile for the site demonstrating lower base load (demand) and less duration of daytime increased load, though a greater disparity between base and peak load.

Source: Charge Bliss

There are two broad categories of load items that contribute to the hospital profile. Lighting, plug loads, and continuously operating machinery tend to contribute to base load and do not vary substantially. There is room for load reduction through efficiencies, though limited options exist because of the regulatory environment. Devices that contribute to peak loads and in particular to rapid spikes include chillers and air handling, inductive motors such as in elevators, large imaging items (MRI, CT), and gas and hydraulic systems. Though there is limited objective data in this regard, it is reasonable to assume that both base and peak loads are scalar functions of building size, occupancy, services rendered, and efficiency of systems.

The costs associated with energy usage and demand vary by utility and tariff but share certain characteristics. Annual consumption may range from 4 gigawatt-hours (GWh) to more than 50 GWh. At an average cost of approximately $0.14/kWh, this results in usage expenses between $0.5 million-$6 million/year. Demand costs not only vary by cost per kW but by month because each utility has a different definition of summer. PG&E, for example, charges summer rates from May through October, including facility demand (highest 15-minute demand during each billing period), mid-peak (highest 15-minute load during mid-peak time-of-use), and on-peak (highest 15-minute load during on-peak time of use). This can lead to a gross cost as high as $42/kW in summer and $25/kW in winter. Aggregate demand costs can range between $0.5 million-$5 million per year.

The Kaiser Permanente facility in Richmond, California is relatively small (50 beds). Approximately 40 to 45 percent of total facility utility energy cost is comprised of demand fees while the remainder is made up of usage and fixed charges. Interestingly, when the detailed tariff, load, usage, and cost data was analyzed, the patterns very much mimicked those of facilities examined by Charge Bliss throughout California, albeit scaled to size. This finding illustrates one of the observable disparities across California healthcare – hospitals located in underserved communities experience the same proportional fixed costs of operation but must meet these costs with much poorer reimbursement rates. Independent hospitals and small systems have had to close operations in communities like Richmond while larger systems presumably spread the incrementally higher proportion of cost across a broader portfolio. Thus, it is increasingly important for hospitals in socioeconomically challenged environments to seek methods to reduce costs while maintaining operations.

Individual facility load profiles help to inform the sizing of microgrid systems. One may optimize solar sizing based on the combination of the space available for solar (inclusive of the type and efficiency of the panels), the bus bar[20] capacity at the point of interconnection, the ability of utility equipment to accept power export, and the budget. In this case, Charge Bliss employed several platforms to determine the best case, including Helioscope™, PVwatts™ Geli™, and Homer™. The first two are robust tools that a) model solar arrays on sites based on satellite imagery and b) use National Renewable Energy Laboratory data to accurately estimate solar productivity every hour throughout the year. The latter two tools use the outputs of the first two to iteratively optimize solar, battery, and inverter types based on economic performance. When the team considered the outputs of these tools in combination with the bus bar capacities and budgetary limitations, 250kW (DC) emerged as the appropriate design.

The same analytics are used to determine battery sizing. Because of bus bar limitations, no greater than 250kW of capacity was achievable at the specific site. This could have been improved with electric panel upgrades, but the financial cost (upwards of $250,0000) regulatory hurdles, and impacts of site shutdowns were simply prohibitive. Therefore, based on the budget, space available, desired amount of peak load reduction, and best practices for long term battery health and performance, one megawatt-hour of nominal capacity was selected. The process is discussed in greater detail in the “Design Process” section later in the chapter.

Existing site tariffs and tariff changes are also important considerations. As large consumers of energy and power, utilities typically place hospitals on time-of-use rates. Interestingly, these rate structures are intended to address utility operating costs (including the increased expense to meet system-wide demand during peak hours) but are also a method to incentivize commercial energy users to alter operations. For example, a manufacturing facility could elect to use the highest intensity systems during the 9 p.m. to 6 a.m. period, thereby cutting both energy and demand costs dramatically. Similarly, commercial buildings could achieve greater efficiencies through upgrades, agreeing to more flexible operations of environmental systems, or through load shedding programs (automated demand response). Unfortunately, hospitals cannot alter their operating hours. Interior temperature, humidity, air flow, lighting, transportation, safety equipment and virtually every system are regulated by code with little discretion for the individual facility. And, while hospitals may wish to deploy more energy-efficient systems, the options are far more limited given the intensive testing required to meet regulatory standards that are specific to the industry.

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[20] A bus bar is a metallic strip or bar housed inside electrical panels and switchgear for power distribution.

Microgrids provide a strategy for hospitals to respond to time-of-use impacts. With the ability to time-shift solar to make the most of its value as well as partially charge the batteries during lowest cost intervals and deploy the power during high-cost times, microgrids can overcome many of the adverse impacts of time-of-use rates that hospitals experience. Moreover, the ability to buffer demand spikes can capture demand cost savings.

It is unclear whether new tariffs will offer advantages to hospitals. Many such tariffs, such as real-time pricing or critical peak pricing, are advantageous to entities that can rapidly alter building operation but are not usable by healthcare facilities as they currently stand. Large standing energy storage could change this paradigm, however, as sufficient reservoirs of power could provide alternative energy when price signals are favorable. Storage was not evaluated during the current project but could be an added advantage of battery-based renewable energy microgrids in the future.

Other resources for energy are also emerging that may impact the costs of commercial power. Direct service providers, including one such entity serving part of the energy needs of the Richmond facility, can deliver energy at a contracted price below prevailing utility rates for a prolonged contract period. Similarly, Community Choice Aggregators (CCA) are non-profit entities that purchase power for the member locations and entities and set prices based on long-term contracts with producers of renewable and other energy. Both of these hold the promise of constraining cost over long periods, but the cost differences are frequently nominal and have no impact on demand fees. Most notably, the CPUC has permitted utilities to levy additional costs on users of their equipment to defray the costs of departing loads, maintenance of transmission and distribution equipment, and backup power.

Monitoring Equipment

Charge Bliss specified the use of innovative monitoring and data processing including Phasor Measurement Units (PMU). These are similar, in some respects, to current transformers that make use of magnetic disturbances to measure voltage, current, frequency, and other variables on each electrical phase. However, PMU add the value of time-stamping data elements to provide truly simultaneous information to analytical and control systems. For example, PMU set at geographically distinct locations can report precisely simultaneous information to a central repository. In turn, a microgrid control systems can determine an action at the point of common coupling and determine the impacts despite physical distance. Through tuning based on conditions and continual updates, the microgrid control system can determine interventions that will have determinate effects at all monitoring points. This architecture is essential as attempts to regulate power quality or make real-time adjustments become part of the technical vocabulary of autonomous microgrids. For microgrids to collaborate with one another, the utility or system operator will depend on such granularity, specificity, and accuracy.

Because these are relatively new devices, special expertise is required to determine the type, location, installation, and operation of the PMU. In addition to participation by the systems engineers, control design team, and general contractor, a specialized installer and OSHPD representation were needed to achieve the necessary central utility plant penetrations for reference voltages, proper connections, and data reporting to the recording systems.

Furthermore, the speed of data acquisition requires the specification of large data storage devices, data compression, or data analysis and conversion in real time. Though this project used the OSIsoft® Pi® platform as well as MatLab® Simulink™, specific additional data processing code writing was required to convert raw data elements into useful parameters for machine decision-making. The critical steps are to involve expert controls engineers at University of California, San Diego (UCSD), a national laboratory such as the Florida State Facility, and the supplier of the DER to ensure proper design. In particular, understanding not only the basic specifications of the power conditioning systems but the more granular matters of communication speeds, response times, ramp and de-ramp rates, and the other physical limitations can define what is achievable with a supervisory control.

Internet Connectivity

Internet connectivity is essential to have visibility into systems performance as well as the ability to control microgrid performance remotely. Though initial plans included tie-in to the existing hospital network, this required detailed discussions between the developer, Charge Bliss, the information technology personnel of the hospital, and the controls design team members. After considering the need for hospital data security, cybersecurity of the microgrid, and system redundancy, all parties agreed that independent internet access was needed. Given the available tools that could be deployed in the battery/inverter/controls rooms, a dedicated DSL line was specified. Thus, the designer of hospital microgrids must specify its own information technology plan and connectivity including the provider, method to bring the wired connection to the electronic hub, whether to use all wired or some wireless networking, and what additional protective measures should be employed. Once again, it is essential that the communications systems have sufficient bandwidth to handle extraordinary data transmission in addition to rapid, closed loop control instructions. In particular, since systems controls must be embedded (local but with remote access to tune, override, shutdown, restart), internet communications must be as fast as is achievable. Cybersecurity is maintained through the use of a static IP address, login and password protection, and encryption of registers.

Other Energy Systems

Prior to project initiation, the intent had been for the microgrid to interconnect in such a way as to island and support previously installed combined heat and power (CHP) systems. At least two methods could be employed to achieve this objective – direct control of the CHP and providing an electrical signal directly from the microgrid, or interconnection of both the microgrid and the CHP on the hospital side of the automatic transfer switches. Either way, the microgrid could provide the necessary frequency and voltage signal to sustain CHP and other system operation. In a general sense, this approach is applicable to any DER, particularly those with "smart" technologies. This could include other forms of electricity generation (wind, fuel cell), energy storage (thermal, mechanical, chemical), or load item.

While the optimal scenario is to receive continuous data regarding the distributed energy resource state and capabilities to then determine coordinated action, it is also possible to combine autonomous and separate elements with other DER that are interactive. In point of fact, the utility grid is treated as an autonomous DER, albeit with theoretically unlimited capacity to deliver energy and a defined tolerance for energy export. Evolving scenarios that have been encountered by the project team include co-location of autonomous, continuous-operation fuel cells and CHP combined with renewable generation and energy storage. In many cases, the manufacturers of fuel cell and CHP technologies do not wish to cede control of their systems but will allow them to be monitored by the microgrid controller and, under islanding conditions, permit the microgrid to provide the dominant signal to support continued generator function.

Health, Safety, and Security

Because of the risks inherent in the use of high-power electrical systems – particularly those in proximity to workers and the general public – physical health, safety, and security must be considered. Whether this entails containerization of battery and inverter systems, physical separation from buildings and public access, barriers, or other approaches, access to systems must be limited to expert personnel. In the case of the Kaiser Permanente installation, an unintended benefit of the site was the need to build cement block rooms with controlled access for the batteries and power conditioning. Moreover, with the addition of visual security and recording, the team was able to determine when the space was accessed, by whom, and for what purpose.

Similarly, solar canopies must have reasonable protections against harm to or by the general public. Unlike rooftop installations that are remote from contact, canopies are generally placed on parking lots or structures in close proximity to cars, pedestrians, workers, and others. Consequently, hardened steel columns that are resistant to impact, deter vandalism, and are difficult to scale are standard design elements. Unfortunately, no configuration is devoid of risk, particularly if an individual goes to unreasonable lengths such as breaking into or scaling a structure.

Cyber-security has become an increasing point of concern and has particular relevance to hospitals. Healthcare facilities must have virtually tamper-proof networks to protect the privacy of patient data, the integrity of information, and the ability to deliver consistent, high-quality services. As demonstrated by multiple hospital shutdowns due to the malware “WannaCry”,[21] even robustly protected, closely monitored networks are vulnerable to attack. This makes healthcare organizations even less willing to provide access to their network systems for purposes of microgrid operations due to concerns about a malicious coder exploiting a flaw in the microgrid communications architecture to gain access to the hospital systems. Therefore, it seems prudent for hospital or other critical infrastructure microgrids to have separate and independent internet and communications systems access.

[21] Daily Beast, “Hackers Cripple Hospitals with Stolen NSA Malware,” https://www.thedailybeast.com/stolen-nsa-tech-shuts-down-hospitals, May 2017.

Design Process

Stepwise Design

During the course of the project, the team determined that specific steps must be taken in a logical order to achieve project success. Failure to recognize and address each matter in a stepwise fashion can result in unanticipated delays or design mistakes. As discussed previously, key stakeholders and specialized team members must evaluate site and project matters and, most importantly, report at regular team meetings to disseminate information correctly and directly. Detailed site information informs initial modeling of energy systems. When this is combined with budget and regulatory constraints, the system sizing and performance specification needs become clear. Systems physical characteristics (shape, weight, connections), safety and communications requirements, codes, site structural, mechanical, and electrical characteristics and cost determine construction.

Team Composition

Because of the innovative nature of this project as well as the perceived risks, it was essential to deploy experts from a variety of fields. A more robust team of people is needed to design tailored microgrids for hospitals than might be required for a less complex commercial environment. Individuals and teams working on the project merged expertise from hospital design, engineering, and operations, regulatory oversight, solar, batteries, and power conditioning, systems controls, de-risking, and implementation, project development, and construction. Because this project represented a new approach, several of the team members may not be needed in all future developments. Team members and services provided included:

- Internal champion: Mr. Seth Baruch, Director of Renewable Energy Services for the Kaiser Permanente National Facilities Services group, played a critical role in identifying key internal stakeholders, advocating for the project, coordinating communications, and supporting completion of essential milestones.
- OSHPD expertise: OSHPD sets and enforces all standards for hospital design, engineering, construction, operation, and repair. The team selected John Griffiths, P.E. from Mazzetti and Associates and later with Contech, Inc. to participate in all engineering design and interact with OSHPD representatives. This is particularly important to discern which matters may require OSHPD review, which can be done independently, and how best to ensure full compliance with regulations.
- OSHPD representation: Though OSHPD normally does not involve its technical staff in design processes, the Charge Bliss team was able to discuss the nature of the specific project with OSHPD leadership who, in turn, approved the participation of Mr. Corey Hiratsuka. OSHPD is aware that renewable energy systems are increasingly important and that opportunities must be made for their use in the healthcare environment. In addition, they recognize that emerging tools such as microgrids have the potential to add to hospital resiliency and, perhaps, improve power quality, emergency power, and operational cost. Perhaps most importantly, this represented an opportunity to

collaborate with the Energy Commission and to begin broader discussion of how the two agencies might collaborate on future energy standards for hospitals.

- Governmental liaison services: Because Kaiser Permanente has a robust governmental team and was interested in the best possible outcomes, they were willing to offer liaison services to the relevant State agencies. This permitted continuous dialogue between the health system and the State and has illuminated a path for a roll-out of similar technologies at other Kaiser facilities.
- Public relations: The Kaiser Permanente group provided robust support for public relations including the very successful public opening ceremony and technical deep dive. This included site-based personnel (Adonna Sullivan, Tara Evans) as well as system-level leadership (Noella Tabladillo, Rick Ginley, Brian Fershtman). In this fashion, the best results for public information were obtained for all parties concerned.
- Hospital-based project manager: Ms. Christina Morgan played a pivotal role in project execution through coordination of relevant personnel, activities, and communications at the host site. Ms. Morgan functioned as the parallel contact for the Project Manager, Jon Harding, and Assistant Project Manager, Jeff Harding.
- Payor representation: Participation of a technical representative of the payor is important to reach key technical and financial goals. Though in this case the payor was the Energy Commission, this remains true whether the funding is public or private. Both of the Energy Commission's contract managers also were trained engineers, facilitating in-depth involvement in technical as well as business matters and ensuring progress in both.
- Project management: This particular project involved three related, but frequently independent, aspects that required real time management. First, project design can be segmented into microgrid design and controller design. Second, management was required for procurement, construction, and commissioning including OSHPD. Third, ongoing project management is needed to tune the controls, ensure systems performance, and communicate results to the stakeholders. Microgrid design was managed by the overall Project Manager, Jon Harding, given his expertise at design/build construction projects. David Bliss, in collaboration with John Griffiths, managed the controller design team. Jeff Harding managed the construction aspects (permitting, interconnection, procurement, construction, and commissioning) and along with John Griffiths managed the subset that involved OSHPD approvals.
- Analytics and controls: A considerable amount of data must be analyzed throughout the process, with different purposes across time. Though this does not require a data scientist to do the initial evaluation (load profiles, tariffs, utility costs, solar performance), considerable expertise is required to design data acquisition, communication, processing, response, validation and storage. This was shared by Dr. Raymond de Callafon (UCSD), graduate student Amir Valibeygi (UCSD), and consultant Rick Meeker (Nhu Energy). During this time, Mr. Griffiths formed his own company

(Contech) and provided applications engineering services to monitor and maintain data and control systems.

- Architect services: The architects from Pacific Design Architecture were essential not only to ensure appropriate physical designs but also as experts at working with the permitting and regulatory agencies including OSHPD.
- Professional engineering: In collaboration with the other design team members, the Professional Engineer, Tanner Engineering, ensured safety and appropriateness of designs, provides legally-required stamp drawings for submittals, and provides construction guidance to the installers.
- Electricians: The licensed electrician must contribute to site interrogation to determine physical and electrical options and tolerances and must interact with the design team to be certain that all specifications are matched, electrically appropriate, and can be executed safely and within the specified budget. Skelly Electric LLC provided extensive services in all of these regards and, because of this level of involvement, was better prepared for project execution.
- Key suppliers: The manufacturers of technologies being considered for a renewable energy microgrid have the option to pre-integrate solutions or to work with the development team to integrate elements individually. In this scenario, the intent had been for Princeton Power Systems® to provide a fully integrated battery, inverter, first layer controller and balance of systems pre-containerized. As the project evolved, a hybrid approach was adopted. Princeton Power remained responsible to provide the inverter, controller and battery/bms systems, pre-configured to work together, but then had to collaborate with other members of the design team to establish the supervisory control architecture. In a less complex matter, the professional engineer working with the solar provider and installer, SunPower®, supplied the design team with the performance specifications to assist the other team members in designing a DC coupled arrangement. Although the battery supplier, Samsung®SDI™, participated only as needed in designs, it is notable for future developers that this is based on Princeton Power Systems® and Samsung® having pre-engineered their systems to work together independently and well before project initiation.

Microgrid System Engineering

Based on the findings of site interrogation, characterization, and budgetary limitations, the team was quickly able to validate the pre-project projections for system sizing. As predicted, 250kW of SunPower® parking structure rooftop canopy solar, one MWh/250kW Samsung® SDI® battery integrated with a Princeton Power Systems® BIGI250™ power conditioning system and the EMOS™ controller was safe, feasible, and site-appropriate.

Solar

SunPower® completed the necessary structural, civil, mechanical, and electrical engineering to design and specify a spanning array. Fortunately, the wide East-West axis of the hospital parking structure, shown in Figure 4, allowed for the design of flush-mount panels at 180 degree azimuth (South) and approximately 20 percent angle. Analytics performed through PVwatts™ using these settings predict an annual productivity for this location of 394,738 kWh. Reduction of the angle to zero or change of azimuth by 30 degrees reduces estimated productivity by nearly 15 percent. Perhaps the only method to further optimize productivity is to use solar tracking systems, but this was beyond the scope of the particular project.

The solar engineering team (Skelly Electric, Tanner Engineering) devised the wiring, combiner box, and conduit specifications to consolidate the DC energy production from the SunPower® array for delivery to one of the two DC ports of the Princeton Power Systems® inverter. Appendix A provides detailed design drawings and solar array specifications.

Inverter Systems

The inverter is somewhat oversized for the rating of the solar array. A standard approach would be to size the inverter at 80-90 percent of the nominal rating of the solar. However, because one of the key goals of the project is to maximize demand reduction, a larger inverter capacity provides the option to discharge the batteries at a higher continuous power than would be safe with a more tightly engineered inverter capacity.

The design team discussed the merits of alternating current (AC)-coupled versus direct current (DC)-coupled solar arrays as part of the overall process. Standard solar arrays are processed with inverters that deliver AC power at the point of common coupling (PCC). These inverters generally depend on grid signals and render solar inoperative when the utility signal is lost as a matter of safety. When solar is included as part of renewable microgrids, AC-coupling may be used but has several notable impacts:

- Dual inverter systems: The solar and battery inverters operate separately though modern systems may allow for coordinated or hierarchical control.
- Separate PCC: The two inverter systems must have separate points of common coupling and may need to be on separate panels.
- Efficiency losses: DC energy produced by the solar array is converted to AC through the solar inverters. Should the same energy be stored in the battery, this is achieved through conversion from AC to DC to charge the battery and back from DC to AC at the time of battery discharging. Losses are additive.
- Islanding: Unless a grid-forming microgrid inverter is used and the two systems (solar and batteries) are connected on the same circuit, solar production can be lost during an islanding event.

On the other hand, DC-coupling presents different advantages and disadvantages. While DC-coupling avoids the losses inherent in the multiple conversions of AC-coupled systems and simplifies interconnection, control, and islanding, it also introduces a smaller number of points of failure. In other words, the solar depends on the main microgrid systems and its productivity is lost if the microgrid power conditioning systems become inoperable. When all factors were considered, the team agreed on the DC-coupled architecture to facilitate maximum productivity and centralization of control and islanding.

Another issue for discussion was whether a single inverter or multiple inverter design was superior. By their nature, power systems have optimal ranges and ratings for performance and experience increasing inefficiencies as conditions move away from optimal. For example, a 100kW rated inverter will be highly likely to operate at or near its optimal efficiency in the delivery of 90kW, while a 250kW rated device delivering the same amount of continuous power might be less efficient. Multiple inverters may operate in parallel with one another to equal the total nominal rating of fewer, larger devices, but can also be dynamically turned on and off to optimize power efficiencies when energy flows vary. Furthermore, in the multiple inverter scenario, the system has a greater chance of remaining at least partially operational when one or more inverters are functioning.

A single, larger, central inverter offers greater engineering simplicity. No inverter operational hierarchy is required, there is a single point of data acquisition and control, cost is reduced, and, in some cases, the weight and footprint profiles may be superior. However, a single inverter design also creates a single point of vulnerability. The entire microgrid can be rendered inoperable during inverter malfunctions in addition to required episodes for maintenance, repair, upgrades, or other modifications. In consideration of the totality of issues, the engineering team elected to proceed with the single, centralized inverter method.

Appendix A provides detailed information on inverter specifications.

Battery and Inverter Rooms

The interiors of the battery and inverter rooms are shown in Figure 9 and Figure 10. To design the adjoining cement block rooms, the team needed to determine the minimum concrete pad size, thickness, and concrete type to bear the weight of the inverter, batteries, and computer monitoring systems. Using the weight and footprint of each item, the distance from one another, the floor mounting requirements for earthquake stability, and the soils plus geotechnical data from the cement contractor, the team determined the appropriate sizing for the concrete pad. In addition, the team considered code requirements for entry/exit, ventilation, penetrations for conduit from the solar array, conduit between inverter and battery rooms, and conduit between the inverter and points of common coupling, space necessary for maintenance and repair of key components, internet communications penetrations, and height limitations to finish overall designs. Appendix C provides detailed design specifications.

Figure 9: Interior of Battery Room Controls, Electrical Systems, and Batteries

Source: Charge Bliss

One notable design nuance was the decision to physically isolate the battery and controls systems from the inverter. In the original specifications, all systems were to have been installed in a single steel shipping container with pre-engineered HVAC and fire-suppression systems sized for the container, heat loads, and chemical fire concerns. However, when it became apparent that this method would not work due to site limitations, engineering had to consider a different environment. Serial discussion between the manufacturers, suppliers, engineers and builders arrived at the conclusion that physical separation of the inverters and batteries would simplify heat load management, mitigate risk of propagation of fire or other destructive impact on both key systems, and provide added security. The engineers also observed that this might have beneficial impacts on long-term battery health and performance.

Figure 10: Interior of Inverter Room Showing BIGI250™ and Electrical Systems

Source: Charge Bliss

Another unanticipated benefit of the location of the solar and batteries was simplification of energy transmission between systems. The position of the solar on top of the same structure as the batteries allowed for direct, minimum distance runs to the inverter room along the structural columns. DC losses could be minimized, there was no requirement for boring, trenching, or overhead lines, and the conduits were virtually invisible to the general public. The cost and time impacts of designing and building the battery and inverter rooms was counterbalanced by the elimination of the more complex conduit runs that had been anticipated prior to project initiation.

Mechanical Systems

As discussed previously, ventilation, cooling, and fire suppression were deemed necessary for proper function and safety of the major electrical systems. Heat loads were determined based on the cement block wall room design, inverter ratings, lighting, and ambient conditions. The necessary penetrations and HVAC system specifications were embedded in the primary room designs to minimize the need for later modifications. Fortunately, through the placement of the inverter/battery rooms inside the parking structure at its north end, direct sun-strike was minimized and exterior ambient conditions were considered less significant. However, the team notes that ambient conditions could play a significant role in calculations for a metal shipping container placed in direct sunlight, particularly in warm environments such as desert communities.

Though fire-suppression is not an absolute requirement for these installations, it was the firm belief of the team that this is prudent. Multiple safety systems within the batteries, their own battery management system, the inverter, and emergency shutoffs should minimize the risk of thermal runaway leading to fire. To the team's knowledge, Samsung® SDI™ have not been involved in any catastrophic fire events. Nevertheless, the team discussed a variety of methods including water, foam, and oxygen evacuation systems. The battery manufacturer suggested that no fire suppression is necessary but that a water/sprinkler system would be sufficient. The Charge Bliss team, working with the hospital fire safety personnel and the City Fire Marshal, selected an appropriate system that could be integrated into the overall hospital fire-safety architecture to best ensure early notification to the facility of any issues. Perhaps most importantly, all teams have agreed on emergency procedures to mitigate the risks to systems, the facility and the public.

Battery Arrangement, Anchoring, Wiring

Battery systems were wired as specified by the manufacturer and supplier. Steel racks were bolted to the floor for seismic safety with adequate frontal access for purposes of care, maintenance, cooling and ventilation. Batteries were physically isolated from the inverter to minimize heat load impacts on battery health. The battery and inverter systems were then coupled according to the engineered drawings and specifications of the inverter manufacturer.

EMOS™

The Princeton Power Systems® first-layer controller or EMOS™ was purchased for the purposes of basic control services. Given the use of a Princeton Power Systems® inverter, the team assumed that there was fairly minimal design or execution work involved in its integration. However, the EMOS™ is a physically separate tool that requires considerable discussion, planning, and integration work between the manufacturer's engineers and design team. For example, the EMOS™ requires site-specific configuration, a backup battery, electrical signal reference points, and other details to achieve satisfactory, sustained operation.

Internet Communications

After determining that independent, secure Internet access was needed, the team concluded that the only available resource for broadband data transmission was a new DSL line. Data transmission rates were examined by the engineering and controls teams who determined that the bandwidth of the DSL line would be sufficient. In addition, the team organized a static IP address to provide greater system stability and closed the network to outside access except from authorized users. The team also considered cellular connectivity which may have greater security but has both cost and bandwidth limitations, cable, and fiberoptic services, but the latter two were not available at the particular site.

Hardware for Monitoring Systems

Synchronized voltage and current phasor can be measured with a PMU and provide real-time and high frequency updates on the electrical properties and real/reactive power flow of the microgrid at the point of common coupling/point of interconnection (PCC/POI). The use of synchrophasor data feedback informs the control of power flow at the PCC/POI. PMU placement at other locations allowed the controller to receive granular, time-stamped feedback regarding the impacts of changing power flows at multiple locations and further informs controller adjustments. Mindful of these objectives, the team elected to place PMU at six key locations including the main, the point of common coupling, the life safety branch, and others.

Microgrid Control Systems

The Princeton Power Systems® EMOS™ was specified as the first layer controller. This is a physically separate unit from the inverter but is pre-configured to connect to both the power conditioning systems and the Samsung® battery management system. Though no specific design was considered necessary at the beginning, once installation was completed, a number of modifications were required as described in Chapter 4.

For supervisory control, the team created a physically redundant architecture, based on Schweitzer Engineering Laboratories SEL 3355 hardware for an electrical substation hardened personal computer onsite and one remotely at the UCSD facilities. This allowed the controller to operate with or without Internet connection and also be observed, modified, and tuned remotely in real-time. Controls architecture was planned to be developed remotely through Charge Bliss, UCSD, Florida State University, and Nhu Energy and embedded in the site-based personal computer controller once validated.

Points of Common Coupling

The installation and engineering teams examined the possible points of interconnection serially. Multiple discussions of options included panel upgrades to increase input capacity, re-wiring of connected systems to allow the CHP and microgrid to be within the same panel, and whether to connect solely to the normal power or to add an optional connection to emergency power. The team examined a combination of factors including the safety and codes, costs, duration and significance of disruptions, and OSHPD regulations and determined that site upgrades and significant modifications were not feasible. Fortunately, one "normal power" and one "life safety" emergency power panel each had adequate remaining input capacity for interconnection without triggering adverse impacts.

Central Utility Plant Penetrations, Connections, and Regulatory Considerations and Approval

The key components of the microgrid are located within the parking structure, adjacent to the central utility plant. While the parking garage falls under the city building department jurisdiction, once materials penetrate the central utility plant the conduit comes under OSHPD regulation. The electrical conduit was routed along the ceiling of the first floor of the parking garage and penetrated the garage wall and central utility plant wall into the main electrical room. The point of shared building structures presented specific construction challenges. First, though these were two buildings for jurisdictional purposes, they had to be considered simultaneously for construction and seismic safety. For this reason, flexible conduit with OSHPD-approved seismic bracing and sealant must be used at the point of intersection of the two buildings. The conduit must have the ability to travel a minimum of six inches in every direction. In addition, the two walls have different compositions. The garage wall is steel reinforced concrete and the central utility plant wall is composed of metal studs and gypsum board. Both have different structural requirements for penetrations. The penetration through the concrete wall could not sever more than one of the structural reinforced steel members embedded inside the concrete. Similarly, the penetrations through the central utility plant wall could not cut through more than one metal stud. This required special planning and layout of penetrations to ensure both requirements were achieved. Most importantly, OSHPD structural review was required for approval and proved to be the longest process with respect to time.

The connection to the electrical bus presented challenges as well as unique achievement. The target bus was rated at 4,000 amps with adequate capacity to receive the full rated output of either the solar or battery systems through the inverter. OSHPD recommended that a second point of interconnection be created within the central utility plant to the life safety branch panel. Since connection to any panel requires that it be de-energized, plans were required for systems operations during that period. Though it might appear logical to simply rely on existing backup diesel generators that all hospitals must have according to OSHPD regulations, this is not permissible for prolonged, planned outages. For such outages OSHPD requires that hospitals maintain at least two sources of power including bringing in an additional, temporary generator. Engineers must specify generator sizing, point of coupling, and methods of procedure for the entire process. These must be reviewed and approved by OSHPD before any work may commence. Fortunately for this project, Kaiser had been planning a shutdown to replace the main breaker inside the bus. Through careful coordination and planning, the interconnection of the microgrid and the main breaker maintenance occurred during the same shutdown. Had this not been available it would have caused a considerable, unanticipated financial burden to the microgrid project.

Though battery and inverter localization within the central utility plant were not considerations in this project because of space limitations, it is noteworthy to discuss the regulatory implications of such deployments. Once systems are within OSHPD-regulated spaces, they must meet strict safety standards, particularly seismic testing. One of the most expensive but frequently required forms of seismic testing is shake table testing. When this is applied to large systems such as containerized batteries, there are only a small number of testing facilities and costs can become prohibitive. Until such time as manufacturers or integrators have undertaken testing for their systems, it will remain cost-ineffective to do such testing on a case-by-case basis.

Equally importantly, the team discovered that having an OSHPD-expert architect execute submittals may avoid considerable pitfalls. Groups such as Pacific Design Architecture, a project partner, understand how to compose complete submission, to whom they should be supplied, how to address subsequent questions, and ensure compliance with all OSHPD requirements.

City Permitting and Inspections

All city-governed construction was performed under one building permit. The team determined that expedited review could be obtained for additional cost, decreasing review time by about half. This addressed all aspects of the rooftop solar, electrical, concrete, HVAC, lighting, and other construction aspects. No significant secondary reviews, additional submittals, or revisions were required and permits were obtained 10 weeks after the applications were submitted.

After construction was completed, the City of Richmond performed standard building department inspections of the electrical systems, concrete work, CMU block walls, and fire safety systems. For the most part, inspections were standard with the possible exception of fire safety. Currently the National Fire Protection Association (NFPA) has not set standards for fire protection requirements for large lithium ion battery systems. After several discussions with the city, they determined that a water-based sprinkler system would be preferred. This allowed for the modification of the existing water based system to be used. NFPA has been working with Tesla on testing systems but has yet to make recommendations or establish standard building codes. In addition, testing of batteries has shown that fire suppression systems are not required when the batteries are stored in NEMA 3R cabinets located outdoors.

Utility Interconnection Testing, Approval, and Installation Agreements

CPUC Rule 21 requires an application be submitted to the serving utility for any generation system that will be tied to the utilities distribution system and regulates interconnection, operation, metering, and safety. Each investor-owned utility has its own Rule 21 process and team. They must determine whether utility equipment has the heat load, voltage, and power flow capacities to tolerate the proposed amount of energy export from the generating facility. They also consider the number and size of interconnected generators on regional circuits. Southern California Edison provides an online map to allow developers to understand current deployments.

PG&E, the serving utility for Kaiser Permanente in Richmond, California, requires detailed systems specifications and a net energy metering agreement. Since the output of this system is well below the load requirements of the hospital, it falls under the "zero output" classification and, therefore, receives an expedited review. More complex processes including expensive parallel testing and utility distribution equipment upgrades may be required. The only requirement from PG&E for interconnection was the installation of a net generation output meter. The meter is purchased from and installed by PG&E.

Obtain Professional Engineering Stamp of Plans

Standard construction practice includes professional engineer stamped plan documents. This was achieved by dividing up the solar array, solar steel canopy, the inverter/battery system and the interconnection to the hospital's electrical bus among four different engineering firms. Tanner Engineering performed the solar array engineering, SunPower® performed the solar steel canopy engineering, Princeton Power Systems® performed the inverter/battery system engineering and Mazzetti® designed the interconnection to the main bus. The architectural firm, Pacific Design Architecture, coordinated all of the different engineering firms and created a plan set that was submitted for permitting.

Islanding – Backup Power Coordination, Methods of Procedure, Site Coordination

Islanding testing required extensive planning and coordination. For critical facilities like hospitals, it is standard construction practice to map out a detailed list of steps to be performed for any activity that may adversely impact the facility. Kaiser refers to this as the method of procedure. The method of procedure lays out, in sequential order, all of the construction activities to be performed for a task, responsible parties, and any contingencies.

As hospitals are currently designed, and in concordance with codes and regulations, all must be able to "island" from the utility during power emergencies using backup diesel generation. Despite their preparation for such events, hospitals are generally averse to intentional disconnections of the facility from the utility for other than the necessary testing required by regulations or needed work on existing systems. Nevertheless, the experience of facility personnel with the concept facilitated the creation of the method of procedure, understanding the requirements for OSHPD compliance and facility operations, and the contingencies required.

In addition, the design of this microgrid connection point to emergency power allowed for the option to select one of two standing energy resources. The point of interconnection for the purposes of islanding, the life safety panel, is located on the facility side of an automatic transfer switch such that the panel may be energized from the utility during normal operations or from backup diesel generators when the switch opens. Once interconnected, islanding testing merely required manually switching of the manual transfer switch to the microgrid side of the automatic transfer switch, and opening the connection to the utility.

Discussion

Microgrid developers, designers, suppliers, and regulators have been working towards generalizable design processes to simplify deployments. Like solar, which has benefitted from streamlining and decreasing manufacturing costs to achieve widespread applicability, microgrid advocates are in search of replicable, cost-effective methodologies. The current project was undertaken during a period of significant change in the marketplace with emergence of new manufacturers, technologies, design and engineering platforms, and evolutions in regulations, tax and other incentives, and interest from the CPUC, system operator, utilities, and other key stakeholders. Indeed, a compelling argument could be made that many of the methods employed within this project have already been improved on elsewhere and continue to undergo rapid evolution.

Many of the approaches employed within this project are specific to California healthcare centers and may not apply in other building types. Hospitals are among the most closely regulated buildings in California, particularly with respect to energy systems. Moreover, the operational requirements for hospitals far exceed those of virtually any other building including operating 24 hours per day, 365 days a year even when events occur that shut down all other commercial buildings. This suggests that other deployments will require more simplified approaches that are faster, cheaper, and less demanding on microgrid performance. On the other hand, it is equally reasonable to observe that regulatory matters such as OSHPD requirements are solely applicable to hospitals. As such, the findings of this project are clearly replicable for California hospitals and provide a framework from which to select replicable processes for non-critical infrastructure.

Replicable Processes

In the course of evaluating multiple host sites, it became apparent that California hospitals share many key features as it pertains to microgrid deployments. In turn, many of the design, engineering, construction, and operations matters are similar and scalable. Though the greatest emphasis is on the technical and performance aspects of prospective sites and the possible microgrids, the process must begin with sufficient interest and, perhaps, an internal "champion" at the host site. Since the success of designs hinges on the objectives of the site, state, quality and capacity of energy systems, and the space available for new DER, the principle concern for replicability is comprehensive engagement and communication. Once this is achieved, teams may expect more effective and efficient processes for the technical and financial aspects of microgrid development including the following:

- Team selection: Perhaps most key is the inclusion of all key stakeholders and experts in their respective fields to design and deploy microgrids. While photovoltaic projects have become rather routine, the same cannot be said of microgrids.
- Site interrogation: Developers, designers and engineers must have comprehensive site electrical drawings and specifications and understand panel capacities and possible points of interconnection, options for physical location of key microgrid systems, and specific regulatory concerns.
- Power profile: Charge Bliss recommends at least one year of complete load data. While 15-minute intervals or better is preferred, this may be imputed as well. Utility tariffs, energy and demand costs, and special arrangements such as direct service contracts or community choice aggregation must be considered.
- Solar sizing: As the amount of solar, in combination with the daytime load profile and whether there is an option to export power, defines how much battery is needed, determining the maximum amount of possible solar is a key first design step. This may

prove to be less or more than what is achievable for reasons of host site objectives, budget, or other considerations.

- Battery sizing: Iterative analysis using any of several software platforms can determine "optimal" solar and battery sizing. While no single tool is superior, several offer options for empiric estimation of sizes prior to "hard" engineering including Homer™, StorageVet™, Geli™, Tesla™, and others. StorageVet™ is arguably the most comprehensive tool and is free to use, but requires considerable time and training to develop expertise.
- Battery integration: Once a preliminary estimate of battery size is determined, the developer has to select commercial products and must choose between truly tailored systems or pre-engineered, "plug-and-play" architectures. Since cost is inevitably linked to whether a system is unique or a scalable building block, Charge Bliss suggests the latter is the more likely choice. Many of the major suppliers have been offering pre-integrated "AC-blocks" that can be added together to scale up for larger projects. Though actual battery capacities may be marginally different than what is considered "optimal" in the battery sizing software tools, they are frequently far more cost effective.
- Control systems: Many, if not all, of the pre-engineered battery + inverter systems come with embedded "microgrid controls" designed to regulate battery charge and discharge, manage the timing of microgrid energy usage, and, perhaps, perform demand reduction. Though many commercial controls providers claim to be able to take more sophisticated actions such as power quality management or automated demand response, there are still gaps in performance that prevent developers from relying on these services. Novel, supervisory controllers such as the one developed herein offer the promise of not only adding further functions but better automation, flexibility, and coordination.

Unanticipated Delays and Design Obstacles

During project conception, the team recognized that specific factors could be sources of delay in the design process. Indeed, innumerable parties suggested that OSHPD regulatory requirements would render this project unachievable and this led to inordinate delays convincing a hospital to host the project. While OSHPD processes took longer than permitting, interconnection, or inspections, these delays were less than the published, standard review times required for all hospital projects. Surprisingly, interconnection into the life safety branch and processes to test islanding proved to be the least problematic while structural review of penetrations through the central utility plant wall were more prolonged than expected. Similarly, the team anticipated a complex and lengthy interconnection process with PG&E. Though this took several months and many exchanges of documentation, no interconnection study was required and interconnection costs were nominal compared to overall project cost.

Unexpected delays and obstacles resulted from a variety of other factors, many of which may have been one-time issues. First, the team had to find and engage a substitute facility when the first hospital chose not to participate once the grant was funded, which resulted in more than six months' delay. Since the completion of this project, numerous hospitals and health systems have expressed interest in microgrids, suggesting that this delay may have been situational. Second, deciding on location and sizing of systems at the hospital required more design and time flexibility than anticipated. The need to engage multiple stakeholders with competing priorities, challenges in determining the locations of easements and obstructions to construction, and sensitivity to the operational constraints of hospitals required several months to arrive at a consensus for they physical siting of systems. Third, the team did not anticipate that site dimensions would preclude the use of a shipping container with pre-engineered and integrated battery, inverter, control, and environmental systems. This required several months of engineering and integration involving multiple teams. Lastly, the ancillary systems that would seem to require far less engineering attention proved to be more difficult to obtain and design. Internet connectivity, HVAC and fire suppression specification, and PMU installation each required specialty contractors. Each required several months to complete designs, find appropriate contractors willing to perform the work, and considerable effort to coordinate with other activities.

Perhaps the greatest source of delay and design modification was the establishment of stable base system function and islanding of the life safety branch. After several months of meetings and systems modifications after commissioning the system on November 1, 2017, full function of the first-layer controls and demonstrably stable performance was achieved by May 2018. Immediately thereafter, the team was able to perform the first successful islanding test showing the ability to serve the load for at least three to four hours and, in all probability, indefinitely. Numerous challenges contributed to this delay including hardware failures, materials changes, missing elements, re-wiring, setting-up error notification and graphical user interfaces, cost disputes, and unavailability of key technical and labor personnel for extended periods.

Unanticipated Costs

Due to the myriad changes required both as a result of a change of venue and the specific characteristics of the new host site, significant additional expenses were required. While many of these were addressed through reallocations of grant funding, others were paid through Charge Bliss without reimbursement. Cost impacts included:

- Solar: The original design called for ground mounted carport style solar arrays. Kaiser Richmond did not have available property for this type of design. The design was changed to build a clear span canopy on the top floor of the parking garage.
    - Additional cost: $125,000.
- Cement block rooms: The inverter, batteries and control equipment normally come as a containerized system. Due to the lack of property, the design was changed to build a room using CMU block.
    - Additional cost: $273,000.

- Controller: During the preliminary design phase, the controller development team estimated that the cost for the controller would be $35,000. This estimate did not include engineering design or installation of the conduit, wiring, CTs or PTs.
    - Additional cost: $74,000.
- Travel: Due to the major change in the scope of construction activities, the duration of construction was extended. This caused an increase in the amount of travel expenses incurred.
    - Additional cost: approximately $20,000.

The total unanticipated costs were $492,000 or 10.3 percent of the original $4.77 million budget. Nevertheless, the project cost above the original estimates was only $35,000 to date.

Sequencing of Hospital Review, Utility, City, and State Regulators

The design and deployment of renewable microgrids for hospitals requires that multiple, dependent processes be sequenced or performed in parallel to reach timely and acceptable completion. At least four critical parties must agree to designs and specification and provide formal or informal approval. From the outset of the project, the development team incorporated hospital personnel including the operations staff, engineering, and electrician(s). This allowed the hospital team to perform independent reviews of equipment, specifications, building impacts, logistics, and many other factors. Most importantly, it provided the design team with near real-time feedback and facilitated the most efficient adjustments possible to plans. Furthermore, this helped the teams address traffic impacts, security, continuity of hospital operations, hospital personnel availability, documentation and procedures required, and established clear standards for communication between the host site and development team. All designs were approved by Kaiser Permanente personnel prior to submission for permits, interconnection, or OSHPD approval.

Similarly, engagement of OSHPD from the beginning of the project significantly limited any meaningful missteps with respect to regulations. In addition, the depth of OSHPD expertise, both within the Charge Bliss team and in the Kaiser Permanente architecture, allowed early recognition of processes that needed direct OSHPD involvement and approval. For example, when modifications of the procedures to penetrate the central utility plant were needed to accommodate PMU wiring and data transmission, the team was able to identify the appropriate submission method to obtain the fastest possible result.

At the same time that relevant issues underwent OSHPD review, the teams sought City of Richmond permits. Municipal permitting processes are relatively straightforward and involve review of engineer-stamped drawings and, in some cases, investigation of specific systems. The permitting process was hastened by paying an additional fee to be expedited and no deficiencies were encountered. Not all permits were needed simultaneously- therefore these were prioritized for electrical and solar, cement pad creation, block wall room construction, followed by mechanical systems and fire suppression.

While the permitting process was ongoing, the interconnection process was also initiated. The Rule 21 group at PG&E performed a preliminary review and agreed that the project could undergo expedited review. This requires submission of plans, permits, and statements that a system will, will not, or might export power. The proposed system, based on the solar production being less than base load, was deemed a non-export scenario and not subject to interconnection studies or more in-depth analysis.

Though the interdependence of these steps created some delays, the prioritization of 1) host site, 2) OSHPD, 3) City of Richmond, and 4) PG&E allowed for the most expeditious construction possible.

CHAPTER 3: Installation of a Hospital Microgrid

Critical infrastructure such as hospitals requires specific sequencing of installation. Procurement, in particular, should be timed to match with the availability of permits, OSHPD approvals, and interconnection agreements with the utility. In addition to these larger governing principles, teams must coordinate with the facility to maximize the safety of visitors, patients, and staff, minimize facility disruptions and, ideally, create no disruptions of patient care, and coalesce as many issues for OSHPD review as possible to render episodes optimally efficient.

After an approximate 18-month interval to identify the host site as well as design, engineer, and receive all approvals for construction, microgrid installation was initiated. The duration from groundbreaking to commissioning was approximately 15 months, comprised of the following, overlapping key elements:

- Solar: 3 months
- Battery/Inverter Room: 6 months
- Battery/Inverter Installation: 3 months
- PMU/Controls/Communications: 3 months
- Interconnection: 3 months
- OSHPD approvals: 4 months

Processes

Although the construction process flows from the designs, engineered plans, and availability of materials and installation personnel, hospitals present additional variables to be considered. Though these matters are common to all commercial installations (traffic control, sequestration from public contact, security, noise, signage, and so on), hospitals are unique in that they operate continuously. Thus, construction teams cannot assume that any particular day of the week or time of day is less disruptive other than based on the ebb and flow of normal hospital operations. For example, while work that could have more adverse impact on parking or traffic might otherwise be best performed on a Saturday, this can be one of the busier days for most healthcare facilities.

Similarly, there is very little discretionary space at most hospitals to store materials, equipment, or machinery. Thus, builders must plan to aggregate tasks to minimize the need to bring heavy equipment back and forth from storage and to expedite the installation of each element. For example, a crane was needed to lift equipment to the roof but could not be left overnight without creating undue risks, hazards, and costs. Thus, the arrival of rooftop solar canopy equipment and materials had to be coordinated with crane arrival which, in turn, had to be coordinated with site and City personnel to coordinate traffic flow and safety.

Key processes, as determined by the team, are discussed below.

Contracts, Payments, and Retention

In general, it is prudent to proceed with contracts for all services, materials, and equipment for large construction projects. Formal agreements serve to set the scope of work, schedule, obligations, recourses, and cost. This is particularly salient, but potentially problematic, when considering contracting for high cost equipment prior to initiating the design of systems. In this case, Charge Bliss obtained a fixed price for fully integrated, pre-installed, containerized battery, inverter, first-layer controls, fire suppression and HVAC systems. While this was useful for budgeting purposes, design revisions during the engineering phase resulted in substantive changes, cost-shifting, and confusion between suppliers and purchasers. When it was determined that the pre-containerized solution was not feasible, the supplier had to provide the hardware as separate elements, and these had to be integrated onsite by the project team. Perhaps a better methodology would have been a purchase agreement with line item values for hardware, engineering, containerization, ancillary systems, shipping, etc.

Second, fixing of contract pricing for large hardware may have beneficial or adverse cost impacts. In the rapidly evolving marketplace for batteries, the cost for supplies dropped nearly 50 percent between when the original supplier agreement was set and when actual procurement occurred. In contrast, the price of steel needed for the solar canopies rose during this same period. Fixed pricing constrains risk of excess cost but also eliminates the ability to capture decreases in supplier costs. This has been made more complex in recent months with changes in tax policy, tariffs, and resource availability.

Attendant costs and the methods to pay for them are somewhat more complex in the grant-funded environment. As specified in EPIC contracts, grant recipients must pay for services, materials, equipment and other costs prior to billing the Energy Commission in arrears. The standard Energy Commission practice for recipients other than the University of California is to hold back 10 percent retention. This may take the form of a holdback at each billing episode or payment of all costs until 90 percent of grant dollar disbursement is reached- after which the remainder is withheld by the Energy Commission until project completion. Final payment of retention is released after approval of the Final Report. This has obvious and significant implications for non-profits, micro- and small businesses, and disadvantaged businesses for whom the cost of money may be prohibitive.

A second factor that may unwittingly add to recipient cost is the need for grant period extensions. While extensions are inevitably to the advantage of the recipient- allowing the team to complete a project – this extends the period for release of retention and exacerbates the financial impacts. In this project, Charge Bliss was granted the opportunity to change host sites and, later, to extend the project deadline by nine (9) months. Without this extension, project completion and controller implementation would have been impossible. However, this required that the company assume all of the cost and other liabilities associated. While Charge Bliss was adequately capitalized to assume the impacts, this may not be true for businesses of similar size and makeup.

Obtain Material and Equipment for Microgrid

As discussed previously, the sequencing of materials and equipment is critical to project efficiency. Solar panels should not arrive in advance of canopy construction. Similarly, batteries, inverters, control systems, and other expensive, sensitive hardware need to come pre-containerized or be placed within a secure space. In this case, SunPower® was responsible for fabricating the spanning canopy, delivering and installing it, and landing the panels. The electrical team from Skelly Electric then performed all of the necessary connections, ran conduit and set combiners to bring the DC power to the battery room, and, ultimately, completed the electrical installation work within the battery and inverter rooms. In parallel, the construction team built the battery/inverter rooms then ordered the delivery of the relevant hardware. Once the battery, inverter, monitoring and controls systems had been anchored, wired together and connected to the communications networks, HVAC and fire suppression systems were obtained and installed by the relevant sub-contractors.

The team had to consider where equipment would be delivered and how it might be stored and secured. In the case of the batteries and inverters, the supplier had a climate-controlled facility in San Diego where the equipment was first shipped and held until the battery room was complete. This allowed the team to place these critical systems within a secure room- avoiding the risk of loss or damage as well as costs of onsite storage. In the future, it is worthwhile for teams to consider contingencies for delayed shipment, shipment to storage, or incremental shipment of key materials.

Site Preparation

Given that the majority of the construction work was on the parking structure used by patients and visitors, considerable coordination was required. Hospital security, building operations, public relations, Charge Bliss, and the relevant contractors collaborated on plans. After clear project schedules were set, signage was placed at the site to inform patients, visitors, and staff of the upcoming project and possible disruptions. Notably, there were no complaints once construction started and through completion with the possible exception of longer times to get to parking spaces.

Host site security was responsible for directing traffic, providing physical barriers to avoid public interaction with systems, and ensuring that all personnel onsite were part of the project team. All appropriate protective measures were undertaken to avoid exposures to excess noise, dust, fumes, or other pollutants to the satisfaction of site personnel.

When shutdowns were necessary for interconnection, islanding, and systems testing, considerable planning was required. Hospital operations, public relations, security, electricians, leadership, and OSHPD experts combined with construction team members, OSHPD, and project consultant engineers to plan the notification to patients, families, staff, prepare with backup generation as required by regulation, have detailed "methods of procedure" delivered to

OSHPD, and have all necessary personnel in attendance for construction or testing. No adverse events occurred nor were any citations, concerns, or complaints issued.

Battery, Inverter, Monitoring, Controls Installation

As noted previously, the original, pre-integrated and containerized battery + inverter systems were obviated by the lack of adequate space for a shipping container at the particular site. This was recognized during the design/engineering phase so alterations to construction planning had already been made and were reflected in revised constructions schedules, contractors and materials, and integration processes.

Samsung® SDI™ batteries were delivered with racking systems, but disconnected to prevent adverse events during shipment. Using engineered plans for battery systems connections, the wiring within and between racks was completed by the electrical contractor, Skelly Electric. Battery racks were then anchored to the cement floor in positions to allow access for maintenance and repair. Conduit was run through penetrations between the battery and inverter rooms to connect the battery to one of the two DC ports of the Princeton Power Systems® BIGI250™ inverter in accordance with engineered specifications from the two manufacturers.

The Princeton Power Systems® inverter was installed in a separate room and also anchored to the floor for stability. Penetrations into this room allowed connection of the solar output, the battery, and interconnection to the normal power and emergency power panels as described below in the interconnection section. The EMOS™ controller was installed and connected to the inverter as specified.

A separate installer performed all of the PMU work. This required placing detectors at the specified locations, running reference voltage lines, and establishing function of the Schweitzer® devices. The hardened PC with embedded controller was connected to the Internet through the installed DSL systems and was connected to the communications input/outputs of the EMOS™ computer.

Install Solar Canopies, Solar Paneling, and Electrical Connections

SunPower® delivered pre-fabricated solar canopies with embedded LED lighting to meet code. These were anchored to structural column of the roof of the parking structure and, once completed, the SunPower® high-performance panels were laid. The electrical contractor, Skelly Electric, performed all of the electrical connections, placed combiner boxes, and ran conduit from the roof, down the structural columns on the north side of the structure and into penetrations to the inverter room.

Perform Microgrid Interconnection to Kaiser Permanente Richmond

With the approval of OSHPD, the team was able to not only interconnect the first renewable microgrid to a hospital in California but to interconnect to both “normal” and emergency power. This was done in stages to allow limited hospital shutdown and disruption. First, approval was obtained from OSHPD to connect a temporary generator to serve loads that would be disrupted by interconnection to the normal power bus. Once this was completed and utility power restored, operational testing of the microgrid was performed to validate safety and efficacy before going on to emergency power interconnection. Again with OSHPD and hospital approval, a separate date was set to install a manual transfer switch (MTS) that would allow the operator to open the connection of the microgrid with normal power and close the connection to the life safety branch. To achieve this, another temporary shutdown with backup power was required. Once connected, the microgrid was returned to normal operations feeding the "normal" power and was tested separately for its ability to "island" emergency power.

Office of Statewide Health Planning and Development Approvals and Inspections

OSHPD is the California state regulatory agency for healthcare other than for payment. The latter is addressed through MediCal, California Children's Services, Medicare, and other agencies. Other entities have input into hospital operations including the Centers for Medicare and Medicaid Services (CMS, cms.gov) and Joint Commission: Accreditation, Health Care, Certification (JCAHO, jointcommission.org), though these entities rarely impact the design, engineering, or devices within healthcare facilities.

Established by California Senate bill 519 in 1973, the Hospital Building Safety Board is given broad oversight over hospital systems based on two basic directives:[22]

- Advise the Director of OSHPD on the administration of the Hospital Facilities Seismic Safety Act.
- Act as a board of appeals for seismic safety and fire and life safety issues relating to hospital facilities.

The Facilities Development Division (FDD) is responsible for adopting building standards of Title 24.[23] Detailed information regarding FDD processes may be found at the site https://oshpd.ca.gov/construction-finance/building-and-construction-projects/. Figure 11 provides a screen shot of plan submission turnaround times.

Seismic safety is interpreted broadly and has come to include all structural, mechanical, electrical, fire and life safety and other systems within governed buildings. Facilities overseen by the FDD include all main hospital buildings, medical office buildings where healthcare services are delivered, and the main buildings or locations that house major building systems such as might be found in a Central Utility Plant. A detailed review of FDD processes and guidance for all stakeholders may be found in the document, "Guide for Working on Projects Under OSHPD Jurisdiction – Tips From the Experts."[24]

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[22] https://oshpd.ca.gov/construction-finance/hbsb/.

[23] https://www.energy.ca.gov/title24/.

[24] "Guide for Working on Projects Under OSHPD Jurisdiction – Tips From the Experts." https://www.calhospital.org/sites/main/files/file-attachments/gwp_101012_final-v4kb.pdf.

Figure 11: Office of Statewide Health Planning and Development Facilities Development Division Turnaround

Plan Review Turnaround Goals

60/30/30 Turnaround Goal Program

The intent of this program is to establish due dates for completion of the review of the construction documents and to apprise our clients of the anticipated date the review will be completed and returned to them. The 60/30/30 Turnaround Goal Program incorporates the following guidelines:

- First Review of New Projects and Deferred Items: within **60** days
- Backchecks: within **30** days
- Amended Construction Documents: within **30** days

Rapid Review Program

Projects that meet the criteria for the Rapid Review Unit will have a turnaround goal of **15 business days** for:

- All first reviews
- Backchecks
- Amended Construction Documents
- Deferred Item submittals

Please refer to the Rapid Review Unit for additional information.

OTHER PROJECT REVIEW TIMELINES

- Projects that include primary gravity and/or lateral load elements/systems (structural) will have a turnaround goal of **80** days for first reviews and deferred item reviews.
- Backchecks will have a turnaround goal of **40** days.
- The review schedules for Managed Projects will be negotiated between the Office and the Client.

If it is determined that FDD cannot meet any of the turnaround goals for a project, it is the Office policy to notify applicants with the date they can expect their project to be completed/returned.

Source: Office of Statewide Health Planning and Development, (https://oshpd.ca.gov/construction-finance/building-and-construction-projects/plan-review-processes-goals/)

Through the OSHPD experts within the Kaiser Permanente system, Charge Bliss consultants, and engineers as well as the early participation of OSHPD engineers in design processes, Charge Bliss was able to receive more expeditious plan review. Areas of particular review included the points of interconnection, central utility plant penetrations, and conduit materials and anchoring. OSHPD oversight did not extend to the adjoining parking structure and all of the elements built on or within it. This has significant implications for future developments- suggesting that emphasis on the use of non-OSHPD spaces for the majority of systems construction may simplify regulatory compliance and shorten project timelines.

OSHPD suggested, and ultimately approved, an innovative strategy for interconnection of the microgrid to the emergency power system. In addition to approving of interconnection to the "normal" power system, OSHPD representatives suggested a second point of interconnection with the life safety branch and the option to toggle between the two using a Manual Transfer Switch (MTS). While automatic islanding was one of the objectives of both the Energy Commission and Charge Bliss teams, this was not acceptable to OSHPD officials at this point in time. OSHPD expressed interest in this approach as a possible bridge towards automation in the future- using this deployment as a stepwise demonstration of safety and efficacy. In addition, OSHPD officials were clear that no supplemental energy system interconnected to the life safety power could be employed as a substitute for the diesel generation that is currently required by code. Though there is substantial interest in the long-term potential of alternative energy systems to provide greater redundancy and resilience to emergency power systems, OSHPD was clear in its directives that diesel backup power must remain the dominant methodology that is continuously available for all emergencies as dictated by regulations. Nevertheless, officials acknowledge the potential for renewable energy microgrids to supplant conventional generation in the future.

Complete Testing and Commissioning

To date, there are no published, uniformly accepted standards for microgrid commissioning. While validation of solar or other generation resource performances are well established, it is unclear what testing is needed to prove that all microgrid elements are functioning individually and collectively. There are a number of performance matters that the team considered as it created a commissioning process:

- Inverter performance: The manufacturer provides a commissioning checklist that requires both onsite and online validation of performance. Each manufacturer's methodology is different. The team's recommendation is to contract for hardware commissioning services with the acquisition of power conditioning systems. At the very least, commissioning must validate safety standards (automatic shutdown for variations of temperature, voltage, amperage, frequency outside of acceptable), bidirectional communication, appropriate effector responses, data acquisition and reporting, and control of connected systems such as battery energy storage. In this installation, initial commissioning was completed by November 1, 2017. However, ongoing systems performance shortfalls required iterative processes to correct. These required approximately 6 more months of planning meetings, onsite work, and remote configuration to achieve system stability by approximately May 1, 2018.
- Batteries: Depending on the battery supplier (manufacturer, inverter supplier, integrator), precise validation processes may vary. Performance testing may be done prior to shipment, particularly in the pre-integrated scenario. In this case, re-establishment of connections on systems receipt and simplified validation of battery performance (charge, discharge, voltages, temperature) may be all that is required. In contrast, onsite integration may require full inspection of all connections, testing of individual modules, comprehensive interrogation of communication systems, and joint testing/commissioning with the power conditioning and controls system. In this deployment, the batteries were supplied by the inverter manufacturer, Princeton Power

Systems®, with guidance and input from the Samsung®SDI™ team. Therefore, battery commissioning was combined with inverter validation. Relatively minor adjustments had to be made to the battery management communications module as well as replacement of one breaker to achieve full battery system operation and stability of performance.

- Solar: With the DC-connected topology of the microgrid design, solar productivity and performance could only be validated once the entire architecture was commissioned. Once the inverter was interconnected to hospital systems, inverter safety and performance validated, and all solar connections inspected, solar production could be initiated. This topology simplifies the commissioning process by consolidating performance validation at the level of the central inverter, but also can render troubleshooting of performance limitations more complex. AC-connected topologies separate variables and allow solar to be viewed as an independent system but require separate commissioning processes.
- First-layer controller: The Princeton Power Systems® EMOS™ controller was specified to be included with the deployment. This is proprietary technology that must be commissioned by the provider. Clarity of purpose and expectations for performance are critical so that teams may achieve reasonable goals for control. This is rendered more complex when it is done in the context of development of a layered, supervisory controller that must integrate with the first-layer system. Ultimately, it became apparent that prolonged validation of the first-layer control only is necessary to establish system stability, agree on base performance, and define boundaries for teams and systems. All parties ultimately agreed on a one-month period of first-layer controller performance validation after which the supervisory control could be implemented and validated.
- Supervisory controller: In the case of an established controller, the expectation would generally be that integration occurs before initial project commissioning. However, in a scenario where controller development is occurring in parallel to physical project construction, a logical approach is to first commission the microgrid and implement the supervisory controller later. Indeed, the team determined that this was the precise methodology needed. As described above, the first-layer Princeton Power Systems® EMOS™ was validated for over one month prior to the implementation of the Charge Bliss supervisory system. The latter was validated remotely using iterative signaling and testing of commands, validation of results through PMU data, shutdown and restart, and real-time performance tuning.

Definition of Successful Operation

Similar to commissioning, successful renewable microgrid performance success is not well defined. Arguably, generation systems have well-understood expectations for production of specified energy amounts based on nominal ratings and conditions of installation, operation, and maintenance. Within the setting of a renewable energy microgrid, teams may begin with defining a minimum system productivity. In this case, PVwatts™ predicted that the system should produce approximately 390,000 kWh per year, ranging from 19,000 to 45,000 per month. In the initial operation period, productivity was unacceptably low. This was ultimately determined to be due to a combination of inverter shutdowns, curtailment from controls configurations, and unanticipated weather variances. This was corrected, and appropriate production validated and accepted as generation "success."

Additional DER such as batteries introduce complexities that stakeholders should consider as they define microgrid "success" beyond simple energy generation. This may be as simple as a defined interval for continuous system uptime or as detailed as delivery of specific technical performance tailored to the installation. The latter might include maintenance of battery state of charge between acceptable percentages, specific peak demand reduction, accurate time-shifting of solar energy usage or energy arbitrage, or any number of other goals. Since the batteries may be used for any of several functions, stakeholders must agree on whether one or more parameters must be met and for what period of time.

In this deployment, all parties agreed that a minimum of one month of continuous system operation without interruption for other than standard care and maintenance was the minimum standard to define "successful operation." Contained within this overarching goal were the objectives to demonstrate daily time shifting of energy stored within the battery for discharge during the 5pm to 9pm time window, charging battery systems with no more than 25 percent of nominal capacity from the utility, and maintaining daily expected solar productivity. This was ultimately achieved during the month of April 2018.

Discussion

The construction process through commissioning provided valuable insights to all project participants for future developers of hospital renewable energy microgrids. Like large capital projects in similarly complex environments, planning, sequencing, and communications are critical to success. In particular, Charge Bliss observes that commissioning standards need further examination and refinement to define industry standards.

Sequencing of Oversight

In environments such as hospitals where multiple parties have regulatory control, it is essential to define the timing of each of their engagement, matters of concern to each entity, possible obstacles that may be encountered, and strategies to optimize timing through overlapping review. The Charge Bliss project at the Kaiser Permanente facility in Richmond, California revealed that OSHPD, the permitting agency (City or County), and the serving utility, must be engaged sequentially, but that this may be done with significant overlap. Though utility interconnection will ultimately depend on proof of approvals and permits from other authorities, the process may be initiated prior to completion of the other matters. In processes that do not require OSHPD approval, permits may be sought as soon as designs are complete whereas OSHPD governed items should first receive written OSHPD approval before seeking City permits.

Option for Multiple Point of Common Coupling/Point of Interconnection

In an unprecedented achievement, Charge Bliss was able to interconnect the renewable microgrid not only to "normal" power but also to the emergency system. This is the first time that a renewable microgrid has been connected to a California hospital and, to the project team's knowledge, the first time a supplemental generation resource of any type other than diesel generation has been connected to emergency power. This has significant implications for the interconnection of microgrids and other energy systems in the healthcare environment and has provoked discussions between the Energy Commission and OSHPD to define clear standards. Indeed, as a direct result of this project, Principal Investigator Dr. David Bliss, was invited to join the OSHPD Hospital Building Safety Board and become the Chair of the Energy Committee.

Documentation

Installation

Full documentation of installation is essential for operations and emergency personnel. Like all electrical systems in a commercial environment, detailed drawings, photos, and specifications provide personnel clear views into what systems are deployed, how they are connected, where they may be accessed, how they might be interrogated directly or remotely, and what the nature of safety and other ancillary systems are. Standard approaches are to provide these details for storage on site, at the builder, and, in some cases, the City. The advent of digital technologies also permits stakeholders to elect online storage for more ready access.

Operations and Emergencies

All power systems require simplified operational and emergency procedure documentation that is available to all relevant personnel through multiple methods. Charge Bliss has created summary documents that guide day-to-day operations, shutdown and restart, emergencies, and notifications. Moreover, remote messaging for system errors ensures that a broader set of stakeholders is made aware of system variances.

Given the complexity of microgrid operations, a combination of emergency documentation can be useful. While a comprehensive binder provides detailed information, simplified placards can assist personnel to address immediate concerns safely and effectively.

Operation and Maintenance

Modern electrical devices are designed with significant redundancies, safety systems, and self-correcting architectures. Nevertheless, they will inevitably require some measure of observation, maintenance, repair, and replacement. Warranties may address defects and failures of physical systems but do not address other needs, while service contracts may address gaps in operation and maintenance plans.

Service Contracts

Despite the durability and validated long-term performance of many systems, teams must consider who will carry out both routine care as well as manage more complex repairs or replacement. Solar panels require periodic cleaning and connections must be checked periodically. This is generally inexpensive and/or can be addressed by semi-annual or quarterly onsite work. Inverters, batteries, control systems, monitoring devices, and communications tools may each require different personnel to monitor, maintain, repair, and replace. As was discovered in this installation, matters as trivial as a failed breaker or backup battery can render a system non-operational for extended periods in the absence of the expert personnel, materials, and contractual expectations for response and resolution.

Given that a considerable percentage of the value of microgrid performance is from non-generating resources such as the smart inverter, batteries and other DER, down-time can be more consequential than just the loss of generation for a period of time. For example, since demand management requires that peak demand never exceed a target level for the entire billing period, even short periods of system shutdown or dysfunction can result in loss of this benefit for a full month. Similarly, as grid services emerge as key sources of additional revenue, reliability of the relevant resources will be essential.

Service contracts may mitigate some of the risks and costs associated with complex systems. Project developers, owners, and operators have to balance the escalating costs that result from rapid response times versus the likelihood of using these services. Moreover, use of the manufacturer or supplier service personnel ensures compliance with warranty requirements and may avoid downstream costs. On the other hand, project teams may use local contractors, site personnel, and remote action to maintain systems and accept that downtime is possible and, perhaps, acceptable.

Warranties

In principle, extended warranties may give developers comfort that certain costs of equipment replacement have been constrained, albeit with higher initial cost. This is particularly valuable when a particular item is likely to be more expensive in the future. However, higher cost warranties are questionable when the replacement technologies may be less expensive, superior, or both. In recent years, battery prices have plummeted. Charge Bliss observed that suppliers have decreased per-unit pricing by 50 percent in the most recent five years. Moreover, battery technologies are being developed with greater energy and power density, longer durability, and faster response times. Thus, purchase of extended warranties may lock a project into a less desirable technology at a higher price than might be paid in the future marketplace. Similarly, inverter and control technologies are changing rapidly, systems are becoming more light weight, less expensive, faster, more efficient, and capable of myriad functions not available in current systems. Again, long-term warranties may ensure like replacement of an installed system at increased initial cost, but may limit options accordingly. This approach can be considered successful when a major system fails “early”, but may be a less worthwhile investment if a system can perform reliably for the longer term. Charge Bliss has increasingly observed that developers and investors alike are eschewing long-term warranties in favor of early cost savings and later flexibility.

Local versus Remote Operation and Maintenance

Traditionally, energy systems are managed and maintained by local personnel. However, the increasing range of capabilities to troubleshoot systems remotely has ushered in a hybrid approach. Many systems can be monitored continuously and variations in performance reported prior to major system problems. Adjustments to system operations including shutdown, restart, software patches and upgrades, and testing can be done through Internet connections. Personnel may then be dispatched to the site when remote actions cannot identify the specific matter or physical interaction is needed.

Implicit in remote management is the need for an individual or team to monitor, interrogate, and act on microgrid systems. While this is not cost-effective for one microgrid, aggregation of multiple systems under the aegis of an experienced group of applications personnel can render this feasible and reasonable. This is precisely one of the services that is made possible by the Charge Bliss controller.

CHAPTER 4: Data Acquisition Systems, Communication Tools, and Microgrid Controller

To realize full value of renewable energy microgrids, novel systems are required for robust data acquisition, communication, analysis, and control. Current generation systems are frequently slow, rely on excessively limited data sets for state determination, or have output shortcomings that limit the range and value of control.

Controller development is a parallel process, but must interact with other systems development to coordinate monitoring, data acquisition and processing, communications, controls execution, and safety measures. Though the design intent of this specific project was to create a novel microgrid controller, this is not meant to suggest that a new control system is required for each microgrid. Indeed, the specific objective of the controls team herein was to devise a control architecture that could be integrated with unlimited numbers of distributed energy resources (DER). For these purposes, the controller design team needed to know the building load profiles, specifications, communications registers, and controls of the proposed DER, utility tariffs, and primary outcome objectives (site cost savings).

Like all "smart" systems, control devices must create closed-loop communications to continuously determine the state of operations, adjust systems performance, and reassess. By their nature, therefore, such systems require a certain amount of non-recurring engineering to receive and deliver information to other devices. Since electronic devices may use different communication systems (Modbus, Canbus, TCP/IP, RS-232, FTP, UDP, DNP3, IEC), engineering teams must share the information that identifies elements or channels ("registers") to ensure fidelity of data and actions. Testing and validation must be done to ensure the accuracy of transmissions prior to implementation in the field. In a practical sense, this means that controller teams must work with inverter/power conditioning manufacturers and, in some cases, with the makers of battery management systems. Therefore, some non-recurring engineering is required with each new pairing of technologies and their embedded communications and controls. The controller design is detailed further in a dedicated section below.

Data Acquisition, Storage, and Communication Tools

A key objective of the Charge Bliss project was to develop a novel microgrid controller. Inherent to such an endeavor is the need to recognize perceived limitations of existing systems. This can be a moving target for developers of electronic controls because all related technologies are improving simultaneously. For example, computing speed, data storage capacities, and internet communication bandwidths are evolving rapidly in parallel to any device or software. At the time of project initiation, many of the commercially-available microgrid controllers were either modifications of conventional power plant control systems or relatively rudimentary tools to manage batteries. Moreover, the more sophisticated tools were too expensive for single-site microgrid application or had too limited capabilities to fully leverage the capabilities of the DER.

The team recognized that several tools and steps were necessary to achieve this goal including:

- Optimal data quality.
- Improved data frequency.
- High-speed, high bandwidth communication.
- An open architecture to receive and interpret multiple relevant data streams.
- A novel decision architecture to dynamically adjust outputs.
- High-speed effectors.
- Security, validation, and tuning methodologies.

Synchrophasor Data

Current generation control systems rely on analog current transformers (CT) and analog potential transformers (PT) to detect power flows. In large measure, this is attributable to the inexpensive nature of CTs and PTs, the wide availability of installers and relative simplicity of installation, established data processing architectures, and acceptable demands on data storage, as well as the simple objectives of most controllers. However, analog CT and PT devices for power flow monitoring are limited by the frequency of data acquisition and the lack of phase angle computation. Absent these key data elements, control architectures are unable to determine true simultaneity and must impute power flow actions based on less granular data streams.

The controls team proposed that PMU would provide superior data to inform more sophisticated controls. The same CT and PT elements are used to provide signal conditioning for the PMU device, but the PMU will provide digital information on the Root Mean Square (RMS) value of 3-phase current, 3-phase voltage, and the angles of each voltage and current phase. With data acquisition rates at 60 Hertz (Hz) or better that are GPS, time-stamped, PMU data provides more granular information about power flows and the ability to determine true simultaneity. For example, data latency, which can adversely impact the interpretation of CT-derived reports, is rendered nearly irrelevant with the use of PMU. At the same time, this introduces the need for specialized equipment, more robust data transmission and storage, and more complex analytics.

To be able to implement the developed microgrid controller on the Kaiser Permanente Richmond actual microgrid, the infrastructure to measure synchrophasor data, import data into a control computer and send control signals to the PPS BIGI inverter needs to be developed. Synchrophasor data at the 6 different PMU locations in the Kaiser Permanente Richmond microgrid are being realized by SEL-2240 Axion based system, whereas computing power for the controller is based on the rack-mounted rugged SEL-3355 computer. The SEL-2240 Axion is a fully integrated, modular input/output (I/O) and control solution that combines the communications, built-in security, and IEC 61131 logic engine of the SEL Real-Time Automation Controller (RTAC) family with a durable suite of I/O modules that provide high-speed, deterministic control performance over an EtherCAT network. Inside the SEL-2240 Axion, the SEL-2241 RTAC Module operates as the CPU for an SEL-2240 Axion Platform. The SEL-2241 RTAC Module interfaces seamlessly with the I/O Modules used to implement the PMU capabilities on the SEL-2240 Axiom platform.

The PMU capabilities for the SEL-2240 Axiom platform are provided by the SEL-2245-4 Metering Module. Together with the SEL-2241 RTAC Module, they provide IEEE Certified PMU devices, capable of sending IEEE C37.118 communication over TCP/IP at 60 samples/second. To power both the SEL-2241 RTAC Module and the SEL-2245-4 Metering Module, the SEL-2240 Axiom platform also needs an SEL2243 power coupler. To accommodate analog signal communications to the PPS BIGI inverter, one of the SEL-2240 Axiom platforms is also equipped with a SEL-2245-3 Analog Output Module. It allows the generation of analog voltage or current (4-20mA) control signals to be sent to an inverter.

PMU data and control commands are processed by a separate Rack-Mount Rugged SEL Computer: the SEL-3355. Designed as a server-class computer, the SEL-3355 computer is built to withstand harsh environments in utility substations and industrial control and automation systems. By eliminating all moving parts, including rotating hard drives and fans, and using error-correcting code (ECC) memory technology, the SEL-3355 has over ten times the mean time between failures of typical industrial computers.

Communication Architecture

Modern hospitals must have robust communication networks to support myriad digital systems. These networks are relatively secure, high-speed, and partitioned to minimize vulnerabilities. However, hospitals face unique challenges in maintaining data privacy and operational safety and security as prescribed by law. Therefore, while the design team first believed that the communications and control architecture could be routed through hospital systems, it became clear that this was not prudent or feasible.

The design team surveyed available resources for communications and considered cellular, cable, fiberoptic, and DSL connections. Digital cellular communications were compelling due to the data security and redundancy of systems. Indeed, cellular networks may continue to operate during limited grid outages and despite events that would disable other networks. However, cellular networks have lower data transmission rates and may have higher costs and were not considered a viable option for this specific application. Nonetheless, it is worthy of note that Charge Bliss has used cellular networks for lower bandwidth applications without any disruptions in service. With respect to other services, in the geographic location of the hospital, the only other option was DSL service. DSL has sufficient data speed, density, and service reliability for the intended purpose and cost-effective performance profile.

Data Storage and Processing

OSIsoft® provided the PI server™ at a significant discount to the project for the purposes of data storage and processing. The OSIsoft™ and PI® tools have been in operation for over 20 years at 20,000 companies worldwide including two large microgrids at Harvard Medical School and UCSD. The data collection is performed using the PI-System as the data historian and system data infrastructure. The system interfaces to the existing PMU based switching and regulation hardware to collect available measurements from each device, including the status of the device with respect to the system topology. For example, if the device is an automated switch, its position status will be reported in the IEEE C37.118 messages. The data is compressed using the standard PI-System recommendations such that there is no process information loss. The data is then available to the decision platform to inform commands to control DER.

Data is also logged and stored by the Princeton Power Systems® EMOS® controller. This stores information regarding power flows from the solar, to and from the batteries, and at the point of common coupling. This uses standard current transformer technologies and may be stored up to one data point per location per minute. However, as the customer selects higher frequency data acquisition the local data storage is filled relatively quickly. Data is backed-up to a secure cloud service by Princeton Power Systems®, with limited access to maintain systems security. This data is used for validation purposes as discussed below.

Data Validation

The Princeton Power System® (PPS) includes the Energy Management Operating System (EMOS™), the BIGI250™ inverter and battery charging systems. The external microgrid controller or "microgrid controller" interfaces with the EMOS™ via Modbus communication to both measure SCADA data (related to Solar Power Production and Battery State of Charge) and provide external power demand signals. The external microgrid controller processes the PMU measurements generated by the SEL equipment to compute the desired external power demand signal for the EMOS™.

A comprehensive tag list for both the PMU data produced by the SEL equipment, the SCADA data produced by the PPS and the power demand signals to the EMOS is used to map measurements to data based entries in the OSIsoft® PI™ system. The same mapping is also used in the microgrid controller to compute the control signals and both PMU data using C37.118 protocol and SCADA, control signals via the Modbus Function 23 (read/write) protocol are implemented over TCP/IP. The communication of both C37.118 and Modbus over TCP/IP allows a controller configuration to be implemented on the SEL3355 (main SEL control computer) that only requires a standard TCP/IP stack for both data gathering and sending power demand commands to the EMOS.

Visualization Tool

It is important for stakeholders in new technological developments to have visual evidence of performance. Each stakeholder (developer, investor/owner, host site, operations personnel, and governmental agencies) will have different needs that must be considered in devising a visualization tool. In the case of microgrids, these may be technical, financial, or environmental performance data. Equally importantly, the data must be presented clearly but with sufficient detail to meet the needs of the viewer.

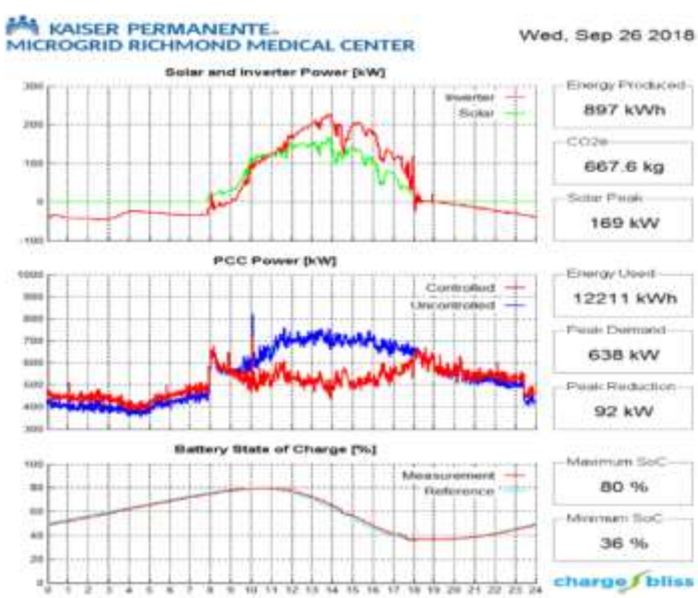
Many first-layer controls, such as the Princeton Power System® EMOS™ offer the option of a visualization tool. This can be useful to track performance of the central inverter and connected system, but may be insufficient to address other DER not under the control of the inverter systems. Nevertheless, in a DC-coupled environment such as that employed in this installation, the inverter reporting may be more than sufficient to provide solar output, load profiles at the point of common coupling, battery charge and discharge, and related technical data.

As the team progressed through controller design, it became apparent that it would be valuable to display additional data in a visualization tool to address stakeholder needs. Key data elements that the visualization tool considers for reporting include:

- Utility tariff (time-of-use energy and demand costs)
- Source of energy usage (immediate use solar, time-shifted solar, arbitrage utility energy, real-time utility energy)
- Peak 15-minute load
- Battery contribution to load reduction
- Battery state of charge

Figure 12 shows examples of the resulting displays.

Figure 12: Visualization Tool Examples



Serial, daily screen shot images from Charge Bliss visualization tool in late May, early June 2018.

Source: Charge Bliss

In this fashion, technical personnel can determine whether systems are producing the desired results with respect to energy production, demand reduction, and systems health. Not shown in this graphic, but included in the actual visualization tool, are financial results that permit operations personnel to understand the real-time fiscal impacts of system performance. Finally, parties interested in environmental impacts such as averted CO_2 production may receive clear indications of system value.

Discussion

Preparation for controls architecture is as important as the controls themselves. Data acquisition systems must provide the necessary type, quality, frequency, and reliability of information needed for systems operations. Communication tools must be fast, high-bandwidth, reliable, and secure. Data processing, storage, and analysis must take large and diverse data streams, combine them with other considerations (utility tariffs, long-term system health, need for backup power and islanding, and limitations of physical systems) to determine actions, send controls signals, validate actions, and report results through a visualization tool.

Many of these elements matter only to those interested in technical performance. The general public, business owners, building operators, and regulatory bodies are more concerned with seeing beneficial outcomes. In this sense, the visualization tool is a more critical element than it may first appear because it can show all parties the real-time impacts of the microgrid irrespective of how it is achieved.

Several issues that arose during the preparation for controller development are worthy of comment. While some of these issues are unique to hospitals, others may affect all commercial applications of microgrids.

Specialty Installation Contractor

PMU installation requires specialty contractors, of which only a small number operate in California. Going through the PMU manufacturer, the Charge Bliss team was able to identify three possible resources in California, only one of whom was available for the particular project. Undoubtedly, this is a function of the relative rarity of PMU use in comparison to CTs which, in turn, is a function of cost.

Installation cost is also substantially higher for PMU. While a standard electrical contractor is able to place CTs and may do so routinely on many commercial energy projects, the specialized nature of the PMU installer requires additional cost. Therefore, development teams that are considering the use of PMU should factor added hardware and installation cost and the need to engage potential installers early in the process.

Office of Statewide Health Planning and Development Limitations

As discussed previously, OSHPD is the apex regulatory agency for hospitals in California. As such, the agency must approve all devices being placed within OSHPD-governed buildings as well as systems that connect with, physically impact, or otherwise modify regulated systems. For example, the placement of PMU on electrical systems within the central utility plant, the penetrations of wiring through central utility plant walls, the placement and anchoring of conduit within the central utility plant, and all ancillary materials to be used must undergo OSHPD review. Notably, the structural review for central utility plant wall penetrations was the longest approval process including consideration of all permitting, utility interconnection, and other OSHPD approvals. Teams who elect to develop microgrids for hospitals are best served by direct, early engagement with OSHPD engineers, inspectors-of-record, and with third-party OSHPD experts.

Data Recording Limitations and Redundancy

At the outset of the project, the team had only a qualitative sense of the data storage that might be required. During the course of project design, consideration had to be given to creating archiving methods, data compression, and whether data should be preserved indefinitely or could be sacrificed once analyzed. As data storage expense continues to plummet, this will be a less significant consideration for future projects. Preservation of granular data streams can allow future analyses that might not yet be imagined, but may also lead to unnecessary dedication of resources for processes that may never arise.

Data redundancy is an important consideration. In this design, the Princeton Power Systems®, utility, and PMU data are all obtained, stored, and analyzed independently. With this internal validation of measurements, stakeholders and designers alike can have greater certainty that observed performances have been verified. In addition, if data acquisition from one resource fails, is corrupted, or lost, other sources can be used to define performance. The importance of this became evident during the current project. Based on the highly granular data acquisition specifications chosen initially, data was being over-written on the local EMOS® system after two weeks. Simple adjustments to the rate of data recording allowed for much longer storage intervals and less onerous need to backup data to other resources.

Importance of Independent, Secure Communication Tools

Despite the increased security of hospital networks and communication tools, use of these systems may present risks for facility and microgrid operations alike. As was shown with the recent “WannaCry” malware that disabled multiple hospital networks, healthcare facilities are vulnerable to attacks that could directly or indirectly impact microgrid operations.[13] Similarly, a cyber-attack through the communication systems of the microgrid could, theoretically, be used to find a “back-door” into hospital networks. Given the legal liabilities that healthcare systems face with any acquisition of protected health information, there is zero tolerance for any degree of resulting risk. For these reasons, microgrid communications and controls require an independent, secure, high-bandwidth network.

Local versus Remote Control

Implicit in this discussion is the need for locally embedded, multi-layer control systems. Communications over any network are vulnerable to unpredictable events. For example, cloud-based control systems depend on continuity of operation of the server “farms” from which they emanate, the communication systems to and from the microgrid, and human factors. Failures or disruptions of any of these can render a microgrid without local control topologies unable to operate. Conversely, controls that are solely embedded in local systems may not be modifiable without onsite actions – creating geographic challenges for operators.

Though no ideal control architecture is possible for all scenarios, a layered, redundant method has greater flexibility and resilience. The default, first-layer controller embedded within the smart inverter can function without supervisory input. As smart inverters become more prevalent and the embedded controls more sophisticated, fewer supervisory commands may be needed in the future. However, if the smart inverter cannot control other DER or cannot be coordinated with remote systems as might become applicable with virtual power plants (distributed resources coordinated to provide services to the grid), additional layers of control are needed. A supervisory controller such as the Charge Bliss system can be embedded in a hardened PC at the site of the microgrid that can function autonomously if outside communications are lost. In this fashion, catastrophic events that damage or disable communications do not impact the ability of the microgrid to function at or near optimal performance. Finally, remote, redundant controls ensure that controller updates and tuning are possible on an ongoing basis, that there is continuous monitoring of controls performance, and can warn operators of evolving discrepancies or performance changes.

As discussed previously, remote connectivity is a balance of risk and benefit. Although unusual in the modern era, it is possible to imagine control architectures that have no outside connection or communications. This would eliminate the need for cybersecurity, but would blind operators and end-users to the performance of systems as well as prevent systems optimization by other than onsite modifications. It is conceivable that the highest risk environments would need to consider this disconnected topology, though a more likely scenario would be the selection of multiple protection layers such as VPN, encryption, multi-factor authentication, and others.

Microgrid Controller Development

One objective of this project was to create a novel, innovative microgrid control system for direct operational and financial benefits to the Kaiser Permanente Richmond Medical Center. This controller was intended to make a significant contribution to the healthcare system corporate sustainability and environmental impact goals and provide additional value streams from utility programs for grid support, including demand response and ancillary services. These capabilities cannot be met through local control only and current generation systems native to the solar photovoltaic (PV) and battery systems supplier's equipment do not have these options.

The overall control of the Kaiser Permanente Richmond microgrid is two-tiered, consisting of basic controls residing locally in the Princeton Power Systems® BIGI-250™ converter as well as supervisory controls developed as part of the project residing on the SEL-3355 utility-industrial grade computer. The supervisory controls provide energy management by control of power at a point of common coupling. This is achieved by automatically setting the power at the AC port of the converter to achieve a battery state of charge (SOC) according to a time-varying profile that can be configured to achieve various control objectives.

Basic Control at Multiport Converter System

The Princeton Power Systems® BIGI-250™ multiport converter system and associated EMOS™ performs basic control of power flow at two DC ports and one AC ports. One DC port is connected to the SunPower® solar PV array and has positive power flow into the inverter based on the PV panel production. The second DC port is connected to the Samsung® SDI™ battery system and has bidirectional DC power flow for charging and discharging the battery system. The AC port can also have bidirectional power flow to supply power to the local hospital distribution system or consume power from the local distribution system to charge the batteries. The BIGI-250™ system is capable of islanded operation, in which case it operates in grid-forming mode, supplying power to life safety panels and regulating the voltage and frequency on the islanded system.

Grid-connected Operation Local Energy Management

When grid-connected, the energy is managed locally within the Princeton Power system as follows:

- If the AC port real power setpoint (normally provided by supervisory control) is less than the PV power, then the excess goes to the battery, until the high SOC limit is reached.
- If the AC port real power setpoint is greater than the PV power, then the difference comes from the battery, until the low SOC limit is reached.

Islanded Operation Local Energy Management

When islanded, the local Princeton Power system performs local control of the island, managing the balance of energy as follows:

- PV energy is always prioritized – load is supplied from PV and supplemented from battery.
- If load is less than the generated PV, PV is used to re-charge the battery.
- PV production is curtailed only if the battery is full and the available PV exceeds the load demand.
- At night the PV converter section shuts down to conserve battery energy and minimize losses.
- The inverter requires the battery to provide island power; If the battery disconnects or shuts down, the inverter will too.

Supervisory Control

A supervisory controller was developed and tested with the following modules:

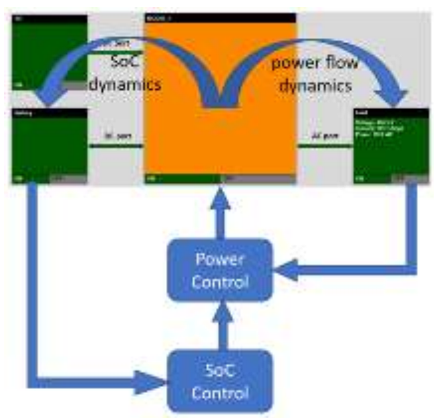
- A decoupling power feedback module that implements the control algorithm to allow for decoupled real/reactive power feedback control.

- A rate limiter operation module used to compute rate limited real/reactive power reference signals with the possibility to allow for independently specified external real/reactive power reference pair (P_r, Q_r).
- A charge monitoring and control module that is used to adjust real power reference signals to control the state of charge (SOC) of the battery energy storage system (BESS).
- A safe output shutdown (SOS) module used to enable operator and automatic shutdown of the microgrid controller in case of islanding switching.

The microgrid controller will support the specification of real/reactive (P_r, Q_r) power flow reference signals via either an independent system operator (CAISO) or an autonomously computed (ramp rate limited) real/reactive (P_r, Q_r) power flow reference signals based on economic incentives to minimize the cost of electric energy and demand charges for the microgrid at the Kaiser Permanente Richmond facility.

Figure 13 shows the combined power feedback and SOC control.

Figure 13: Integrated Control of Power and State of Charge



Power flow dynamics for integrated, controlled microgrid systems

Source: Charge Bliss

Reactive power control functionality was tested and validated with real-time hardware in the loop simulation, but is not used in the present field-deployed controller, primarily because there is no significant benefit presently in doing so.

Use of Synchrophasor Data for Feedback

Synchronized voltage and current phasor can be measured with a PMU and provide real-time and high frequent updates on the electrical properties and real/reactive power flow of the microgrid at the PCC/POI. The use of synchrophasor data for feedback has been integral part of the development of the microgrid controller as synchrophasor data provides valuable information to control power flow at the PCC/POI using feedback. Unanticipated real and reactive power fluctuations at the PCC/POI due to load variations or intermittency in PV power production can be measured in real-time by synchrophasor data. As a result, those unanticipated real/reactive power fluctuations can be compensated in real-time instead of trying to predict and plan for those load fluctuations.

Controller Testing and Risk Reduction

The proposed microgrid controller was tested using real-time controller hardware in the loop (CHIL) simulation by the Nhu Energy, Inc. and Florida State University (FSU) Center for Advanced Power Systems (CAPS) team. Test results of the microgrid control are running at the Synchrophasor Grid Monitoring and Automation (SyGMA) lab at UCSD, communicating in real-time over a secure VPN to the RTDS system at FSU CAPS – demonstrating real time control from east coast to west coast before implementing the microgrid controller at the Kaiser Permanente Richmond site.

Specifically, the Kaiser Permanente Richmond electrical system is simulated on a real-time digital simulator (RTDS) system at FSU-CAPS and the controller is tested by interacting in real-time with the simulated microgrid. The results from the CHIL experiments verify the capabilities of the proposed microgrid controller. For example, the CHIL experiments show decoupling real and reactive power feedback control to maintain an arbitrary specified Thevenin equivalent[25] complex impedance g at the POI of an electric network. The CHIL is primarily used for de-risking and development of controls for planned hardware additions to the Kaiser Permanente Richmond electrical system including PV and batteries.

Figure 14 shows a high-level illustration of microgrid model in the RTDS design environment, along with annotations. The microgrid model has loads that can be categorized as non-emergency and emergency. The emergency loads draw much less power than the non-emergency loads and can therefore be powered solely by the planned hardware installation. The emergency and non-emergency loads each consist of a constant impedance-current-power (ZIP) load and two induction machines. The grid interconnection is modeled using an infinite source and transformer equivalent impedance. The modeled additions to the microgrid include 6 PMUs, a PV array, an inverter, and a battery. The inverter and battery storage are rated at 250kW/250kVar and 250kW/1MWh, respectively.

TCP/IP Modbus and C37.118 data communication is implemented in the real-time simulation. The model includes 6 PMUs that send C37.118 messages providing measurements throughout the microgrid. The C37.118 interface is used to communicate PMU data which include 3-phase voltage phasors (voltage amplitude and angle), current phasors (current amplitude and angle), and positive sequence 3-phase real and reactive power. Additional details on the individual PMUs include:

- PMU 1: at the Point of Common Coupling or PCC for observing overall power flow.
- PMU 2/3: at the AC connection of the Emergency Load (EL) for observing potential EL power flow.

[25] "Thevenin's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single voltage source and series resistance connected to a load" ("Thevenin's Theorem," https://www.allaboutcircuits.com/textbook/direct-current/chpt-10/thevenins-theorem/).

- PMU 4/5: at the Automatic Transfer Switch, used to emulate the islanding condition of the 250kW Princeton Power Systems Inverter with the emergency loads.
- PMU 6: at the AC connection of the 250kW Princeton Power Systems Inverter for observing PPS power flow.

Figure 14: Controller Hardware in the Loop Testing

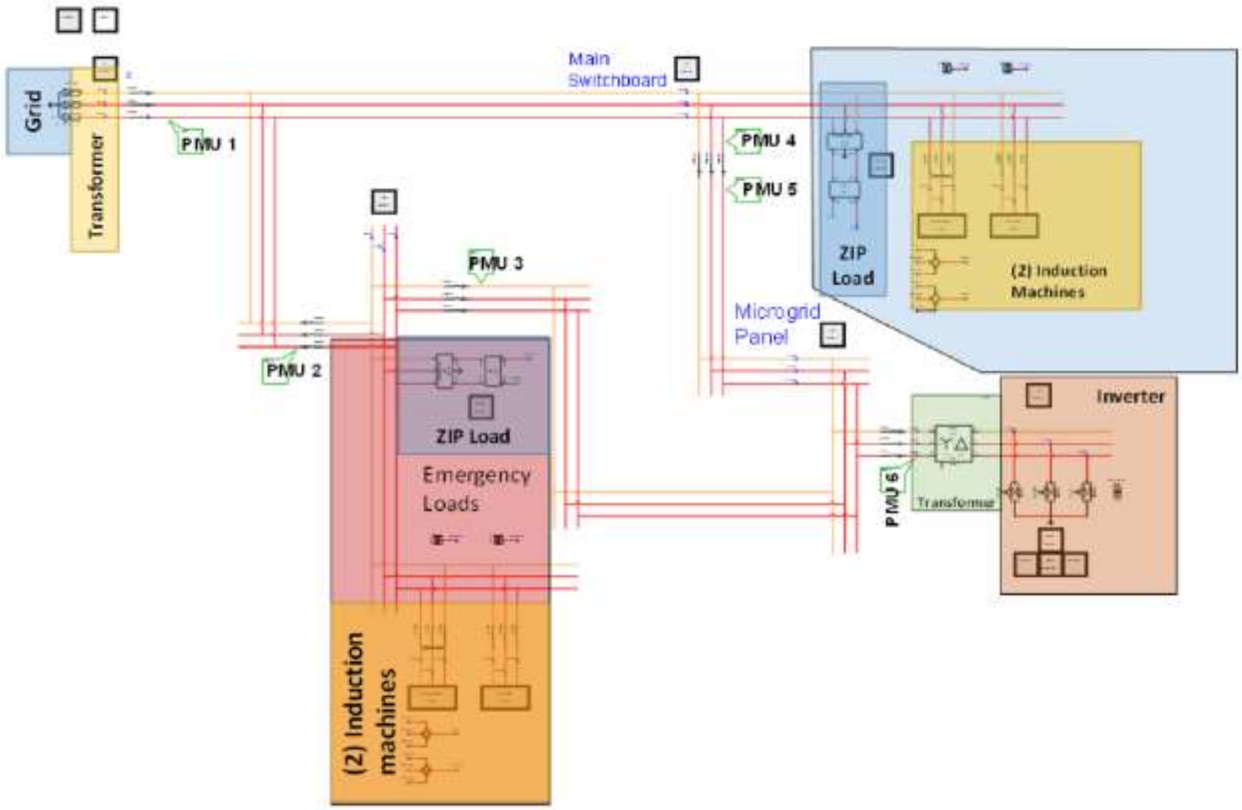


Diagram of the modelled Kaiser Permanente Richmond microgrid in real-time digital simulator with phasor measurement units and controllable inverter.

Source: Charge Bliss

The simulated inverter provides a Modbus TCP/IP interface, which is the communication channel for controlling real and reactive power and information including battery SOC and PV power.

The microgrid model and associated HIL components are used to create various environments for the testing the developed controls. These environments are intended be meaningful representations of the actual system to characterize the effect of the controls on the actual system (when deployed). A variety of environments are available and described below to verify and refine the developed control.

1. Parameterized scenarios including peak power demands as seen at the utility interface (POCC). Selected scenario parameters are:

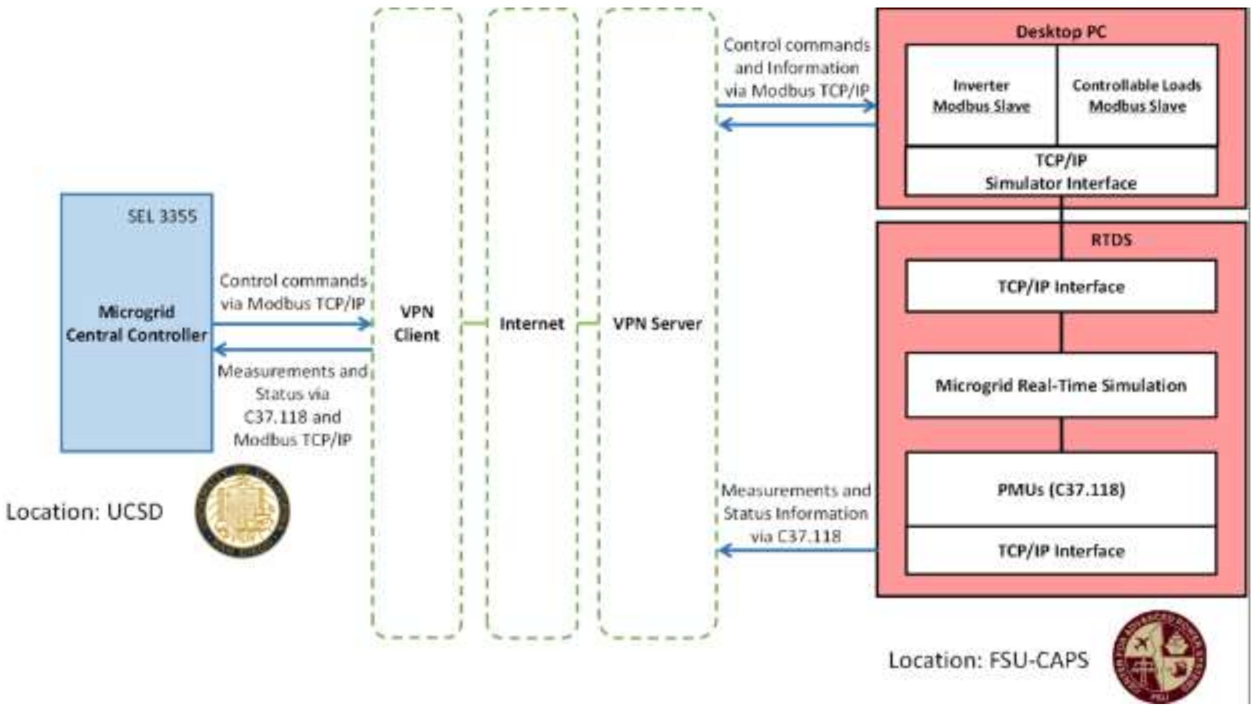
    a. Time of day and demand profile: normal demand patterns, large load pick-up, loss of large load.
    b. Solar PV generation profile.
2. System under closed-loop control with PMU failures
    a. Data communications
        i. Prolonged network outage: Intended to simulate an unresponsive device or unplugging a network cable and plugging it back
        ii. Lost packets
        iii. Packets delayed
        iv. Packets reordered
    b. Sensor anomalies intended to represent malfunctioning (or poor quality sensors). Measurements from voltage and current sensors are modified (for example, 2 percent of actual value).
3. System under closed loop control with either failure of the inverter to respond to control commands or saturation of the inverter P or Q at high or low limits.
    a. Prolonged network outage: Intended to simulate an unresponsive device or unplugging a network cable and plugging it back
    b. Unresponsive commands
        i. Active Power (input)
        ii. Reactive Power (input)
    c. Incorrect information
        i. Battery state of charge (output)
        ii. PV power generation (output)

Overview of Controller Hardware-in-the-Loop Testing

The CHIL setup includes the real-time simulated microgrid (also referred to as virtual microgrid), controller, field measurements, and interfacing (controller, simulation, sensing, and converter). The controls developed by the Charge Bliss team and operated at UCSD are remotely interfaced to the real-time simulated model of the Kaiser Permanente Richmond microgrid to test operational and performance characteristics. The major benefit of the CHIL-based testing of the microgrid controls is the possibility to reduce the risks involved in deploying new means of controlling and operating distributed energy resources. The developed controls can be evaluated for stability and performance before installation and operation within the actual system.

An overview of the CHIL data communication interfaces is summarized in Figure 15. The microgrid control algorithm (controller) communicates with the CHIL testbed over a virtual private network (VPN). The VPN provides an interface that allows the controller, PMUs, and inverter to communicate with the illusion of being on the same local data communications network. Simulation data from the CHIL testbed is communicated to the controller via TCP/IP at the rate of 10Hz.

Figure 15: Controller Hardware in the Loop Communication Architecture



Communication setup of the CHIL testbed with microgrid controller at UC San Diego and microgrid simulator at FSU-CAPS communicating in real time over the Internet.

Source: Charge Bliss

The communicated data items are shown in Table 3. PMU communication adheres to the IEEE C37.118 standard, which is the common IEEE standard for PMUs in power systems and inverter communication follows the Modbus TCP/IP protocol.

Open-Loop Test Results

The first test that is performed is an “open-loop” or “uncontrolled” microgrid test to estimate the dynamics of individual rational transfer function models for deriving the Simplified Dynamic Power Model (SDPM) $R(s)$. The transfer functions in the SDPM $R(s)$ are estimated by performing experiments on the (virtual) microgrid and collecting time domain data the real/reactive (P_u, Q_u) power demand signals for the inverter and the real/reactive (P_y, Q_y) power flow pair at the POI/PCC. The time domain data of “input” (P_u, Q_u) and “output” (P_y, Q_y) signals are used to estimate the parameters of the numerator and denominator coefficients of the rational transfer function models in either continuous- or discrete-time. For the parameter estimation, the step response-based realization methods developed at UCSD or Prediction Error Minimization (PEM) methods developed by Ljung (1999) are used.

Table 3: Controller Communications

COMMUNICATED DATA IN THE CONTROLLER HIL TEST SETUP

Data	From	To	Comm. Protocol
Active and reactive power at 6 points	PMUs 1-6	Controller	IEEE C37.118
Voltage, current, and frequency at 6 points	PMUs 1-6	Controller	IEEE C37.118
Battery SoC	Inverter	Controller	Modbus
PV Generation	Inverter	Controller	Modbus
Inverter active and reactive power reference	Controller	Inverter	Modbus

Source: Charge Bliss

The open-loop test consists of small step input signals to both the real and reactive power reference signals of the inverter. The periodicity of the signals is chosen such that power can settle within each real or reactive power step applied to the (Virtual) microgrid. For performing the test, input/output (IO) modules are developed with the following functionality:

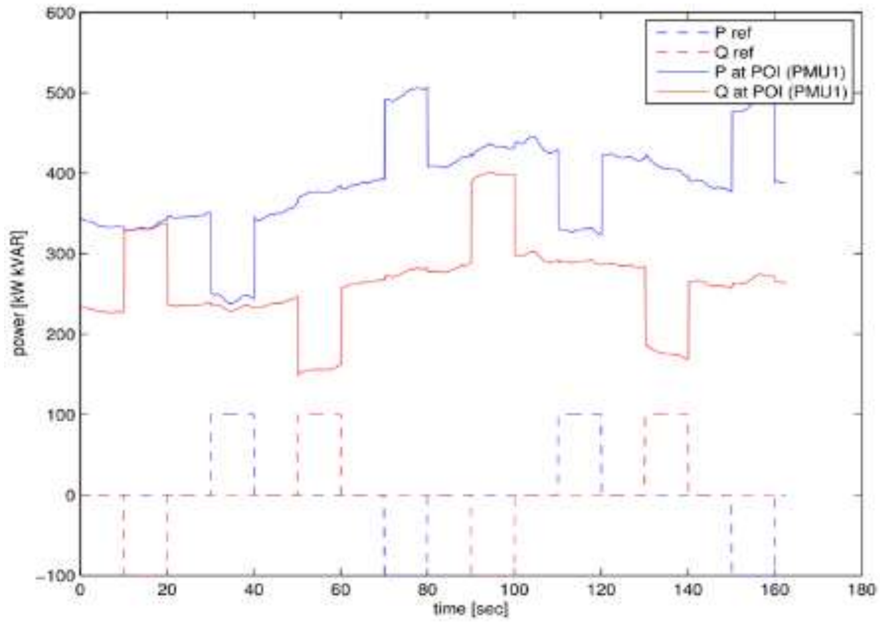
- A C37.118 read interface is developed to run under Matlab Simulink to gather experimental data set by PMUs in the microgrid.
- A Modbus master/slave interface is developed to run under Matlab Simulink to send power reference signals to user-specified Modbus registers over TCP/IP.

Real-time measurements of both real- and reactive power flows provided by the PMUs are used to formulate the dynamic model $R(s)$ and used to tune and test the feedback controller on the Simplified Dynamic Power Model (SDPM) $R(s)$.

The control signals use the Modbus TCP/IP protocol to send active and reactive power reference commands to the simulated inverter. The PPS BIGI inverter accept real/reactive power demand signals (P_u, Q_u) at a rate of only 1 sample/second with an additional delay of 1 second. The simulated inverter the virtual microgrid model can accept fast update rates of 10 samples/second over the internet to FSU-CAPS (east coast) from the SyGMA lab at UCSD (west coast). The maximum rate of real/reactive power demand signals (P_u, Q_u) is primarily limited by the speed of the network connection between FSU and UCSD.

The open-loop test data is depicted in Figure 16. It can be observed from the open-loop test data that real and reactive power (P_y, Q_y) at the POI changes due to real and reactive (P_u, Q_u) demand signals, but also (small) coupling can be observed in the (P_y, Q_y) signals. Furthermore, the RTDS simulation shows (uncontrolled) large variations of the real and reactive power (P_y, Q_y) at the POI causing real and reactive power control to drift and change. The control algorithm of the microgrid controller aims to reduce these power fluctuations. As a final note, it should be observed that the simulation model has not been fully validated against high resolution data from the actual Kaiser Permanente Richmond microgrid, but the approach illustrates that dynamics and coupling between real and reactive power (P_y, Q_y) at the POI can be modelled with step-based changes on the real and reactive (P_u, Q_u) demand signals that can be replicated on the actual Kaiser Permanente Richmond microgrid.

Figure 16: Graphical Controller Test Data (P,Q)



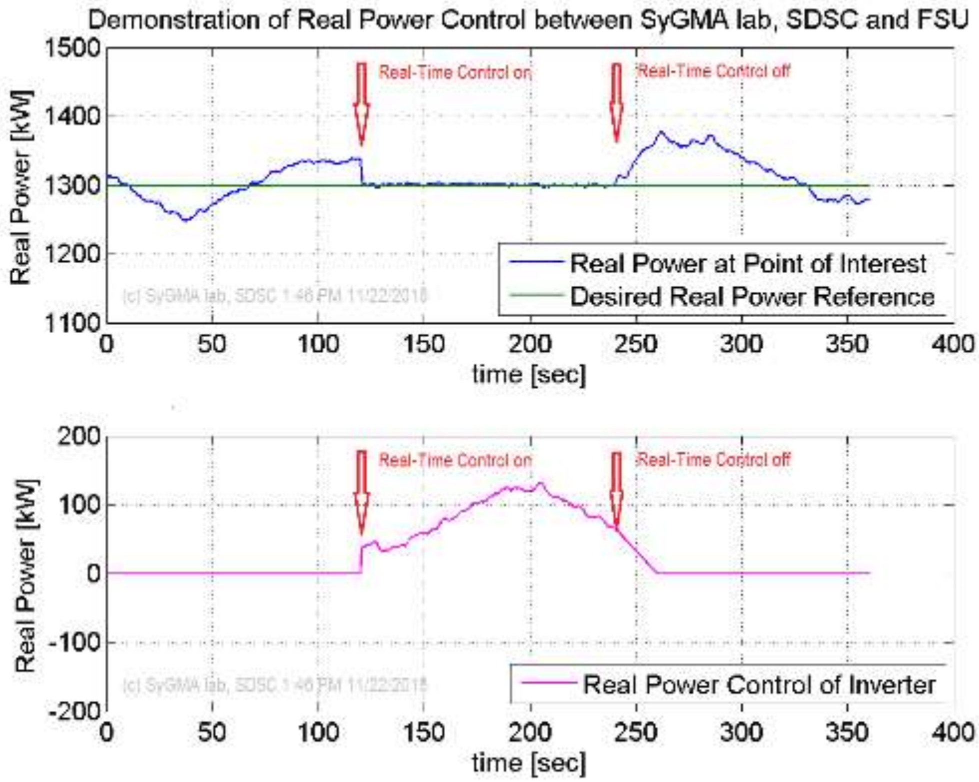
Open-loop test data, measuring real and reactive power flow (P_y,Q_y) “output” signals (solid lines) due to real and reactive power flow “input” (P_u,Q_u) demand signals (dashed lines) at the POI.

Source: Charge Bliss

Closed-Loop Tests: Externally Specified Real Power Reference

Based on the “open-loop” test data, an open-loop model of the (coupling) power flow in the microgrid model simulated by the RTDS. The model was used to formulate a decoupling filter $D(s)$ as described above and tune the PID controllers $C_P(s)$ and $C_Q(s)$ for real/reactive power flow control and tracking. The results of tracking an externally specified real power flow reference P_r over a short time interval (2 minutes) is depicted in **Error! Reference source not found.**.

When the control is started, the real power demand of the inverter jumps up bounded by rate constraints. When the control is stopped, the SOS module forces the control to ramp down to zero subject to its regular ramp rate limitation and demonstrating a safe controller shutdown. The results depicted in Figure 16 show the powerful effects of the microgrid controller: the real power can be held at a user-specified value for a short time, only dependent on the available SOC of the battery. It should be pointed out that these results were obtained by running the RTDS (Virtual Grid) model at FSU (east coast), while running the control algorithm at the SyGMA lab at UCSD (west coast). All this was done at 10Hz sampling and shows that the controller testing and tuning can be done even over a long distance.



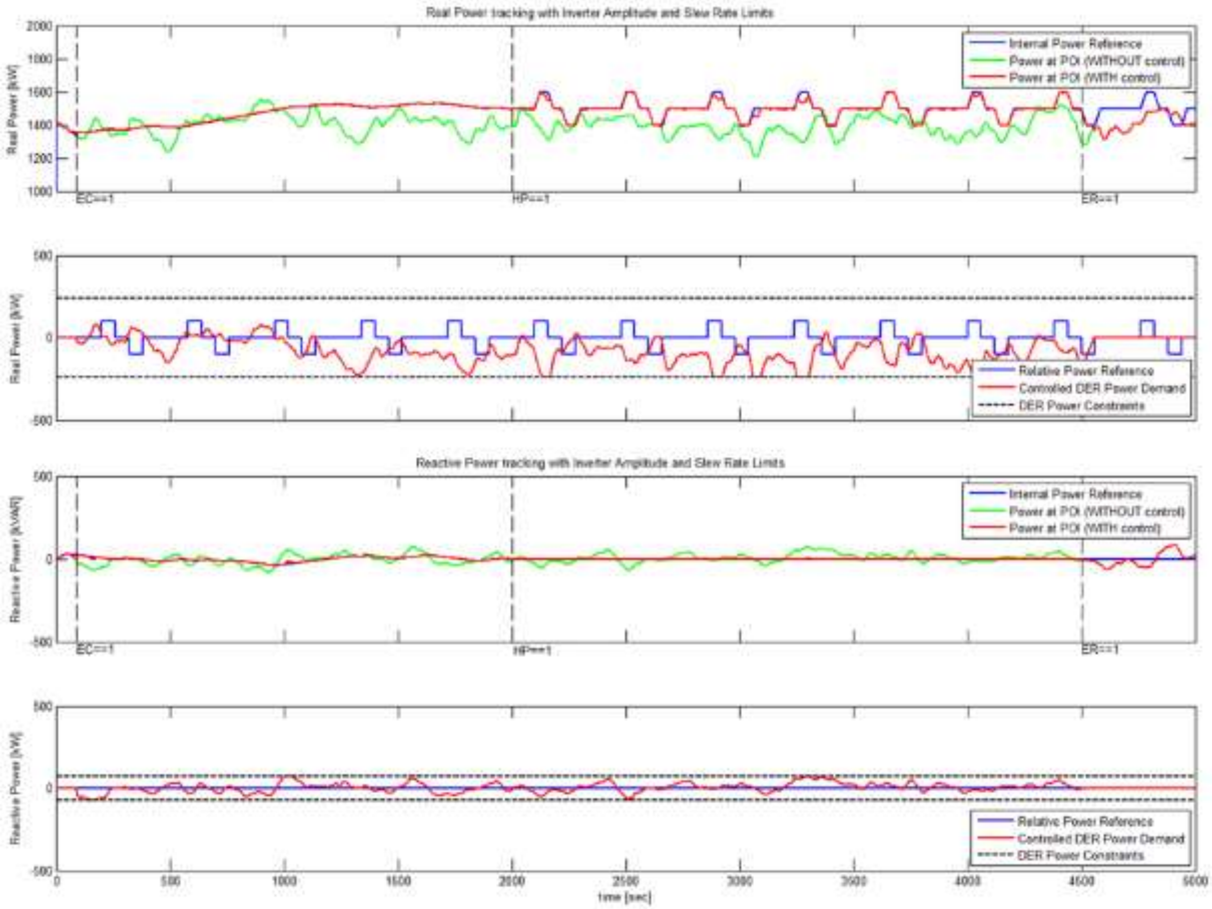
Demonstration of real power tracking, where an Independent System Operator (CAISO) externally specified real power reference signal of 1.3MW (indicated in green) is followed (tracked) for 2 minutes. In this test only the real power is subjected to a fixed reference signal, while reactive power is allowed to change.

Source: Charge Bliss

Closed-Loop Tests: Decoupling Real/Reactive Power Control

Independent real/reactive power control capabilities of the microgrid were tested. **Error! Reference source not found.** shows the results demonstrating decoupled real and reactive power tracking, where an Independent System Operator (CAISO) externally specified +/- 100kW step-wise changing real power reference signal and a constant reactive power reference signal are followed (tracked) whenever the binary signal Hold Power (HP) is set to true (HP=1). The control is started when Enable Control (EC) is set to true (EC=1), starting the microgrid controller in the autonomous ramp rate mode. The control is stopped when Enable Ramp (ER) is set to true (ER=1), where the SOS module forces the control to ramp down to zero subject to its regular ramp rate limitation and demonstrating a safe controller shutdown. In these experiments an externally specified step-wise changing real power reference signal and a constant reactive power reference signal are used to demonstrate the decoupled real/reactive power tracking capabilities of the microgrid controller.

Figure 17: Graphical Results of Closed Loop Testing



Demonstration of decoupled real and reactive power tracking

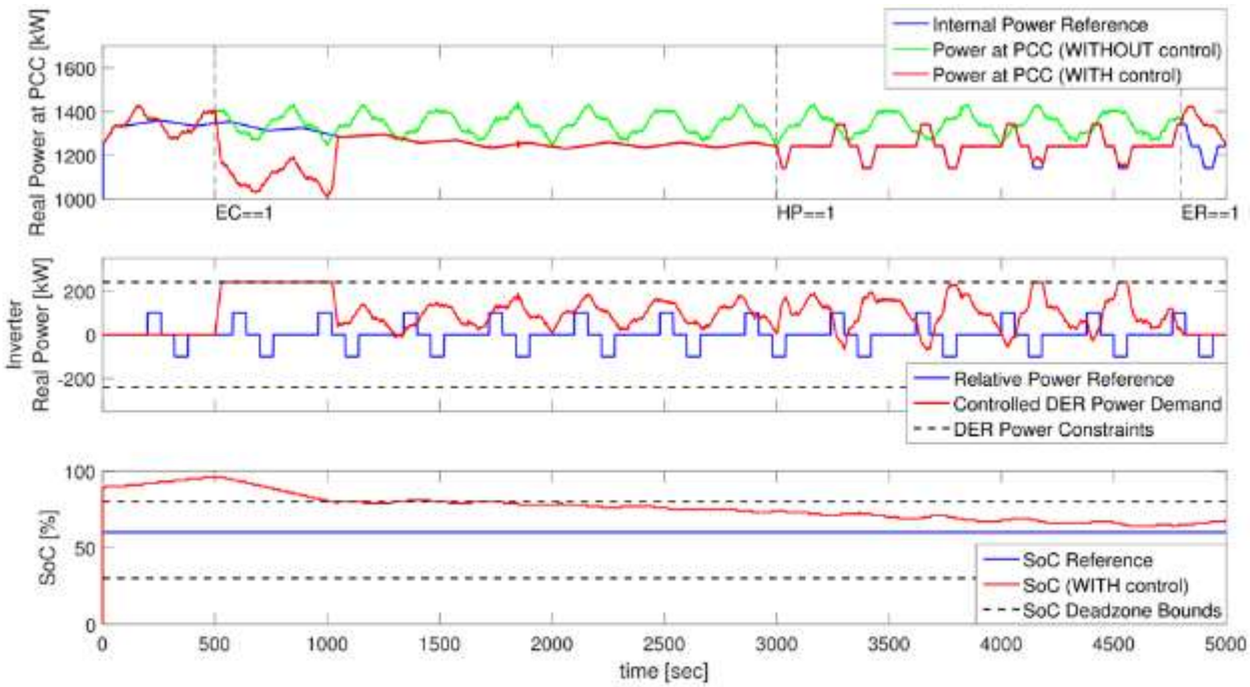
Source: Charge Bliss

Closed-Loop Tests: Decoupling Real/Reactive Power and State of Charge Control

The independent real/reactive power control capabilities of the microgrid controller summarized earlier in **Error! Reference source not found.** demonstrate the powerful feature of the microgrid controller: to be able to follow or track real and reactive power demands at the POI/PCC independently. Although these features are important for a microgrid, the ability to independently track real and reactive power is limited by the inverter (actuator) saturation (seen in Figure 17), but also by the amount of energy available. As such, it is important to also maintain and control the SOC of the BESS to be able to maintain the control authority to track and regulate real power.

The capabilities to be able to follow or track real and reactive power demands at the POI/PCC independently despite a large discrepancy in the SOC of the BESS is demonstrated in Figure 18. In these experiments the BESS started out with a relatively large SOC level of almost 80 percent, whereas significant real/reactive power fluctuations at the POI/PCC were present due to periodic load switching in the microgrid.

Figure 18: Graphical Representation of Decoupled Real and Reactive Power



Demonstration of (decoupled) real power tracking, where an Independent System Operator (CAISO) externally specified +/-100kW step-wise changing real power reference signal and the BESS started out at an 80% SOC with large (real) power fluctuations at the PCC/POI of the microgrid.

Source: Charge Bliss

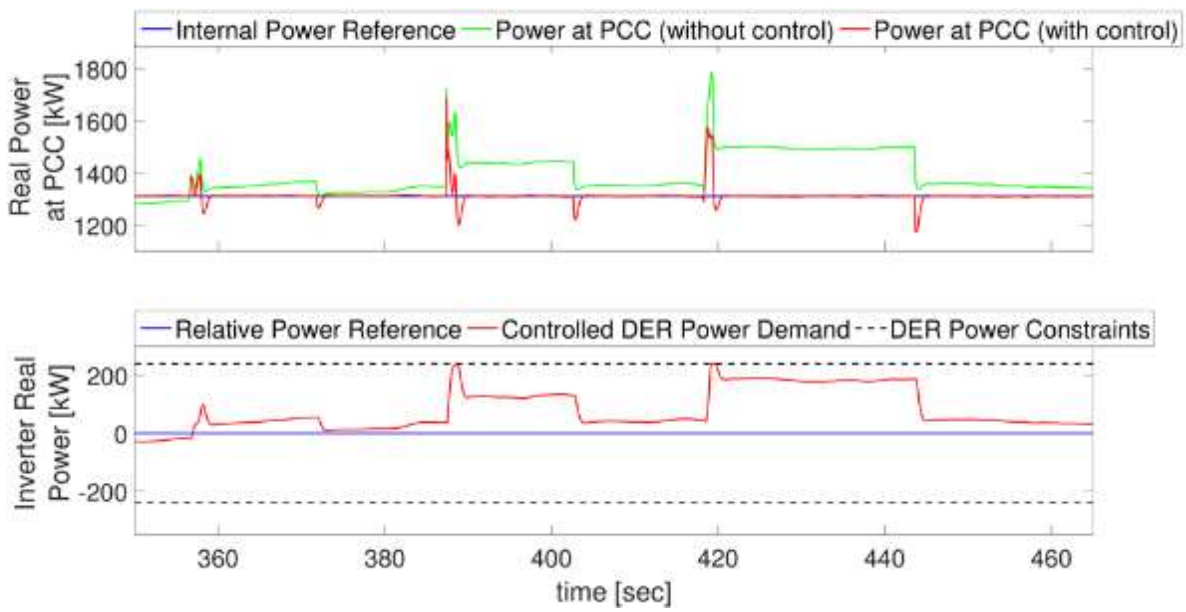
Similar to the results displayed earlier in Figure 17, the power reference signal is followed (tracked) in Figure 18, whenever the binary signal Hold Power (HP) is set to true (HP=1). The control is started when Enable Control (EC) is set to true (EC=1), starting the microgrid controller in the autonomous ramp rate mode. The control is stopped when Enable Ramp (ER) is set to true (ER=1), where the SOS module forces the control to ramp down to zero subject to its regular ramp rate limitation and demonstrating a safe controller shutdown.

The results in Figure 18 indicate the adjustments the microgrid controller makes to the real power to ensure the BESS will not be over-charged. As observed in the SOC plot (bottom plot in Figure 17), the starting SOC of the battery is set outside the dead zone band for test purposes. The controller is activated at 500s from when it is commanded to operate in the autonomous rate limited mode (or also called adaptive reference mode). However, by this time, since the SOC has already grown largely out of limits and passed its absolute limits, the only priority of the control system becomes SOC recovery until it reaches the safe zone. This is done by operating the inverter in the full power mode (subject to ramp rate limitation) and continues until SOC reaches safe zone at around 1000s. Afterwards, the controller switches back to adaptive reference mode and the power measured at POI/PCC is able to follow the reference. The reference computed by the adaptive reference computation module is shown by blue in the top figure. This scenario continues until time 3000~. The inverter's control input during this period is shown by red in the middle figure and falls within the inverter's power limits. At time 3000s, the controller is switched from adaptive to manual reference mode, where the controller is able to follow a modulating trapezoidal reference set by the user. The bottom plot shows that the SOC is within acceptable limits after time 1000s. As observed previously, the inverter's control input is barely reaching its limits after time 1000s, which means the reference variations are within the inverter's power control capability. The controller is finally switched off at 4800s.

Closed-Loop Tests: Dynamic Load Switching

Although very good results have been obtained by the CHIL using the microgrid controller to track real/reactive power reference signals, a final test was performed with dynamic load switching. The dynamic load switching demonstrates the capabilities of the microgrid controller to reduce power flow disturbances at the POI/PCC caused by (fast) dynamic load changes. The results are summarized in Figure 19.

Figure 19: Decouple Real Power Disturbance



Demonstration of (decoupled) real power disturbance rejection, where real power fluctuations at the POI/PCC are generated by (periodic) on/off switching of fast dynamic loads in the microgrid.

Source: Charge Bliss

The test results summarized in Figure 19 are designed to emulate more transient microgrid events and examine the controller's ability to continue to perform in the presence of transient power fluctuations. In particular, the test results in Figure 18 emulate abrupt load switching events and the effect of inverter's ramp rate limitation and the communication delay on the controller's ability to control those events. The test scenario comprises the microgrid with its usual time-varying load demand while an additional 50kW motor is suddenly switched in. The switch-in event causes POI/PCC real power to experience a sudden jump, however, the controller should be able to recover the previous POI/PCC power level in a timely manner. After successful recovery, the 50kW motor is switched off and a 100kW motor is switched in this time. A similar scenario then happens for a 150kW motor.

The results will depend on the ramp rate limits of the inverter and to demonstrate the control capabilities of the microgrid controller. Figure 19 shows controlled power for a relative fast inverter with ramp rate of 80kW/s in the presence of a controller delay of one time step and a communication delay of one time step (0.1sec at 10Hz). The microgrid controller performs well with the relatively fast inverter by quickly reducing the power disturbances. This is apparent in both the POI/PCC power plots (top) and inverter power plots (bottom) in Figure 19. The microgrid controlled inverter not only corrects the steady state power level but also partly diminishes the effects of fast power transients that occur during the load switching (apparent in the instantaneous spikes after each event.

Implementation Microgrid Controller and Validation of Phasor Measurement Unit Data Using Schweitzer Engineering Laboratories Equipment

Phasor Measurement Unit Locations

To be able to implement the developed microgrid controller on the actual Kaiser Permanente Richmond microgrid, the infrastructure to measure synchrophasor data, import data into a control computer and send control signals to the PPS BIGI inverter needs to be developed.

Schweitzer Engineering Laboratories-based Synchrophasor Platform

Synchrophasor data at the 6 different PMU locations in the microgrid are being realized by SEL-2240 Axion based system, whereas computing power for the controller is based on the rack-mounted rugged SEL-3355 computer. The SEL-2240 Axion is a fully integrated, modular input/output (I/O) and control solution that combines the communications, built-in security, and IEC 61131 logic engine of the SEL Real-Time Automation Controller (RTAC) family with a durable suite of I/O modules that provide high-speed, deterministic control performance over an EtherCAT network. Inside the SEL-2240 Axion, the SEL-2241 RTAC Module operates as the CPU for an SEL-2240 Axion Platform. The SEL-2241 RTAC Module interfaces seamlessly with the I/O Modules used to implement the PMU capabilities on the SEL-2240 Axiom platform.

The PMU capabilities for the SEL-2240 Axiom platform is provided by the SEL-2245-4 Metering Module that provides a 4CT/4PT metering capabilities. Together with the SEL-2241 RTAC Module, they provide an IEEE Certified PMU devices, capable of sending IEEE C37.118 communication over TCP/IP at 60 samples/second. To power both the SEL-2241 RTAC Module and the SEL-2245-4 Metering Module, the SEL-2240 Axiom platform also needs an SEL2243 power coupler. To accommodate analog signal communications to the PPS BIGI inverter, one of the SEL-2240 Axiom platforms is also equipped with a SEL-2245-3 Analog Output Module. It allows the generation of analog voltage or current (4-20mA) control signals to be sent to an inverter.

PMU data and control commands are processed by a separate Rack-Mount Rugged SEL Computer: the SEL-3355. Designed as a server-class computer, the SEL-3355 computer is built to withstand harsh environments in utility substations and industrial control and automation systems. By eliminating all moving parts, including rotating hard drives and fans, and using error-correcting code (ECC) memory technology, the SEL-3355 has over ten times the mean time between failures of typical industrial computers.

To enable a cyber-secure network, all SEL hardware discussed above are copper wired onto firewall protected local network. The SEL 2240 hardware (PMUs and analog output) are all daisy changed on the same Local Area Network and connected only to the SEL-3355 computer. For hardware redundancy, two SEL-3355 computers are configured in a High Availability (HA) mode to allow independent (security) patching of each SEL-3355, while allowing the microgrid controller to run uninterruptedly.

Configuration of the Schweitzer Engineering Laboratories Synchrophasor Platform

PMU capabilities for the SEL-2240 Axiom platform is provided by the SEL-2245-4 Metering Module that provides a 4CT/4PT metering capabilities. Together with the SEL-2241 RTAC Module, they provide an IEEE Certified PMU devices, capable of sending IEEE C37.118 communication over TCP/IP at 60 samples/second. To power both the SEL-2241 RTAC Module and the SEL-2245-4 Metering Module, the SEL-2240 Axiom platform also needs an SEL2243 power coupler. To accommodate analog signal communications to the PPS BIGI250™ inverter, one of the SEL-2240 Axiom platforms is also equipped with a SEL-2245-3 Analog Output Module. It allows the generation of analog voltage or current (4-20mA) control signals to be sent to an inverter.

PMU data and control commands are processed by a separate Rack-Mount Rugged SEL Computer: the SEL-3355. Designed as a server-class computer, the SEL-3355 computer is built to withstand harsh environments in utility substations and industrial control and automation systems. By eliminating all moving parts, including rotating hard drives and fans, and using error-correcting code (ECC) memory technology, the SEL-3355 has over ten times the mean time between failures of typical industrial computers.

To enable a cyber-secure network, all SEL hardware discussed above are copper wired onto firewall protected local network called the "Control Network". The SEL 2240 hardware (PMUs and analog output) are all daisy changed on the same Local Area Network and connected only to the SEL-3355 computer. For hardware redundancy, two SEL-3355 computers are configured in a High Availability (HA) mode to allow independent (security) patching of each SEL-3355, while allowing the microgrid controller to run uninterruptedly.

The SEL equipment for the Kaiser Permanente Richmond microgrid comes in 4 chassis (called SEL-2240) and 1 computer (called SEL-3355). The different chassis has the following modules:

- Each chassis always has a "power coupler" module (called SEL-2243) that requires 110/240 VAC to power the chassis.
- 3 out of 4 of the chassis have a "Digital Output" module (called SEL-2244).
- 1 out of 4 of the chassis has a "Analog Output" module (called SEL-2245-3).
- 1 out of 4 of the chassis has a "RTAC" module (called SEL-2241).
- Each chassis has at least 1 (or sometimes 2) "4CT/4PT" module (called SEL-2245-4) that requires 3 phase voltage, 3 phase current and (optional) neutral voltage/current signals.

- The team has a total of 6 ”4CT/4PT” modules (or PMUs) distributed over the 4 chassis and each “4CT/4PT” module is configured to act as the actual PMU measuring synchronized power flow at different locations in the Kaiser Microgrid.

The “Power Coupler”. “Digital Output”, “Analog Output” and “PMU or 4CT/4PT” modules are distributed over the 4 chassis according to chassis configuration. Each “4CT/4PT or PMU” module (called SEL-2245-4) requires 3 phase voltage, 3 phase current and (optional) neutral voltage/current signals for actual measurement of phasors and frequency so that 3 phase power flow can be calculated.

The SEL-2245-4 measurement range for voltage is:

- VNOM: 300 V.
- Measurement Range: 5–400V L-N, 9–693 L-L Vac.
- Fundamental/RMS (UL): 5–300V L-N, 9–520V L-L Vac.
- Maximum: 600 L-N, 1039 L-L Vac Fundamental/RMS for 10s.

The SEL-2245-4 measurement range for current is:

- INOM: 1 A or 5 A (no settings required).
- Measurement Range: 0.050–22 A Continuous, 22–100 A Symmetrical for 25 s.

Scaling can be adjusted in software in case measured voltage/current is adjusted via CT and PT devices.

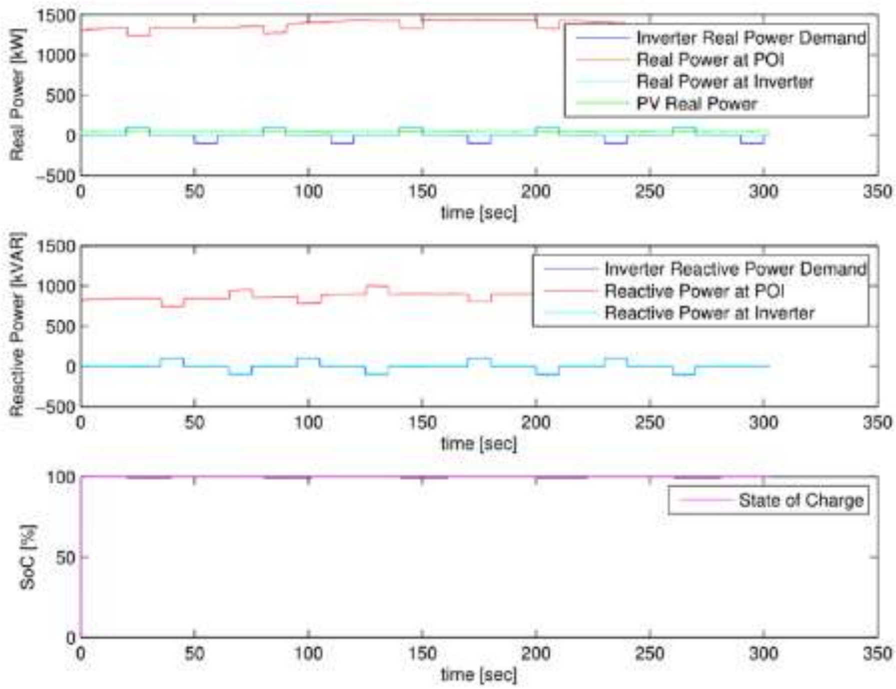
Validation of Power Data

The Princeton Power System® (PPS) includes the Energy Management Operating System (EMOS™), the BIGI250™ system with the inverter and battery charging systems. The external microgrid controller or “microgrid controller” interfaces with the EMOS™ via Modbus communication to both measure SCADA data (related to solar power production and battery state of charge) and provide external power demand signals. The external microgrid controller processes the PMU measurements generated by the SEL equipment to compute the desired external power demand signal for the EMOS™.

A comprehensive tag list for both the PMU data produced by the SEL equipment, the SCADA data produced by the PPS and the power demand signals to the EMOS is used to map measurements to data based entries in the OSIsoft® PI™ system. The same mapping is also used in the microgrid controller to compute the control signals and both PMU data using C37.118 protocol and SCADA, control signals via the Modbus Function 23 (read/write) protocol are implemented over TCP/IP. The communication of both C37.118 and Modbus over TCP/IP allows a controller configuration to be implemented on the SEL3355 (main SEL control computer) that only requires a standard TCP/IP stack for both data gathering and sending power demand commands to the EMOS™.

The mapping of the I/O signals of the controller has been tested extensively with the RTDS system running the Kaiser hospital microgrid model. The validation test results show successful monitoring of both the PCC/POI PMU, the inverter PMU and the inverter Modbus register (read/write) reproduce power data that is consistent with the models and summarized in Figure 20 below.

Figure 20: Graphical Representation of Phasor Measurement Unit Power Reporting



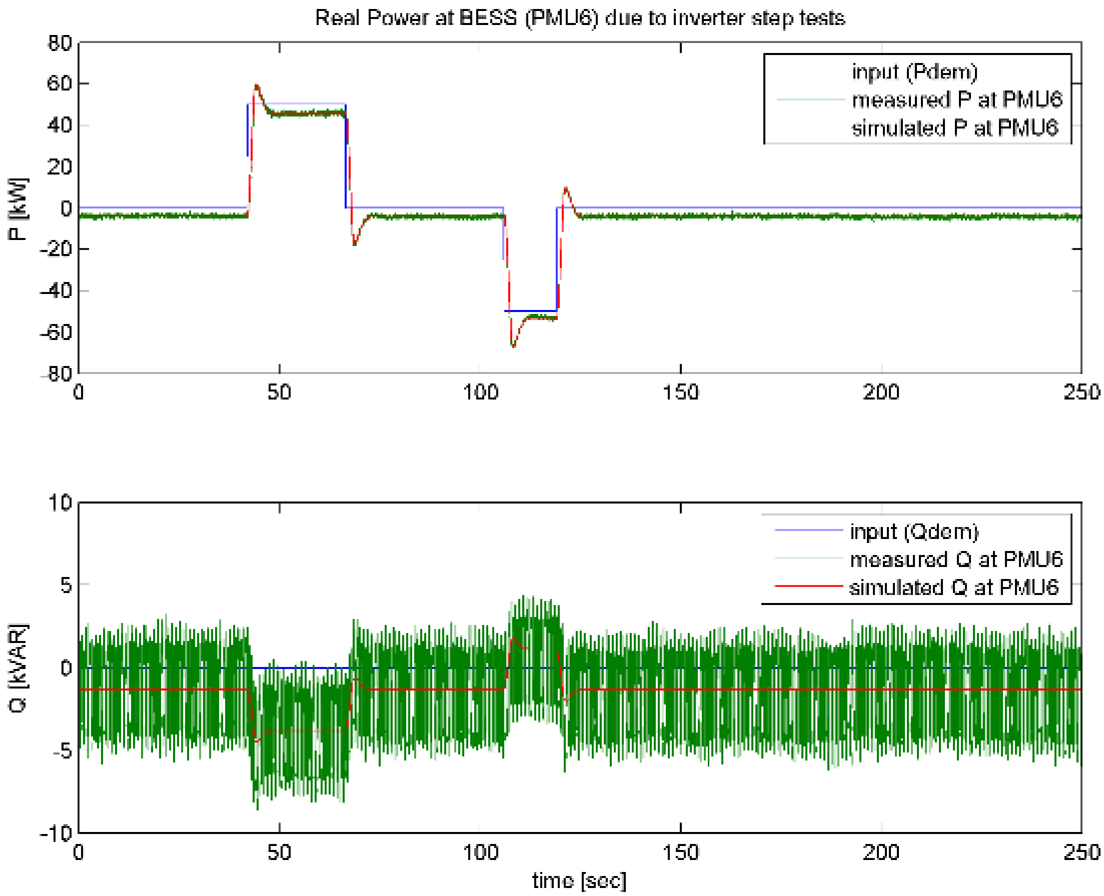
Real-time measurements of PCC PMU (PMU1, C37.118), inverter PMU (PMU4, C37.118), Solar Power (PV, Modbus register) and State of Charge (SOC, Modbus Register) obtained via communication to RTDS at FSU while updating the real and reactive power demand signals to the PPS inverter. The results show how SOC has reached a maximum value, limiting negative real power demand signal.

Source: Charge Bliss

With the inverter and battery system properly installed and the SEL hardware with the PMUs reliably collecting phasor data 60 times a second, a simple inverter step response was carried out at the medical facility. The inverter steps response was carried out by sending a 50kW real power demand response to the inverter, while the PMUs were collecting the measurements of power flow. Such a step response can be used to model slew rate, latency and dynamic settling of the power flow at the PCC at the medical facility. Figure 21 summarizes the test results and the modeling efforts to characterize the dynamic behavior of the power flow.

The blue line in the top figure of Figure 21 refers to the step-wise change in the real power demand signal send to the inverter. It can be seen that step wise change was a step of +50kW and s step of -50kW. A positive value of the real power demand signal of 50kW causes the battery to be discharged, while a negative value is used for charging of the battery. The green line is a measurement of the real power flow computed from the 3 phase phasor measurement of PMU6, located at the AC port of the inverter. It can be seen that the inverter exhibits a slew rate limitation and a small overshoot in power flow. The red line is a dynamic model fitted on the measured data, modeling the inverter slew rate and dynamic response. Main conclusion from this plot is that the SDPM of the power flow on the inverter is able to simulate the measured real power flow very well. As such, the model is used for off-line tuning of the Charge Bliss microgrid controller to ensure the controller will work with the anticipated inverter dynamics.

Figure 21: Point of Interconnection Power Flows with Demand Changes



Dynamic characterization of real power flow at the PCC/POI by the measurement of power flow at the PCC/POI due to a step demand change of 50kW of real power on the inverter.

Source: Charge Bliss

While measuring and modeling the dynamic response of the inverter for the real power flow, a similar procedure has been carried out for the reactive power flow. The reactive power flow is noisier, mostly due to the switching control logic in the inverter. Moreover, the step wise change of the real power has caused (dynamic) interaction on the reactive power flow at the AC port of the inverter, as the reactive power flow demand signal was set to 0. It can be seen that the inverter again exhibits a slew rate limitation and a small overshoot in power flow. The red line is a dynamic model fitted on the measured data, modeling the inverter slew rate and dynamic response. Main conclusion from this plot is that the SDPM is able to simulate the measured reactive power flow very well. As such, the model can be used for off-line tuning of the Charge Bliss microgrid controller to ensure the controller will work with the anticipated inverter dynamics.

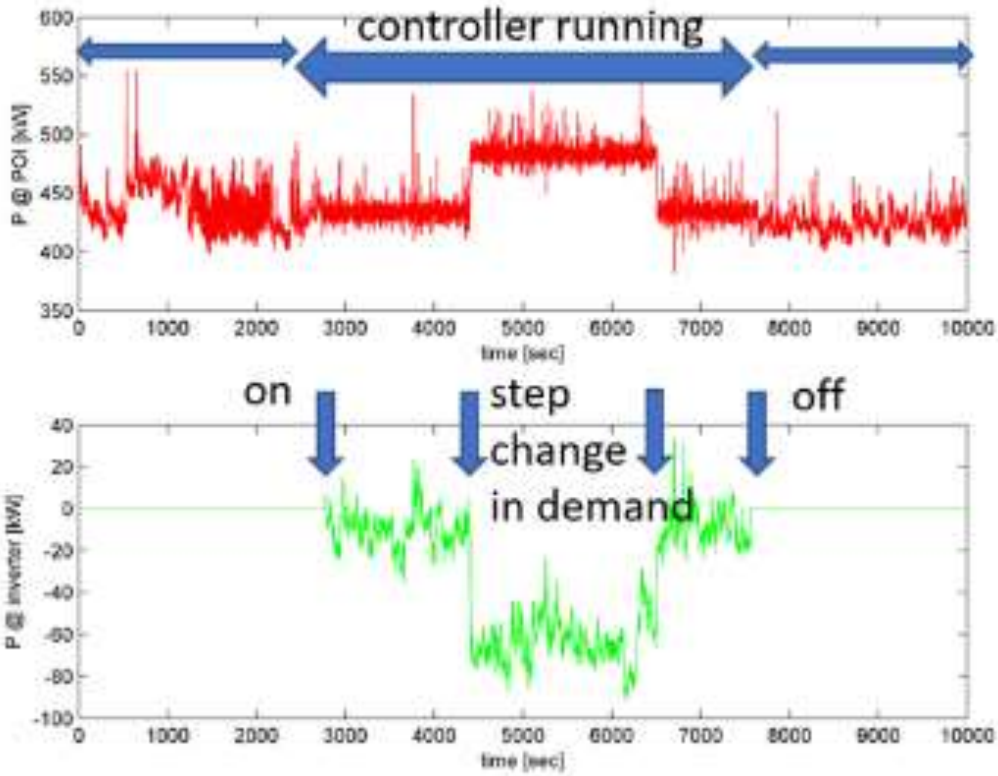
Short-term and Long-term Performance Validation

Real and Reactive Power Tracking

For the actual implementation of the microgrid controller at the Kaiser Permanente medical facility, the control algorithms developed in Matlab/Simulink were converted to C++ code and compiled under Microsoft Visual Studio to be able to run in real-time on the Windows Server 2012 SEL3355 computer installed at the medical facility. The translation of Matlab/Simulink code to C++ code was unit tested by generating random input data for the Matlab/Simulink control algorithm and comparing the output of the C++ code given the same input with the output produce by Matlab/Simulink.

Most of the C++ code was associated with the overhead of opening TCP/IP communication ports (WinSockets) to allow PMU and modbus data over TCP/IP to flow in/out of the controller. TCP/IP PMU and Modbus data flow was tested with separate C37.118 and modbus testers. In particular, for the C38.118 communication with the C++ implementation for the microgrid controller the PMU connection Tester software by the Grid Protection Alliance was used. For Modbus communication the Modbus Slave by Witte Software (http://www.modbustools.com/) was used. The closed-loop real and reactive power control tracking of the actual microgrid controller is performed by confirming the power tracking capabilities of the microgrid controller. To illustrate the performance of the microgrid controller, measurements of power flow at the PCC/POI were taken at 60Hz WITH and WITHOUT power tracking and the results are summarized in Figure 22 below.

Figure 22: Power Tracking Testing



Testing and illustration of power tracking capabilities of the microgrid controller applied to the Kaiser Permanente Richmond site.

Source: Charge Bliss

The difference between without/with power tracking is tested and illustrated in Figure 22 by simply turning on/off the microgrid controller. The microgrid controller has the ability to seamlessly turn on/off and provide for a "bumpless" transfer of power flow when the controller is switched on/off.

The top figure is the 60Hz measurement of real power flow obtained by the PMU located at the PCC/POI. It can be seen that power fluctuates +/- 100kW around 425kW when the microgrid controller is turned off. As soon the microgrid controller is tuned on and switched to power tracking/stabilization mode, the average power flow fluctuations are diminished as the average power flow stays constant around 425kW. High frequency fluctuations in power flow can still be observed due to the 60Hz sampling rate, bust such power flow fluctuations are not controllable due to the much slower update rate of the inverter power flow demand signal at 1Hz. The conclusion of this test/figure is that power flow can be regulated to desired values (in this case of 425kW and 500kW) if needed. Such step wise change sin desired power flow at the PCC/POI are in-line with ADR 2.0 demand response request and the microgrid controller is able to provide such power tracking.

The bottom figure shows the demand signal sent to the inverter during the actual closed-loop testing of the microgrid controller. Clearly, zero power demand signals are sent when the microgrid controller is turned off, while modulated power to keep the power flow at the PCC constant despite (internal) power demand fluctuations occur within the medical facility.

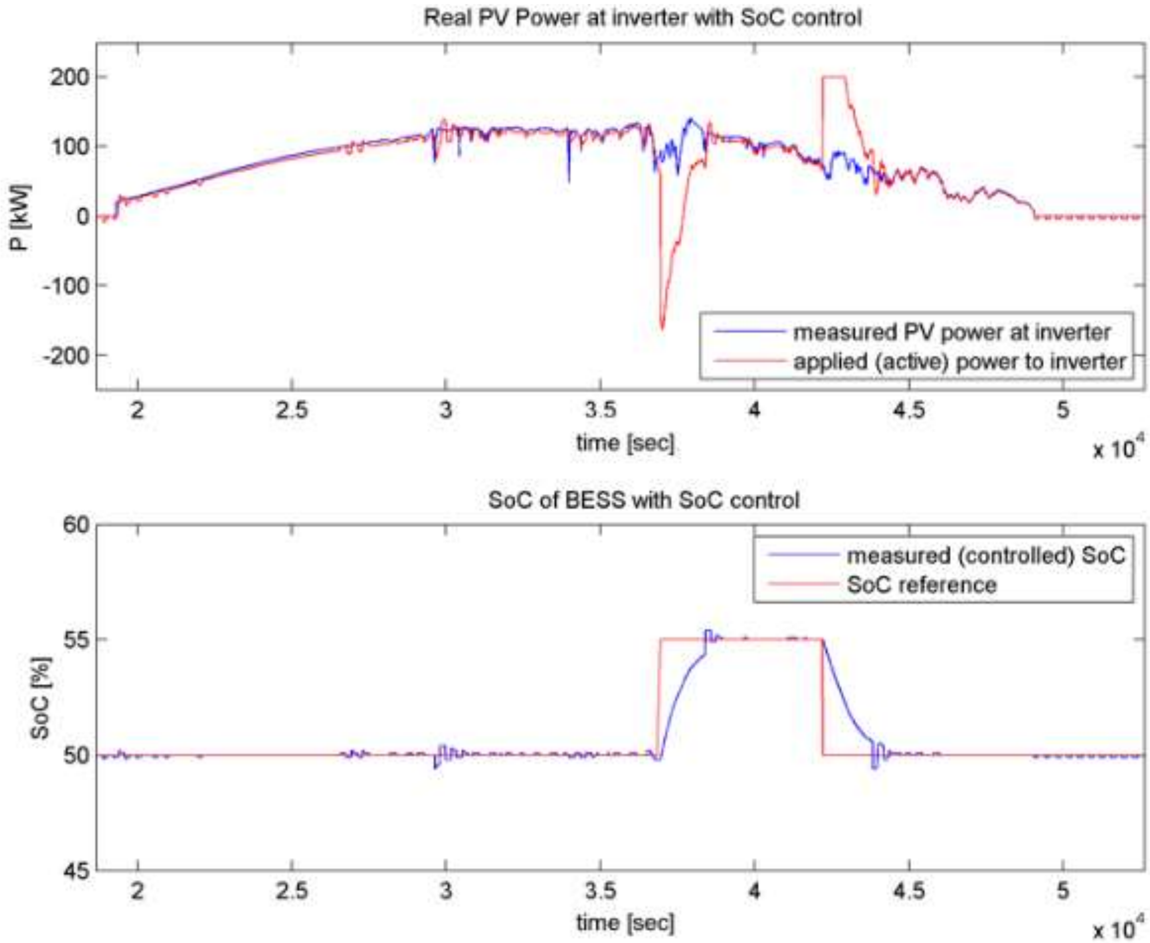
State of Charge Gated Real Power Control

In line with the requirement to manage the SOC of the BESS, SOC-gated closed-loop (feedback) control testing of the microgrid controller is used to demonstrate that the microgrid controller is able to carefully keep the SOC of the battery at any desired level. Variations in the SOC of the BESS occur due to the presence of solar power and its variations during a full day of operation of the three-port PPS inverter. The results of SOC tracking for a full day of operation has been summarized in Figure 23.

Figure 23 demonstrates how well the microgrid controller is able to keep the SOC of the battery at a desired level over a whole day during PV power generation. The figure consists of two plots. The top figure has two lines. The blue line shows the measurement of the PV power as processed by the PPS BIGI inverter during the solar generation part of the day. It can be observed that the solar power peaks to approximately 160kW. The red line shows the active/real power demand computed by the microgrid controller and send to the PPS BIGI250™ inverter.

From this plot it can be concluded that the real power demand signal nicely follows the generated PV power most of the time, but two large deviations from the generated PV power can be observed. These two large deviations coincide with a change in the desired SOC level of the batter depicted in the bottom plot. The bottom plot has also two lines. The red lines now refer to the desired SOC level of the battery. It can be observed that is set to 50 percent but a step wise change is made right after the peak solar generation to go to 55 percent. The blue line is the actual measure SOC as reported by the Battery Management System (BMS). Form this plot it can be concluded that the measured SOC reported by the BMS nicely tracks the desired SOC of 50 percent throughout the times when PV power is changing (ramps up/down), and when the SOC reference is changed stepwise to 55 percent, the microgrid controller modulates the inverter demand signal (AC power output) to ensure the battery reaches the desired SOC of 55 percent as fast as possible.

Figure 23: Battery State of Charge-gated Control

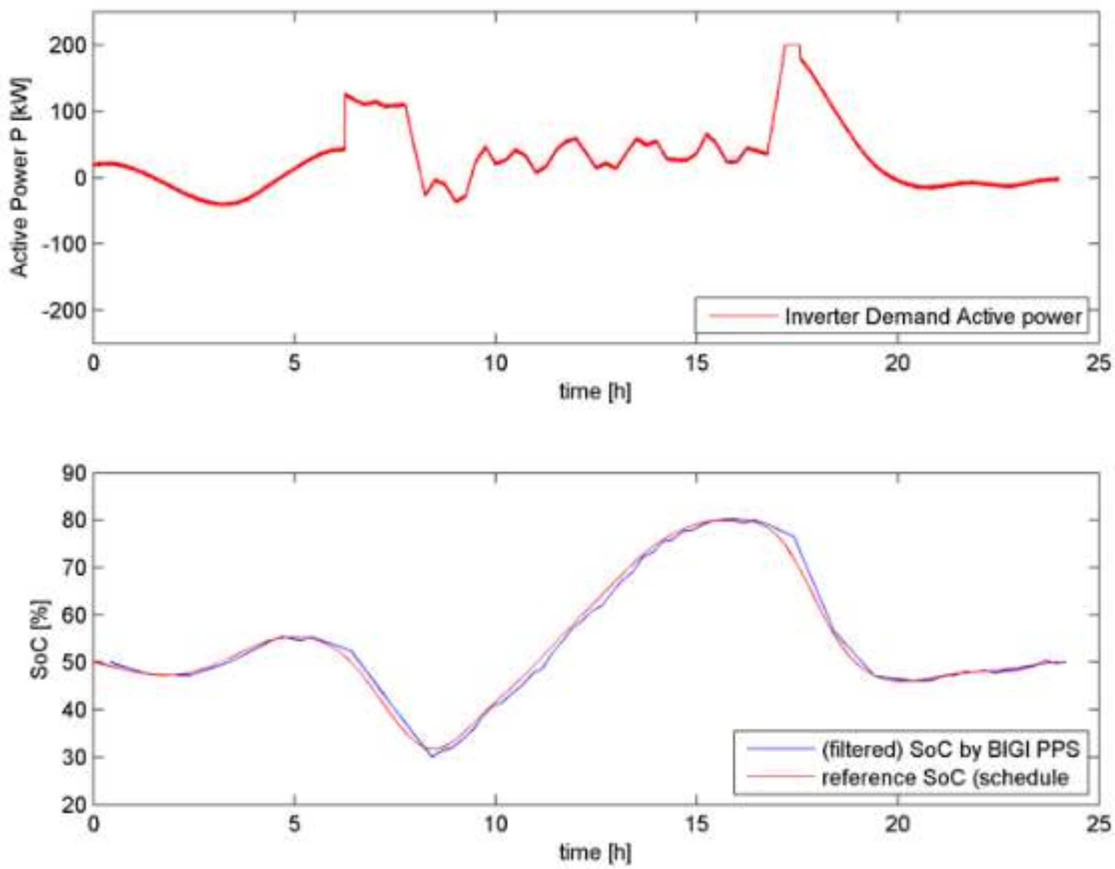


Closed-loop control testing of the SOC-gated microgrid control for SOC management of the battery over a full day, with an additional stepwise change in the SOC reference profile.

Source: Charge Bliss

The SOC tracking has been tested for more complex SOC tracking profiles, optimized to give the best financial benefit of charging/discharging the battery throughout the day. A more complicated SOC profile and the performance of the microgrid controller to be able to track that profile has been summarized in Figure 24.

Figure 24: Battery State of Charge Financial Optimization



Closed-loop control testing of the SOC-gated microgrid control for SOC management of the battery using a SOC reference for a financially optimal battery charging/discharging profile.

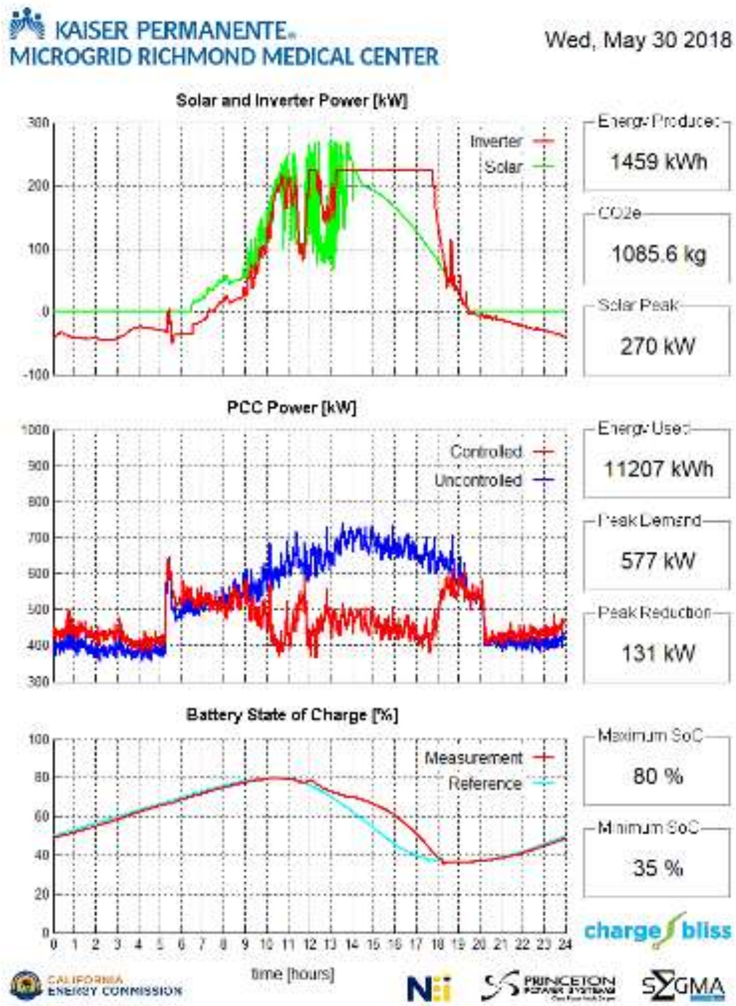
Source: Charge Bliss

Autonomous State of Charge-gated and Demand Limit Real Power Control

In line with the requirement to manage both the SOC of the BESS and limited the real power demand at the PCC/POI, the autonomous SOC-gated and Demand Limit closed-loop (feedback) control testing of the microgrid controller is used. This fully functional microgrid control algorithm now ensures daily battery charging/discharging to minimize TOU pricing, while at the same time limit peak demand at the POI/PCC to reduce demand charge costs. An overview of the combined effect of SOC management and demand limit reduction is shown in Figure 25 that provides a quick overview of all the important performance characteristics for a single day, in this case for May 30, 2018.

The figure illustrates that inverter real real-power output is smoothened (red line, top figure), despite large variations in PV real power production (green line, top figure). At the same time, the inverter produces power to reduce peak demand (middle figure) and manage the SOC (bottom figure) to charge/discharge the battery on a daily schedule.

Figure 25: Facility Demand Regulation



Overview of daily real power PV production and inverter output (top figure), uncontrolled and controlled power demand at the PCC/POI (middle figure) and SOC with its reference (bottom figure).

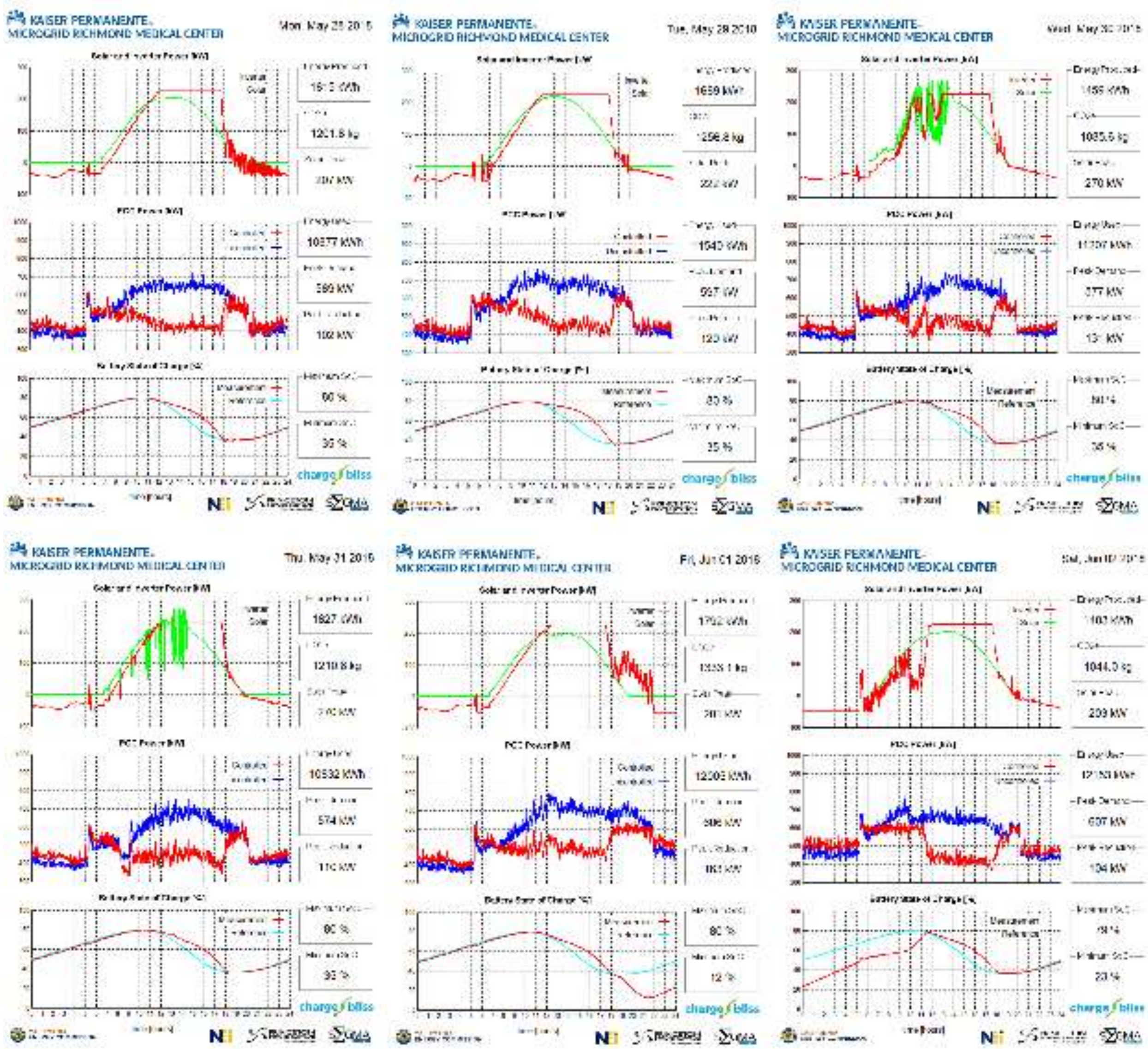
Source: Charge Bliss

Long term evaluation of the performance of the microgrid controller is provided by generation of the data displayed in Figure 25 for every single day that the microgrid controller is running. Such images are available via a web interface and a sample of multi-daily performance is given in Figure 26.

Long-Term Performance

With the microgrid controller running reliably since May 4, 2018, monthly performance data has been gathered. Performance data includes daily solar energy produced, daily demand limit reduction and financial savings due to TOU energy reduction and demand limit reduction. These are reported elsewhere within this report.

Figure 26: Daily System Activity



Overview of multi-daily real power PV production and inverter output (top figure), uncontrolled and controlled power demand at the PCC/POI (middle figure) and SOC with its reference (bottom figure).

Source: Charge Bliss

Discussion

The development of the innovative Charge Bliss controller was directed towards augmenting the value proposition of renewable microgrids. To capture multiple revenue streams, balance and optimize options and opportunities, and have capabilities to meet emerging markets, the controller development had to consider existing as well as future states of site, installed DER, utility, and CAISO requirements and capabilities.

Utility and Independent System Operator Services Emerging Markets and Limitations

Initially, the controller design team sought to participate in a full range of utility and CAISO services. Some of these have relatively well-defined performance standards (demand response), others are being considered and defined currently (reserve capacity) while others are largely hypothetical at this time (virtual power plants). In turn, each has different performance requirements with respect to being non-exporting, exporting, or conditionally exporting systems. While capture of value from energy and power export may be valuable, it may also trigger more complex interconnection processes, testing costs, and even upgrades of distribution systems at project expense.

When a system such as the project described herein is sized to be smaller power capacity than the base load of the host site, export is largely unachievable. Dispatchable resources such as batteries must have greater output capacity than load in addition to meeting minimum sizing criteria for the utility or CAISO. The existing microgrid can produce no greater than 250kW with a base hospital load that never dips below 500kW. Moreover, larger power injection capability would not have been possible without interconnection to the main, panel upgrade, or utility-side of the meter – each of which was either not in the design parameters set by the Energy Commission or would have been prohibitively expensive and disruptive to hospital operations.

Charge Bliss team members met with both PG&E and CAISO representatives to discuss scenarios in which the project could participate in programs other than demand response. In particular, detailed discussions were held about emerging marketplaces, direct service contracting versus the use of intermediaries, and technical requirements. Several learning points emerged:

- Aggregation: Current utility and CAISO processes lean heavily on auction mechanisms for grid services. These require demonstrated technologies, verifiable capacities, compliance with reconciliation processes, acceptance of dynamic price variability, and, in some cases, defined penalties for failure to perform. While the utilities and CAISO do not advise parties whether to align with an aggregator or provide direct, contracted service, it was clear that there is considerable complexity to be considered if a party wishes to integrate directly for grid services.
- Power quality: Given the inertia of the grid as well as the response time of electronic systems, it may be difficult for an individual microgrid to participate in power quality regulation. As was discovered in this particular deployment, the inverter response time is insufficient to regulate frequency and would have limited capacity to impact voltage variation. Nevertheless, the granular data with GPS-stamping provided by the PMU, combined with the rapid, autonomous computing capability of the novel controller may be able to pair with faster power conditioning systems to more effectively regulate frequency and voltage.
- Real/reactive power: While most controllers treat real and reactive power as linked phenomena, the novel controller has been designed to adjust each of these independently. Though power factor, a measure of the balance of the two, is largely a function of utility supply and the nature of site inductive loads, it appears possible to optimize this in the future with systems that are scaled for the purpose and using the new Charge Bliss controller.

- Automated demand response (ADR): All of the California investor-owned utilities have initiated ADR programs wherein a participant agrees to reduce net site load a defined amount (kW), for a minimum period (1-4 hours), for a specific number of events per season or year, and based on the timing of advanced notification (day before, four hours before, one hour before). Payment is generated from the utility to the participant based on the parameters selected and can reach as high as $200/kW.[26] Nonetheless, a number of technological and performance hurdles must be overcome to participate. First, the controller architecture must either take a direct signal from the utility (ADR2.0b) or go through an aggregator. In the latter scenario, the controller must have an alternative method to communicate with the aggregator to offer or decline services as well as perform. Second, the controller must have real-time knowledge of DER state in comparison to the utility "need." While demand response events typically occur on the hottest days of the year between midday and early evening, the precise day and interval may not be predictable. Finally, with the relatively new application of microgrids, it remains to be determined whether the amount of demand response will be considered the total battery discharge (rate, time) or the net reduction below the already "managed" peak demand. Charge Bliss has elected to incorporate ADR 2.0b signaling in the interest of having the most fully integrated, flexible architecture and in the interest of combining multiple microgrids for greater capacity and performance. Incorporation of ADR signaling is imminent as of the writing of this report.

Integration with Power Conditioning System and First Layer Controller

Each power conditioning system has its own embedded and ancillary control architectures. In turn, communication tools, registers, and actions differ. Therefore, the Charge Bliss team had to work with the engineering representatives of Princeton Power Systems® to clearly define each of these elements for the BIGI25™ inverter and the first layer, EMOS™ controller. This process required regular meetings between the Charge Bliss and Princeton Power Systems® teams, validation of communications, exchange and testing of registers, and confirmation of actions. From design through execution, this process required over 12 months.

The Smart Inverter Working Group (SIWG, http://www.cpuc.ca.gov/General.aspx?id=4154) is defining standards for power conditioning and controls system performance. While many of their requirements include the control architecture, this may be that each manufacturer develops independent, fully-embedded solutions or that external controls are combined with embedded tools to meet performance requirements. The Charge Bliss supervisory controller may be integrated with any first-layer control system, assuming that the smart inverter manufacturer can share the needed specifications for communications, registers, and reporting.

In the interest of best overall performance, the project team recommends that standards organizations consider requiring uniformity of systems. This is the norm for ubiquitous for other communications technologies such as Internet, radio, and television. Internet-connected

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[26] Pacific Gas and Electric Company, https://www.pge.com/en_US/business/save-energy-money/energy-management-programs/demand-response-programs/automated-demand-response-incentive/automated-demand-response-incentive.page.

devices must conform to uniform standards to be “plug-and-play” in virtually all environments. Similarly, Charge Bliss suggests that the SIWG, IEEE, and other relevant organizations consider the following approaches to standardize inverter and microgrid control systems to foster more flexible, effective, consistent, and reliable combinations of DER:

- Communications: Standard for communication protocols, bandwidth requirements, and message prioritization will facilitate integrations.
- Registers: Standardized mapping of registers should be considered to ensure similar capabilities and methods to integrate.
- Directable functions: Standard functions such as real/reactive power, voltage, frequency, and others must not only be available but directly controllable through external signals.
- Response times: Inverters and embedded controls must have minimum speed and reliability of electrical response to meet industry standards for power absorption or delivery.

Remaining Pathway for Commercialization

The Charge Bliss controller can be implemented at other sites as it stands today. However, to provide this to users outside of the extended Charge Bliss team, additional development is required and is underway. A basic visualization tool has been developed, but the team is looking to enhance the user experience with a more robust graphical user interface (GUI). During the ensuing 3-6 months, the team plans to develop a secure, configurable interface that will allow designated users to customize displays for the purposes that they find most useful. For example, a site might wish to have one display showing CO_2 emission averted, equivalent number of trees planted, or the number of cars that would be taken off of the road to equal while operations personnel might want to see power quality, battery state of charge, energy production and peak load. In parallel, the team is developing a more comprehensive “state machine” that will allow the controller to understand all relevant conditions in real-time, make dynamic system adjustments, and even self-correct errors. Thirdly, the team is exploring methods to coordinate multiple sites to form a virtual power plant and the team expects to have a commercially-available system for sale or license by early 2019.

CHAPTER 5: Results and Lessons Learned

The application of renewable energy microgrid technologies and a novel controller to a healthcare facility has demonstrated a pathway for the rollout of these systems to hospitals and other critical facilities across California and the nation. While challenges persist and suggest that only expert teams may be qualified to design microgrids for healthcare, the broader accomplishments and lessons are applicable to commercial buildings in general and critical infrastructure in specific.

Project Achievements

The Charge Bliss microgrid at the Kaiser Permanente healthcare facility in Richmond, California realized several achievements and breakthroughs. As the first installation of its kind in a California hospital and only one of approximately four in the nation, this microgrid opened new opportunities for the application of renewable energy technologies in venues previously thought to be excluded from these options.

Final Project Technical Specifications

Systems Details

The Charge Bliss team installed 250kW of high efficiency, rooftop canopy, SunPower® solar as shown in Figure 27 and centralized in one of the two inverter DC ports. In addition, the team built ground-floor level, adjoining, block wall rooms to house 1MWh/250kW of Samsung®SDI™ batteries, a three-port (two DC, one AC) Princeton Power Systems® BIGI250™ 250kW inverter, fire-suppression and HVAC, an extensive network of PMUs for monitoring, high-speed internet communications, OSIsoft® Pi™ data management tools, and a novel control architecture embedded in an onsite hardened PC as well as under remote control.

Operational Objectives

The installation intended to achieve the following operational objectives:

- Produce 395,000kWh/year of solar energy (achieved)
- Derive 75 percent or greater of energy stored in battery from site solar production (achieved)
- Time-shift solar production to capture optimal time-of-use value (achieved)
- Arbitrage early morning utility energy for use during highest time-of-use cost (achieved)
- Reduce peak site load by 100-150kW (achieved)
- Island hospital emergency power (achieved)
- Establish CAISO collaboration (pending or not achievable)

- Participate in automated demand response (pending or not achievable)

Innovations

- Novel controller*:* The team designed, engineered, tested, implemented and studied a novel controller demonstrating the operational objectives shown above. Automated demand response is under development and is expected within 1-2 months.
- Interconnection to a California hospital: The team interconnected the first renewable energy microgrid to a hospital in the State of California.
- Interconnection to hospital emergency power*:* The team pioneered the first interconnection of a supplemental energy system other than diesel power to the emergency power of a California hospital.
- Islanding: The team demonstrated the first-ever capability of islanding an emergency power branch of a California hospital for at least three hours.
- Pathway for dissemination to other hospitals*:* The team demonstrated the methods necessary to overcome regulatory, engineering, construction, and performance barriers to achieve value for California hospitals. This has resulted in previously skeptical systems seeking engagement for development of systems.

Systems Financing, Ownership, and Tax Implications

The rapidly changing landscape of incentives and rebates may have substantial implications for the development of renewable microgrids. Whether these value streams may be captured depends on the entity that owns the systems, the source of monies used for purchase, the nature and performances of systems, and complex tax regulations.

Safe Harbor Statement

The information provided in this section and throughout this report should not be construed as financial advice nor definitive tax interpretation. Readers must consult their own tax, financial, and legal consultants before choosing any course of action and should not, under any circumstances, rely on the observations in this report for the purposes of related decision-making. Observations, opinions, and recommendations contained within this report, whether explicit or implied, should only be considered the views of the project team members and should not be considered definitive or conclusive.

Ownership Entity Type

Currently, solar microgrids may qualify for up to a 30 percent federal income tax credit and depreciation of 85 percent of project value in year 1. The tax credits are scheduled to sunset over the next several years, though this is subject to modification by Congress. To capture tax incentives, the claimant must be a taxable entity, have sufficient income and tax burden to set against the incentives, and comply with the technical requirements for system performance. Non-profit or not-for-profit entities are barred from receiving direct benefits from tax incentives. As virtually all hospitals in California are non-profit entities, they are prohibited from claiming these incentives. Therefore, hospitals may need to consider third-party investment to lower the total cost of project development and render services affordable and cost-effective.

Self-generation incentive program, advanced energy storage (SGIP-AES) is a California program that incentivizes the deployment of batteries. Incentive amounts decline over time and are subject to reservation and availability. In addition, incentives may only be claimed if the owner paid for battery systems with resources other than grants. For example, batteries funded by EPIC program grant funding may not be used to claim SGIP-AES incentives.

Energy Commission Grants

Based on the interpretations provided to the Charge Bliss grant team from expert accountants and tax attorneys, funds provided from the Energy Commission's EPIC program as reimbursement for project expenses may have complex tax options and implications. Federal tax law appears to allow such grant funding to be treated as income and then recognized for calculation of tax incentives OR to not be treated as income and to not be included for the purposes of tax equity calculation. By way of example, consider a scenario in which $1million of grant funding is applied to a $3 million renewable energy project design and construction. A variety of options can be considered, but two more likely possibilities include the following:

- Scenario 1: The project team treats the grant funding as income and claims a $3 million basis for calculation of tax incentives. Based on current incentives, the project owner may receive up to $900,000 in federal tax credits and $2.55 million in depreciation.
- Scenario 2: The project treats the grant funding not as income and reduces the basis for tax credit calculation to $2 million. Based on current incentives, the project owner may receive up to $600,000 in federal tax credits and $1.7 million in depreciation.

California tax rules appear to be different than federal rules. Though there are no state tax credits, depreciation may be allowable. In general, systems that are eligible for state-level depreciation will use the same basis used for federal tax calculation but will schedule it over 5 years.

How these complex matters are addressed is subject to a number of variables including, but not limited to, the type of taxable entity (S-corporation, C-corporation, limited liability corporation, limited liability partnership, and others), internal legal structures, income, tax brackets, and the legal and tax advice from experienced professionals.

Alternative Financing Resources

For-profit, commercial entities may qualify for a variety of creative funding resources. Property Assessed Clean Energy (PACE) funding, allows such entities to qualify for bank financing of renewable energy projects and pay through their property tax bill. This "off-balance sheet" method may be attractive as a means to reduce visible debt burden. Conventional debt funding may allow for-profits to avoid significant cash expenditure but receive large incentives and rebates early.

Other funding mechanisms are potentially available to both for-profit and non-profit entities. Some utilities allow for “on-bill” finance of renewable energy projects, much like the PACE mechanism. Federal programs through the Department of Energy, Department of Defense, and the Department of Agriculture fund certain regions, project types, or end-users including both for profit and non-profit entities.

Non-profits may take advantage of special programs designed for this sector. Municipalities, for example, may obtain low-interest loans for energy and other capital projects through the Energy Commission, private lenders, and federal programs. This could apply to hospitals owned by municipal entities as well. To the project team’s knowledge, there are no hospital-specific renewable energy finance mechanisms.

Final Project Technical Performance Specifications

Measurement and Verification

Energy Production

Total system energy production is shown in Table 4. The months of November 2017 and January 2018 are notable for low productivity due to the ongoing issues of system shutdowns, need for component replacements, and systems tuning.

Table 4: Energy Production

	Nov. 2017	Dec. 2018	Jan. 2018	Feb. 2018	Mar. 2018	Apr. 2018	May 2018	Jun. 2018	Jul. 2018	Aug. 2018
kWh	540	20,751	4,879	11,361	18,494	12,031	41,824	35,618	38,711	17,420*
TOTAL: 184,209 kWh; Annualized 232,685 kWh										

***through August 15, 2018**

Source: Charge Bliss

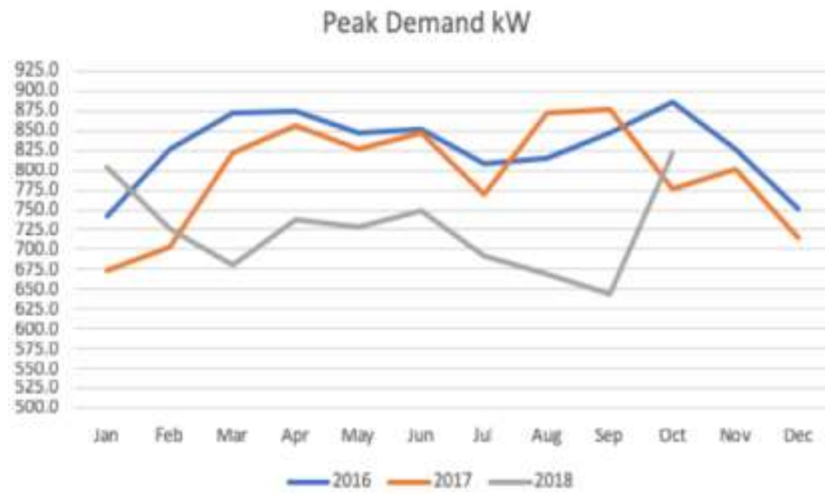
Demand Reduction

Demand reduction has varied by month and continues to be adjusted through tuning of systems. As noted in Figure 27, when peak demand is compared to the same month prior to project institution, reductions vary from a maximum of 204 kW less than baseline to 130 kW more than baseline. The months in which higher peak demands were experienced by the hospital corresponded to episodes of hospital chiller systems malfunctions. Note the relatively consistent load patterns in 2016 and 2017 with progressive, sustained reductions since project commissioning in November 2017.

Cost Savings

Cost savings are determined using a similar method to demand: comparing current costs to baseline costs the year prior to system commissioning. As of now, the hospital is projected to save over 15 percent of its baseline utility cost. Thus far, 15 percent of savings is the result of

Figure 27: Demand Profiles



Graph of peak demand by month prior to and after November 1, 2017 commissioning of microgrid. Note significant and sustained reduction of demand after system tuning.

Source: Charge Bliss

peak demand reduction, another 10 percent may be attributed to decreased energy consumption, and the remainder is accounted for by the value of time shifted solar and arbitrage of utility energy.

Using the calculator for averted CO_2 emissions per kWh, 167 metric tons of CO_2 production has been avoided from the time of system commissioning through the end of June 2018. On an annualized basis, this suggests that the hospital microgrid will reduce CO_2 emissions by over 250 metric tons.

System Uptime

Once system stability was established in May 2018, system uptime began to approach acceptable levels. During the month of June 2018 there was virtually no downtime while in July 2018 uptime was 90 percent. The lone period of system downtime in July was due to an unspecified battery management system issue that is still undergoing analysis by the Samsung® team. Operation has been continuous throughout August for 100 percent uptime. The goal for uptime going forward is greater than 98 percent.

Islanding Reports

The successful test described in the islanding procedures section took place on Tuesday, May 22, 2018 with representatives from the Energy Commission, Charge Bliss, Kaiser Permanente, ASCO, and Contech-CA. Because of limitations on allowable time for Kaiser Permanente to operate backup generators as required by OSHPD regulations and at the direction of the Energy Commission representative, Dr. Qing Tian, the test was conducted for 90 minutes. Test objectives included:

- Synchronization: Demonstrate ability to synchronize with or create dominant waveform.

- Resynchronize: Demonstrate ability to resynchronize with utility waveform.
- Duration: Demonstrate capacity to island for 3 hours or more.
- Stability: Demonstrate adequate power quality to preserve continuity of services.

Testing Preparation

Per Rule 21, the inverter will immediately shut off when there is a loss of the utility. It was questioned if this did in fact occur since the breaker on the inverter did not go into a tripped status, but after further review, it was determined that the system did, in fact, shut-off before restarting to island. The breaker did not go into a tripped status because the inverter was being powered with the 24V backup battery in the EMOS. There is an additional level of safety built into the system to prevent the inverter from back-feeding the grid if the utility is lost that relies on signal wiring. This is a standard three-wire setup that consists of a Common, Normally Open, and Normally Closed. Through this wiring, the inverter determines if the system is mechanically disconnected from the grid. The original design called for this wiring to be tied into the Manual Transfer Switch. However, after the first islanding test, the team determined that this was not the best location to receive this signal. At that location the system could, under a specific set of circumstances, be energized and potentially back-feed the grid during a loss of utility power. After further review, it was determined this signal wiring should be tied directly to the 400A breaker located in panel PPS1 that is tied to the grid. At the time of the test, this wiring had not been fully tested. It has since been confirmed by Princeton Power that this is wired correctly and there is no potential for the system to back-feed the grid during an outage.

Test Conduct

The microgrid was successfully operated in islanding mode, and returned to grid-tied operation following the steps below:

1. Using Kirk Key switching arrangement, load was transferred to energize the manual transfer switch (MTS).

Figure 28: Microgrid Output Measured at Manual Transfer Switch

Source: Charge Bliss

2. On operation of the MTS and automatic transfer switch (ATS) – 1 (life safety branch) the microgrid powered the life safety branch.

Figure 29: Manual Transfer Switch Status Prior to Transfer of Power Back to Grid-tied

Source: Charge Bliss

3. Power quality was monitored during test, and on return to normal power, the microgrid continued to operate in grid tied mode.

Figure 30: Automatic Transfer Switch-1 Life Safety Returned to Normal Operation

Source: Charge Bliss

The team determined that the battery state of charge, rate of discharge to support the life safety branch, and the overarching stability of power delivery suggested that the system could island far beyond the required three hours.

The first attempt to test the islanding was unsuccessful. At the time of testing, the EMOS™ controller was missing a 24-volt backup battery from the manufacturer. This battery keeps the operating system powered during a utility outage. The first test also revealed a second, more complex challenge. Similar to the ATS, the MTS also has two possible sources for power- the backup diesel generators or the microgrid. The nature of this power input design did not allow unrestricted MTS connection and disconnection. After discussions with the manufacturer of the MTS a design modification was installed to facilitate the ability to return to the normal state of the switch without energizing the normal side.

A subsequent islanding test revealed two remaining issues. First the project team discovered that even though the EMOS remained energized, the controls inside the inverter did not due to the lack of appropriate wiring between the EMOS™ backup battery and the inverter. The second issue arose from a complexity related to inverter function and utility rules. Princeton Power System's inverter (BIGI 250™) is designed to function in parallel with the grid or to be grid-forming. However, CPUC Rule 21 does not allow an immediate switchover between the two states. Per Rule 21, a generation system must immediately disconnect from the grid if the utility signal is lost and this functionality is embedded in the BIGI250™. For the BIGI250™ to restart in grid-forming mode it has a safety measure in place to guarantee that it is completely disconnected from the grid consisting of signal wiring connected between the BIGI250™ and a breaker connected to the grid. At the time of the first test, this wiring was installed per the original design. During the second test it was discovered that the original design did not meet the specific criteria needed to guarantee the BIGI250™ was fully disconnected from the grid. After reviewing the requirements, it was determined that the best location to receive this signal would be at the Main Service Breaker (MSB) located in panel PPS1. This required the installation of a modification to the MSB. After installing the modification, the point of connection for the signal wiring was rewired and a third test was scheduled.

Before the third test was performed, extensive, additional validations were performed on all aspects of the grid-forming functions of the BIGI250™. So as not to disrupt the hospital, this testing was performed by islanding only the battery room itself. Once this was successfully demonstrated, the hospital permitted a third, successful islanding test of the life safety branch. The microgrid supported essential functions without interruption or disruption of services for over 3 hours and retained sufficient energy to carry forward for several additional hours. However, as the target time was met, and the hospital faces potential penalties for the time they island, the test was concluded. During the test, voltage, frequency, and power quality were maintained within the appropriate standards per code. There have not been any unanticipated outages since the successful islanding test to take advantage of microgrid capabilities. The team will discuss periodic testing and validation to ensure microgrid capabilities over time.

Multiple testing episodes were required to validate islanding capacity. While the original Energy Commission objectives were to demonstrate automatic islanding, OSHPD would not permit this and required that manual transfer be used. In this manner, testing involves an individual moving the transfer switch into the position to serve the emergency load, allowing the microgrid to operate, then opening the automatic transfer switch to isolate from the grid. This recapitulates the scenario in which utility service is lost. First the ATS opens and the backup diesel generator operates. In the future, a site operations team member may then move the MTS to provide service to the emergency power branch and decrease or even eliminate the need for diesel operation.

This aspect proved to be one of the most challenging from both installation and operations viewpoints. Although the first attempts to island were initiated in November and December of 2017, iterative discussions and site visits from Princeton Power System® revealed a number of matters that remained to be addressed. These included the need for a backup battery for the EMOS™ that had not been included originally, replacement of the EMOS™, correction of wiring, and inverter adjustments. Similarly, islanding testing required the presence of the construction leadership team, electricians, engineers, site personnel, OSHPD, and others to troubleshoot and identify the remaining matters.

Ultimately, successful islanding was demonstrated, and the system proved capable of sustaining operations on the specific emergency power branch indefinitely.

ATS Opening, Grid Outages

To the project team's knowledge, there have been zero, non-discretionary episodes of ATS opening or grid outages affecting the hospital during the microgrid operational period. However, this cannot be attributed to microgrid function for several reasons. First, at the behest of all parties, microgrid islanding capability was limited to emergency power. As such, utility supply instability or outage cannot be ameliorated and microgrid performance will only impact the continuity of life safety circuit performance. Second, grid inertia far exceeds the capacity of the microgrid to meaningfully impact frequency and it remains unclear whether voltage regulation is possible. Thus, utility voltage sags that may trigger ATS opening are unlikely to be impacted by microgrid performance. Third, there appear to not have been any significant utility outages in the immediate region despite high demand circumstances, particularly during the summer.

Project Changes, Limitations, and Residual Barriers

Changes

Host site

The original project was slated for a hospital located within the same county. After the facility in question elected to decline to participate, the Charge Bliss team was afforded the opportunity by the Energy Commission to seek an alternative host site. The Kaiser Permanente Health System agreed to host the project at the Richmond, California site.

Battery/Power Conditioning System Enclosure

The proposal to the Energy Commission included the use of a pre-engineered, integrated, and installed battery + power conditioning system, controls, HVAC, and fire suppression within a shipping container. The design intent was to drop-ship the system to the host site for immediate connection to the solar array and interconnection to the site electrical systems. However, the lack of available space led to identification of a location inside the first floor of the parking structure adjoining the hospital central utility plant. Unfortunately, the dimensions of standard shipping containers precluded their use. The pre-containerized, integrated systems were disaggregated and integrated by the Charge Bliss team on site and within new block wall rooms built exclusively for project purposes.

Limitations

Grid Services (Automated Demand Response Integration, Changing Services Landscape)

Because of the ratio of system size and discharge capacity to the base load of the site, there is no opportunity for power export to the utility. Indeed, this very fact proved to be an advantage for purposes of interconnection with the utility and precluded the need for an interconnection study of utility systems upgrades. In discussions with utility and CAISO representatives, it became apparent that microgrid dispatchable resources would need to have a ratio of greater than 1 to base load to qualify to participate in many of the grid services. Moreover, other than automated demand response (ADR) other services remain in the germinal stages of development. The marketplaces for capacity reserve, frequency and voltage regulation, and real time pricing are evolving rapidly and standards have yet to be fully agreed on by all stakeholders.

ADR remains a distinct option and the capability is being actively pursued through the Charge Bliss microgrid controller. The team expects to have incorporated the bidirectional signaling capacity within the next two months and to then undergo validation testing. Charge Bliss will re-engage with the utility to determine steps for direct contracting or participating in the next Demand Response Auction Mechanism (DRAM).

Power Quality Regulation (Power Conditioning System Speed)

Though the novel microgrid controller devised through this project has the capability to adjust real and reactive power independently in addition to responding to variations in frequency and voltage, microgrid systems limitations combined with significant grid inertia constrain effectiveness in power quality regulation. Specifically, the response times, ramp rates, and resulting lag time of specified hardware in the current microgrid certainly appear to exclude frequency regulation, particularly when the degree of grid inertia is considered compared to microgrid system sizing. Voltage regulation remains a possibility, but is likely best tested in the islanded circumstance. Future applications will need to consider the use of PCS with faster response times and larger capacities to meaningfully impact power quality.

Residual barriers+

Cost versus Yield of Systems

The microgrid project cost, in total, exceeded $4.8 million, though a considerable portion was directed towards the design, engineering, testing, implementation, and study of the novel microgrid controller. Nevertheless, the cost of the rooftop canopy solar (approximately $4/watt installed or $1 million) and the battery, inverter, controls, and ancillary systems (approximately $1.5 million) as well as the design, engineering, permitting, interconnection, OSHPD approval, and other processes (approximately $1.5M) are unlikely to comport with beneficial financial incomes for a private investor. At the rate of total savings estimated for the facility, after consideration of net cost reductions by tax equity and other incentives, a model of 50 percent shared savings would require upwards of five years or more to achieve gross recapture of cost.

Notably, in the interval since the project was first proposed, there have been significant reductions in battery + PCS costs, engineering of far smaller footprint systems that do not require special containerization, and design processes have been defined that will streamline new project developments and related costs. When these changes are considered, the team estimates that the same system today would cost perhaps as little as 50 percent of the Richmond installation, particularly if ground floor parking lot canopy solar and pre-engineered battery/inverter systems can be used. This will reduce cost recapture times to potentially outperform solar only installations. Microgrid systems costs are declining over time and dependent upon tax and other incentives, system sizing, component types, ownership structure, and financial arrangements between system owner and user. Systems such as the one installed at the Richmond facility may expect to reach cost recapture in as little as two to three years.

Hospitals and investors alike are focused upon financial value as the principal metric. While less well-defined potential values of renewable energy microgrids such as resiliency, power quality regulation, sustainability, and others generate discussion and variable expressions of interest, these are generally not given significant consideration. Indeed, across the spectrum of commercial enterprises including hospitals, even those with publicly-expressed commitments to sustainability and renewable energy will virtually uniformly express that such efforts remain either purely symbolic or at least significantly behind financial considerations. This suggests one of three pathways by which renewable energy microgrids will achieve broad commercial viability: 1). Decreasing cost and increasing value streams; 2). Legal directives to achieve sustainability targets; or 3). A combination of 1&2.

Investor-Owned Utilities Reconciliation

Despite the design of the microgrid as a zero export system wherein the facility would consume all onsite generation and not feed power back to the utility, the serving utility treats such systems as part of their net energy metering (NEM) portfolio. Though this was not made explicit at the outset, utility reconciliation processes withhold a portion of charges for energy consumption during each 12-month period and then bill for the remainder in the thirteenth month. As a consequence, all stakeholders mistakenly interpreted utility bill data to suggest that microgrid-related savings were substantially higher until the November 2018 bill revealed that significant charges had been withheld by the utility. This renders monthly cost reconciliation for savings largely unachievable and, therefore, creates barriers to funding mechanisms such as shared savings models. Visual representation of the differences in financial outcomes is shown in Figure 31. The left panel demonstrates the graph of costs as shown on monthly facility bills while the right represents adjusted costs after the annual utility reconciliation:

Figure 31: Impact of Utility Reconciliation Process

Monthly utility costs as shown on monthly facility bills — **Monthly utility costs after annual reconciliation**

California Independent System Operator/California Public Utilities Commission Rules

Although the utilities, CAISO, and CPUC have recognized the importance of emerging energy technologies and have created appropriately targeted regulations for renewable microgrids, a number of barriers persist. First, Rule 21 constraints have yet to address how to factor microgrid designs when determining whether interconnection studies are required. It remains an open question whether the amount of site-based generation above contemporaneous peak load should be a defining criteria or whether the capacity of the co-located battery storage should be considered as a reliable resource to prevent export above an acceptable threshold. In addition, there are technological complexities such as incorporation of signaling and communications architectures (ADR2.0b) that either must be embedded within the microgrid or be administered by another party that specializes in grid services. Finally, the CAISO has strict needs for reliable, consistent, and predictable systems performance that may exceed what current generation systems may be able to do. Moreover, since pricing for services is fluid and, in many cases, entirely indeterminate, developers and end-users alike are uncertain whether grid services are dependable revenue streams for which system should be designed or merely a future state that should be ignored in the short term or until clear standards and values are set.

Optimal Facilities and Systems

While California hospitals share many design elements due to the declarative standards of the oversight agency, OSHPD, there is considerable variability in facility sizing and energy requirements. Larger, urban centers could theoretically realize greater benefits from renewable energy microgrids, but have physical and operational barriers that limit applicability. First, these facilities tend to have too little physical space for energy generation systems. For example, a high-rise facility that uses parking structures may have very little room for a solar array, yet have large power requirements. In such scenarios, the low ratio of solar to energy consumption and load is likely to eliminate the value of a microgrid. Second, older electrical systems that may have inadequate capacity to interconnect generation and storage resources will limit applicability. Third, the more-costly nature of canopy solar, due to the design, construction and maintenance costs of the steel structures, renders solar deployments in many such scenarios too expensive. Therefore, the experience at the Richmond facility suggests that rural healthcare centers (hospitals, clinics, specialized nursing facilities) and select suburban facilities with adequate space for physical systems may realize the greatest benefit.

Impending commercial energy and demand tariff changes will also change the landscape for renewable energy microgrids. The California Public Utilities Commission approved a change in the rate structures of the Investor-Owned utilities to shift the highest peak period from early afternoon to evening. Consequently, the value of solar energy generation as an offset for utility energy will decline, unless it is matched with energy storage and redeployment during the more-costly evening hours. In addition, the highest peak demand cost period will also be in the evening- thus providing a second incentive to redeploy solar generation in the evening. Hospitals will generally be better candidates in this regard as they have relatively level, though high, power demand during the day that wanes during the early evening. Healthcare facilities therefore stand to reap greater benefits from the demand reduction capabilities of microgrids.

System sizing is a balance of the hierarchy of purposes (financial savings, resiliency, sustainability, other) and the limitations of space available, electrical system capacity, regulatory constraints, and utility interconnection limitations. However, one may surmise that the largest possible solar generation achievable will generally be best. Because of the tariff changes discussed above, it will prove most valuable to store and redeploy the vast majority of this power during the early evening. This suggests that battery systems will need to have at least 5-fold the AC rated output capacity of the solar for optimal performance. For example, a facility that can accommodate one megawatt (1MW DC) of solar and that has a peak evening facility load greater than 1MW, may be best served by a 5 megawatt-hour (5MWh) battery array or larger. Optimization of sizing will depend upon whether the facility is best served by having backup energy storage capacity, demand reduction, demand response, or a combination of features.

Despite these observations, it should be stated that the value of microgrids is incremental and, therefore, potentially applicable in a broader set of environments. While the system at the Richmond facility may be construed as “small” with respect to facility energy consumption and load, it has nonetheless demonstrated the ability to regulate demand cost and reduce energy cost commensurate to its sizing. Arguably, the limiting factor is not system sizing per se, but that system cost is non-incremental. Design, engineering, permitting, interconnection, and even installation costs decline as a percentage of overall project expense as projects become larger. Therefore, small projects may be technically capable of having an incremental impact upon site energy consumption and load, but may not be financially viable in the final analysis due to the “floor” for many of the fixed costs. On these bases, Charge Bliss observes that the greatest value for all parties will, for the short term, reside with systems that combine greater than 500 kW of solar and two or more MWh of battery.

CHAPTER 6: Evaluation of Project Benefits

Benefits to the Hospital, Community, Ratepayers, and California

Replicable models

One of the most important benefits of the project to communities, ratepayers and the State of California is the realization of replicable processes for the design, engineering, permitting, interconnection, commissioning, and operation of renewable microgrids for hospitals. Having not only demonstrated success in performance, but also recognizing challenges, pitfalls, and barriers, the project illuminates a path for hospitals, developers, investors, and regulators to collaborate to expand the role and significance of renewable energy microgrids for hospitals in California.

Hospital Engagement

While hospitals were virtually uniformly skeptical that such a project was achievable prior to its completion, many have come to realize the applicability and value of renewable energy microgrids. Indeed, Kaiser Permanente issued an RFP and selected groups to develop microgrids in both Northern and Southern California and two other major health systems have engaged with Charge Bliss to explore deployments at flagship facilities. Critical in this process has been Charge Bliss' ability to engage with and receive expeditious approval from OSHPD, build safely and securely on hospital facilities, and interconnect with both normal and emergency power systems. Now that robust data demonstrates systems safety, effectiveness, operational reliability, and positive public response, the team believes that hospital engagement will increase.

Design and Engineering Process

The Charge Bliss team provided a roadmap for microgrid design and engineering in the hospital environment. Respectful of regulatory constraints and mindful of the need to engage critical stakeholders, Charge Bliss demonstrated how to use hospital characteristics (load, utility bills, physical space, electrical systems, operational goals) to quickly model what is potentially achievable. These designs can be rapidly refined by an expert team to define "feasibility" and then "hard engineering" may proceed.

Utility Collaboration

Early engagement of the serving utility was shown to speed the development process. Through identification of the Rule 21 team, clarification of the specific utility rules, mutual decision about defining non-export, export, or conditional export label of the design, and efficient provision of documentation can be done in an overlapping fashion with the other regulatory evaluations. In this fashion, teams may limit risks inherent in interconnection and define early in the process whether site, regional distribution network, or other considerations might cause undue delay or cost.

Office of Statewide Health Planning and Development Collaboration

In the specialized environment of healthcare in California, it is essential that the development team not only recognize the regulatory oversight of OSHPD, but engage the appropriate personnel as early as possible through experienced and knowledgeable team members. Charge Bliss identified that team experience in OSHPD-related engineering, administrative processes, review and appeals, and costing can save considerable lost time and cost. Moreover, this has provided OSHPD for a roadmap for the consideration of future microgrids and for the development of joint standards with the Energy Commission. As a direct consequence of this project, Principal Investigator David Bliss, MD was appointed to the OSHPD Hospital Building Safety Board and, recently, appointed the Chair of the Energy Committee.

Community

Increased Hospital Resources for Healthcare

Because hospitals in California face increasingly challenging fiscal margins, rising costs, and declining revenue, options to reduce operational costs are paramount. Few new hospitals are being built or expanded and many existing facilities are at risk of closing. Many communities already face significant shortages of beds, clinicians, and services. The demonstrated ability of the healthcare microgrid to significantly reduce energy cost, particularly when it is scaled to the size of larger facilities in the State, could contribute substantial discretionary funds to reinvest in healthcare services. For example, the annual savings at a large hospital could be sufficient to start and maintain a major new clinical initiative each year.

Improved Power Availability

Hospitals have one of the most intensive power requirements, indexed to floor space, of any commercial building. The option to supply a significant percentage of this need from site based renewable energy generation and to dispatch the energy when need is greatest and power the most expensive means that additional power will be available for regional rate payers. Demand response, in particular, has the capability to forestall outages and allow continued services to vulnerable populations during the increasing number of heat emergencies.

Community Safety

The ability to sustain healthcare operations despite grid outages is a compelling development to invest in community safety. As regulations advance and allow renewable systems to become the dominant producer of backup power, one may imagine scenarios in which hospital operations could continue indefinitely regardless of regional or systemic failures in the energy supply system. Given the critical nature of healthcare services, especially during catastrophic events, this resilience and reliability is an unmeasurable benefit to ratepayers.

System Impacts

Energy Consumption Reduction

The system, as designed, should produce approximately 395,000 kWh of renewable energy annually. Although current annualized performance is approximately 233,000 kWh, this reflects prolonged system downtime during extended tuning, modifications, and upgrades. Since the system has achieved stability, it is on-track to perform as estimated.

Demand Reduction

The microgrid has the capability to discharge from the batteries at up to 220 kW for four hours. However, in the interest of maintaining best long term battery performance, preserving some stored energy for emergencies, and mitigating risks to electrical systems, the team has targeted 100-125 kW of consistent demand reduction. To date, systems have delivered variable results, though significant variations in performance can be attributed to ongoing systems tuning, periods of downtime, and variations in site load. Nevertheless, the evolving pattern suggests that the target reduction threshold is achievable on a consistent basis and may be able to be extended to 150-175kW.

Demand Response Capability

Pending the onboarding of automated demand response capability, system capacity should allow for up to 200 kW demand response for four hours. However, to attain this level, power must be held in reserve and not used for demand management. One of the unique features of the novel microgrid controller is its ability to consider multiple sources of value and calculate whether real-time or delayed energy usage is valuable. Because demand response and demand management can prove to be competitive during summer months, additional calculation algorithms will be included with ADR capabilities to achieve optimal results.

Greenhouse Gas Reduction

Estimated annual reduction of CO_2 emissions, based on solar productivity, are 250 metric tons. Additionally, the project team suggests that energy arbitrage may further decrease CO_2 emissions. By drawing energy during the late night and early morning hours when the majority of the Western grid's energy is derived from hydroelectric power, then using it during the peak utility daytime demand periods that require operation of fossil fuel peaker plants, another 292,000kWh/year of generation may be averted. The consequent decrease in CO_2 emissions of approximately 314 additional metric tons may achieve a total reduction of over 739 metric tons of CO_2/year.

CHAPTER 7:
Technology Transfer Activities

Opening Ceremony

On July 6, 2018, Charge Bliss, Kaiser Permanente, and the Energy Commission held an official opening ceremony for the microgrid at the Richmond Facility. The event was covered by the local CBS television station, digital media companies, and the media teams from all three project hosts. Dignitaries from government, healthcare, the community, and advocacy groups attended and were presented project information as well as tours of the facilities.

Technological Deep Dive

More than 30 in-person and several online participants convened to hear a detailed presentation of microgrid performance at the "technological deep dive" held at the Kaiser Permanente facility following the opening ceremony. Key project designers, engineers, contractors, and leadership provided data regarding energy production, arbitrage, demand reduction, and barriers overcome and still remaining. Attendees included CAISO, the CPUC, PG&E, Energy Commission, Kaiser Permanente, Stone Edge Farm engineering, Princeton Power Systems®, Charge Bliss, Contech, UCSD, Nhu Energy, and others.

Publications and Presentations

- de Callafon, R., Bliss, D., "The Kaiser Richmond Microgrid: scheduling and control of renewable power with phasor feedback." NASPI conference, 2017.
- Presentation/Publication IEEE ISGT 2017 (Callafon)
- Valibeygi, A, de Callafon, R, Stanovich, et al, "Microgrid Control Using Remote Controller Hardware-in-the-Loop Over the Internet." 2018 (submitted for publication).
- OSHPD Hospital Building Safety Board Energy Management Committee meeting presentation (John Griffiths), 2018.
- Presentation to SEPA Microgrid Working Group, "Renewable Energy Microgrid Control – Development, De-risking, and Deployment", R. Meeker 10/24/18
- California Society of Healthcare Engineers, Richmond, California, 2018 (Griffiths).
- Solar Power International, Anaheim, CA September 2018 (Bliss).
- Homer International Microgrid Conference, San Diego, CA September 2018. (Bliss)
- PG&E Microgrid Educational Conference, Sonoma, California, October 2018 (Griffiths).
- Presentation to American Society of Healthcare Engineers (upcoming, Griffiths)
- Submitted IEEE PES under review (Callafon, Meeker, Bliss)

Website

Charge Bliss has featured articles, links, and images on its commercial website, www.chargebliss.com.

Marketing

Charge Bliss presented microgrid system performance on its website, in postings on Linkedin®, Facebook®, and Twitter®, and received media coverage from several digital media companies and local CBS news in the San Francisco Bay Area. Charge Bliss hosted an event for an industry engineering group (CSHE) at the Richmond site in September 2018 and presented results at the Homer® conference in San Diego, California and the SPI™ conference in Anaheim, California. In addition, the team held an opening ceremony and separate technical "deep dives" attended by representatives of the Energy Commission, the California Public Utilities Commission, the California Independent System Operator, electric utilities, Kaiser Permanente representatives, and hospital engineers, microgrid designers, and other stakeholders. Charge Bliss presented data at multiple Energy Commission events including the annual EPIC symposium and Dr. Bliss shepherded the development of standards for renewable energy microgrids through his role on the Hospital Building Safety Board of the Office of Statewide Health Planning and Development. The team also presented at international conferences (SPI™ and Homer®). Two academic papers were published and presented at national scientific meetings. Charge Bliss is now engaged in designing and executing a healthcare facility microgrid in Santa Cruz, California and is preparing to unveil a multi-party campaign to develop microgrids for healthcare facilities throughout the Western United States.

CHAPTER 8: Production Readiness Plan

Controller

Utility/California Independent System Operator Relationship Report

Participation in grid services is a complex and rapidly changing endeavor. While rules, communication systems, and financial reconciliation for purely behind-the-meter services such as demand response are relatively well-defined, others are less readily available or methodologies are undergoing development. CAISO, for example, provided four significant insights that should be considered:

1. Technical complexity: Communications tools require specific testing and validation. Existing entities that have won DRAM contracts have already demonstrated the technical capacity and have demonstrated experience. The barrier for entry for new groups or technologies are high both based on expense and technical requirements.
2. "Perfect" performance: CAISO services participants must be able to guarantee a response time, ramp rates, duration, intensity, and quality. Failure to meet obligations may result in penalties.
3. Value: Because many of the emerging markets involve dynamic pricing, microgrid services providers are experiencing difficulty modeling future revenue streams and, therefore, creating decision algorithms whether to use capacities locally or in service of the grid.
4. Services target: Providers may integrate with the utility, the CAISO, or a third-party aggregator, but may not contract with more than one of the three.

Charge Bliss investigated collaborations with DRAM providers as an alternative approach to direct service provision. The advantages of integration through another party include the avoidance of contract complexities, documentation of performance, and reconciliation. The disadvantages include dependence on an intermediary with attendant impacts on net revenue, control of systems operations, and competing priorities. The team has decided, for the time being, to embed the controls and communications necessary to be a direct provider of utility services, but may return to collaborations with DRAM providers where appropriate.

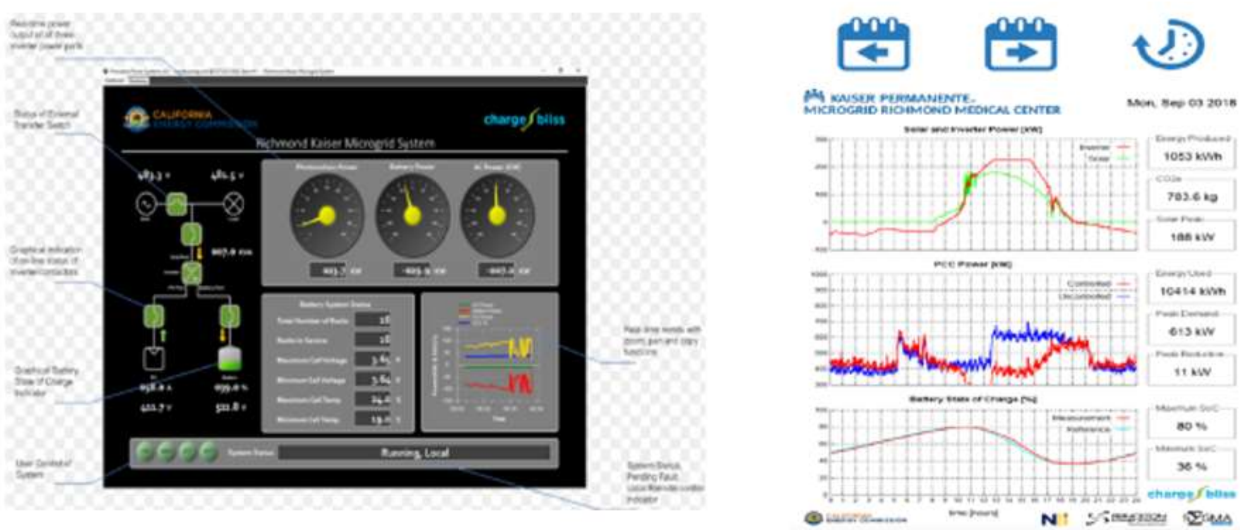
The deployment at the Kaiser Permanente facility has certain technical limitations that constrain options to participate in utility services that require power export. In discussions with utility and CAISO representatives, it became apparent that microgrid dispatchable resources would need to have a ratio of greater than 1 to base load to qualify to participate in many of the grid services. Despite meeting minimum CAISO sizing criteria (250kW), the Charge Bliss microgrid produces less than 50 percent of the base facility load and is unlikely to be able to export power to the utility or CAISO. This fact proved to be an advantage for purposes of interconnection with the utility and precluded the need for an interconnection study of utility systems upgrades. At the same time, system sizing essentially eliminated the ability to participate in capacity reserve, frequency and voltage regulation, and real time pricing. Notably, these services have unclear value streams and operational principles. Further marketplace maturity will be needed to consider integration into these arenas.

ADR remains a distinct option and the capability is being actively pursued through the Charge Bliss microgrid controller. The team expects to have incorporated the bidirectional signaling capacity within the next two months and to then undergo validation testing.

Online Visualization Portal

A graphical user interface (GUI), often referred to as a "visualization tool," is an important element for stakeholder engagement and system performance tracking. Objectives for tool display may vary by user- suggesting that some degree of user-configurability may be advantageous. Moreover, elements such as financial returns may be sensitive and should have restricted access. The Charge Bliss controller design team created a customizable tool as shown in Figure 32. This is amenable to public displays for environmental performance (CO_2 emissions averted, "trees planted," "cars taken off of the road," etc.), technical outcomes (energy generated, battery state of charge, load, power quality), and financial value (energy cost savings, demand cost savings, other revenues). In addition, operations teams and ownership may have continuous, real-time insight into systems to facilitate early recognition of unfavorable variances.

Figure 32: Visualizations



Screen shot of visualization tools demonstrating technical performance in real time

Source: Charge BlissDevelopment Pathway 2018

The novel Charge Bliss controller is undergoing completion of two parallel paths of development to reach commercializable status. First, additional endogenous capabilities are being added in the ensuing three to six months. Automated demand response signaling (ADR2.0b) is being incorporated to facilitate participation in potentially lucrative demand response markets. Once this is established, capabilities will be verified in the Richmond installation to meet utility and CAISO requirements for validation. A more robust GUI will be added with greater user configurability, more attractive display, and more clearly interpretable outputs. Lastly, internal state monitoring will be instituted to allow the controller to continuously receive and interpret all DER capacities, site load, utility supply, and quality measures to anticipate and avert errors or malfunction, stop and restart as appropriate, and improve the continuity of operations.

In parallel, the controls team is examining methods for integration with additional smart inverters. The team will inventory existing and emerging systems, opportunities for collaboration, and how such collaborations fit within a commercialization schema.

Commercialization Plan

The Charge Bliss team is considering two possible pathways for commercialization of the novel microgrid controller. Currently, Charge Bliss intends to retain ownership of the intellectual property, continue controller development, and deploy the controller in company projects. This may feed into the use of the controller in Charge Bliss developed microgrids or microgrids developed by partners and collaborators. At the same time, Charge Bliss is exploring options for licensing or sale of controller technology. Charge Bliss is meeting with several large firms that manufacture energy hardware that are interested in incorporating the controller capabilities. The expectation is to have a fully-developed control system ready for use, sale, or license by early 2019.

ACRONYMS AND GLOSSARY

Term	Definition
AC	Alternating current: electric current that reverses its direction at regularly recurring intervals.
ADR	Automated Demand Response: an arrangement between utility and customer in which the utility offers financial incentives in exchange for the ability to automatically reduce the customer's energy use during critical energy peak demand periods.
ATS	Automatic transfer switch: isolates electrical services when the utility power quality or supply is inadequate
Behind-the-Meter	Includes all electrical elements connected on the customer side of the utility meter
BESS	Battery energy storage system.
CAISO	California Independent System Operator: the entity that organizes and integrates utilities within the Western Grid
CARB	California Air Resources Board: sets standards for air and environmental quality in the State of California
CCA	Community Choice Aggregator: entity that assembles customers and service providers to contract for energy services separate from utilities
CHP	Combined heat and power: the use of a heat engine or power station to generate electricity and useful heat at the same time.
CMS	Center of Medicare and Medicaid Services: the federal regulatory entity that oversees healthcare.
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
CSHE	California Society for Healthcare Engineering: a group of engineers with focus in healthcare systems design.
CT	Current transformer: detects power flows through changes in magnetic fields.
DC	Direct current: continuous electric current that flows in one direction only, without substantial variation in magnitude, such as is produced by solar panels.

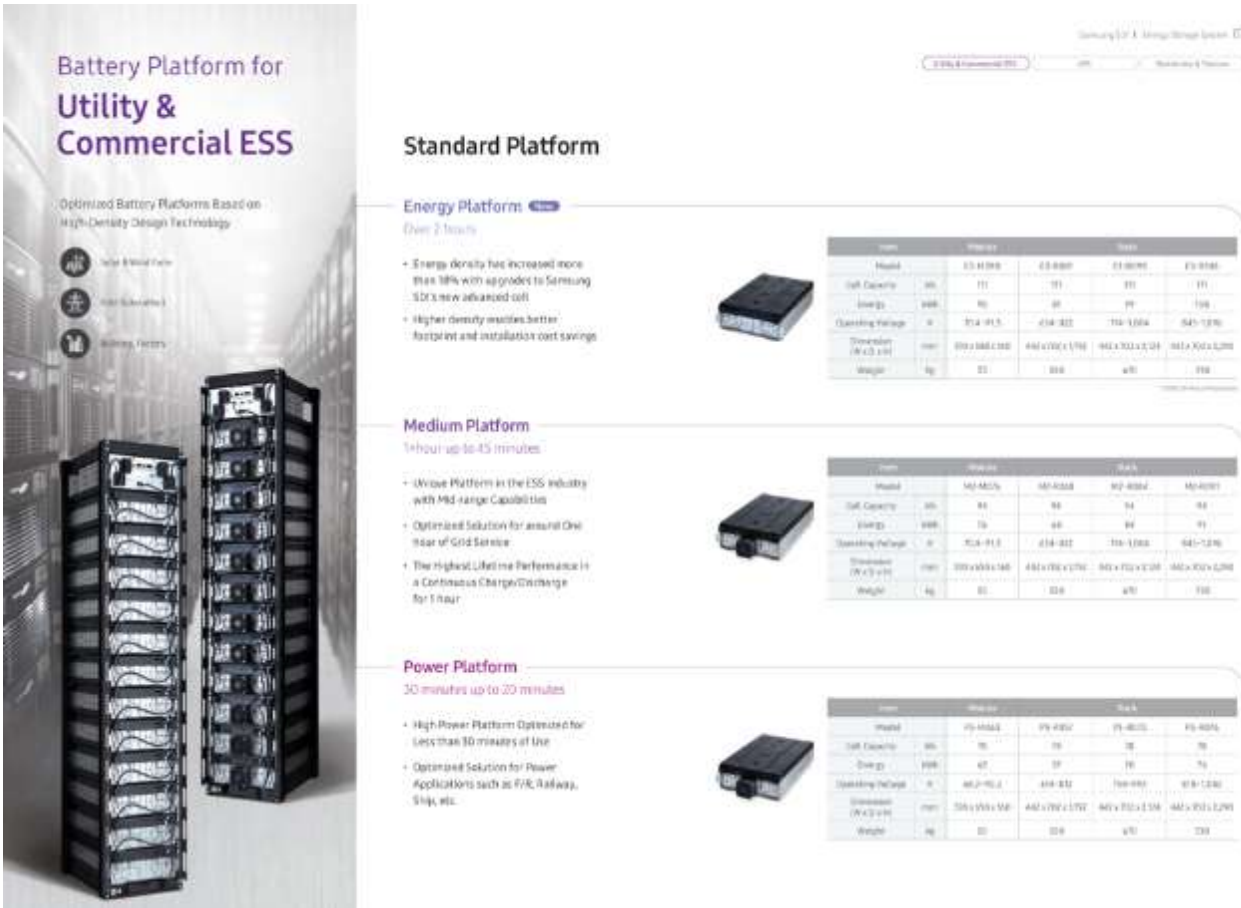
Term	Definition
DER	Distributed energy resources are energy producing, storing, or load devices connected in decentralized locations
DERIM	Distributed Energy Resource Interconnection Map: shows existing utility infrastructure and interconnected distributed generation systems.
DRAM	Demand Response Auction Mechanism: a tool through which utilities auction provision of demand response services.
DSL	Digital Subscriber Lines: a form of high-bandwidth Internet communication tools.
EPIC	Electric Program Investment Charge: created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
GPS	Global Positioning System: an array of satellites that reports precise locations and time.
HVAC	Heating, ventilation, and air-conditioning: systems that modify environmental conditions including air flow, temperature, and humidity.
IEEE	Institute of Electronic and Electrical Engineers: a leading standards organization for electrical and electronic devices and communications.
JCAHO	Joint Commission: Accreditation, Health Care, Certification: a voluntary membership organization for hospitals that sets standards for operations and care.
Kaiser Permanente Richmond Medical Center	Host healthcare facility located in Richmond, California
kW	Kilowatt is a standard measure of power equivalent to 1,000 watts.
kWh	Kilowatt-hour is a standard measure of electrical energy equivalent to power consumption of 1,000 watts for 1 hour
LED	Light-emitting diode
MTS	Manual transfer switch: a device that requires human operation to open or close a circuit.

Term	Definition
MWh	Megawatt-hour: a measure of energy equal to 1,000 kWh.
Non-recurring engineering	Engineering work that either cannot or need not be repeated
OSHPD	Office of Statewide Health Planning and Development: the apex regulatory agency for hospital design, construction, and operation in the State of California.
OSHPD-FDD	OSHPD Facilities Development Division: the arm responsible for review, approval, and inspection of plans and processes for hospitals in California.
PACE	Property Assessed Clean Energy: programs that fund clean energy construction projects and allow repayment through property tax billing.
PCC/POI	Point of Common Coupling/Point of Interconnection: the location where the generation or DER systems connect to site systems
PCS	Power conditioning systems: hardware tools that modify power including converting AC and DC power.
PG&E	Pacific Gas and Electric Company: one of the three investor-owned utilities in California
PMU	Phasor measurement unit: detects and reports power flows with added value of location and time-stamping.
PV	Photovoltaics: convert solar energy to DC power.
R-DER	Renewable distributed energy resources
RFP	Request for Proposals: solicitations for services.
RPS	Renewables Portfolio Standard: statutory goals for percentages of energy production in California produced by renewable resources.
SCADA	Supervisory Control And Data Acquisition: a computer system for gathering and analyzing real time data. SCADA systems are used to monitor and control a plant or equipment in industries such as telecommunications, water and waste control, energy, oil and gas refining and transportation.
SEL	Schweitzer Engineering Laboratories

Term	Definition
SGIP-AES	Self-Generation Incentive Program – Advanced Energy Storage: allows deployments of approved energy storage technologies to receive incentive payments based on systems sizing and performance.
SIWG	Smart Inverter Working Group: develops standards for smart inverter performance
SPI	Solar Power International: an annual conference for stakeholders in the solar power industry.
UCSD	University of California, San Diego
Volatile organic compounds	Organic substances with a relatively high vapor pressure at ambient temperature that therefore enter the atmosphere readily.
VPN	Virtual Private Networks: Internet communication protocols that obscure the location of the user.
Virtual power plants	Distributed resources that are coordinated to provide services to the grid.

APPENDIX A:
Inverter and Battery Specifications

Figure A-1: Samsung Battery Specifications Sheet



Performance Specifications for Samsung SDI Batteries

Source: Charge Bliss

Figure A-2: Princeton Power Systems® BIGI Inverter Specifications Sheet


Battery Integrated Inverter (BIGI)

PRINCETON POWER SYSTEMS

Princeton Power Systems
Clean power made simple.

Lead-Acid
Lithium-ion
Solar

Battery Integrated Grid-Interactive Inverter (BIGI)
250 kW Battery Integrated Inverter designed for Combining Batteries and PV

Grid-Interactive Functions

The BIGI-250 is a 250kW battery integrated inverter that offers high efficiency, proven reliability, and unprecedented flexibility. The highly-configurable BIGI-250 has three independent ports, designed to combine batteries with PV.

Efficient

Maximize power and minimize cost

With 96.5% efficiency, the BIGI has built-in MPPT for solar arrays and high round-trip efficiency for battery charging.

Advanced Functions

Built-in Smart Grid Functions

Demand Response, Peak Shaving, Island Mode, Demand Dispatch, Solar Firming, VAR Compensation, Frequency Regulation and other Functions are built-in and easily configurable.

Flexible

Configurable for Various Applications

The BIGI is compatible with advanced communication protocols. The BIGI-250 offers a wide input voltage range.

Features & Options

- Microgrid "off-grid" and back-up power capable
- Web-based remote performance monitoring, control, fault clearing, firmware upgrade
- Ethernet Compatible and Web UI access
- Ground fault detection and interruption (GFDI)
- Revenue-grade kWh meter (optional)
- Built-in AC disconnect

For more options please see our website → www.princetonpower.com

Source: Princeton Power Systems

APPENDIX B: Testing and Commissioning Protocol

Testing and Commissioning Plan

Introduction and Goals

The goal of this task was to articulate the plans to test the renewable energy microgrid at the Kaiser Permanente hospital facility in Richmond California (CEC EPC-14-080). The microgrid consists of a 250kW SunPower(™) rooftop canopy solar array, a Princeton Power Systems BIGI250(r) 250kW power conditioning device, the Princeton Power Systems first level microgrid controller, and 1MWh/250kW Samsung SDI(™) battery system. Prior to full system operation, the subtasks below will be executed and the following functions and safety procedures will be validated:

1. Subtask 1: Create the Commissioning Test Plan
2. Subtask 2: Verification of Equipment and Installation
3. Subtask 3: Perform Isolation Subpanel Testing
4. Subtask 4: Verify Battery Installation and Connection
5. Subtask 5: Verify Manual and Automatic Disconnects, Alternate Points of Site Coupling (Normal and Life safety)
6. Subtask 6: Verify Availability of Safety and Operations Manuals, Shutdown and Restart Procedures, and Key Contacts.

Overall task purposes include validation of complete installation of all equipment according to engineering specifications, appropriate connections between key elements (photovoltaic to inverter, battery to inverter, inverter to site electrical), identification of necessary safety equipment, and system function under standard and abnormal parallel conditions as well as in "Island" Mode. Finally, the commissioning process will validate the ability of the microgrid systems to resynchronize with the Utility to return from islanded to parallel mode.

Definitions

Commissioning is a systematic process confirming that all microgrid elements have been properly installed, initiated, and are operated in according to engineering designs, electrical safety principles, relevant codes, and requirements of governing bodies. In the specific case of interconnection with the hospital, the latter functions include meeting standards for the Office of Statewide Healthcare Planning and Development (OSHPD). A commissioning plan is the order or schedule of processes, organized according to the responsible parties for their execution, with a documentation methodology to record and disseminate results. The commissioning team is comprised of the General Contractor (Charge Bliss, Inc.), the main electrical subcontractor (Skelly Electric LLC), the architect and engineering team (Mazzetti and Associates, Inc.), the key suppliers (Princeton Power Systems, Inc. and Samsung SDI), the serving Utility personnel (PG&E), and the site electricians and buildings operations personnel (Kaiser Permanente).

The commissioning team is a working group made up of representatives from the architect/engineering firm, the contractor, the provider of the inverter/battery system, specialty manufacturers and suppliers, and Charge Bliss, Inc (CBI). The contractor will provide ad-hoc representation of subcontractors on the commissioning team as required. The system owner is a CBI representative who is responsible for any changes to, or maintenance of, the microgrid system's capacity, reliability, integrity, and overall long-range plan.

The project manager is a CBI representative who is responsible for managing the project's schedules, costs, and construction. The quality assurance/quality control inspector is a CBI representative who is responsible for reviewing and approving the electrical/mechanical installations for design compliance. This inspector must sign off at three levels:

1. Level 1, safety sign-off. A review of electrical/mechanical facilities systems and subsystems associated with the equipment or process must be completed prior to any hazardous energies being introduced. This includes a review of disconnects, guarding of energized circuits, and emergency shutdown capabilities.
2. Level 2, equipment sign-off. All Level 1 items must be completed. All environmental health and safety requirements must have been reviewed, including labeling and interlocks.
3. Level 3, project turnover. All Level 1 and 2 items must be completed. All punchlist items and specifications must have been completed and the systems ready for full operation. Completion of this system startup and commissioning specification is a component of, but not limited to, achieving Level 3 project turnover.

Testing of microgrid systems observes component and overall project function under standard operational conditions, during predictable variations in inputs and outputs to and from the systems, and under circumstances that require automatic and/or manual shutdown procedures. Moreover, this includes determination of function and safety under conditions of operation in parallel with the serving Utility (PG&E), when Utility service is absent (islanded mode), and when Utility supply returns after a period of disconnection or downtime.

Startup is the step where the equipment is initially energized, tested, and operated. Startup is completed before functional testing begins.

Functional testing involves performance testing of the dynamic functions and operations of the equipment and systems, using manual (direct observation) or monitoring methods. Functional tests are performed after pre-functional checklists and startup is complete. Functional testing is the dynamic testing of whole systems, rather than just their components, under full operation.

Manual testing uses handheld instruments, immediate control system readouts, or direct observation to verify performance. This is in contrast to analyzing monitored data taken over time to make the observation.

Permitting and approvals are written approvals by governing agencies to proceed with construction in accordance with submitted drawings and designs. These include City permits for electrical, structural, and mechanical elements of the microgrid, OSHPD approval of designs for physical entry into the central utility plant, interconnection to hospital electrical systems, and related safety devices, and Utility (PG&E) approvals for interconnection. The latter approval is finalized at the time of commissioning.

Inspections are official validation functions carried out by independent entities such as the City, County, Utility, or governmental agencies such as OSHPD that installations meet their respective requirements and are approved for operation. Each entity executes their own examinations and provides independent rulings.

Installation includes the acts and processes to physically place and connect systems prior to any testing or validations of system functions.

Installation

The Testing and Commissioning Plan includes the critical elements of the microgrid that have been installed and this list below shows the components of the microgrid:

- 250kW SunPower™ parking garage rooftop canopy solar
- Solar panel balance of systems
- BIGI 250™ Power Conditioning device
- Battery racking, Samsung SDI battery
- HVAC and Ventilation Systems
- Fire Suppression and Detection Systems
- Hardened PC and PMU installation
- Installation of central utility plant Kirk Key and Disconnect

Installation success and quality will be validated through several processes:

- Visual Inspection: Project management personnel (Charge Bliss Construction CA) will view all visible elements either directly or using drone video and photography. This includes, but is not limited to, the solar canopy structure, panels, balance of systems, conduit, battery room construction, HVAC, fire suppression, battery racks, batteries, wiring, inverter, PMU, hardened PC, interconnection point(s), and safety systems. Host site electrical and building personnel will be granted full access to perform their own visual inspection.
- Engineering Design Team Inspection: The Professional Engineer who has stamped the system design plans will inspect the installation to assure that the installation conforms with specifications for physical locations, connections, and safety equipment.

- Electrical Evaluation: Appropriate personnel designated by Princeton Power Systems(r) and Samsung SDI(r) will examine the battery systems (racking, wiring, balance of systems, safety devices), inverter and its related connections (battery, solar), and the control systems. Please refer to appendices 1 and 2 for further detail.
- Inspections: In accordance with municipal regulations, City inspectors will evaluate structural, electrical, and mechanical elements. In addition, PG&E engineering staff and the OSHPD Inspector of Record (IoR) will evaluate their respective areas of interest.
- Manuals and Materials: The PM will validate that the site operations offices and staff, Charge Bliss Construction CA, host site electricians, and (if required) PG&E have the following items to optimize system operational safety and effectiveness:
    - As-built drawings of physical and electrical systems
    - Certificate of Occupancy
    - Engineering specifications
    - Equipment Manuals
    - Photographic Images of Key Safety Devices
    - Emergency Procedures:
        - Shutdown
        - Restart and Resynchronization
        - Islanding
        - Switchover to Life and Safety Connection
        - Return to Normal Power Connection
        - Contact List

Electrical Commissioning

Pre-Functional Testing and Startup

The contractor is responsible for the pre-functional checklists and startup. Pre-functional checklists must be complete before functional testing begins. The following step-by-step procedure applies to all electrical switchboards, panelboards, and other electrical equipment within the microgrid:

1. Switch all controls off and isolate microgrid.
2. Check that all connections on incoming power supply cables are securely fixed and torqued to manufacturers' requirements.
3. Check all equipment nameplates and ensure that all operational limits are within the current rating on the nameplates.

4. Test the main neutral to earth and all main power supply cables to ensure neutral cables not crossed to any of the power cables.
5. With all plant switched off, turn on the main power supply to the switchboard and check that 480 Volts are connected to the incoming cables.
6. Inspect and test equipment in accordance with manufacturers' instructions, then systematically energize the equipment beginning with the new main service switchboard.
7. Perform startup of the main disconnect switch in accordance with the manufacturer's Installation, Operation, and Service Manual. The switch can then be placed in the bypass mode to permit commissioning of all downstream equipment prior to startup.
8. Manually start the fans and check each one's current draw. Should the draw exceed the nameplate rating, isolate the motor and investigate the reason.

Preparation

Prior to final commissioning, all testing tasks must be completed satisfactorily according to the microgrid project specifications, best practice standards, and relevant codes as judged by Charge Bliss Construction CA and Charge Bliss Inc.

- Create and distribute a checklist for operation and control of commissioned equipment.
- Prepare and distribute alarm parameters, critical states, and Prepare the specific functional performance test procedures and ensure that they address feasibility, safety, and equipment protection. Provide necessary written alarm limits to be used during the tests.
- Develop the commissioning plan using manufacturer's startup procedures and the pre-functional checklists. Submit manufacturer's detailed startup procedures, the commissioning plan and procedures, and other requested equipment documentation to the owner for review.
- During the startup and initial checkout process, execute and document related portion of the pre-functional checklists for all commissioned equipment.
- Perform and clearly document all completed pre-functional checklists and startup procedures. Provide a copy to the owner before functional testing begins.
- Address current punchlist items from the owner and the engineering firm before functional testing.
- Provide skilled technicians to execute starting of equipment and to assist in execution of functional performance tests. Ensure that the technicians are available and present during the agreed-on schedules and for a long enough time to complete the necessary tests, adjustments, and problem-solving.

- Correct deficiencies (differences between specified and observed performance) as interpreted by the CBI project manager and the engineering firm. Re-test the system and equipment.
- Compile all commissioning records and documentation to be included in a commissioning and closeout manual.
- Prepare O&M manuals according to the contract documents, including clarifying and updating the original sequences of operation to as-built conditions.
- During construction, maintain as-built marked-up drawings and specifications of all contract documents and contractor-generated coordination drawings. Update these after commissioning is complete (including deferred tests). The as-built drawings and specifications must be delivered to the owner both in electronic format and as hard copies.
- Provide training for the owner's operating personnel as specified.
- Coordinate with equipment manufacturers to determine specific requirements to maintain the validity of the warranty.
- Correct deficiencies and make necessary adjustments to O&M manuals, commissioning documentation, and as-built drawings for applicable issues identified in any seasonal testing. Another element of electrical systems commissioning is evaluation by an independent electrical testing agency if/when requested by CBI. This agency's work generally requires checking and testing of the electrical power distribution equipment per the National Electrical Testing Association. In addition to attending project meetings, the electrical testing agency will –
    - Obtain all required manufacturer's data to facilitate tests.
    - Provide assistance to the contractor in preparing the pre-functional checklists and functional test procedures. Generally, the agency would provide its standard forms to document the National Electrical Testing Association tests to be incorporated.
    - During related tests, execute and document the tests in the approved forms and test records.
    - Perform and clearly document all completed startup and system operational checkout procedures, providing a copy to the contractor.
    - Clearly indicate any deficiencies identified during testing and add to an action list for resolution and tracking. The field technicians will keep a running log of events and issues. The electrical testing agency will submit hand-written reports of discrepancies, deficient or uncompleted work by others, contract interpretation requests, and lists of completed tests to the contractor at least twice a week and provide technical assistance in resolving deficiencies.

    - Provide skilled technicians to execute testing. Ensure that they are available and present during the agreed-on schedules and for sufficient duration to complete the necessary tests, adjustments, and problem-solving.

Elements to Commission

Electrical systems to be commissioned include the following:

- Photovoltaic systems
- Battery energy storage
- Inverter/Power Conditioning System
- First Layer Microgrid Controller
- PMU
- Hardened PC
- Safety systems

Documentation Submittals

The documentation will include the following:

- Detailed startup procedures
- Full sequences of operation
- O&M manuals
- Performance data
- Functional performance test procedures and results
- Control drawings
- Completed equipment startup certification

Testing

General

All parties engaged in the Testing, Commissioning, and Operations procedures must have appropriate licensure and must follow all relevant professional standards and best practices for safe conduct of procedures, testing, operations, and modifications. Testing and Commissioning Plan requirements provided herein are not intended to require the contractor(s) or other parties to act in a manner that would violate the provisions of warranties and guarantees or create a safety hazard to personnel or property. The reporting parties will indicate in the subsequent report whether any significant actions were not taken due to warranty or safety considerations.

Pre-Energization

Once all systems are ready to be energized, a formal checklist procedure will be undertaken to assure that all safety requirements are met:

1. Pre-Testing Documentation Signoff:

The General Contractor and Host Site will sign verifications that the Documentation set forth in the Installation Section are complete and delivered.

2. Support System Verification:

The General Contractor will obtain certification from the installation contractors that the HVAC and Fire Suppression systems are operational in advance of testing and obtain a Certificate of Occupancy for the Battery/Inverter room from the City of Richmond.

3. Safety Signoff:

A review of presence, accessibility, and function of disconnects, isolation panels and circuit breakers, guarding of energized circuits, and emergency shutdown capabilities will be performed by Skelly Electric, Mazzetti and Associates, and supervised by the General Contractor. System grounding and fault detectors will be validated.

4. Manufacturer Checklist.

All Level 1-2 items must be completed. The Manufacturer Checklists for system testing must first be performed according to manufacturer specifications and signed off by the relevant contractor.

Site Electrical Shutdown

1. Timing:

   The date and time of electrical utility energy supply shutdown will be determined by the host site and PG&E.

2. General Method:

   California has special requirements for hospital electrical supply the details of which may be found at the relevant OSHPD links. In summary, the facility must be able to electrically isolate from the utility by opening Automatic Transfer Switches (ATS) and initiating emergency diesel generation to support critical systems. The microgrid is primarily interconnected on the utility side of the ATS on the branches labeled “normal power” by OSHPD. This supplies non-critical systems that can be sacrificed during inadequate utility energy supply but which can potentially be supported by the microgrid. A secondary, alternative connection between the microgrid and a specific branch of the emergency power is also being established, but can only be deployed with a manual switchover. Additional salient methodologic details that will be accomplished during utility supply shutdown will be:

   a. Phasor Measurement Unit (PMU) placement: The current transformer components will be placed during the de-energized period

b. Hardened PC/Novel Controller: The controller systems will be embedded in advance and then installed onsite with connections to both detector (PMU) and effector (inverter) systems

c. Point of Common Coupling (PCC): The designated PCC will be established according to engineering and permitted drawings. Final approval for interconnection and energization will be obtained from PG&E and the OSHPD Inspector of Record (IoR)

d. Safety Systems Interrogation: Once all systems are installed and interconnected, grounding, breakers, isolation systems, and disconnects will be inspected and validated.

3. Inverter:

   The representatives of the manufacturer will carry out the comprehensive, systematic testing of the inverter and first layer control systems to validate safety prior to energization in accordance with the manufacturer specification.

4. Batteries:

   The representatives of the manufacturers will carry out the comprehensive, systematic testing of the battery systems to validate safety prior to energization in accordance with manufacturer specifications.

5. Solar:

   The electricians will validate the pre-energization safety of the solar array and related equipment in accordance with prevailing industry standards.

Testing after Energization

1. Preparation:

   All pre-energization tasks must be completed and permission obtained to energize from the governing entities and host site.

2. Responsibility:

   The relevant agent (contractor, inspector, manufacturer) will be solely responsible for providing all necessary equipment, materials, personnel, and other systems as might be necessary to fully execute their activities and will be responsible for providing written reporting attesting to their findings. Furthermore, the contractor will be solely responsible for calibration of their equipment and application of best practices to all testing procedures.

3. Functional testing:

   a. Definition: Visual, manual, and digital/analog study of whole microgrid functions under dynamic conditions.

b. Purposes: Run through all the microgrid equipment sequences of operation to verify that they are responding as the design, engineering, and operations sequences state that they should.

c. General Methods:

    i. Manual testing: Manual testing uses handheld instruments, immediate control system readouts, or direct observation to verify performance.

    ii. Monitoring: Monitored data taken overtime to make observations regarding system safety and effectiveness.

    iii. Simulation: In simulated condition testing, circumstances are created for the purpose of testing the responses of the microgrid to specific changes such as variations in power quality, power intensity, flow directionality, parallel and islanding modes, generation, storage, and loads.

    iv. Acceptable Results: Tolerances for systems function, automated safety responses, and outcomes are specified in manufacturer's documents appended. Failure to meet acceptance criteria requires resolution of cause before process completion.

    v. Calibration: Systems that require reference points or that may experience drift in value reporting are calibrated to acceptable standards to optimize their function and reliability.

    vi. Documentation:

        1. Equipment, and components to be verified and tested.

        2. Certificate of completion certifying that installation, pre-start checks, and startup procedures have been completed.

        3. Certificate of readiness certifying that microgrid systems, subsystems, equipment, and associated controls are ready for testing.

        4. Test and inspection reports and certificates.

        5. Corrective action documents.

        6. Verification of testing, adjusting, and balancing reports.

d. Specific methods:

    i. Inverter: Specific, detailed manufacturer specs.

    ii. Batteries: Specific, detailed manufacturer specs.

    iii. Isolation Panel: Specific, detailed manufacturer specs.

iv. Solar: The Solar/Electrical contractor will perform industry-standard voltage testing of solar strings and verification of installation of photovoltaic systems as specified by manufacturer specs.

4. Remediation: In the event that system defects are discovered including mechanical, structural, electrical, or overall performance, the following steps will be taken:

    a. Findings Report: The contractor will produce a signed report with detailed description of the defect and will define the priority for remediation as Critical (microgrid operation cannot proceed without remediation), Necessary (microgrid operation may proceed, but matter will need to be remediated within a specified time), or Discretionary (microgrid operation may proceed without modification and alteration is preferable but not necessary).

    b. Remediation Plan: The General Contractor, in consultation with the contractor identifying any defect, will submit a written plan including timing, technical description, materials and methods, cost, and responsible parties. For example, an inverter defect that requires inverter replacement at the time of testing would trigger a warranty replacement by the manufacturer.

    c. Material Change: Any change to system design or operation that is material to the schedule, budget, technical performance, or capabilities of the microgrid will result in a written report to the Energy Commission CAM.

    d. Execution: Once the remediation plan is accepted by the Host Site, Energy Commission, and Charge Bliss, it will be executed under the supervision of Charge Bliss Construction CA.

    e. Re-Testing: Testing processes for the affected system will be repeated after completion of the remediation process. If satisfactory results are obtained, the Testing and Commissioning process will continue to completion. If the defect(s) are not successfully ameliorated, the remediation process will repeat.

Reporting and Products

Charge Bliss will be responsible for gathering reports from relevant contractors and project partners.

1. Pre-Testing Documentation:

    a. Pre-testing documentation signoff

    b. Support system verification

    c. Safety system signoff

    d. Manufacturer Checklist

        i. Inverter Checklist

        ii. Battery Checklist

e. Solar Checklist

f. Code inspection certificates

g. OSHPD IoR approval

2. Functional Testing Documentation:

   a. Solar Checklist

   b. Manufacturer Checklist

      i. Princeton Power Systems

      ii. Samsung SDI

   c. Controller execution

   d. Equipment start-up certifications

   e. Electrical testing reports

   f. 72-hour performance acceptance report

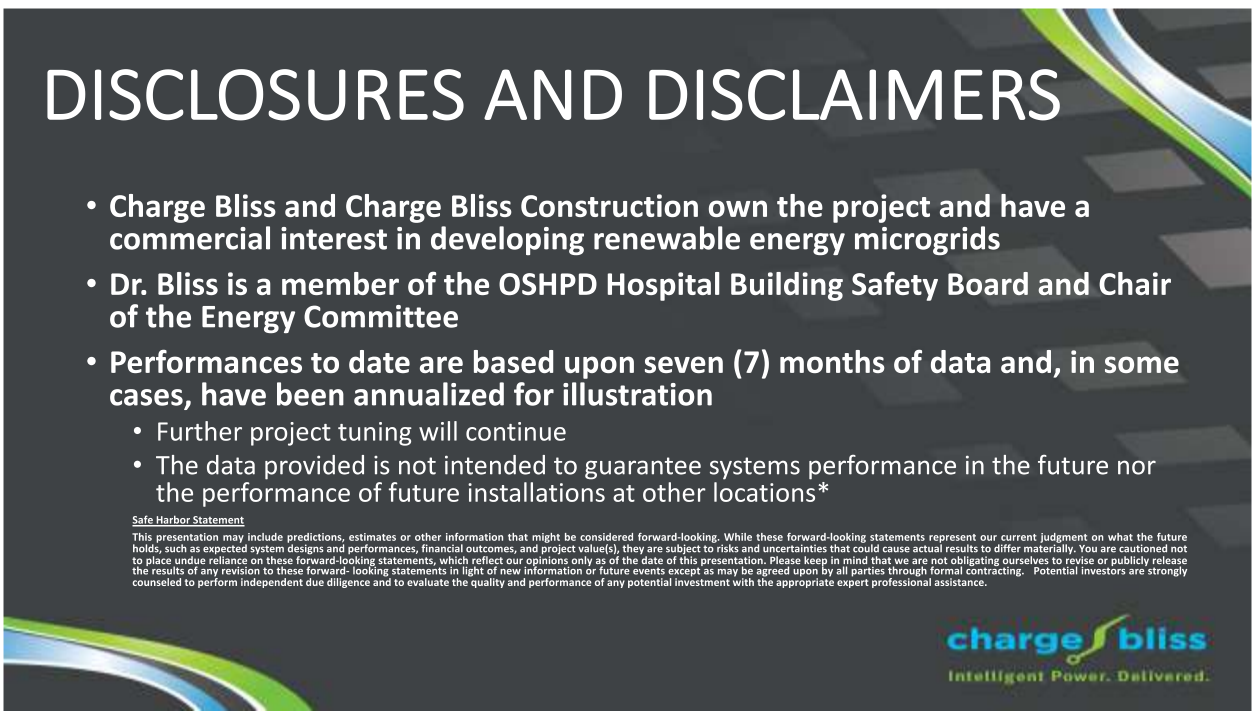
   g. Remediation finding report(s)

      i. Remediation plan(s)

      ii. Material change(s) report

      iii. Re-testing report(s)

APPENDIX C:
Tech Transfer Presentation



DISCUSSION OBJECTIVES

- **PROJECT GOALS**
- **OBSTACLES**
  - Overcome
  - Remaining
- **ACHIEVEMENTS**
  - Technical
  - Economic
  - Social
- **FUTURE STEPS AND ACTIONS**

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PROJECT GOALS

- **DESIGN, ENGINEER, BUILD, AND OPERATE A PHOTOVOLTAIC MICROGRID FOR A CALIFORNIA HOSPITAL**
  - **250kW PV (SunPower®)**
  - **1MWh/250kW batteries and smart inverter (Princeton Power Systems® and Samsung SDI®)**
- **DEMONSTRATE IMPORTANT TECHNICAL ACHIEVEMENTS**
  - Use of Phasor Measurement Unit (PMU) data
  - Compliance with OSHPD requirements
  - Appropriate safety and redundancy
- **DEMONSTRATE KEY PERFORMANCE FUNCTIONS**
  - Clean energy generation
  - Load (demand) management
  - Islanding of hospital operations
  - Novel controls
  - Independent control of real and reactive power
  - Demand Response/Grid services
- **DEFINE FUTURE STEPS AND ACTIONS**

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WHY A HOSPITAL?

- **TECHNICAL**
  - High intensity, non-discretionary loads
  - “Two” Energy Systems
  - Complex regulatory environment (hardest use case)
- **ECONOMIC**
  - Thin or negative operating margins
  - Ratio of beds to patients one of the lowest in the Nation
  - Minimal current options for either energy efficiency or load reduction
  - Tax-exempt (unable to capture tax benefits)

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PROJECT ACHIEVEMENTS

- **<u>DESIGN/BUILD PROCESS</u>**
  - Comprehensive engineering/build
    - 250kW photovoltaic canopy
    - 1MWh/250kW battery
    - Dual interconnection
    - PMU monitoring
  - Permitting, Inspections, CEQA, Interconnection approval
    - Normal *AND* Life and Safety
  - Communication and Safety systems (Internet, fire suppression, disconnects, shutdown processes)
- **<u>OPERATIONS</u>**
  - Solar production
  - Battery charge and discharge
    - Timed
    - SOC-gated
    - Demand regulation
  - Controller development
    - Automation verified
    - Real-time adjustable

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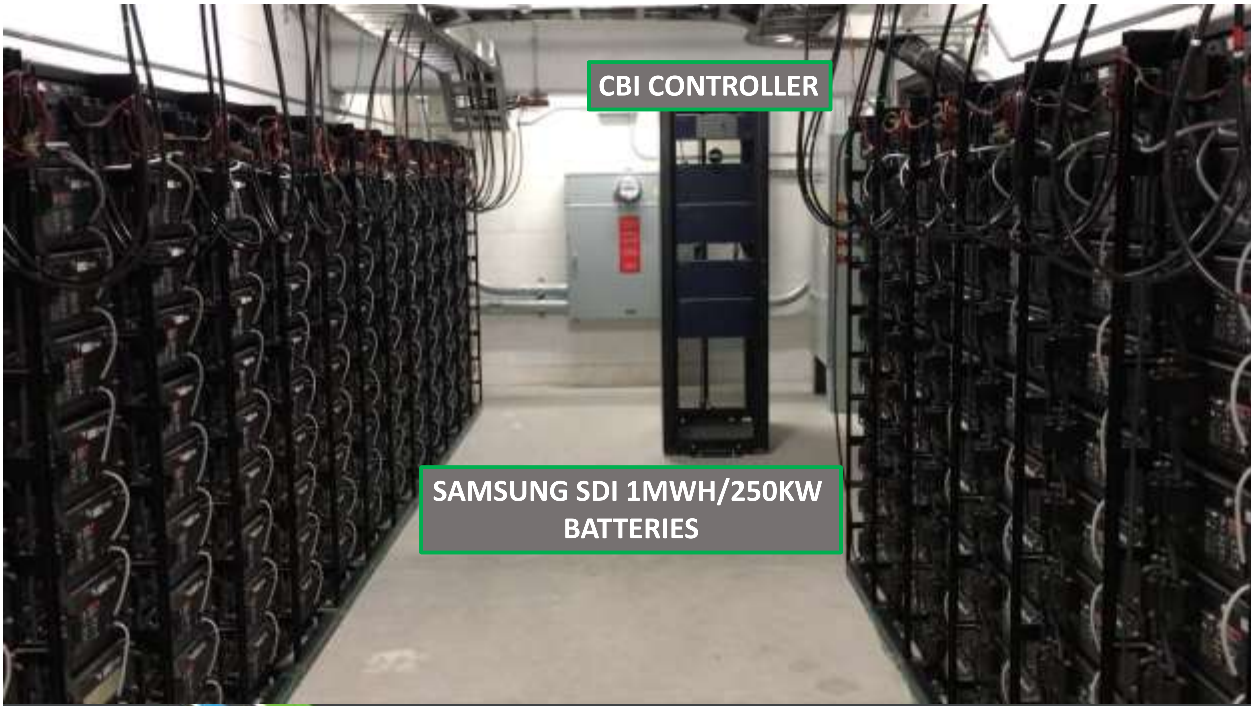
CBI CONTROLLER
SAMSUNG SDI 1MWH/250KW BATTERIES


PRINCETON POWER SYSTEM 3-PORT INVERTER

PERFORMANCE DATA

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PERFORMANCE DATA

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#	Value	Unit	Where does the data come from	Month 1 (2017 January)	Month 2 (February)	Month 3 (March)	Month 4 (April)	Month 5 (May)	Month 6 (June)	Month 7 (July)	Month 8 (August)	Month 9 (September)	Month 10 (October)	Month 11 (November)	Month 12 (December)
	Kaiser Richmond Performance Report PG&E data			2017		Billing Cycle									
1	Hospital monthly energy usage - baseline	kWh	PG&E bills	345,534.00	324,964.00	383,885.00	372,188.00	394,100.00	414,815.00	388,799.00	394,882.00	553,458.00	398,866.00	369,597.00	327,972.00
2	Hospital monthly energy usage – with microgrid	kWh	PG&E bills	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	372,122.00
3	Hospital monthly peak load - baseline	kW	PG&E bills	673.00	704.00	821.00	857.00	827.00	847.00	769.00	873.00	876.00	885.00	827.00	751.00
4	Hospital monthly peak load – with microgrid	kW	PG&E bills	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	777.00	802.00	715.00
9	Monthly solar energy production	kWh	EMOS												20,751.00
10	Monthly solar minimum and maximum daily peak power	kWh	EMOS												458 / 745
11	Hospital annual equivalent CO2 emissions associated with electric energy - baseline	tons	EPA Calculator	257.08	241.77	285.61	276.91	293.21	308.82	289.27	293.79	411.77	296.76	274.98	244.01
12	Hospital annual equivalent CO2 emissions associated with electric energy – with microgrid	tons	EPA Calculator	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	276.86

#	Value	Unit	Where does the data come from	Month 1 (2018 January)	Month 2 (February)	Month 3 (March)	Month 4 (April)	Month 5 (May)	Month 6 (June)	Month 7 (July)
	Kaiser Richmond Performance Report PG&E data			2018		Billing Cycle				
1	Hospital monthly energy usage - baseline	kWh	PG&E bills	345,534.00	324,964.00	383,885.00	372,188.00	394,100.00	414,815.00	
2	Hospital monthly energy usage – with microgrid	kWh	PG&E bills	340,379.00	320,397.00	328,054.00	350,628.00	324,639.00	362,701.00	
3	Hospital monthly peak load - baseline	kW	PG&E bills	673.00	704.00	821.00	857.00	827.00	847.00	
4	Hospital monthly peak load – with microgrid	kW	PG&E bills	803.00	725.00	680.00	738.00	729.00	748.00	
9	Monthly solar energy production	kWh	EMOS	4,879.00	23,045.00	19,248.00	21,231.00	41,824.00	TBD	
10	Monthly solar minimum and maximum daily peak power	kWh	EMOS	778 / 0	954 / 0	1505 / 0	1964 / 0	2060 / 0	TBD	
11	Hospital annual equivalent CO2 emissions associated with electric energy - baseline	tons	EPA Calculator	257.08	241.77	285.61	276.91	293.21	308.62	
12	Hospital annual equivalent CO2 emissions associated with electric energy – with microgrid	tons	EPA Calculator	253.24	238.38	244.07	260.87	241.53	269.85	

SIGNIFICANT CALCULATED SAVINGS

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POWER FACTOR

Kaiser Richmond Performance Report PG&E data			2017		Billing Cycle									
			January	February	March	April	May	June	July	August	September	October	November	December
Value	*Unit*	*Where does the data come from*	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Power Factor - 2016		PG&E bills									0.78	0.77	0.78	0.77
Power Factor - 2017			0.77	0.78	0.77	0.77	0.79	0.78	0.77	0.82	0.80	0.78	0.77	0.78
Power Factor - 2018			0.78	0.75	0.74	0.75	0.74	0.74						

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CONTROLLER PERFORMANCE

(de Callafon, Meeker)

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Data Collection and Microgrid Performance

- DATA COLLECTION, VALIDATION & STORAGE
  - PMU locations and data (60Hz, C37.118 via SEL2240)
  - Inverter data (1Hz, MODBUS via EMOS)
  - Meter Data (15 min sampling)
  - Validation of power data (Meter v. PMU)
  - Data storage (3 locations)
- MICROGRID PERFORMANCE
  - Commissioning with Up/Down time
  - Solar Generation
  - Active Demand Reduction
- ECONOMIC ANALYSIS
  - Energy and CO_2 reduction
  - Time of Use Energy Savings
  - Demand Reduction Savings
- NEW DEVELOPMENTS
  - Web Interface for Public Visualization
  - Microgrid control with State Machine

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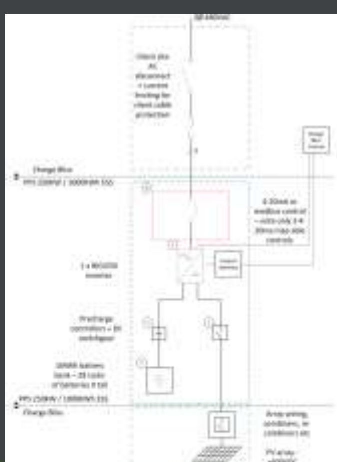
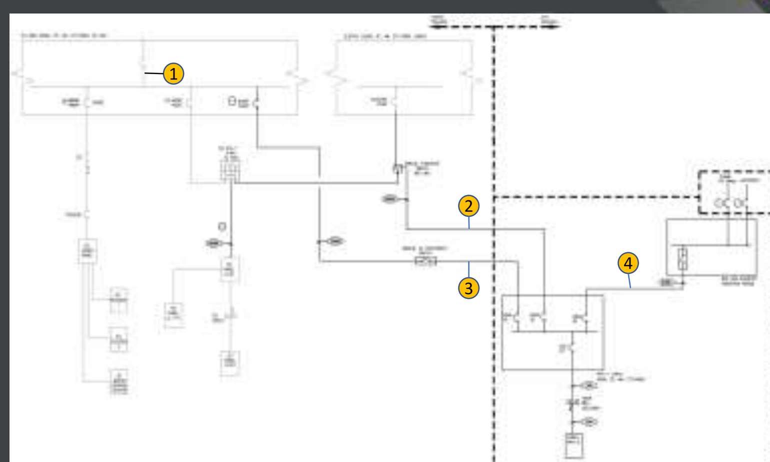
DATA COLLECTION, VALIDATION & STORAGE
PMU locations





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DATA COLLECTION, VALIDATION & STORAGE
PMU data

- Data collection up to 60Hz
- C37.118 interface
- 3 phase voltage amplitude and voltage angles
- 3 phase current amplitude and current angles
- Computation of positive sequence real and reactive power flow

Measurement	*Range*	*Units*	*Accuracy*
Current, at main switch board (MSB), 4000:5 CT	0-5	Amps	+/- 0.6%
Voltage, at main switch board (MSB), 480:120 PT	0-120	Volts	+/- 0.6%
PMU 1, SEL-2245-4, main switch board V, I, ϕ			
Current, at manual transfer switch (MTS), 400:4 CT	0-5	Amps	+/- 0.6%
Voltage at manual transfer switch (MTS), 480:120 PT	0-120	Volts	+/- 0.6%
PMU 2, SEL-2245-4, manual transfer switch V, I, ϕ			
Current, at manual disc. switch (MDS), 500:5 CT	0-5	Amps	+/- 0.3%
Voltage, at manual disc. switch (MDS), 480:120 PT	0-120	Volts	+/- 0.6%
PMU 3, SEL-2245-4, manual disc. switch V, I, ϕ			
Current, at Princeton Power Inv. (PPS), 400:5 CT	0-5	Amps	+/- 0.6%
Voltage, at Princeton Power Inv.. (PPS), 480:120 PT	0-120	Volts	+/- 0.6%
PMU 4, SEL-2245-4, Princeton Power Inv. V, I, ϕ			

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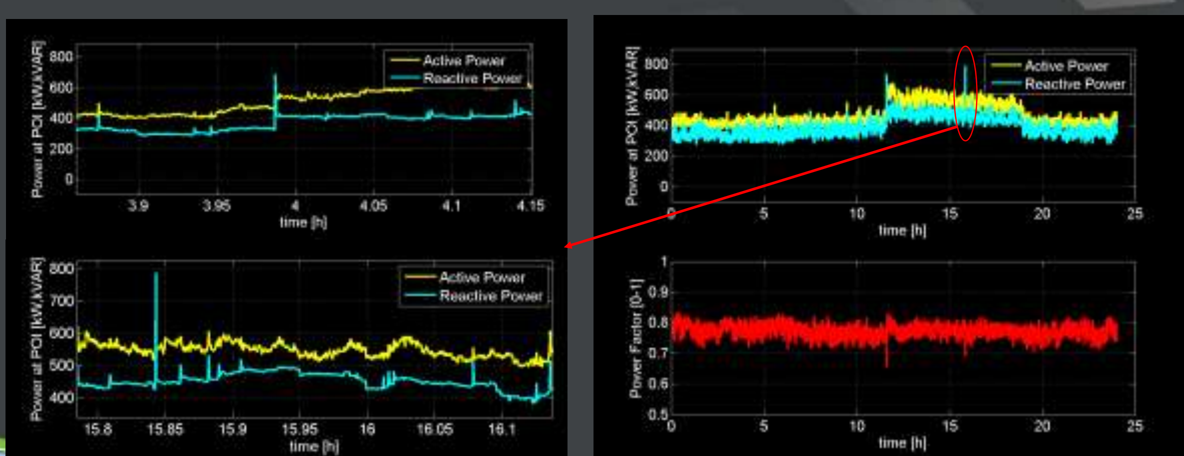
DATA COLLECTION, VALIDATION & STORAGE
Illustration of PMU data



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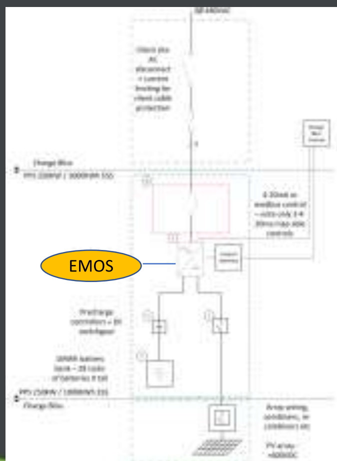
DATA COLLECTION, VALIDATION & STORAGE

Inverter Data



- Data collection at 1Hz
- MODBUS over TCP/IP interface
- MODBUS server: PPS EMOS

Measurement	*Range*	*Units*	*Accuracy*
Princeton Power BIGI250 inverter real power	-250, +250	kW	+/- 1kW
Princeton Power BIGI250 inverter reactive power	-100, +100	kVAR	+/- 1kVAR
Princeton Power BIGI250 battery power	-250, +250	kW	+/- 1kW
SunPower PV Power	0 – 250	kW	+/- 1kW
Samsung battery system state of charge (SOC)	0-100	%	+/- 0.2%
Samsung min and max cell temperature	?	Deg C	+/- 1deg C
Samsung min and max cell voltage	0 – 4.5	V	+/- 10mV
No. of Samsung racks on-line	0 – 18	racks	N.A.

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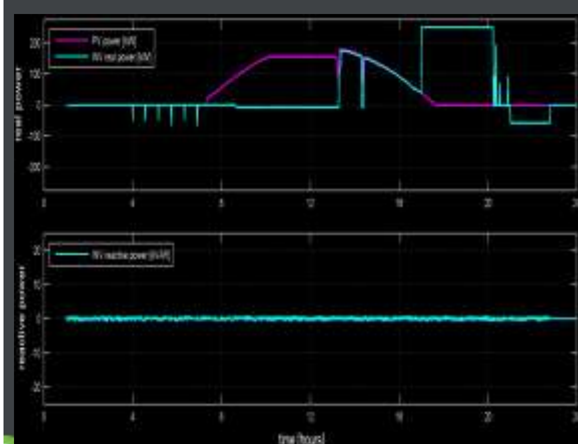
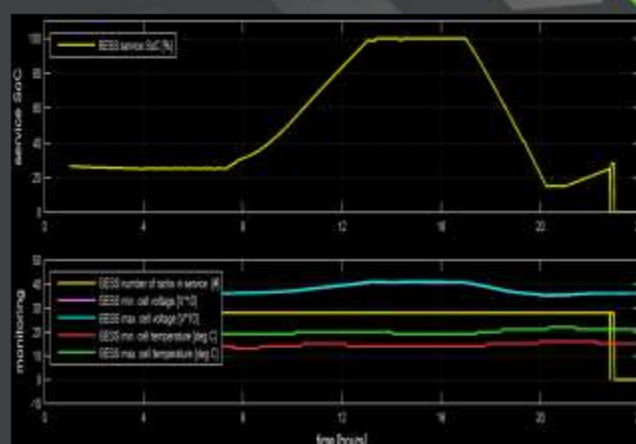
DATA COLLECTION, VALIDATION & STORAGE

Illustration of Inverter Data (03/05/18)





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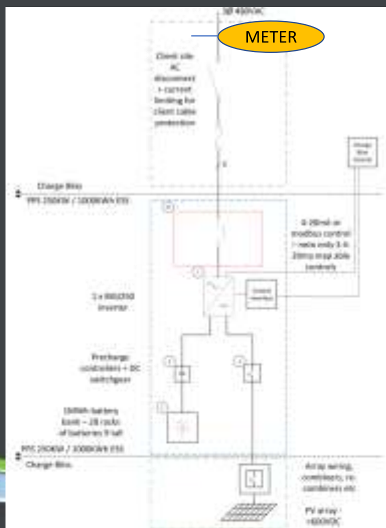
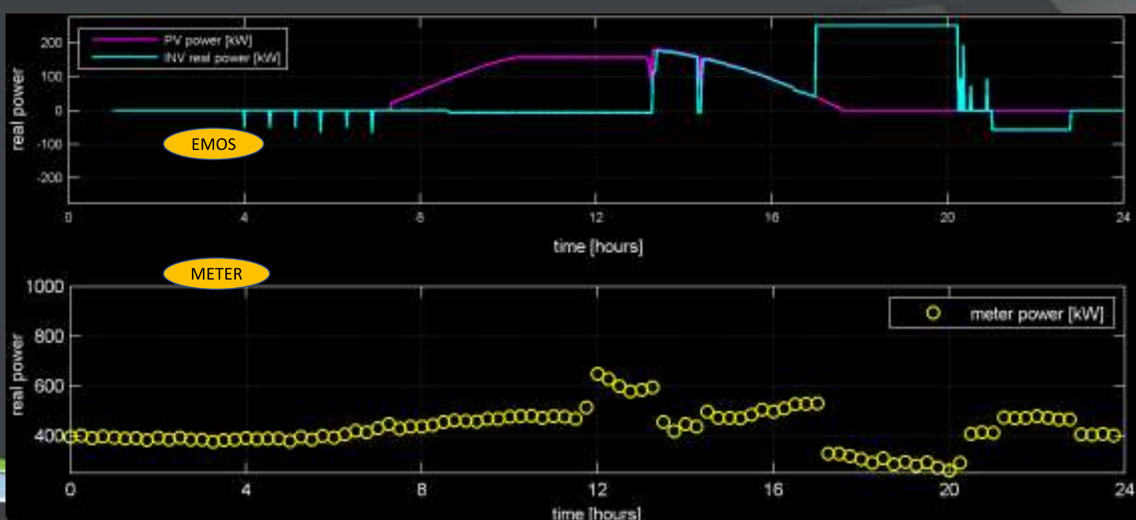
DATA COLLECTION, VALIDATION & STORAGE
Meter Data



- Data collection at 15min interval (96 pts/day)
- Obtained via PG&E request
- SP ID 1699719005 reporting kWh/15min used for computation of real power flow

Measurement	*Range*	*Units*	*Accuracy*
Revenue grade electric utility meter no. 6074664499		kWh	
Revenue grade electric utility meter no. 6074664499		kW	
Revenue grade electric utility meter no. 6116331163		kWh	
Revenue grade electric utility meter no. 6116331163		kW	
Revenue grade electric utility meter no. 6157997827		kWh	
Revenue grade electric utility meter no. 6157997827		kW	

DATA COLLECTION, VALIDATION & STORAGE
Illustration of Inverter/Meter Data (03/05/18)



DATA COLLECTION, VALIDATION & STORAGE
Validation of Power Data

With measurements of power provided by:

- PMU (60Hz) denoted by $P(t_k)$
- Inverter (1Hz) denoted by $P(t_i)$
- Meter (15 min. interval) denoted by $P(t_m)$

Important to validate consistency between power measurements:

$$E(t_k) = \frac{1}{60}P(t_k) + E(t_{k-1})$$

$$E(t_i) = E(t_k), k = 60i \quad E(t_m) = E(t_k), k = 900m$$

$$P(t_i) = E(t_i) - E(t_{i-1}), P(t_m) = 900(E(t_i) - E(t_{i-1}))$$

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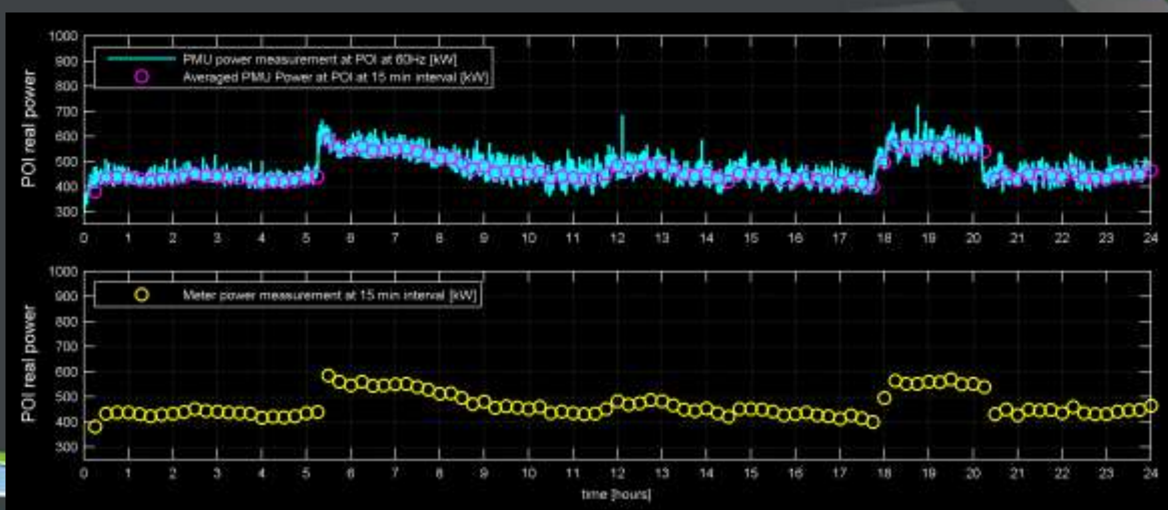
DATA COLLECTION, VALIDATION & STORAGE
Illustration of Validation (05/04/2018)



DATA COLLECTION, VALIDATION & STORAGE
Data Storage

Measurements of power provided by PMU (60Hz), Inverter (1Hz) and Meter (15 min. interval) is stored multiple locations:

- SEL3350 Control Computer
  - PMU data stored by PI system
  - PMU data and Inverter Data at 1Hz stored by microgrid controller
  - Data backups and visualization to SyGMA lab computers at UCSD
- PPS Computer
  - Inverter Data at 1Hz stored by EMOS
  - Cloud Data backups

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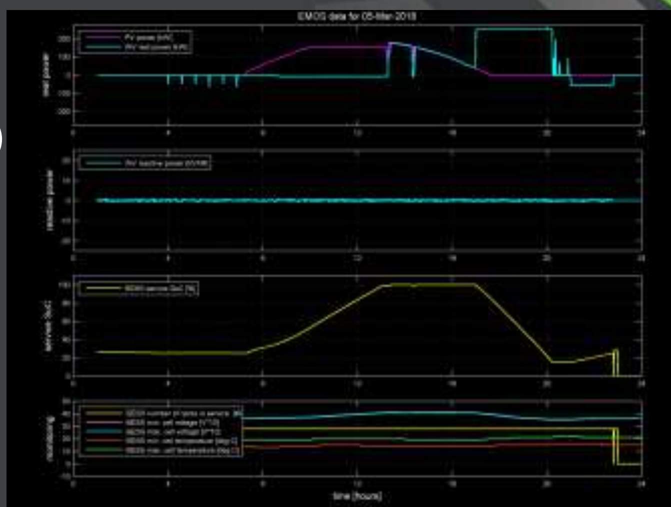
DATA COLLECTION, VALIDATION & STORAGE
Data Storage

Daily data since 03/05/2018

- PV generation
- Inverter Output (Real/Reactive)
- Battery SoC
- System Monitoring (min/max temperature, min/max cell voltage racks online)
- Stored in DAILY CSV files with naming YYYY-MM-DD-log.csv



DATA COLLECTION, VALIDATION & STORAGE
Data Storage

Daily data since 05/04/2018

- PV generation
- Inverter Output (Real/Reactive)
- Battery SoC
- POI power flow (Real/Reactive)
- Demand management
- Stored in DAILY CSV files with naming YYYY-MM-DD-log.csv

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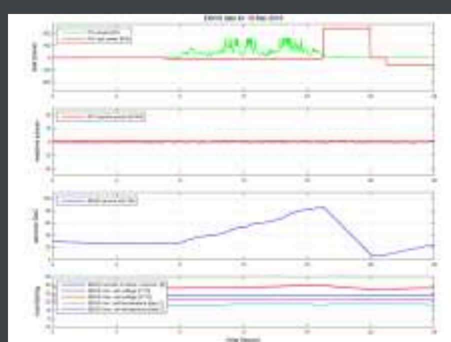
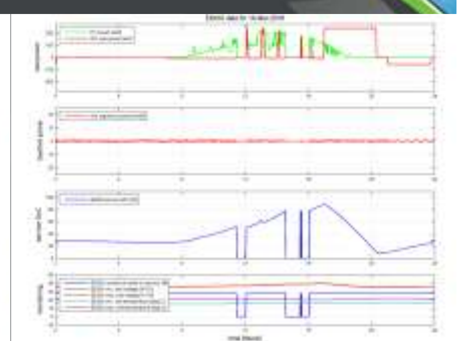
MICROGRID PERFORMANCE
Commissioning with Up/Down time

During Tuning:

- Log PV power
- Log inverter power
- Log SoC
- Log faults/trips
- Resolve errors



OPTIMAL



SUB-OPTIMAL

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MICROGRID PERFORMANCE
VISUALIZATIONS

- Development of local GUI
- GUI runs locally on PPS computer to inspect system operation and reset system in case of faults

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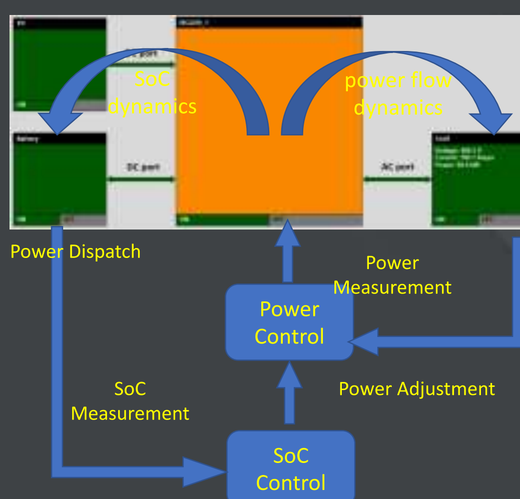
MICROGRID PERFORMANCE
CHARGE BLISS CONTROLLER DIAGRAM



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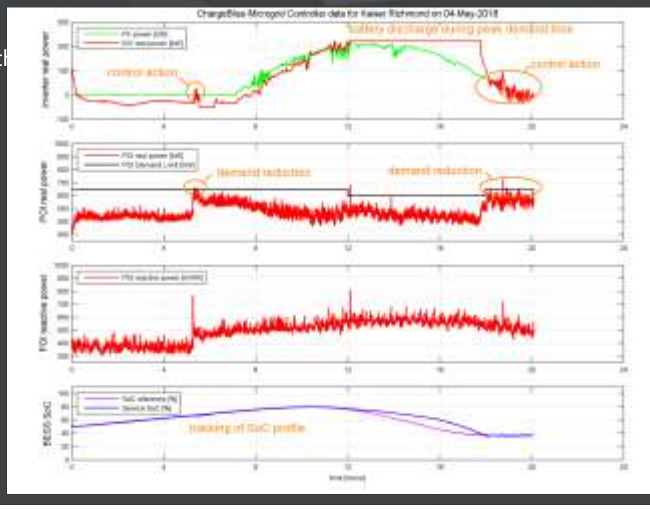
MICROGRID PERFORMANCE
Switch to Microgrid Control with Up/Down time

Features and Performance

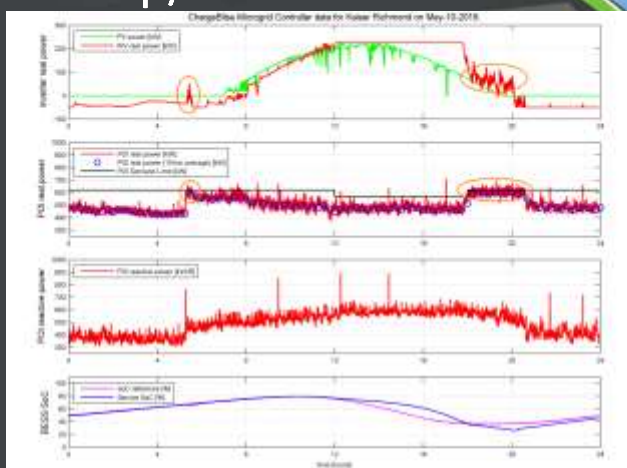
- Start of summer tariffs on May 15th
- Monetary savings determined by:
  - Solar Power time shifting
  - Energy Arbitrage
  - Demand Management



MICROGRID PERFORMANCE
May Performance and Up/Down time

External Microgrid Control Performance:

- Ran successfully until planned shutdown for installation of new auxiliary switch
- Stopped on May 22nd at 9pm for island testing and resumed on May 23rd
- Demonstrated demand management reduction of typically 100kW
- May 4, 2018 – May 31, 2018:
  up and running 26 days out of 27 days



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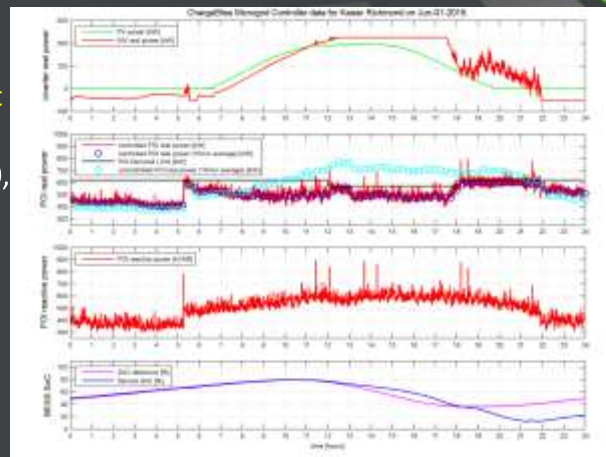
MICROGRID PERFORMANCE
June Performance with Up/Down time

External Microgrid Control Performance:

- Again demonstrated demand management reduction of typically 100kW
- Ongoing tuning: June 1, 2018 – June 30, up and running 21 days out of 30 days



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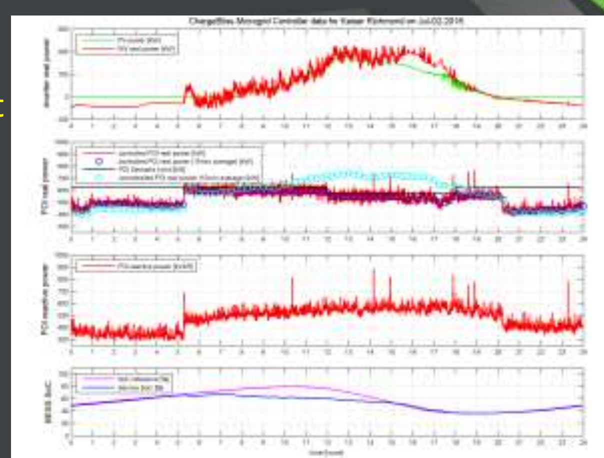
MICROGRID PERFORMANCE
July Performance with Up/Down time

External MicroGrid Control Performance:

- Demonstrated demand management reduction up to 140kW.
- No outage/trip yet



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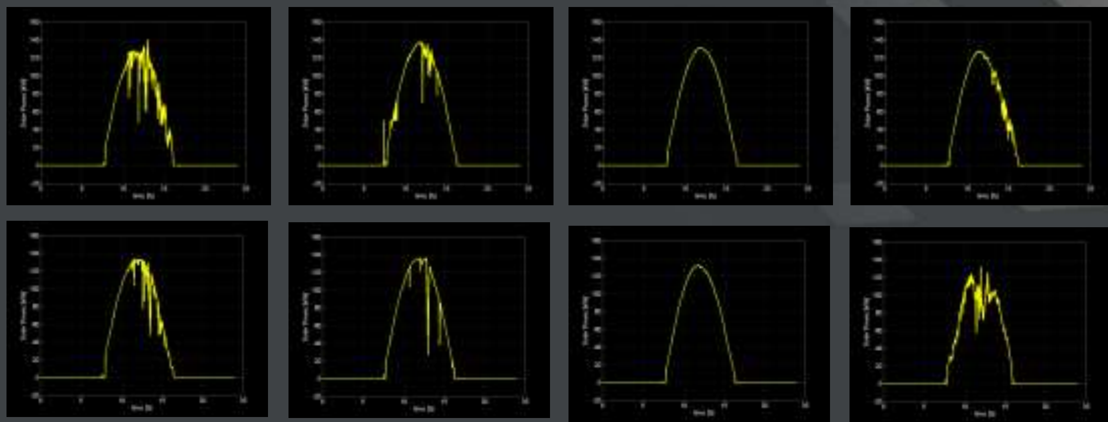
MICROGRID PERFORMANCE
Solar Generation



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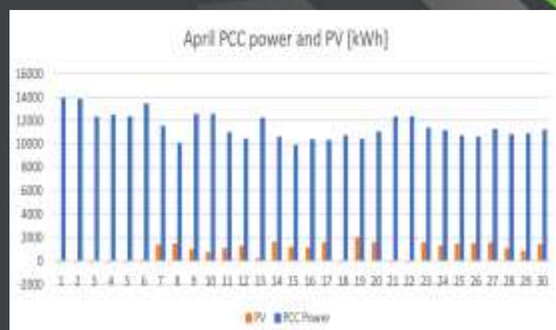
MICROGRID PERFORMANCE
Energy Generation via Solar

April:

- Average daily hospital energy consumption: 12330 kWh
- The average hospital peak load: 513.78 kW
- Average daily PV production: 862.93 kWh
- Total PV production/month: 25887 kWh
- Peak PV production: 1964 kWh on April 19th

7% of the hospital load was supplied by PV and remaining 93% was supplied by the Grid.



ECONOMIC PERFORMANCE FAR EXCEEDS THAT PREDICTED WITH PV ONLY

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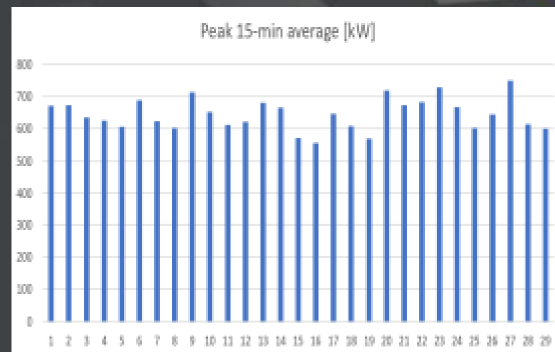
MICROGRID PERFORMANCE
Without Active Demand Reduction

April:

- Suspended active demand reduction for system tuning
- Without demand reduction, peak load baseline: 750 kW, on Friday April 27th



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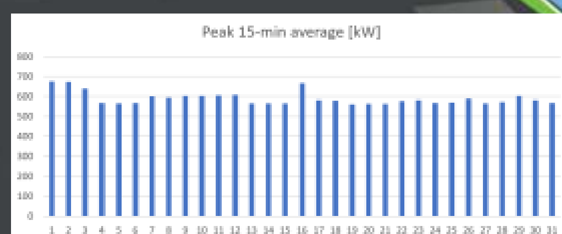
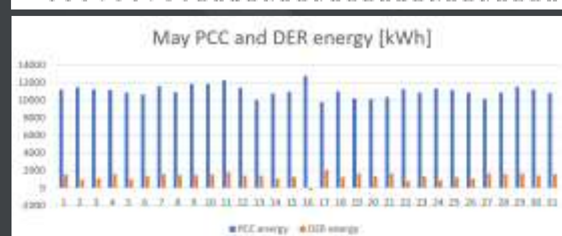
MICROGRID PERFORMANCE
Energy Generation + Active Demand Reduction

With external microgrid control in May:

- Active demand reduction
- Without demand reduction, peak load: 674 kW, on Friday May 1st
- Similar peak loads on May 1st, 2nd, 3rd and 16th due to External Microgrid controller being off.
- All other days peak is less then 600kW
- Demonstrates peak load reduction of +100kW





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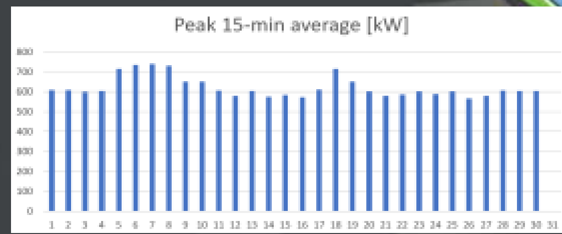
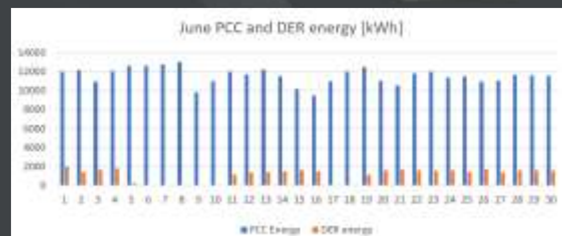
MICROGRID PERFORMANCE
Energy Generation + Active Demand Reduction

Ongoing tuning in June:

- Active demand reduction
- Without demand reduction, peak load: 740 kW, on Thursday June 6th
- Similar peak loads on June 7th, 8th and 18th ,19th due to External Microgrid controller being off (part of day) and peak load due to week day.
- June 9 and 10 are weekend
- All other days peak is less then 600kW
- Demonstrates peak load reduction of +100kW





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ECONOMIC ANALYSIS
Time of Use Savings

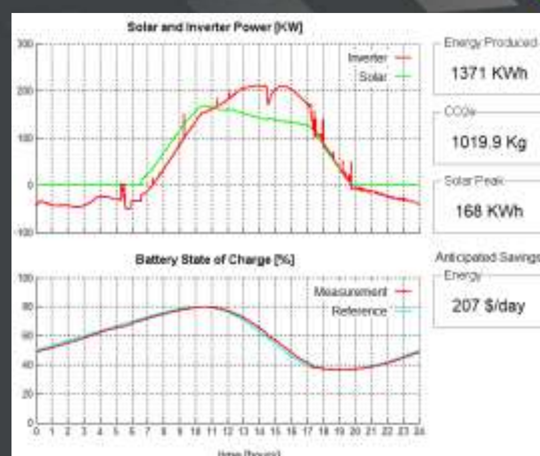
Energy pricing for Summer Tariffs:

- 0.15245 $/kWh 12pm-6pm (peak time)
- 0.11194 $/kWh 8:30am-12pm & 6pm-9:30pm
- 0.08512 $/kWh 9:30pm-8:30am and weekends

To optimize time of use savings:

- Battery is charged during off-peak time and when solar is available
- Battery is discharged during peak time

External Microgrid Controller:
tracking of the SoC reference profile



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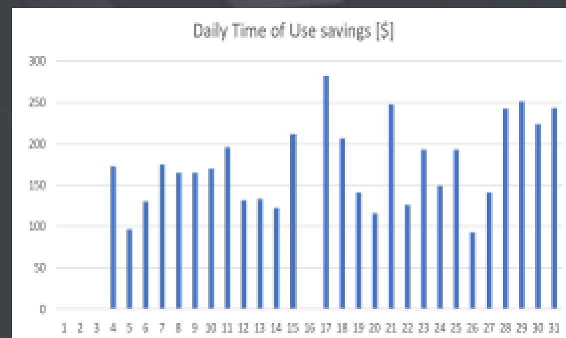
ECONOMIC ANALYSIS
Time of Use Savings

Time of Use Savings based on Summer Tariffs:

- 0.15245 $/kWh 12pm-6pm (peak time)
- 0.11194 $/kWh 8:30am-12pm & 6pm-9:30pm
- 0.08512 $/kWh 9:30pm-8:30am and weekends

Computed using the power generated by the inverter (red line)

SUBSTANTIAL SOURCE OF SAVINGS; ALSO CREATING LESS STRAIN ON UTILITY BY RELYING UPON LATE NIGHT ENERGY/POWER



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ECONOMIC ANALYSIS
Demand Reduction Savings/WEB PORTAL

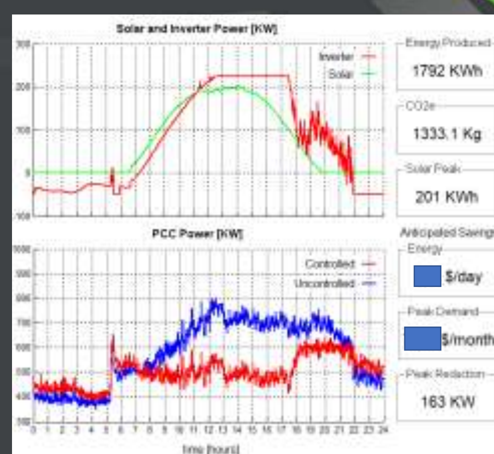
Demand pricing for Summer Tariffs:

- 18.64 * (peak of 12pm-6pm) +
- 5.18 * (peak of 8:30am-12pm & 6pm-9:30pm) +
- 17.57 * (peak of all day)

To optimize demand reduction savings:

- Real-Time Measurement of Power at POI/PCC
- Battery charge is used to provide power whenever Power at POI/PCC peaks above 600kW

External Microgrid Controller:
controlled power modulation of inverter, while racking of the SoC reference profile



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NEW DEVELOPMENTS
Microgrid Control with State Machine

Microgrid Controller:

- Scheduling of battery SoC to provide Time of Use savings
- Real-time measurements and power control for Demand Reduction Savings
- Works great if battery/solar/inverter are all working

In case of fault/trip:

- Email notification
- Manual restart

Desirable to automate restart via built-in state machine

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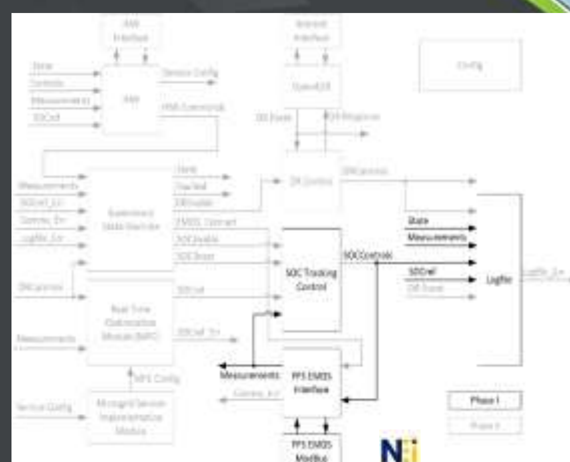
Future Controller Development Plan

- Phase 2.1 (in progress)
  - Implement OpenADR 2.0b interface
  - Design/implement DR Control module for PG&E Peak Day Pricing (PDP) program with static SOCref profile
  - NEI-funded; will provide royalty free license for Kaiser Richmond site
- Phase 2.2 (future)
  - Add Supervisory State Machine
  - Perform Failure Mode Analysis and develop Mitigation Strategy
  - Add Automatic Fault Recovery
- Phase 2.3 (future)
  - Add Real-Time Optimization Layer (MPC)
  - Add Microgrid Service Interface/Implementation modules
  - Implement Microgrid Services for PG&E Capacity Bidding Program (CBP) and PDP real-time optimization
  - Implement External Human-Machine Interface (HMI)



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PROJECT SUMMARY

- **ACHIEVED**
  - All design, engineering, permitting, interconnection construction, commissioning
    - OSHPD
    - Rule 21
  - Solar energy production
  - Energy arbitrage
  - Demand Reduction
  - Controller design, inverter communication and regulation
  - Islanding
  - Visualization tool
- **ONGOING**
  - Power quality regulation
  - Demand response/Grid services

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NEXT STEPS

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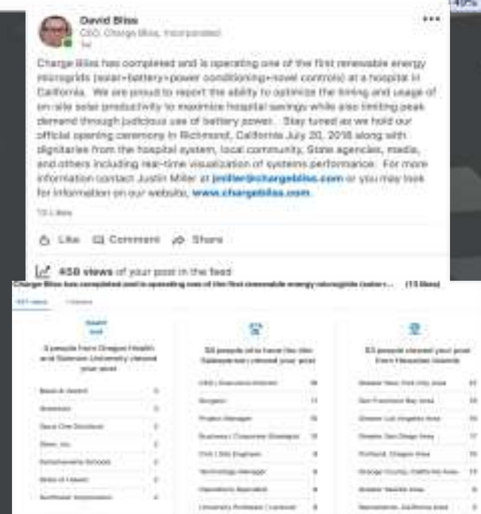
KNOWLEDGE DISSEMINATION

1. WEBSITE INFORMATION: www.chargebliss.com
2. Publications and Presentations
   A. De Callafon, Bliss, "The Kaiser Richmond Microgrid: scheduling and control of renewable power with phasor feedback." NASPI
   B. CEC microgrid conferences x3, Bay area architects, upcoming Homer, SPI/ESI, and ESNA conferences
   C. Upcoming Opening Ceremony, Technical Deep Dive (CPUC, CAISO, PG&E, Kaiser, CEC, Media)
   D. Teaching PG&E Microgrid Course

3. Linked-in
4. CHARGE BLISS ROLL-OUT TO HOSPITALS

Number of web hits on web pages that describe project research results	290/month
Average session duration*	2 min, 9 sec
Bounce rate*	49%



1. FOLLOW-UP MEETINGS BETWEEN CHARGE BLISS, IOU, ISO, CPUC TO REFINE GRID SERVICES COMMUNICATIONS AND VALUE

2. DETERMINE TARGET INFRASTRUCTURE

3. DETERMINE OPTIONS FOR COLLABORATION

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