Energy Research and Development Division
FINAL PROJECT REPORT

CERTS MICROGRID DEMONSTRATION WITH LARGE-SCALE ENERGY STORAGE AND RENEWABLES AT SANTA RITA JAIL

Appendices A - C

Prepared for: California Energy Commission
Prepared by: Chevron Energy Solutions Company A Division of Chevron U.S.A. Inc.

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APPENDICES

APPENDIX A:
NREL: Santa Rita Jail Microgrid Report

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Santa Rita Jail Microgrid Report

W. Kramer, D. Martin, G. Martin
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Technical Report for **Subtasks 23.1-A and 23.1-B**
Santa Rita Jail Project
June 2013

Contract No. DE-AC36-08GO28308

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NOTICE

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List of Acronyms

CERTS	Consortium for Electric Reliability Technology Solutions
DOE	U.S. Department of Energy
HOMER	Hybrid Optimization Model for Electric Renewables
NREL	National Renewable Energy Laboratory
PCC	Point of common coupling
pf	Power factor
PG&E	Pacific Gas and Electric Company
PV	Photovoltaic
VAR	Volt Ampere Reactive

Executive Summary

The Santa Rita Jail is located in Dublin, California within Alameda County. The Jail is the 5th largest in the United States and houses between 4,000 and 4,500 inmates. The microgrid provides critical power to the Jail when the site loses utility power. The microgrid is designed using multiple generation sources including: diesel generators, a combined heat and power gas driven fuel cell, electrochemical energy storage, small wind and various types of both fixed and tracking photovoltaic systems. Even when the jail is connected to the utility, the microgrid assets provide much of the power to serve the site's electrical loads without back-feeding power to the utility. The object of this report is to provide the monitoring and verification results for the 1st year including an assessment of hardware and software capabilities to monitor, collect data, and control the microgrid system. The first task, 23.1-A, provides an assessment that informed system designers about any limitations or issues with the installed system and provides an outline some best practices of how to achieve robust and optimal microgrid system control, and provides recommendations for future installations and/or upgrades. The second task, 23.1-B, provides the results of a system level evaluation through simulation of the microgrid using the Homer modeling tool to provide further insight in the cost savings for various scenarios.

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Introduction

The objective of the overall microgrid project is to design, deploy and optimize the performance of an advanced microgrid that includes a photovoltaic (PV) solar array, a fuel cell, a battery and diesel fueled engine generators at the Alameda County Santa Rita Jail located in Dublin, California. The primary purpose of the microgrid is to provide backup power to critical electrical loads at the facility if there is a loss of power from the electric utility. Under normal conditions, when the microgrid is electrically connected to the utility, power generated by the solar array, fuel cell and battery are operated together with electrical power from the utility to provide power to the jail facility. The system monitors the status of the utility and provides a seamless transfer between grid-connected and islanded operation in cases of when utility outages or power quality issues occur. Alameda County, California Public Utilities Commission, Pacific Gas and Electric, the U.S. Department of Energy, the Department of Defense Climate Change Fuel Cell Program, the California Energy Commission, the California Public Utilities Commission, and California Self-generating Incentive Program provide funding for the microgrid project.

Under funding provided by the U.S. Department of Energy (DOE), The National Renewable Energy Laboratory (NREL) provides technical support to the project to monitor and validate the performance of the microgrid's sensors, components, systems, and controls, and suggest recommendations for operational and equipment improvements through site visits, analysis and simulation.

The overall layout for the Santa Rita Jail Microgrid is given in Figure 1. The facility includes: Two 1.2 MW engine-driven generators that are fueled using diesel; roof-mounted solar arrays at the housing units; tracking solar arrays, a natural gas-fueled, molten carbonate fuel cell fueled by natural gas; four 500 kW lithium ion battery storage systems; and five small wind turbines. Each of the generating sources is connected at different points on the campus electrical distribution system.

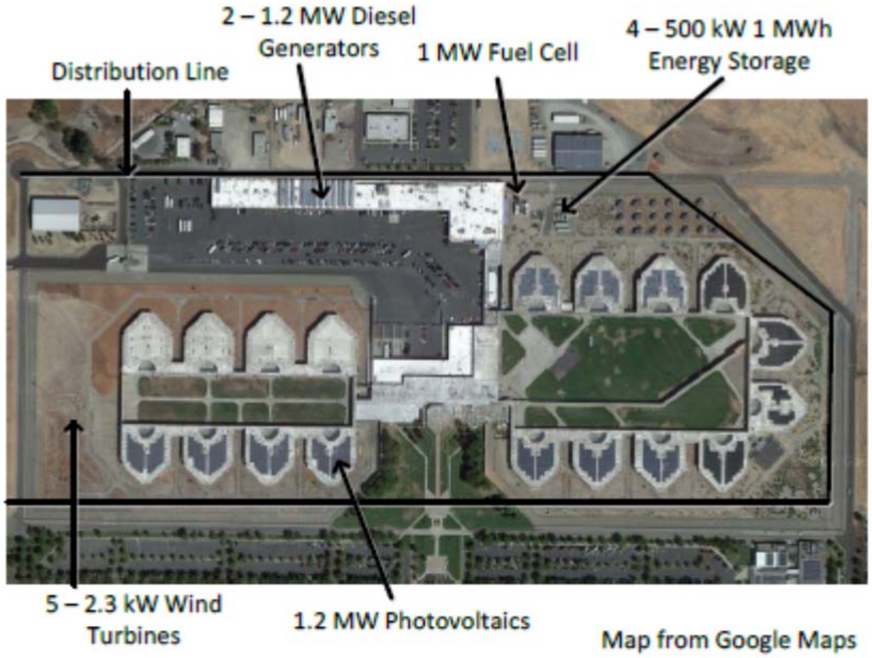

Figure 1 Santa Rita Jail Microgrid Layout

Prior to the deployment of the microgrid, the two 1.2 MW diesel generators were the only sources of power for backup power. The addition of the new microgrid generation resources provides redundancy in power generation, reduced diesel usage during emergency microgrid operation, and a reduction in the power provided by the utility during grid-connected operation. The jail uses automated systems that deliver laundry, supplies, and food to the campus. It also includes on-site medical and mental health services. Continuous electric power delivery is essential for the facility's operation.

The primary reason the microgrid was installed is to provide backup power to critical electrical loads at the jail should there be a loss of power. Under normal conditions, when the microgrid is electrically connected to the utility, power generated by the solar array, fuel cell and battery are operated together to reduce the power required from PG&E. The fuel cell operates with an efficiency of approximately 47%. The energy storage control design is intended reduces load during the peak period from noon to 6 pm and also prevents power export. The energy storage is designed to charge during the night. Table 1 below provides the rated capacity for the on-site generation systems installed at the campus.

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Table 1 Santa Rita Jail Microgrid Generation Resources

Rated Power	Generator Type
1.2 MW	Solar PV array
1 MW	Fuel cell with heat recovery for domestic hot water, molten carbonate technology
2.4 MW	Diesel Generators
2 MW	Lithium ion energy storage, 4 MWh capacity (3 MWh useable)
11.5 kW	5 Wind Turbines
6.61 MW	**Total generation**

The Santa Rita Jail uses a loop distribution system as shown on Figure 2. The electrical distribution circuit is designed to provide both reliability and flexibility for electricity delivery. If a device fails, such as a transformer within the Santa Rita Jail distribution system, the device can be isolated from the distribution circuit using switches to allow remaining systems to operate. The distribution circuit is designed so that the electrical loads can be fed from two different electric busses.

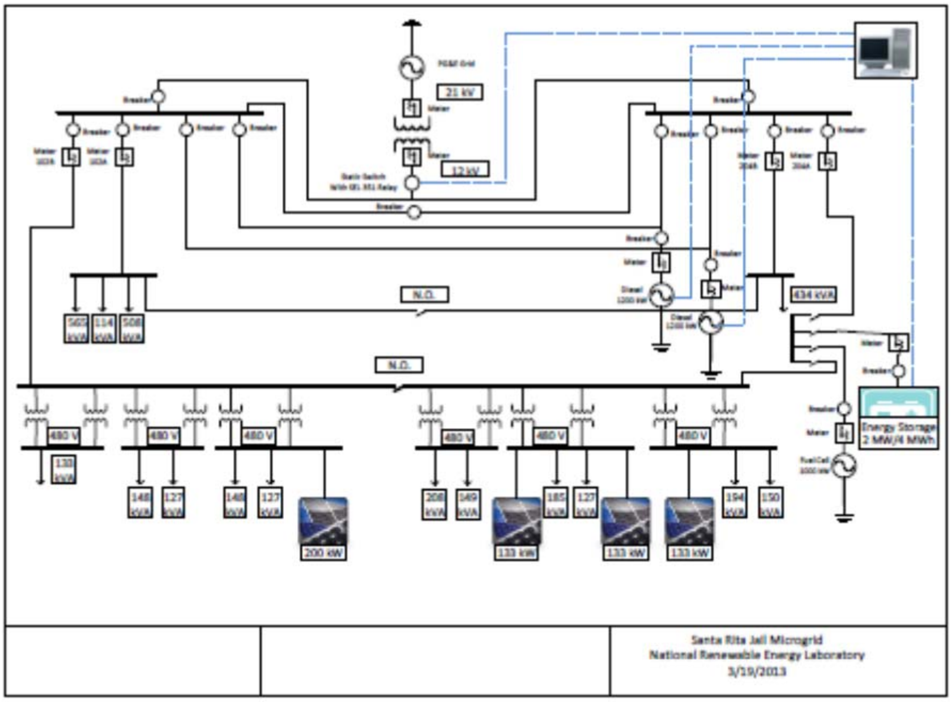

Figure 2 Santa Rita Jail Electric Distribution System

If a utility outage occurs, the Santa Rita Jail microgrid is designed to disconnect from the utility feed using the static switch at the 12 kV service entries shown at the top of Figure 2. The static switch is a fast acting switch that can switch much faster than a conventional circuit breaker. Once isolated from the utility, the design intent is to immediately utilize the microgrid generation assets to provide the power required to serve the facility's loads. The system is designed using the Consortium for Electric Reliability Technology Solutions, CERTS, control methodology. CERTS provide a seamless transition back and forth between utility-connected and islanded conditions. The advantage of this control methodology in that it allows the entire microgrid generating resources to always operate in voltage mode control, even when connected to the utility.

This report provides the results for Subtask 23.1-A and 23.1-B listed in the Chevron statement of work to Alameda County. The report is separated into six sections and includes an Executive Summary, Bibliography, and List of Acronyms. Section 1 of the report provides an evaluation of the monitoring, metering and data acquisition systems. Section 2 of this report describes the simulation results for sizing energy storage needed for different fuel cell and PV output power using the simulation tool Homer. The section also estimates monthly demand and energy savings and other financial opportunities for cost saving

1 Task 23.1-A Evaluation of Monitoring, Metering and Data Acquisition Systems

1.1 Metering

The metering at the site includes two main power meters: the ION 6200 and the ION 7650. Each meter is currently set to measure power and energy variables in 15-minute intervals. The power meters have the capability for more frequent measurements through a program interface including event triggering. The type of measurement and communications available for the two power meters are given in Table 2 and Table 3.

Table 2 ION 6200 Power Meter

Measurements	Communications
Voltage L-N	Modbus
Voltage L-L	RS-485
Frequency	
Current	
kW	
kWh	
pf	
Voltage THD	
Current THD	

Table 3 ION 7650 Power Meter

Measurements	Communications
Power, energy, demand	IEC 61850
Harmonics	RS-232/485; Ethernet; optical
Symmetrical components: zero, positive, negative	Internal Modem
Flicker	DNP 3.0
Time Stamp	Modbus; Modbus TCP

	EtherGater, Modem Gate, MeterM@il, WebMeter
	Relay outputs

1.2 Network and Servers

The communication network for the microgrid contains components from both Encorp and Applied Power Technologies, Inc. (APT). Encorp installed "Gold Boxes" which are programmable logic controllers (PLC) for the static switch, the diesel generators, the energy storage, and the load control. It provides the hardware interface between many power devices including meters, relays, human machine interface, servers, and other equipment. APT provided the power meters and programmed the PLC for control of the energy storage. APT provided a server that acts as a supervisory controller and stores power data from the microgrid meters and can display power data in real time.

1.3 Load Control Summary

The Encorp control system includes a method for load shedding. The loads are classified into three categories: 'A', 'B', and 'C'. 'A' loads are the most critical loads; 'B' loads are the next most critical loads, and 'C' loads are the least critical loads. The human machine interface allows the controllable loads to be programmed into any category at anytime. The microgrid control defines which loads will be connected under various conditions. For example, during grid-connected, non-islanded operations all of jails loads are connected. Should power from the utility be lost and the microgrid disconnects from the utility, 'C' loads are shut off while 'A' and 'B' loads remain connected to the microgrid sources. If the frequency falls out of a set frequency range, the 'B' loads will be disconnected.

1.4 Recommendations for Metering and Monitoring

- Develop procedures and companion software for the operations staff to follow should in case of the failure of the communications or supervisory control.
- Perform regular security audits and maintain software revision control as the system undergoes software and hardware upgrades.
- Provide a redundant server that can take control in real-time should the primary server fails.
- Calibrate meters and sensors on a six or twelve month cycle.
- Add a weather station including solar irradiance sensing and full sky imagery.
- Instrument or provide a means to collect data on un-monitored PV systems at the site together with the other microgrid data.

2 Task 23.1-B System Modeling and Analysis

2.1 Homer Simulation Tool

The HOMER simulation tool can be used to estimate the best equipment sizes for optimizing the economics, and overall dispatch operation of a microgrid. The model uses cost and simulated power output predictions for the optimization. The HOMER calculations used in this report were made based on an hour time step. HOMER does not calculate voltages and currents or simulate grid transients in the sub-millisecond time. A simulation study was conducted to estimate necessary energy storage sizes for each recommendation. The primary inputs used for the simulation are given in Table 4.

Table 4 HOMER Simulation Inputs and Outputs

Inputs	Outputs
Wind resources Solar resource Electric costs from PG&E Schedule E-20 (Table 6) Diesel operation Natural gas costs for fuel cell Wind operation and maintenance costs Solar operation and maintenance costs Fuel cell operation and maintenance costs Energy storage operation and maintenance Costs	Operation of loads and generation

HOMER uses yearly profiles for each source. At the time the simulation was conducted, only two days of data for site were available. The Homer simulation utilized a scaled yearly load profile that PG&E's publishes on their website to describe the average dynamic load profiles for each of its rate customers. The average customer load profile was scaled to match the Jail's measured loads for July 17, 2012 and July 18, 2012 as shown in Figure 3. The solar production profile for the site was approximated using yearly solar irradiance data for the site from a software tool called PVWatts developed at NREL. PVWatts approximates solar output of a theoretical PV array based on past irradiance data for sites across the world. An Irradiance meter located close to Dublin, CA was used to estimate the yearly irradiance data. The PV solar system size was adjusted to match the solar output from the data in Figure 3. As a result, the modeled PV system was a single 550 kW PV system which represents where the amount of PV power the site is currently producing which is much less that the rated power.

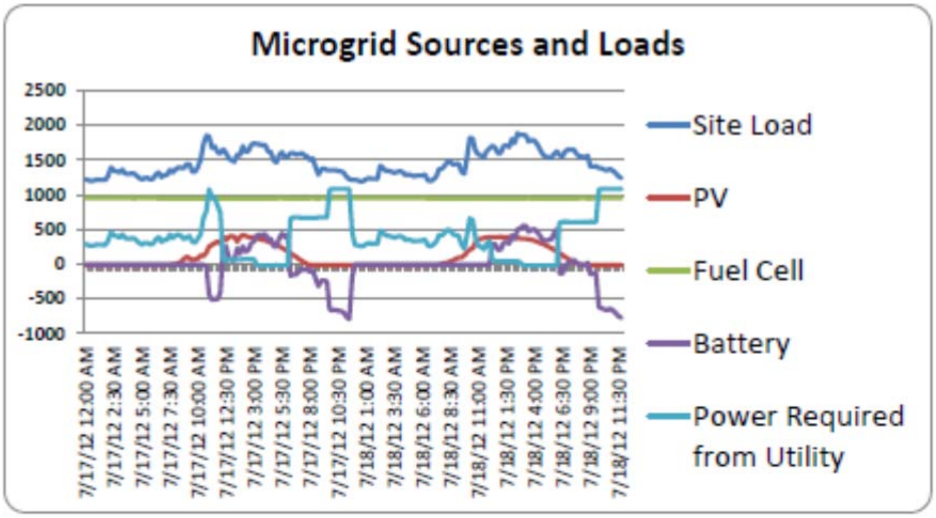

Figure 3 Site Load and Microgrid Energy Sources

The HOMER simulation was setup to predict the minimum required energy storage power and energy storage capacity necessary for preventing export to the utility using the existing PV and Fuel Cell generating sources as well as due to increasing the fuel cell and solar PV power production. The analysis assumed that the PV and fuel cell power could not be modulated or controlled to match the estimated scaled electrical site load described above. Homer simulations were conducted and analyzed for one year. Figure 4 through Figure 7 show the results to determine the days that would have the greatest impact on the energy storage requirments given the generation scenario that was simulated avoid power export to the utility and is depicted as the "Excess Electricity" curve in each of the Figures. The required energy required by the battery was estimated by integrating the area under the "Excess Electricity" curve. The plot labeled "AC Primary Load" is the approximate load of the site using the two days of data used for the model and scaled site load based on PG&E's published load profiles. The plot labeled "PV Power" is the approximate PV electric power output. The plot labeled "Fuel Cell Power" is the electrical power output of the fuel cell.

Table 5 provides a summary of the simulation results to estimate the energy storage requirements should the jail consider adding additional PV and fuel cell generation resources.

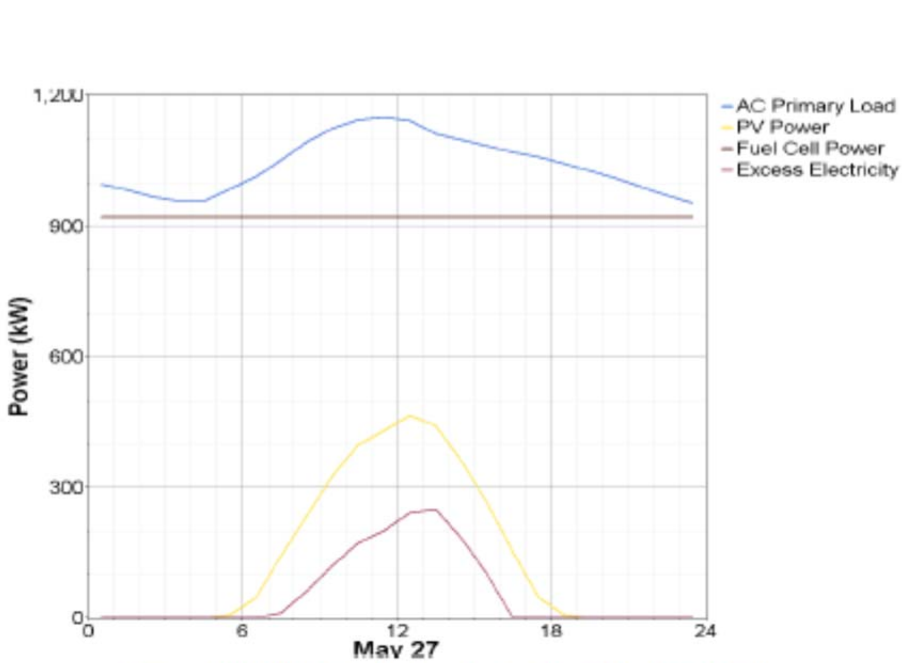

Figure 4 HOMER Simulations for Baseline PV and Fuel Cell

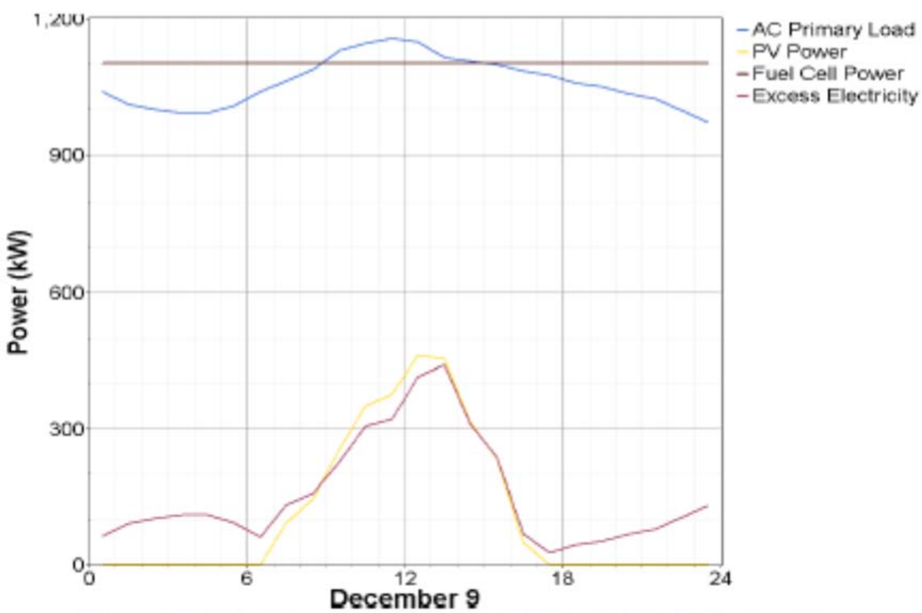

Figure 5 HOMER Simulations for 1,100 kW Fuel Cell and Baseline PV

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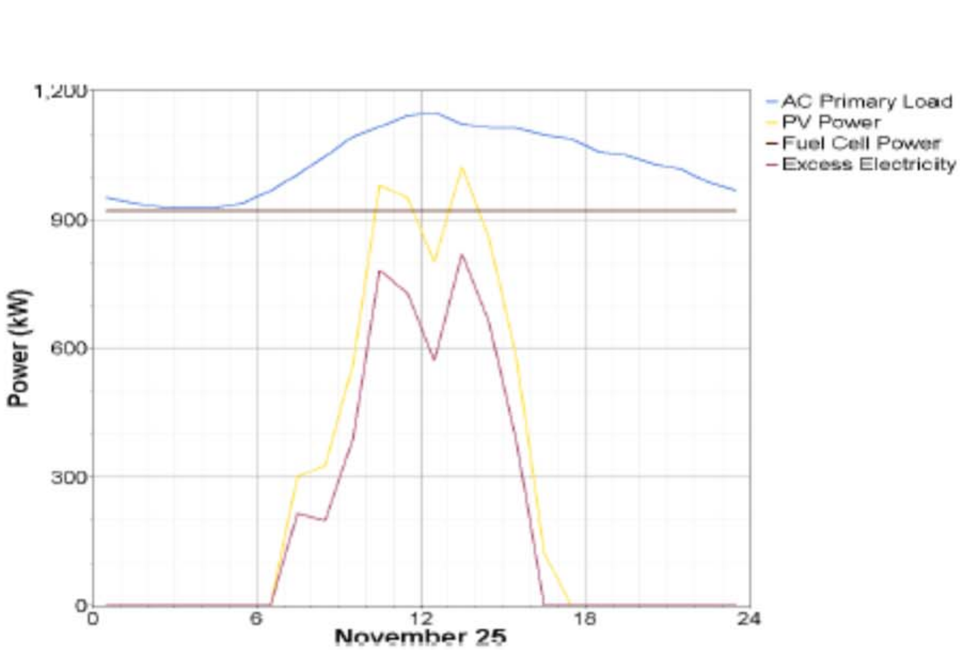

Figure 6 HOMER Simulations for Baseline Fuel Cell and 1,200 kW PV

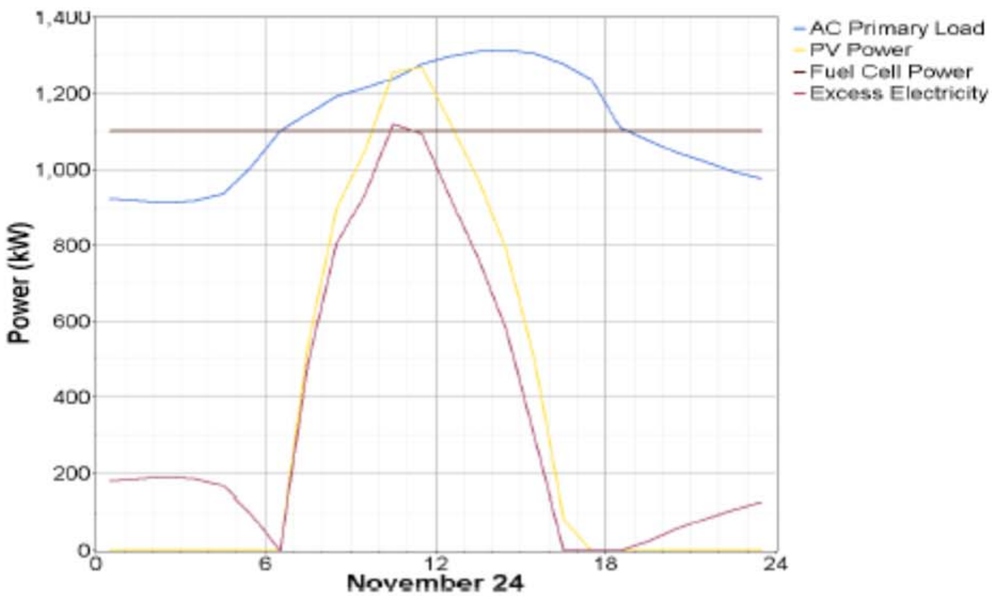

Figure 7 HOMER Simulations for 1,100 kW Fuel Cell and 1,200 kW PV

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Table 5 Estimated Energy Storage as a Function of Fuel Cell and PV Size

Fuel Cell Size	PV Operation	Required Energy Storage	Figure Reference
950 kW	550kW (existing)	500 kW, 3 MWh (existing)	(Figure 4)
1100 kW	550 kW (existing)	1 MW, 5 MWh	(Figure 5)
950 kW	1.2 MW output	2 MW, over 5 MWh	(Figure 6)
1100 kW	1.2 MW output	2 MW, 10 MWh	(Figure 7)

It should again be noted that actual loads for a year were not available at the time the Homer simulation was conducted. The control strategy implemented at the time of this report charges the battery during the off-peak hours with the goal of being at full SOC in order to reduce peak electric demand. Future dynamic simulations could be conducted using actual yearly load data to evaluate existing and future generation resource scenarios and control methodologies.

2.2 Santa Rita Load Analysis

Alameda County provided operational data for microgrid operations to NREL for one year beginning in January 2012. Analysis of the data for the year showed that the minimum demand occurred between January 14, 2012 and January 21, 2013. Figure 8 shows a plot of the demand during this time period. Analysis of the data shows that site exported 4.8 kW back to the utility for a few of the 15-min demand time intervals during this time period.

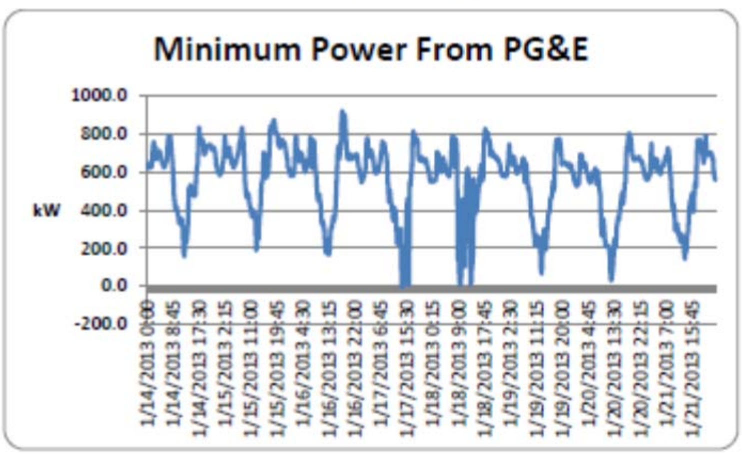

Figure 8 Minimum Power Demand Provided from PG&E 1/14 to 1/21

Figure 9 shows that the maximum demand provided by the utility for the site occurred between November 25, 2012 and December 1, 2012. The data shows that the power spiked to about 2,300 kW. The average demand during the first part of the week was 500kW and the average demand at the end of the week was about 1,500 kW.

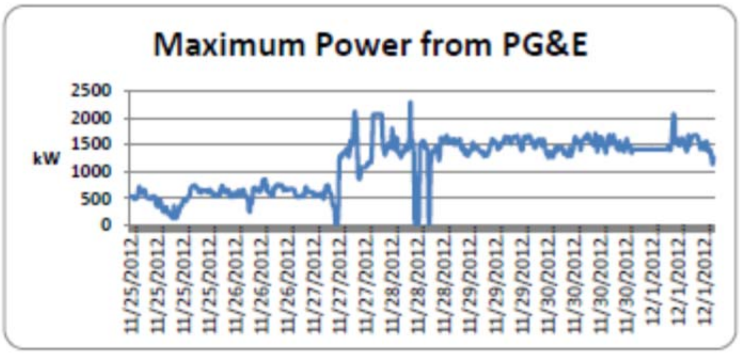

Figure 9 Maximum Power Demand Provided from PG&E 11/25 to 12/1

The total site demand is a measurement of the total power required to serve the site's load that is provided by both the utility and the microgrid generation assets. Analysis of the data for a year shows that the minimum total demand occurred between November 25, 2012 and December 1, 2012. A graph for the total demand during this time period is given in Figure 10. The outages shown in the Figure represent the expected outages that occurred during commissioning.

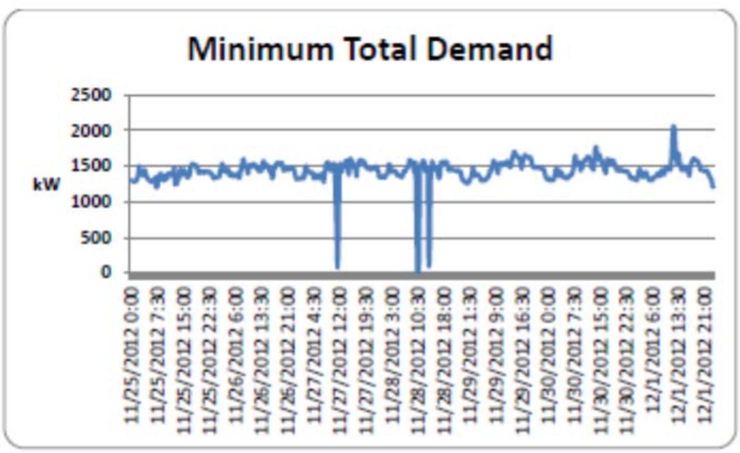

Figure 10 Minimum Total Site Power Demand 11/25 to 12/1

Table 6 PG&E Electricity Rate Schedule E-20 Primary

Rate Name	Times	Days	Rate ($)
Maximum Peak Demand Summer ($/kW)	12:00 noon to 6:00 p.m.	Monday-Friday except holidays	$15.40/kW
Maximum Part-Peak Demand Summer ($/kW)	8:30 a.m. to 12:00 noon and 6:00 p.m. to 9:30 p.m.	Monday-Friday except holidays	$3.23/kW
Maximum Demand Summer ($/kW)			$9.33/kW
Maximum Part-Peak Demand Winter	8:30 a.m. to 9:30 p.m.	Monday-Friday except holidays	$0.25/kW
Maximum Demand Winter ($/kW)			$9.33/kW
Peak Summer ($/kWh)	12:00 noon to 6:00 p.m.	Monday-Friday except holidays	$0.13097/kWh
Part Peak Summer ($/kWh)	8:30 a.m. to 12:00 noon and 6:00 p.m. to 9:30 p.m.	Monday-Friday except holidays	$0.09268/kWh
Off-Peak Summer ($/kWh)	9:30pm to 8:30 a.m. and All day on weekends/holidays		$0.07028/kWh
Part-Peak Winter ($/kWh)	8:30 a.m. to 9:30 p.m.	Monday-Friday except holidays	$0.08835/kWh
Off-Peak Winter ($/kWh)	9:30 p.m. to 8:30 a.m. and all day on weekends/holidays		$0.07376/kWh

Note: pf Adjustment rate ($/kWh/%): $0.00005/kWh/%

Note: Summer (May 1 to October 31), winter (November 1 to April 30)

Additionally, the pf charge is $0.00005/kWh/%. The rate states:

> The rate charges (based on actual utility bill for the site) are adjusted based upon the power factor. The power factor is computed from the ratio of lagging reactive kilovolt-ampere-hours to the kilowatt-hours consumed in the month. Power factors are rounded to the nearest whole percent. The rates in this schedule are based on a power factor of 85 percent. If the average power factor is greater than 85 percent, the total monthly bill will be reduced by the product of the power factor rate and the kilowatt-hour usage for each percentage point above 85 percent. If the average power factor is below 85 percent, the total monthly

bill will be increased by the product of the power factor rate and the kilowatt-hour usage for each percentage point below 85 percent. Power factor adjustments will be assigned to distribution for billing purposes.

For example, if the meter used for billing at the point of common coupling (PCC) measures a pf of 0.7 and a power level of 300 kW for one hour then the rate will be (1):

$$pF_{rate} = 0.00005 \times (0.85 - 0.7) \times 100 \times 300kW \times 1_{hour} = \$0.225 \quad (1)$$

Table 7 provides the costs/therm rates for each month during 2012 for the site.

Table 7 Santa Rita Jail Monthly Natural Gas Rates

Month	Natural Gas Rate
January 2012	$0.469/Therm
February 2012	$0.459/Therm
March 2012	$0.44/Therm
April 2012	$0.417/Therm
May 2012	$0.431/Therm
June 2012	$0.476/Therm
July 2012	$0.46/Therm
August 2012	$0.48/Therm
September 2012	$0.459/Therm
October 2012	$0.477/Therm
November 2012	$0.494/Therm
December 2012	$0.493/Therm

When the microgrid is grid-connected the amount of power and energy required by the Jail from the utility the microgrid generation resources assist the utility resources to serve the Jail's electrical load. Figure 12 provides an estimate of the monthly electrical demand savings and Figure 13 provides an estimate of the electric energy reduction required from the utility. Both measurements are measured at the point of common coupling between the Utility and Jail's microgrid. Figure 12 shows that during July 2012, 3 different demand rates must be considered for to determine demand including: the maximum peak demand, part-peak demand, and the maximum demand. The part-peak summer period shown in red occurs from 8:30 a.m. to noon and 6:00 p.m. to 9:30 p.m. The reduced demand is primarily due to the fuel cell and PV power generation. If the microgrid generation was not operating properly for only one-15 minute interval during the month, Alameda County would have been assessed an estimated demand charge of 825 kW at a rate over $15/kW.

The maximum total demand occurred during the week of March 23rd to March 30th in 2013 and is given in Figure 11. The maximum total demand used by site's loads was over 3,000 kW during this week.

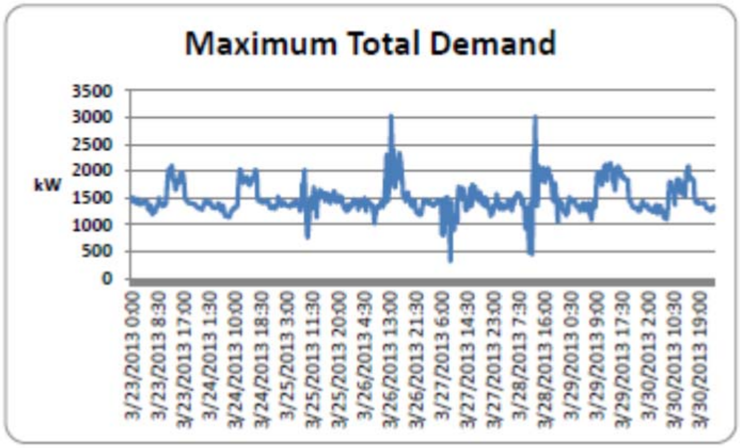

Figure 11 Maximum Total Site Power Demand Used 3/23 to 3/30

2.3 Microgrid Cost Savings During Grid-Connected Operations

Further analysis was performed to estimate the monthly electrical energy and demand savings that the microgrid generation assets provide during grid-connected operations. When the microgrid is grid-connected to the utility the amount of power and energy required by the Jail from the utility is reduced as the microgrid generation resources assist the utility resources to serve the Jail's electrical loads. Table 6 gives a summary of costs that PG&E's charges during various time and season intervals. The data for the table is based on The E-20 rate structure from PG&E's web site. The table shows that he highest utility costs for both demand and energy occur between 12AM and 6PM Monday through Friday during the summer where the peak demand charge is $15.40/W and the peak energy charge $0.13097/kWh.

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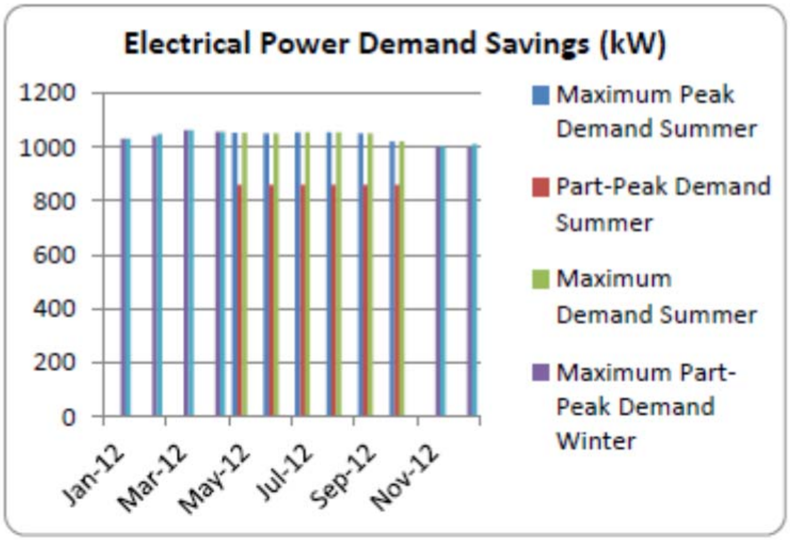

Figure 12 Estimated Monthly Demand Savings (kW)

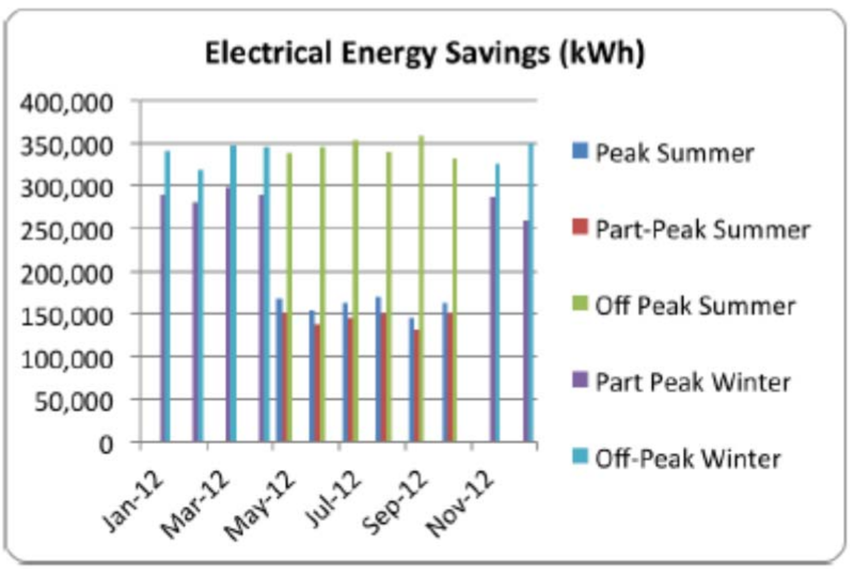

Figure 13 Estimated Monthly Energy Savings (kWh)

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Using the data from Figure 12, Figure 13 and the rate tables above, the estimate dollar cost savings for both demand and energy are given in Figure 14 and Figure 15 respectfully.

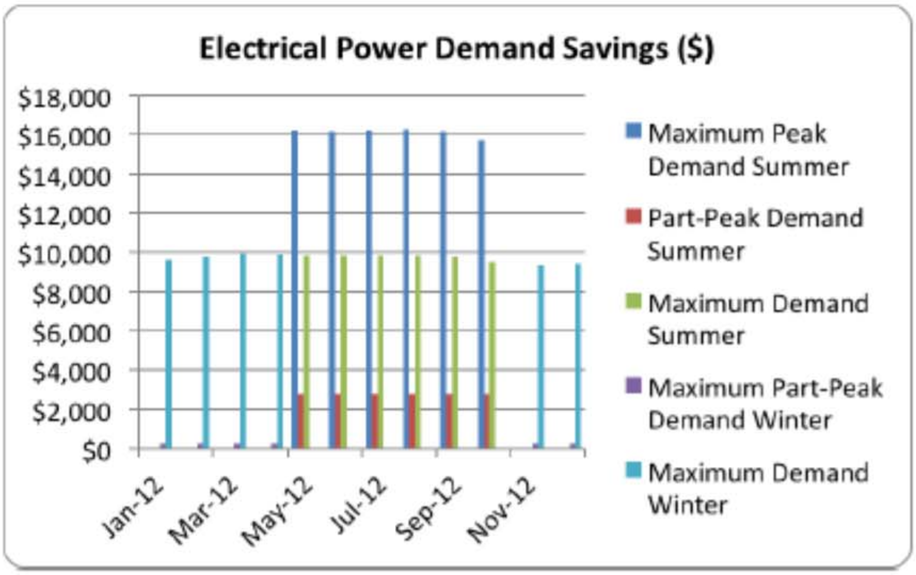

Figure 14 Estimated Monthly Demand Savings ($)

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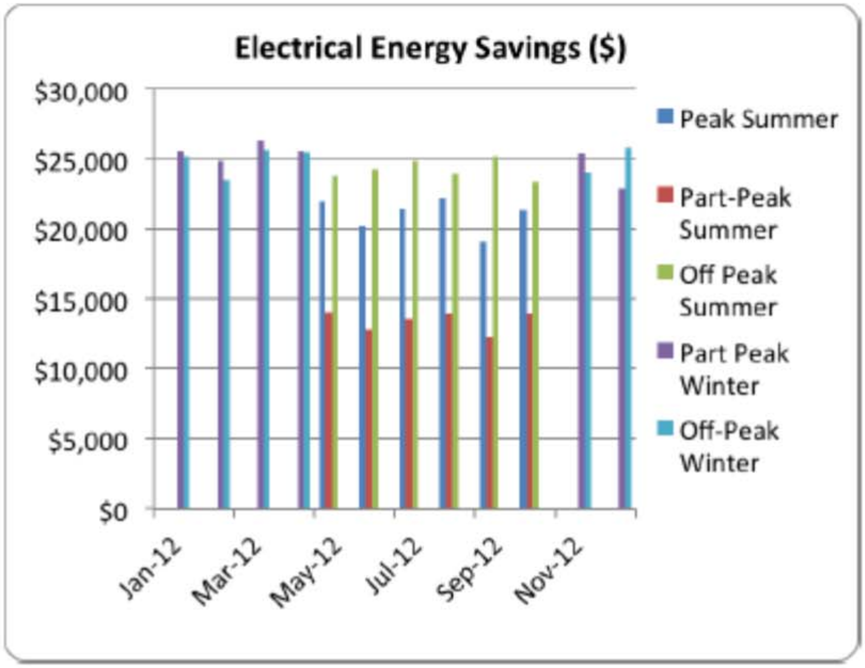

Figure 15 Estimated Monthly Energy Cost Savings ($)

The predicted total utility cost savings for each month is the sum of the demand and energy cost savings.

2.4 Recommendations

- An advanced control strategy to control both the generation sources and loads together should be considered that can more effectively reduce the summer electric demand and to allow Alameda county to effectively participated in PG&E's demand response programs. Table 8 provides a description of each demand programs from PG&E's website for Alameda County to consider together with PG&E.
- Hardware and software control systems should be designed to keep the system running 24/7 to avoid peak demand and energy charges from the utility.

Table 8 PG&E Demand Response Programs 2013

Program	Incentive	Requirement	
Peak Day Pricing (PDP)	**Reduced Rates**	Customers who participate in PDP will experience between 9 and 15 PDP Event Days annually in addition to time-of-use pricing. On PDP Event Days, a surcharge is added to a portion of the peak period (i.e., from 2 p.m. to 6 p.m.) which customers will pay in addition to their regular peak electric rate.	http://www.pge.com/mybusiness/energysavingsrebates/timevaryingpricing/peakdaypricing/
Base Interruptible Program (BIP)	**$9/kW**	BIP gives you 30 minutes advance notice. You will receive a monthly incentive payment even if no events are called. However, failure to reduce load down to or below your Firm Service Level during an event will result in a charge of $6.00/kWh for any energy use above the Firm Service Level. There is a maximum of one event per day and four hours per event. The Program will not exceed 10 events per month, or 120 hours per year.	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/baseinterruptible/
Demand Bidding Program (DBP)	**$0.50/kW or $0.60/kW**	For day-ahead events, you will receive an event notice by noon on the business day before the planned event. You will have until 3 p.m. that day to submit bids via InterAct. For day-of events, you will have one hour after receiving the event notice to submit bids via InterAct. PG&E will notify participants of bid acceptance within 15 minutes of the bid acceptance window closing.	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/dbp/
Optional Binding Mandatory Curtailment (OBMC) Plan	**Varies**		http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/obmcp/
Scheduled Load Reduction Program (SLRP)		You select one to three four-hour time periods (between 8 a.m. and 8 p.m.) on one or more weekdays. You are required to reduce load each and every time your selected SLRP options (day of the week and corresponding elected time) occur. Your load reduction cannot be shifted to an on-peak time period (noon to 6 p.m.) on another day.	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/slrp/
Permanent Load Shift	**Under Development**		
SmartAC	**No Longer Available**		
Aggregator Managed Portfolio (AMP)	**Varies**	Many aggregators possible	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/amp/

Capacity Bidding Program (CBP)	**Varies**	Load reduction commitment is on a month-by-month basis, with nominations made five days prior to the beginning of each month. Customers must enroll with (or as) a third-party aggregator to join the Capacity Bidding Program. 1-4 Hour: June: $4.27/kW. July: $17.94/kW. August: $24.81/kW. September: $15.30/kW.	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/cbp/
Automated Demand Response	**Between $125/kW and $400/kW**	PG&E pays between $125 per kilowatt (kW) and $400 per kW of DR load reduction (dispatchable load) that will be controlled by the technology, depending upon the technology category program selected.	http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/adrp/
Dual Enrollment	**Many options**	Varies options with PDP, BIP, DBP, OBMC, AMP, CBP	http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/demandresponse/baseinterruptable/DR_DualParticipation.pdf

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APPENDIX B:
IEEE: CERTS Microgrid Demonstration with Large-Scale Energy Storage and Renewable Generation

CERTS Microgrid Demonstration with Large-Scale Energy Storage and Renewable Generation

Eduardo Alegria, *Member, IEEE;* Tim Brown, *Member, IEEE;* Erin Minear, *Member, IEEE;* Robert H. Lasseter, *Fellow, IEEE*

***Abstract*—. The Consortium for Electric Reliability Technology Solutions (CERTS) Microgrid concept captures the emerging potential of Distributed Energy Resource (DER) using an automatous plug-and-play approach. CERTS views generation and associated loads as a subsystem or a "Microgrid." The sources can operate in parallel to the grid or can operate in island, providing high levels of electrical reliability. The system can disconnect from the utility during large events (i.e., faults, voltage collapses), but also may disconnect intentionally when the quality of power from the grid falls below certain standards. CERTS Microgrid concepts have been demonstrated at the Alameda County Santa Rita Jail in California. The existing system included a 1-MW fuel cell, 1.2 MW of solar photovoltaic, and two 1.2-MW diesel generators. Adding a 2-MW, 4-MWh storage system, a fast static switch, and a power factor correcting capacitor bank enabled microgrid operation. The islanding and resynchronization methods met all Institute of Electrical and Electronics Engineers Standard 1547 and the reliability requirements of the jail.**

***Index Terms*—Distributed Generation, Distributed Resource, Islanding, Microgrid, Smart Grid, Renewable Energy, Advanced Energy Storage.**

I. Introduction

The Alameda County Santa Rita Jail Microgrid project is a demonstration of Consortium for Electric Reliability Technology Solutions (CERTS) Microgrid concepts, [1-3]. The goal from a research and design perspective is to understand the potential for large commercialization of CERTS Microgrids in the future for customers with demand for reliable power. The CERTS Microgrid concept has been developed over the last 10 years with support from the California Energy Commission and the US Department of Energy. CERTS basic research focus is the design and application of automatous controls for the full range of DER component. The CERTS approach provides standard automatous controls that enable plug-and-play functionally without the need of communication or custom engineering for each application. These features minimize engineering cost and errors and maximize flexibility. Most microgrid implementations combine loads with sources and allow for intentional islanding, but rely on complex communication and control and require custom design including extensive site engineering.

CERTS concepts demonstrated to date at American Electric Power's microgrid test bed include autonomous load following, local islanding and re-synchronizing with the grid, voltage and frequency control, reduction of circulating reactive power and stable operation for microgrids with multiple DER units. These tests where done without storage or communication between units, [4-7]. This functionality is achieved using two droop controllers. One is a power vs. frequency droop much like the tradition droop control on generators. Protection from self-overloading drives the frequency down when the unit becomes overloaded. This results in the other sources off-loading the overloaded unit. The second droop controller is a voltage vs. reactive power controller. When there are voltage error between two or more units there can be large circulating VARS. The reactive power output provided by each source is used modifies its own voltage regulation point. This corrects for the voltage errors and minimize the circulating VARS. Alameda County Santa Rita Jail project provides a platform to extend these concepts to storage, diesel generation and energy management systems.

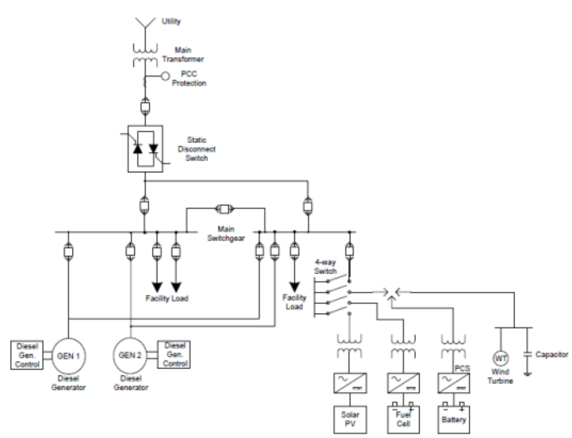

Fig. 1 Santa Rita Jail Microgrid Single Line Diagram

The work is coordinated by Chevron Energy Solutions and funded by the U.S. Department of Energy and the California Energy Commission Public Interest Energy Research Program.

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This project integrates existing 1.2 MW solar photovoltaic, 1 MW fuel cell and conventional diesel generators with large-scale energy storage, a static disconnect switch and a capacitor bank. The project also upgraded the controls of the generators to make them CERTS-capable. An overarching control system referred to as Energy Management System (EMS) to economically optimize was added the use of all generation sources. Refer to Appendix A for a summary of equipment details, fig.1.

II. Design Considerations

Prior to the Microgrid project, the Santa Rita Jail facility was susceptible to momentary utility outages and power quality events. Maintaining power free of momentary or sustained outages is critical to the safety of the officers, staff and inmates. To prevent sustained outages, diesel generators were available to power essential facility loads. However, the diesel generators relied on a load-shed system and required approximately 10 seconds to start, during which the facility had no power.

Additionally, the solar photovoltaic and fuel cell generators were unable to operate in parallel with the diesel generators. This was due to a couple of reasons. One, it is challenging for the system to maintain proper microgrid system voltage and frequency within operational limits during transitions to the back-up diesel generators. Additionally, the diesel generator frequency itself is not as stable as the grid and may trigger anti islanding functions on PV or Fuel Cell inverters to trip the equipment offline. This is a disadvantage from an economic and environmental perspective because the clean, renewable sources were not being utilized during island conditions. Upon restoration of utility power the fuel cell would take several hours to restart, resulting in increased demand and energy charges on the utility bill. The solar photovoltaic and fuel cell operation also was impacted by utility power quality events such as voltage sags, [8-9]. These impacts related to utility issues were resolved with incorporation of a fast static disconnect switch (SDS), which enabled autonomous operation and seamless islanding of the Jail. The Jail's ability to autonomously island was key to providing the highest system reliability. Due to the practical limitations of matching the existing generation and load for a successful island transition, advanced energy storage (battery) was utilized to stabilize system voltage and frequency during transient conditions. Using CERTS Microgrid protocol aided in simplifying the integration of the battery and SDS with existing on-site resources. The "plug-and-play" nature of the CERTS protocol gives CERTS-based sources (diesel generators and battery) the ability to interconnect with each other without the need for a customized supervisory generator control system.

In addition to the battery providing system reliability and stability, it would also be used to optimize on-site generation to decrease the total cost of energy purchased from the utility. The current utility tariff schedule has time-of-use rates under which energy consumption and maximum power demand vary based on time of day and season. The battery can store energy purchased during less-expensive off-peak periods to be utilized during peak periods.

III. The CERTS Concept

One of the objectives of the CERTS Microgrid concept was to reduce microgrid system cost and increase reliability. This includes *plug-and-play* functionality without communications. Plug-and-play concepts reduce engineering cost and errors since little site modification is required for different applications. Each CERTS device regulates voltage and frequency both grid connected and while islanded. These key concepts have been demonstrated at the American Electrical Power Microgrid Test Facility. This includes such transient events such as seamless separation and automatic re-synchronizing with the grid, Class I level power quality during utility faults, large unbalanced loading and stable operation during major events [5]. The CERTS concept has three critical components: the static disconnect switch, the micro-sources, and loads. The static disconnect switch has the ability to island the microgrid autonomously for disturbances such as faults, IEEE 1547 events or power quality events. Following islanding, the reconnection of the microgrid is achieved autonomously after the tripping event is no longer present. Resynchronizing to the utility uses the frequency difference created by the islanding event [6].

Each CERTS-controlled source seamlessly balances the power on the islanded microgrid using a power vs. frequency droop controller. In this project the battery storage system and the backup diesel generators have the CERTS frequency and voltage control. The fuel cell and the photovoltaic inverters run in a power mode and do not track load, control voltage or frequency. For example, if the load increases while in island operation, the storage system will provide the extra power instantaneously and reduce the operational frequency. At maximum output the frequency controls are designed to drop no more than 1%. If there is inadequate energy to meet the load, the frequency will drop below the normal operating range, signaling the non-critical loads to shed. The coordination between sources and loads is through frequency.

The storage inverters and the diesel generators not only control the voltage but they also ensure that there are no large circulating reactive currents between units. With small errors in voltage set points, the circulating current can exceed the ratings of the units. This situation requires a voltage vs. reactive power droop controller so that, as the reactive power, Q, generated by the unit becomes more capacitive, the local voltage set point is reduced. Conversely, as Q becomes more inductive, the voltage set point is increased. At Santa Rita Jail this droop is 5%. In addition to the system voltage stability demonstrated at the AEP test site extensive analyses indicates that microgrid's stability is independent of the number of CERTS devices in a microgrid [7]. Theoretically the system remains stable as we approach an infinite number of CERTS units.

The CERTS Microgrid controls do not rely on a "master" controller or source. Each source is connected in a peer-to-peer fashion with a localized control scheme implemented for each component. This arrangement increases the reliability of the system in comparison to having a master-slave or centralized control scheme. In the case of master-slave controller architecture, the failure of the master controller could compromise the operation of the whole system. Santa Rita Jail uses a central communication system to dispatch storage set points, voltage and power as needed to control the state of charge. However, this communication network is not used for the dynamic operation of the Microgrid. This plug-and-play approach allows for expansion of the Microgrid to meet the requirements of the site without extensive re-engineering. Plug-and-play implies that a unit can be placed at any point on the electrical system without re-engineering the controls, thereby reducing the chance for engineering errors.

IV. Design Implementation

The key considerations for the Microgrid system design were meeting the criteria for operation under the CERTS protocol and integrating with the existing infrastructure.

A. Battery

The battery technology selected for this project was a 2-MW, 4-MWh Lithium Iron Phosphate ($LiFePO_4$) battery. This is a type of lithium ion battery that uses $LiFePO_4$ as a cathode material. Several battery technologies were compared during the design process. Some of the highly weighted selection criteria included round trip efficiency, cycle life, maximum temperature rating, safety, environmental considerations, and maintenance requirements. Compared with other lithium-ion battery chemistries, the $LiFePO_4$ battery offers improved safety because of the thermal and chemical stability exhibited by the technology. The tradeoff is a slightly lower energy density than other lithium ion chemistries. The specified AC-AC round trip efficiency was 85% while the actual measured AC-AC round trip efficiency was 88%.

The energy stored in the battery can be used either for tariff-based rate arbitrage or power quality and reliability. When grid connected, the battery can charge or discharge as dictated by the Energy Management System in order to maximize the economic benefit of the battery. The rate arbitrage scheme is based on the utility tariff structure and not on real time pricing. During a grid disturbance or outage, the energy in the battery is used to continuously supply high quality power to the on-site loads.

The battery was sized at 2 MW, 2.5 MVA to be able to serve the facility demand, which peaks at 2.8 MW, 2 MVARs in the summer afternoons. This would allow the facility to island from the utility grid when the fuel cell or part of the PV system are on-line, but may require load shedding in the unlikely event that all PV inverters and the fuel cell are off-line.

The 4-MWh storage capacity was sized such that on a typical summer day the battery, fuel cell and solar photovoltaics could serve all of the facility peak-period energy usage. 80% of storage capacity is used for rate arbitrage, reducing the facility peak load. The remaining 20% is reserved for power quality events when the system transitions from grid connected to island operation. This provides enough energy to maintain the system until the diesel generator starts, if required. The battery has an upper and lower state-of-charge limitation of 90% and 10% respectively during grid connected operations to maintain the reserve for power quality. To ensure reliability during island operation a new load and generation management system will control the shedding and adding of load and generation sources (i.e. PV generation or fuel cell) in order to prevent the battery from reaching a full charge or discharge state and shutting down.

B. Power Conversion System

A CERTS-compliant power conversion system (PCS) was required to interface the battery with the Microgrid and utility source. The installed PCS is rated 2MW, 2.5MVA, consisting of four DC-to-DC converters that interface with each of the four 500-kW, 1-MWh battery enclosures. Each of the battery enclosures is independent and capable of operating if any or all of the other three containers are shut down. There are two DC-to-AC inverters that interface with two DC-to-DC converters, each through a common DC link bus. This system architecture makes the system highly flexible, allowing for proper maintainability and testing. The PCS was sized such that it could supply some, but not all of the facilities reactive power needs. This is discussed further in the capacitor bank section.

When grid-connected, the EMS dispatches charge or discharge signals to the PCS to provide the highest level of economic benefit to the Jail. To change the rate of power charge or discharge, the PCS responds to "raise speed" or "lower speed" signals, similar to those used in frequency/load control of traditional generation units. The PCS frequency droop curve moves up or down, without changing its slope, thus changing the rate of power charge or discharge of the battery. Similarly the reactive power flow is controlled with the voltage droop curve.

During the transition from grid-connected to island, the PCS remains connected, operating as a voltage source, even if the voltage and/or frequency are outside normal operation limits. The transient recovery voltage period is typically within one cycle, but may last several cycles depending on the circumstances of the islanding process. During this time, the PCS is constrained only by its internal current and power limiting functions.

When the Microgrid is islanded, the CERTS algorithm programmed in the PCS determines the appropriate battery charge and discharge levels within the range established by the frequency and voltage droop curves of the PCS [10].

During passive synchronization with the utility, the PCS is required to remain online even with a wider delta V and Delta F synchronization window than traditionally used.

C. Capacitor Bank

The Jail currently has high reactive power demand due to large rotating loads. This large reactive demand coupled with the on-site renewable sources operating near unity power factor led to a low power factor at the utility point of common coupling. Reactive power compensation would be needed in order to avoid low power factor penalties on utility billing. More importantly, according to a dynamic analysis study, the Microgrid would not be able to island successfully without another reactive power source supplying the rotating equipment. An economic analysis revealed that a capacitor bank was the preferred alternative for supplying the reactive power needs compared to increasing in the PCS MVA rating. A 900-kVAR capacitor bank was installed to provide the remaining reactive power to allow the Microgrid to island.

D. Static Disconnect Switch

A static disconnect switch (SDS) was installed between the utility and Microgrid to allow for very fast islanding and autonomous operation of the Microgrid. There are voltage and current transformers on the line and load sides of the SDS to constantly detect the voltage and frequency of both the utility and Microgrid systems. These measurements allow the system to island during power failures or power quality events exhibited by the utility. The SDS operates within a quarter cycle on the order of 4 to 10 milliseconds. Disconnection and islanding from the utility are fast enough that any utility events go undetected by the inverter sources in the Microgrid.

TABLE I

Protection Settings for the Static Disconnect Switch

Protective Function	Device Design Range	Implemented Value
Overvoltage	105 – 115%	115%, 10ms (Fast) 110%, 2ms (Instanteous)
Undervoltage	95 – 80%	80%, 10ms (Fast) 50%, 3ms (Instanteous)
Overfrequency	60.1 – 63 Hz	60.5Hz, 0.5ms
Underfrequency	59.9 – 57 Hz	59.5Hz, 0.5ms
Directional Overcurrent	0 – 500%	130%, 60 sec

The SDS is rated 12.47 kV, 60 HZ, three–phase, with a BIL of 95 kV, for use on a 4–wire solidly grounded system. It has a continuous and load interrupting rating of 300A and an overload rating of 375A (125%) for 120 seconds. The unit thyristor valves have the capability to withstand the surge current of 35 kA for one cycle and 8kA RMS symmetrical for fifteen (15) cycles. It was designed to operate with N+2 redundancy on the thyristor valve devices. This allows the SDS to operate with two thyristor levels shorted out. The overall efficiency is 99% or greater.

The SDS contains islanding and synchronization functions compatible with CERTS protocols. This requires passive synchronization, without the need for external signals for islanding or synchronizing.

Islanding operations are triggered by overvoltage, undervoltage, overfrequency, and underfrequency. There is also directional overcurrent, with current flowing towards the utility grid, required by the utility, programed in the external protective relay that trips the main 12kV utility breaker. These functions are coordinated with revised overvoltage, undervoltage, overfrequency and underfrequency settings in the fuel cell inverters and PV inverters to ensure that all renewable generation stays online following and islanding transient. The protective setting ranges and implemented values for islanding are listed in Table I.

This SDS was installed in conjunction with bypass and isolation switchgear to allow for servicing of the unit and shutdown in case of any failures.

E. Diesel Generator Upgrade

Santa Rita Jail currently has two 1.2-MW backup diesel generators. These diesel generators would operate only when there was a utility power outage. As part of the Microgrid, the generators are now operated to charge the battery if the battery has a low state of charge when islanded or if the Microgrid fails. This significantly reduces the operation time of the diesel generators.. The old speed and voltage controls of the diesel generators were isochronous, meaning they maintained a constant frequency and voltage over any real and reactive power output, within the generators' rated capacity. The controls were modified and upgraded to be CERTS-compliant. CERTS compliant means allowing voltage and frequency droop operation, similar to the operation mode used when operating diesel generators synchronized with the utility grid. Since controllers to operate reciprocating engine-generators synchronized to the utility grid are readily available, off-the-shelf generator control equipment was used for the diesel generator control upgrades, avoiding the need for costly special-design equipment. This is one of the advantages of using CERTS; it simplifies the integration of renewable or large-scale energy storage equipment with conventional generation.

The Santa Rita Jail backup diesel generators are not permitted by air quality regulations to operate when utility power is available. When the microgrid islands due to a utility outage and the diesel generators are called into operation, the generators synchronize with the microgrid and operate in voltage and frequency droop mode (CERTS mode). In this mode of operation, the kW output of the diesel generators are controlled by biasing the frequency droop curve, without changing its slope, until the desired kW output is achieved. Again, this is similar to the strategy used to control kW output of conventional generators when operating synchronized to the utility grid. To minimize the operating hours of diesel generators during a sustained utility outage, the diesel generators are only called into operation when needed; that is when the battery state of charge reaches a minimum island-operation set-point. In addition, when operating in parallel with the microgrid, the kW output of the diesel generators is set to operate close to its rated output, where the operation is most efficient. However, by operating below rated output, there is margin in the output for the diesel generators to share frequency and voltage control functions with the battery per their respective voltage and frequency droop curves. The generators transition back to isochronous control in the event the Microgrid is not operational; that is when the battery is out service. In this case, the system operates just like a traditional backup generation system, the utility power outage would cause a brief power outage in the facility, followed by isochronous operation of the backup diesel generators.

F. Energy Management System

A centralized control system was installed at Santa Rita Jail to optimize the use of the on-site generation sources when grid-connected based on the applicable utility energy rates [11-12]. This system monitors power flow at various points to determine system loads and available generation. The EMS controls the flow of power across the Point of Common Coupling (PCC). Depending on the actual time-of-use rate (in this project they are peak, partial peak, and off-peak) the EMS will determine its control strategy. For example, during off-peak the system's goal is to charge the battery to a maximum SOC while not setting a new demand peak. The calculation parameters, which are utilized in an algorithm, include predicted average demand load, the available discharge energy from the battery, and the required average charge of the battery. The power flow at the PCC is determined as a function of tariff rate structure, predicted generation profiles, and historical load profiles. Thus the EMS gives the battery extra functionality to reduce operating costs while still maintaining high system integrity and reliability.

G. Systems Studies

Extensive system studies where performed to better understand the dynamic response of the microgrid. A PSLF model of the Santa Rita Jail system, that included the dynamic models of the battery system, the diesel generators and rotating loads, was completed. The PSLF model also included a thyristor-based switch at the PCC (modeled as a switching element able to respond in 10 milliseconds) and elements of the system that do not have a dynamic response to changes in voltage an frequency like the capacitor banks, the fuel cell, the photovoltaic systems, cables, static loads, etc. See figure 1. The PSLF model was verified with dynamic response tests performed during the PCS factory acceptance test and during commissioning tests at the Santa Rita Jail site. .

As an example consider the transient when the two diesel generators are introduced to charge the storage system while in island operation. In this case the storage autonomously moves from maximum output of 2 MW to charging while increasing the island's frequency by approximately 1/4 Hz.

The top two plots in Figure 2 show the real and reactive power for the storage system, the pv, the fuel cell, the capacitor bank and the diesels. The lower two plots are phase-a current and voltage waveforms for the diesels and storage inverter. Before the diesels are introduced the storage is discharging at 2 MW. At time = 0 seconds the generators are connected. Once connected, the power-transition between the battery and the generators occurs over approximately one second. The power oscillations seen here are a result of a non-zero load-angle during synchronization. The inertia of the diesel results in power fluctuations as the power accelerates and decelerates as a function of the position, resulting in a classical second-order response.

The synchronization process is evident from the relative blurring of the voltage waveform prior to t=0 and subsequent alignment of the voltage waveforms after synchronization. The power increase from the gensets and the subsequent reversal of power flow from the storage system is also evident in these figures. These voltage wave forms also demonstrate the robustness of the voltage controller during this event.

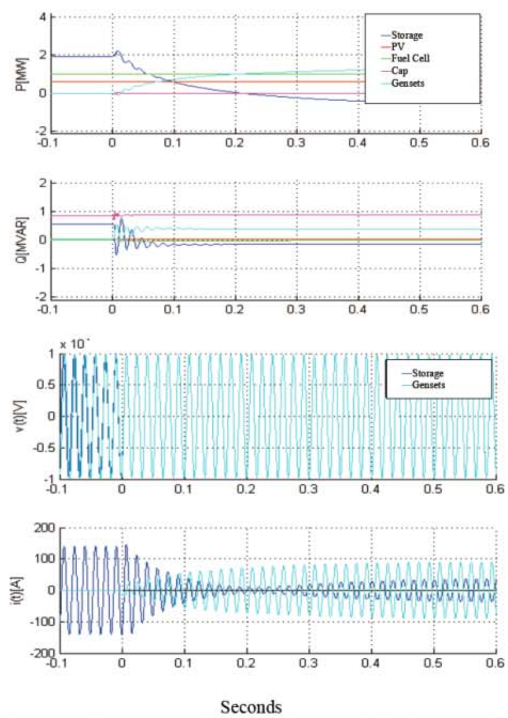

Figure 2. Simulation of Starting Generators while Islanded

V. Commissioning Test and Lessons Learned

A. PCS Factory Acceptance Test

To ensure successful commissioning at the site, a complete test of the CERTS functions of the PCS was performed at the factory before shipping. This factory acceptance test included both island and grid-connected operation in CERTS mode. In island operation, the PCS operated alone with a real and reactive power load bank and in parallel with a diesel generator operating in voltage and frequency droop mode. The simplicity of integrating CERTS-capable inverters with other resources operating in voltage and frequency droop was apparent at the factory acceptance test. An off-the-shelf diesel generator was integrated easily with a CERTS-capable inverter. There were no complications other than appropriately setting the droop voltage in the voltage regulator and the droop frequency in the engine governor. During the factory acceptance test, the two sources appropriately shared real and reactive power with no communication lines between the two. The speed at which the PCS adjusts its real and reactive power output on islanding also was verified, within 20 milliseconds for both real and reactive power. The CERTS protocol allows seamless islanding because of the ability of a CERTS-capable inverter to change its real and reactive power output upon sensing frequency and voltage variations at its terminals. Seamless island tests without communication between the utility interconnection breaker and the PCS were demonstrated at the factory acceptance test, even when the PCS was required to change from discharge to charge mode or vice versa (i.e., from positive to negative real power flow).

B. Site Acceptance Test

The system also had to be tested at the site with all of the existing distributed energy resources and the SDS. Once the PCS and the battery enclosures were installed and integrated, island tests of the battery system and the fuel cell with a load bank were completed without including the facility load. However, these tests did not yet include parallel operation of the Santa Rita Jail diesel backup generation system. Once the battery had demonstrated reliable grid-connected operation and island operation with the fuel cell and load bank, a whole-facility island test was scheduled. This whole-facility island test had to be witnessed by Pacific Gas and Electric (PG&E), the local electric utility, as part of the utility's routine pre-parallel inspection process, which any conventional generator has to complete. At that point all of the protective functions required by PG&E were successfully demonstrated and Santa Rita Jail was seamlessly islanded and resynchronized with PG&E for the first time. Only after this had been completed could island operation of the battery, in parallel with the facility diesel backup generation system, be tested. The controls of the diesel backup generation systems had previously been modified to allow voltage and frequency droop operation. The diesel generators with their modified controls were tested and appropriate real and reactive power sharing was demonstrated. This was done at different transient conditions that included battery discharging and charging using diesel generator power.

C. Lessons Learned

Utilities are not yet very familiar with the use of static disconnect switches as a disconnection device at the point of common coupling (PCC). Until SDSs become more common and standards for their use as a PCC disconnection device are developed, conventional equipment must be used to satisfy utility interconnection requirements. In the Santa Rita Jail Microgrid case, a standard 12-kV vacuum breaker and conventional utility-grade protective relays were used upstream from the SDS. Since the SDS operates much faster than conventional equipment in the islanding process (in 8 milliseconds or less), the conventional equipment only operates in the event of SDS failure or when the SDS is out of service and bypassed. In the resynchronization process, after the electric utility restores service, the SDS synchronization function is supervised by a conventional sync-check relay (device 25).

On the battery side, the integration of the battery enclosures and PCS has to be carefully managed. The Battery Management System (BMS) that manages and monitors the condition of the batteries in the battery enclosures needs to communicate with the PCS to report state of charge (SOC), charge and discharge limits, malfunctions, alarms, etc. It may be a challenge to achieve reliable communication in the noisy environment created by fast switching power electronics. Also, accurate SOC reporting is key in a battery system that is charged and discharged daily for rate arbitrage, but also needs to leave energy available for power quality functions.

In a Microgrid system that has so many functions, an overarching control system such as the one employed on this project is an important component. The Energy Management System has different priorities depending on the system operating mode. In grid-connected operation, EMS controls minimize electric power costs while ensuring that enough energy is available in the battery for the power quality functions. In island operation, EMS controls maximize reliability, starting the diesel generators at low SOC and shedding generation as appropriate at high SOC. This is done with the purpose of keeping the battery continuously operating with safe margins in island mode. EMS also has an archive system that records a variety of information, including energy consumption by feeder, real and reactive power flow, power quality monitoring, battery condition, etc. This archive system has proven to be an important tool in improving the system performance. After reviewing archived information, the settings that control grid-connected and island operation were adjusted to improve the benefit the battery provides to the facility. There is still much to be learned about maximizing the benefit that a battery system can provide. The EMS archive system will continue to provide information to support additional improvements.

As was expected, the CERTS protocol simplified the integration of conventional generation equipment with the large-scale energy storage system. This is because the CERTS protocol actually does not require any communications between the large-scale energy storage system and the conventional generation equipment, as long as the large-scale energy storage system follows the CERTS protocol and the conventional generation equipment operates in droop mode. The voltage and the frequency at the terminals of the equipment provide all the communications required for the system to operate and share real and reactive power between conventional generation and the large-scale energy storage system appropriately. This characteristic of the CERTS protocol not only adds simplicity, but also improves reliability. When function beyond simple sharing of real and reactive power are require, like charging or discharging of the large-scale energy storage system at a certain level, at a certain time, these are achieved with simple programming and low speed communication between off-the-shelf designed to control conventional generation that needs to be part of the generation system anyway. This results in lower integration cost and lower communication/control hardware and software cost compared to systems that do not use the CERTS protocol and droop operation, and require sophisticated, high-speed communications among the different elements of the system.

VI. Next Steps

The commissioning test results and system performance monitoring will outline the path forward to further enhancing the CERTS Microgrid operation.

A new load-shedding system will be installed. In Microgrid island mode, the new scheme will have traditional frequency-based shedding. It also will have the ability to control the load and solar photovoltaic, fuel cell, and diesel generation by shedding and adding based on the battery state of charge. In grid-connected mode, the system has the ability to accept an external load curtailment command as a part of a utility demand-side management program.

Future analysis of the battery performance will help in refining operational set points. The current maximum and minimum battery SOC limits used in the grid-connected dispatch algorithm leave a margin of capacity to account for the difference between the predicted and real-time load and generation profiles, plus leave spare capacity to be used in the event of a utility power outage. Refining these values will further optimize battery usage.

The CERTS Microgrid also has the potential to support the grid with ancillary services. The increasingly high penetration of renewable power such as solar photovoltaic and wind put the grid at risk of sudden and unpredictable power fluctuations due to shifts in weather conditions. The Independent System Operator (ISO) is looking for fast-ramping sources such as batteries that can provide frequency regulation to help increase the stability of the grid.

VII. Conclusions

The CERTS protocol has proven to be a powerful tool for integrating distributed energy resources. This first became apparent at the PCS factory acceptance test and later on-site during commissioning and operation of the system. Only minor modifications in the existing diesel backup generation systems were needed to allow it to operate in parallel with the CERTS-capable battery.

Until SDSs are more common and standards are further developed for their use as PCC disconnection devices, conventional equipment like electromechanical breakers and conventional protective relays will continue to be used to satisfy utility interconnection requirements for Microgrids.

Even when CERTS-capable distributed energy resources can operate without necessarily having communication among them, an overarching control system like EMS is necessary to maximize the benefit of a battery system. EMS should include an archive system to provide the information needed to make continued improvements on the system.

The accurate data supplied by the battery management system provides information needed by EMS to adequately manage the battery system. This becomes more important in a battery system that is charged and discharged daily.

To improve the reliability of the Microgrid during island operation, especially at high and low battery state of charge, a load and generation shedding scheme should be considered. It is critical to keeping the battery operating with safe margins and to ensure the reliability of the Microgrid island operation.

VIII. Appendix A – Equipment Summary

Equipment	Rating	Microgrid Function
Static Disconnect Switch	12.47kV, 300A	Separate from grid upon disturbance
Capacitor Bank	12.47KV, 900KVAR	Provide reactive power during grid connected and island operations
Battery + PCS	Battery – 2MW, 4MWh PCS – 2MW, 2.5MVA	Support transition from grid connected to island; reduce facility peak demand and energy usage
Diesel Generator	(2) 1.2MW	Support island operation when battery is at low state-of-charge
Fuel Cell	1MW	Supply power to facility in grid connected and island operation
Solar PV	1.2MW	Supply power to facility in grid connected and island operation

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X. Biography

Eduardo Alegria received his MS in Electrical Engineering from the California Polytechnic State University San Luis Obispo in 1990. He worked for PG&E and PG&E Energy Services in Power Generation and later as the supervisor of the Power Quality Group. With PG&E Energy Services he developed the first application of 25 kV class static transfer switches. He joined Chevron Energy Solutions in the year 2000. He works in the areas of power system reliability, power generation interconnection, large scale energy storage, microgrids, and power system stability.

Tim Brown P.E. received his BS, *Summa Cum Laude,* and MS, *with Distinction*, in Electrical Engineering from California Polytechnic State University in San Luis Obispo. Tim has worked as a project engineer at Chevron Energy Solutions since 2009. His work involves solar photovoltaics, advanced energy storage, energy efficiency, power reliability, and power system protection. Tim is a registered professional engineer in the state of California.

Erin Minear P.E. received her BS and MS in Electrical Engineering from California Polytechnic State University San Luis Obispo. She has worked as a facilities engineer at Chevron Energy Solutions since 2007. Her work involves power system reliability, power system protection, energy efficiency, advanced energy storage and solar photovoltaic system design. Erin is a registered professional engineer in the state of California.

Robert H. Lasseter (F'1992) received the Ph.D. in Physics from the University of Pennsylvania, Philadelphia in 1971. He was a Consulting Engineer at General Electric Co. until he joined the University of Wisconsin-Madison in 1980. His research interests focus on the application of power electronics to utility systems and technical issues which arise from the restructuring of the power utility system. This work includes interfacing micro-turbines and fuel cells to the distribution grid, Microgrids, control of power systems through FACTS controllers, use of power electronics in distribution systems and harmonic interactions in power electronic circuits. Professor Lasseter is a Fellow of IEEE, and an IEEE Distinguish Lecturer on Distributed Generation.

APPENDIX C:
LBNL: Integration & Operation of a Microgrid at Santa Rita Jail

LBNL-4850E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Integration & Operation of a Microgrid at Santa Rita Jail

Nicholas DeForest, Judy Lai, Michael Stadler, Gonçalo Mendes, Chris Marnay & Jon Donadee

Environmental Energy Technologies Division

presented at the Jeju 2011 Symposium on Microgrids, Jeju Island, Korea, May 27 - 28, 2011

http://eetd.lbl.gov/EA/EMP/emp-pubs.html

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Disclaimer

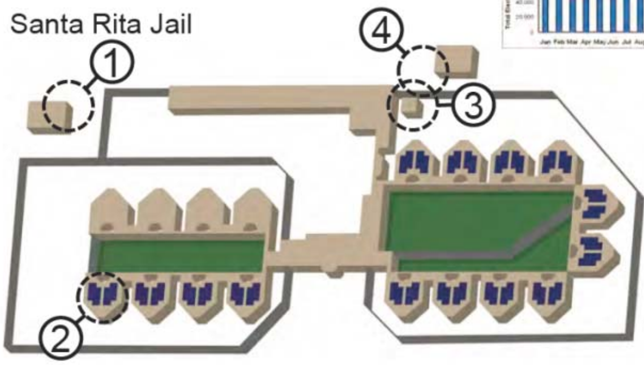
Integration & Operation of a Microgrid at Santa Rita Jail

Team: Nicholas DeForest, Judy Lai, Michael Stadler, Gonçalo Mendes, Chris Marnay & Jon Donadee
Project Partners: Lawrence Berkeley National Laboratory, Chevron Energy Solutions & Alameda County

Introduction

Santa Rita Jail is a 4,500 inmate facility located in Dublin CA, approximately 40 miles (65 km) east of San Francisco. Over the past decade, a series of Distributed Energy Resources (**DER**) installations and efficiency measures have been undertaken to transform the **3MW** facility into a "Green Jail". These include a **1.2MW** rated rooftop PV system installed in 2002, a **1MW** molten carbonate fuel cell with CHP, and retrofits to lighting and HVAC systems to reduce peak loads. With the upcoming installation of a large-scale battery and fast static disconnect switch, Santa Rita Jail will become a true microgrid, with full **CERTS Microgrid** functionality. Consequently, the jail will be able to seamlessly disconnect from the grid and operate as an island in the event of a disturbance, reconnecting again once the disturbance has dissipated. The extent to which that jail is capable of islanding is principally dependant on the energy capacity of the battery—one focus of this investigation. Also presented here are overviews of the DER currently installed at the jail, as well as the value it provides by offsetting the purchase of electricity under the current Pacific Gas & Electric (**PG&E**) tariff.

Santa Rita Jail



Tariff Structure

Santa Rita Jail currently purchases its electricity under PG&E's **E-20 tariff**. The tariff (**Table 1**) employs time of use (**TOU**) charges for energy and power demand. TOU rates vary both by month, with "**summer**" and "**winter**" periods, as well as hour of the day, with "**off-peak**", "**part-peak**" and "**max-peak**" periods. There is an additional charge for the maximum monthly power demand. Given the time sensitivity of the E-20 tariff, there is strong incentive to push electricity purchases off-peak. (see Optimization & Scheduling) 2009 monthly electricity bills are given in **Figure 1**, by power and energy charges.

Fig 1: Composition of Electricity Bill

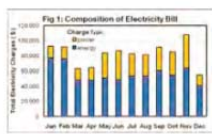


Table 1: Structure of PG&E E-20

Charge Type		power	energy	Duration
Summer	Max Peak	$11.04	$0.14040	12:00-18:00, M-F
	Part-Peak	$2.59	$0.09807	8:30-12:00, 18:00-21:30, M-F
	Off-Peak	-	$0.07992	21:30-8:30, M-F; Weekends
	Maximum	$7.45	-	
Winter	Part-Peak	$0.82	$0.08585	8:30-21:30, M-F
	Off-Peak	-	$0.07664	21:30-8:30, M-F; Weekends
	Maximum	$7.45	-	
		[$/kW]	[$/kWh]	

1 - Microgrid/Macrogrid Connection

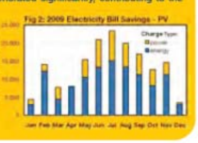
Currently, the jail does not have the ability to seamlessly disconnect from the grid in the event of a disturbance. Also, under its current agreement with the utility, it cannot export electricity produced on-site. These conditions have frequently contributed to problems with DER at the jail; sometimes requiring the fuel cell to trip off. Once off, the fuel cell requires several hours to ramp back up to full output. While short, these outages have a potentially significant economic impact by setting monthly power demand charges. Outages are also suspected to have a detrimental effect on the life of the fuel cell stack. By installing a fast static disconnect switch and battery, these issues can be avoided in the future, while also improving reliability at the jail, by way of CERTS Microgrid functionality.

2 - PV System

Rated at **1.2MW**, the roof-mounted PV system at Santa Rita Jail has a historic peak generation of only about **700kW**. Of the four PV arrays present at the jail, one has deteriorated significantly, contributing to the low output.

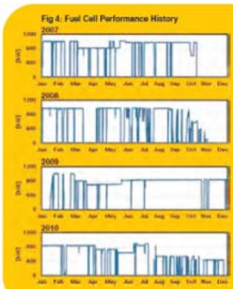
Despite this underwhelming performance, the value of PV is evident in **Figure 2**. Because PV output coincides with peak times, it effectively offsets some purchases of electricity at the most expensive rates.

Fig 2: 2009 Electricity Bill Savings - PV



3 - Fuel Cell

Fig 4: Fuel Cell Performance History



Santa Rita Jail is equipped with a **1MW** molten carbonate fuel cell with CHP. Waste heat from the fuel cell is used to provide approximately **15%** of hot water demand at the facility. The 2009 electricity bill savings from the fuel cell are given in **Figure 3**. Natural gas cost calculations are not presented here. The fuel cell has been plagued by frequent outages—a fact made clear by **Figure 4**. The fuel cell stack required replacement at the end of 2008 and again in 2010. The 2009 cost of outages can be seen in **Figure 5**. Observe that even short outages can have a significant impact on power demand charges. (**see June, November 2009**)

Fig 3: Electricity Bill Savings - Fuel Cell

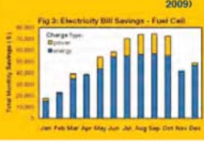
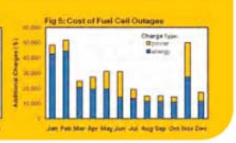


Fig 5: Cost of Fuel Cell Outages



4 - Battery

The installation of a large-scale battery at Santa Rita Jail provides added reliability, plus the potential to shift electricity purchase to less expensive off-peak times. The specifications of the battery will determine the extent to which it can accomplish these tasks. The jail has considered two battery technologies recently, and while this decision is not based entirely on economics, such a comparison has been conducted here to demonstrate how well each fit this specific microgrid application. Assumptions for battery specifications are outlined in **Table 2**.

Table 2: Battery Specifications

Battery		A	B
Technology		Sodium-Sulfur	Li-Iron Phosphate
Energy Capacity	[kWh]	**12,000**	**4,000**
Power	[kW]	2,000	2,000
Roundtrip Efficiency	[-]	0.77	0.83
Decay	[%/hr]	0.002	0.005
Min. SOC	[-]	0.2	0.2

Optimization & Scheduling

The battery is the only truly dispatchable DER at the jail. Utilizing LBNL's Distributed Energy Resources Customer Adoption Model (**DER-CAM**) optimal battery scheduling is determined for several scenario-weeks. This has been conducted for an operational fuel cell (**Scenario 1**) and, more realistically, a short fuel cell outage (**Scenario 2**). The savings as a result of the battery are also tabulated (**Table 3**).

The higher capacity of Battery A allows it to reduce max-peak power demand charges more than Battery B. A is also capable of islanding for longer durations than B, which is of value to microgrid applications. Despite its lower capacity, B still captures a significant portion of potential demand charge savings. B can allow for short periods of islanding. Its installation should also help mitigate disturbance-related fuel cell outages.

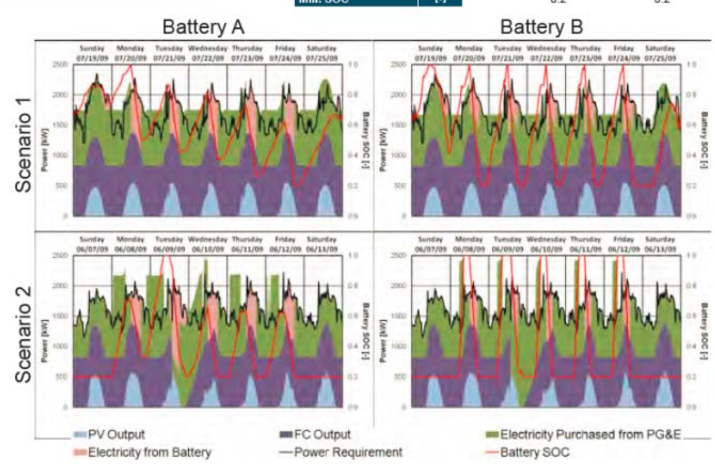


Table 3: Results of DER-CAM Weekly Operations Optimization

Savings from Storage				
Battery			A	B
Scenario	1	energy	$626	$459
		power	$12,586	$9,560
	2	energy	$747	$570
		power	$21,244	$11,363

Note: Power savings assume that monthly demand charges are set during the week investigated.

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