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BORREGO SPRINGS MICROGRID DEMONSTRATION PROJECT

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Prepared by: San Diego Gas & Electric

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Borrego Springs Microgrid Demonstration Project is the final report for the PIER’s Systems Integration Program project (contract number 500-08-025) conducted by the San Diego Gas & Electric Company. The information from this project contributes to Energy Research and Development Division’s Energy Systems Integration 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

This project focused on the design, installation, and operation of a community scale “proof-of-concept” Microgrid. The Microgrid was an existing utility circuit that had a peak load of 4.6 MW serving 615 customers in Borrego Springs, California, a remote area of the San Diego Gas &Electric service territory. The key aspects of the project were integrating and operating the following types of equipment and systems:

- Distributed Generation
- Advanced Energy Storage
- Price Driven Load Management
- Fault Location, Isolation, Switching and Restoration
- Integration with utility control systems and Microgrid Controls

This project was funded through a US Department of Energy and California Energy Commission grant, and cost share provided by San Diego Gas &Electric and other project team members. The Energy Commission portion of the project focused on the integration of resources on the customer-side of the meter and evaluated their contribution to Microgrid operations - primarily on the Price Driven Load Management aspects of the Microgrid.

The Price Driven Load Management solution addresses the design and implementation of six unique and innovative control approaches that include:

- Automated demand response
- Locational demand response
- Optimized demand response
- Price based demand response
- Advanced demand response forecasting and analytics
- Integration with the other components of the Microgrid

**Keywords:** Microgrid, demand response, price driven load management, home area network, energy storage, distributed energy resources

Please use the following citation for this report:

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EXECUTIVE SUMMARY

The smart electric power grid (smart grid) uses analog or digital information and communications technology that gathers and acts on data to improve the efficiency, reliability, costs, and sustainability of producing and distributing electricity. A smart grid provides many diverse functions and benefits to investor-owned and public utilities, technology manufacturers and vendors, ratepayers in the residential, commercial and industrial segments, and ultimately to California in meeting its energy policy objectives. Emerging smart grids are spurring development and demonstration of advanced energy conversion, energy storage, and reliable and secure power delivery technologies.

San Diego Gas & Electric (SDG&E) has been developing the foundation for its Smart Grid initiatives for three decades – beginning with its innovations in automation and control technologies in the 1980s and 1990s. More recently, through its Smart Meter deployment and re-engineering of operating processes by new software applications in its OpEx 20/20 (Operational Excellence with a 20/20 Vision) program. This project focused on the design, installation, and operation of a community scale “proof-of-concept” Microgrid. The Microgrid was an existing utility circuit that had a peak load of 4.6 MW serving 615 customers in Borrego Springs, California, a remote area of the San Diego Gas & Electric service territory.

Industry observers have consistently acknowledged SDG&E’s Borrego Springs microgrid. SDG&E’s commitment and progress in microgrids has been recognized by consultants IDC Energy Insights and the Intelligent Utility Magazine as the nation’s “Most Intelligent Utility” for three consecutive years. SDG&E also received the “Top Ten Utility” award for excellence in Smart Grid development from GreenTech Media.

Purpose and Objectives

This Microgrid Demonstration project brings customer systems and their control into utility operations. While a few microgrid trials have taken place in the US, they have typically been a smaller scale and not directly applicable to the real utility operating environment. This project differs from previous efforts and has extended the knowledge base as follows:

- The Microgrid supported actual customers in a real operating environment
- The project is a significant scale of 4 megawatts (MW)
- The Microgrid design incorporates reliability and economic operations
- Microgrid operations investigate the technical and economic interactions of multiple resources
- The project investigates using pricing signals to encourage customer behavior

The project consisted of several team members and funding sources. A majority of the funding were grants from the US Department of Energy and the California Energy Commission, and a cost share provided by SDG&E and other project team members. The Microgrid demonstration project integrated and operated these equipment and systems:

- Distributed Generation (DG)
- Advanced Energy Storage (AES)
• Price Driven Load Management (PDLM)
• Fault Location, Isolation, Switching and Restoration (FLISR)
• Integration with utility control systems and Microgrid Controls

The Energy Commission portion of the project focused primarily on the PDLM aspects of the Microgrid, integrating resources on the customer-side of the meter and evaluating their contribution to Microgrid operations. The Energy Commission project was conducted in two phases with these objectives:

1. Demonstrate a 15 percent or greater reduction in feeder peak load
2. Demonstrate reactive power management
3. Develop a strategy and demonstration of information integration focused on both security and overall system architecture
4. Develop a strategy and demonstrate integrating Advanced Metering Infrastructure into Microgrid operations
5. Demonstrate using automated distribution control to intentionally isolate customers in response to system problems
6. Develop information/tools addressing the impact of multiple Distributed Energy Resources (DER)
7. Demonstrate Programmable and Controllable Thermostats to achieve Demand Response goals within the Microgrid

Price-Driven Load Management (PDLM) Demonstrations

The PDLM system was used for managing customer load on the Microgrid. The PDLM system was interfaced with SDG&E’s smart meter system and included Home Area Network systems as well as the PDLM controller.

The PDLM controller is the system to forecast Demand Response (DR) capacity, schedule DR events and present price signals to meet the load reduction objectives within the Microgrid. The PDLM controller was used to demonstrate DR capability in standard events that reduces customer load and price events where the customer could respond to the price signals.

The demonstration project explored how the PDLM resources could be managed in the Microgrid environment and if in aggregate, the PDLM resources could be managed like the other DER resources. Ideally, PDLM could be managed in the Microgrid the same way that generators or storage systems are managed.

Delivering load reductions by the PDLM depends upon many factors including weather, time of day, and customer behavior. Customers had the option to opt-out of events. One of the methods to help manage Microgrid resources was for the PDLM system to forecast the demand reduction capacity on an hourly day-ahead basis. The forecasts that were developed were not as accurate as required and the system’s approach for improving the forecast required much iteration of events.
Results
This project demonstrated specific scenarios for operating Microgrid resources under real operating situations while serving actual utility customers. This work helps advance future deployment of Microgrids by both California utilities and electric customers. One of the highlights of the project was the ability to effectively island (isolate) the entire Microgrid supporting more than 600 customers. The islanding demonstrations transitioned in and out of the island mode without affecting the quality of customer service (seamless transitions). The island demonstrations evaluated the island operations with the DG units only, the DG units operating with the substation energy storage in both charge and discharge modes, and the DG units operating with the substation energy storage unit providing a majority of the reactive power requirements.

All demonstrations were successful and demonstrated the stated operational objectives. For example, the Microgrid successfully reduced the peak load on the circuit by 15 percent or more, energy storage was shown to firm the intermittency of rooftop solar photovoltaic (PV) systems, it was learned that operating storage in parallel with the local distribution grid is much more difficult than than storage vendors indicated. It was challenging to resynchronize the energy storage after islanding events.

The project also successfully implemented a price-driven load management program that sent electricity price signals to Home Area Networks (HANs) and devices such as pool pumps, electric vehicles, and thermostats. This enabled demand response and home area networks, allowing SDG&E to demonstrate how residential customers will respond to price signals. The project also showed that the microgrid could be used to power the surrounding distribution grid.

Benefits
Microgrids, using Distributed Energy Resources and their control strategies can provide benefits to California ratepayers that include system reliability, consumer cost reductions by managing their electricity use and effective support to integrate renewable generation into the grid.

Microgrids provide a locally controlled resource to address issues of new electric use and impacts on the grid especially with more Photovoltaics, electric vehicles, and energy storage systems. Given proper design, integration, and controls, Microgrids can be part of a portfolio of energy solutions that help advance renewable energy standards in the state. With more installation and standardization of Microgrids, a competitive market for supply and demand management can be developed where small and large customers may be market participants. Dynamic Pricing advances the concept of market-based electric tariffs where customers are empowered to make informed decisions on electric purchases based on their willingness to pay at various price points throughout the day. Customers may be rewarded for adopting technologies by participating in the dynamic pricing market and incentives.
CHAPTER 1: Introduction

The foundation of existing electric utility systems is based on delivering power from central station generation units to a diverse group of end users. Market, technological, and regulatory forces have created opportunity with Microgrids to leverage distributed energy resources (DER) in delivering highly reliable and cost effective electricity through a new approach to the delivery system. At the same time, customers are also investigating and investing in energy assets and distribution systems for their facilities ranging from backup power systems to on-site generation to renewable energy resources. While some progress has been made on developing interconnected loads and DER there has been little attention to developing an integrated energy system that can operate in parallel with the grid and in an intentional island model. There is a critical need to understand how Microgrids, consisting of interconnected loads and DER, can be operationally optimized and developed in a cost effective manner.

Concurrently, there is an increasing need to assess the role, impact, and contributions of sustainable communities in integrated Microgrid designs and their potential to contribute to demand response objectives and programs.

This project focused on the designing and implementing an innovative Microgrid design that integrates the resources of the electrical distribution network and resources on the customer-side of the meter. The Microgrid was an existing utility circuit that had a peak load of 4.6 MW serving 615 customers in Borrego Springs, California, a remote area of the San Diego Gas &Electric service territory. The design looked at optimizing assets, managing costs, and increasing reliability. Technologies that were integrated into the Microgrid included automated demand response, renewable resources, and advanced technologies. This project also laid the framework for assessing the impact and viability of microgrids on energy costs and price volatility.

While a few Microgrid trials have taken place in the United States, they have been small scale and not directly applicable to the real operating environment. This project differs from previous efforts and has extended the knowledge base from a design, operations, and economic perspective as follows:

- The Microgrid supported actual customers in a real operating environment
- The project is at significant scale (4 MW)
- The Microgrid design incorporates both reliability and economic oriented operations
- Microgrid operations investigate the technical and economic interactions of multiple resources
- The project investigates the ability to use pricing signals to guide operations

The project consisted of several team members and funding sources. A majority of the funding were grants from the US Department of Energy and the California Energy Commission, and a cost share provided by SDG&E and other project team members. The key aspects of the
Microgrid demonstration project were the integration and operation of the following equipment and systems:

- Distributed Generation (DG)
- Advanced Energy Storage (AES)
- Price Driven Load Management (PDLM)
- Fault Location, Isolation, Switching and Restoration (FLISR)
- Integration with utility control systems and Microgrid Controls

Energy Commission portion of the project focused on integrating resources on the customer-side of the meter and evaluated their contribution to Microgrid operations. The project targeted primarily the customer-side of the meter resources - Price Driven Load Management aspects of the Microgrid. The PDLM system components included PDLM Controller and Home Area Network System.

This report addresses the entire overall Microgrid Demonstration Project but focuses more detail on the PDLM aspects of the project.
CHAPTER 2: Project Objectives

The overall objectives for the Microgrid Demonstration Project are to develop a demonstration that will:

1. Demonstrate the ability to achieve more than 15 percent reduction in feeder peak load through the integration of multiple, integrated DER – distributed generation (DG), electric energy storage, and price driven load management - on a San Diego Gas and Electric Company feeder;
2. Demonstrate capability of Volt-Amperes-Reactive (VAr) electric power management - coordinating the DER with existing VAr management/compensation tools;
3. Develop a strategy and demonstration of information integration focused on both security and overall system architecture;
4. Develop a strategy and demonstrate the integration of AMI into Microgrid operations;
5. Demonstrate the capability to use automated distribution control to intentionally island customers in response to system problems;
6. Develop information/tools addressing the impact of multiple DER technologies including:
   ● Control algorithms for autonomous DER operations/automation that address multiple DER interactions and stability issues
   ● Coordination and interoperability of multiple DER technologies with multiple applications/customers.
7. Demonstrate Programmable and Controllable Thermostats to achieve Demand Response goals within the Microgrid.

The PDLM solution addresses the design and implementation of five unique and innovative control approaches that include:

● Automated demand response
● Locational demand response
● Optimized demand response
● Price based demand response
● Advanced demand response forecasting and analytics

Integration with the other components of the Microgrid
CHAPTER 3:  
Project Approach

The complexity of the project dictated a two-phase approach with multiple tasks (Table 1) with detailed descriptions of the project tasks provided in the following sections.

<table>
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3.1 Task 3: Site Selection

Task 3 selected a candidate substation for the design, implementation, and demonstration of a microgrid in SDG&E service territory. The process for site selection was based on the characteristics of the local substation, feeders, and customers of the candidate substations.

The site selection team evaluated 18 substations using an evaluation matrix that addressed the following factors:

- Permitting requirements
- Level of AMI penetration
- Level of customer-owned renewable resources
- Environmental requirements
- Communications environment
- Existing customer-owned non-renewable generation resources
- Anticipated community acceptance of the microgrid project
- Potential customer participation in Energy Efficiency and DR programs
- Potential distribution system impacts on peak load and reliability
- Transmission system impacts on peak load, reliability, and congestion pricing
Ultimately, a circuit served by the Borrego substation was selected as the Microgrid Circuit due to the following characteristics:

- Relatively high penetration of customer-owned PV
- Potential for improvement in reliability
- Availability of land adjacent to the substation
- Reasonable peak load on the circuit (4.6 MW)
- Remote location
- Few customers near the substation
- Mostly residential customers on circuit

Some challenges that the Borrego substation presented include:

- No AMI infrastructure (at the time of selection)
- Substation located in a flood zone
- Need to work with the community to gain acceptance
- Travel time
- Potential communication issues
- No natural gas infrastructure
- Population fluctuates with the seasons (higher in the winter and lower in the summer)
- Desert climate (summer high temperatures greater than 100 °F)

The community of Borrego Springs is approximately 75 miles northeast of the city of San Diego. The Borrego substation is located about three miles from the community’s center, near the Borrego Valley airport.
The Borrego substation is served by a single 69 kV transmission line. At the substation, the voltage is stepped down to 12 kV and serves three radial 12 kV distribution circuits.

As of 2009, the population of the Borrego Springs was 4,354 with a total of 2,923 homes according to San Diego Association of Governments (SANDAG). Borrego Springs has a seasonally varying population. The area attracts a seasonal population of 10,000 annually (during the winter months). The visitor count to Borrego Springs exceeds 1 million visitors annually. SDG&E serves approximately 334 Commercial and Industrial (C&I) Customers and 2,256 Residential Customers in the Borrego Springs Community area.

### 3.2 Task 4: Network Evaluation

This task conducted the conceptual design necessary to carry out a successful microgrid demonstration. Various technologies were evaluated for inclusion into the Project, followed by definition of operational requirements and system controls for the conventional grid and the Microgrid.

#### 3.2.1 Evaluation of System Resources

The transition of the Grid to the Smart Grid required support from technology and applications. All Smart Grid technologies can be included in the key technology areas (Figure 2).
Systems applications are needed to integrate the various Smart Grid technologies to achieve maximum improvement in the following key value areas:

- **Reliability** — reduce the cost impact of interruptions and power quality disturbances and probability and consequences of widespread blackouts
- **Economics** — keep downward pressure on electricity prices, reducing the amount paid by consumers as compared to the Business as Usual (BAU) grid, creating new jobs, and stimulating the United States gross domestic product
- **Efficiency** — reduce the cost to produce, deliver, and consume electricity
- **Environmental Friendliness** — reduce emissions when compared to BAU, by enabling a larger market penetration by renewable energy sources
- **Security** — reduce the probability and consequences of physical attacks, cyber-attacks, and natural disasters
- **Safety** — reduce injuries and loss of life from grid-related events

The scope of the Energy Commission project addresses customer-side of the meter technologies. These technologies empower customers by giving them the information, tools, and education to manage energy use to meet their needs. These options include solutions such as advanced metering infrastructure, home area networks with in-home displays and two-way communicating load control devices, distributed energy resources, and demand response programs. The following types of technologies were considered.

### 3.2.1.1 Advanced Metering Infrastructure (AMI)
Integration of AMI with other Electric Distribution Operations, EDO, applications to improve distribution operations including Microgrid Operations. AMI also potentially provides a path for the utility to communicate cost and usage information to customers

### 3.2.1.2 Customer Systems
Customer systems include “behind the meter” technologies that enable customers to fully
engage with the Smart Grid. Technologies such as the consumer portal, home area networks (HAN) that communicate with smart meters, smart appliances that respond to price signals or system operational parameters, and home energy management systems. Other technologies empower consumers to conserve energy and participate in demand response programs.

3.2.1.3 Demand Response (DR):

Demand Response programs provide incentives for customers to conserve electricity to reduce the peak load on the electrical system. Possible demand response programs include:

- Dynamic pricing without enabling technology
- Dynamic pricing with enabling technology
- Direct load control
- Interruptible tariffs

3.2.2 Operational Requirements

The Project focuses on a utility Microgrid that provides an operational methodology for integrating a diverse set of Distributed Energy Resources (DER). Use cases were developed to identify the functional requirements for the Microgrid. This work captured various scenarios for operation and control of the DER within the Microgrid. The use cases were developed with a group of stakeholders that included subject matter experts from numerous SDG&E departments, vendors, and project partners. In all, ten Use Cases were identified and many had more than one scenario that were analyzed and documented. A summary of the Use Cases and scenarios are as follow:

3.2.2.1 Use Case 1: Utility Manages Utility-Owned Distributed Generation

- Scenario 1: Utility uses communications infrastructure to communicate with utility-owned distributed generation to start/stop generator in constant output mode.

3.2.2.2 Use Case 2: Real-time VAr Support

- Scenario 1: Capacitor reads Circuit VAr data real time and automatically turns on or off based upon prearranged setting. Change in status reported to DMS through SCADA.
- Scenario 2: Capacitor reads line voltage and relays it to DMS through SCADA.
- Scenario 3: Distribution operator places capacitor in Manual mode and manually turns capacitor on or off and the Microgrid Master Controller (MMC) re-optimizes.

3.2.2.3 Use Case 3: FAST

- Scenario 1: Microgrid in island operation, a fault occurs inside Microgrid.
- Scenario 2: Microgrid in island operation on DG only, a fault occurs inside Microgrid.
- Scenario 3: Microgrid in island operation on AES with DG available, a fault occurs inside Microgrid.
- Scenario 4: Capacitor automatically comes online or offline because of FAST operation.
3.2.2.3 Use Case 4: Independent Energy Storage Operations

- Scenario 1: Energy storage executes charge/discharge sequence independent of DMS and MMC control as part of ongoing Peak Shaving Operations (similar to Capacitor Bank operations)
- Scenario 2: Energy storage executes charge/discharge sequence in response to over voltage or under voltage on circuit (load-following mode)

3.2.2.4 Use Case 5: Directed Energy Storage Operations

- Scenario 1: Energy storage executes basic charge/discharge sequence due to command from DMS/MMC
- Scenario 2: Energy Storage executes change in VAr flow during charge/discharge operations due to request from DMS/MMC. SCADA capacitor detects change in VAr status and reacts accordingly
- Scenario 3: Utility uses energy storage for energy arbitrage (financial)

3.2.2.5 Use Case 6: MMC monitors grid system status and exerts control to maintain system stability and prevent overloads

- Scenario 1: MMC detects line outage, arms appropriate response, and executes
- Scenario 2: Microgrid executes a planned transition to island operation
- Scenario 3: Microgrid reconnects to the main grid
- Scenario 4: MMC controls individual Microgrid resources

3.2.2.6 Use Case 7: MMC monitors grid system status and passes information along to DMS

- Scenario 1: MMC incorporates all system information into a status evaluation

3.2.2.7 Use Case 8: MMC curtails customer load for grid management due to forecast

- Scenario 1: Forecast load expected to be subject to curtailment and pass to DMS
- Scenario 2: Execute curtailment in response to pre-scheduled pricing event on system
- Scenario 3: Customer opts out of curtailment for pre-scheduled event
- Scenario 4: Load at the customer site is already below threshold
- Scenario 5: Forecast DR event incorporating 3rd party aggregators with localized control and measurement capabilities

3.2.2.8 Use Case 9: MMC curtails customer load for grid management due to unforeseen events

- Scenario 1: Execute emergency curtailment in response to load on system
- Scenario 2: Customer opts out of curtailment for Grid Management (same as scenario 1)
- Scenario 3: Customer already operating at DR commitment level (same as scenario 1)
3.2.2.9 Use Case 10: Planners Perform Analyses Using Multiple Data Sources
Scenario 1: Planners perform studies with data from a designated subset of meters

3.3 Task 5: Microgrid Design
This task compiled information gathered in prior engineering tasks (Task 3 and 4) to create an implementation design. The Microgrid was designed based on the major outcomes from the use cases. Design discussions were conducted to develop an operational methodology for design and integration of the following resources and systems in the Microgrid:

- Distributed Generation (DG)
- Advanced Energy Storage (AES)
- Price Driven Load Management (PDLM)
- Fault Location, Isolation, Switching and Restoration (FLISR)

Integration with utility control systems and Microgrid Controls

3.3.1 Architecture
The Microgrid is designed to operate in two distinct operational modes:

3.3.1.1 Parallel mode (grid-connected)
Microgrid resources support the electric service provided by the conventional grid. In this mode, resources are managed to the following operational objectives:

- Peak Demand Reduction
- Reliability
- Economics
- Environmental Factors

3.3.1.2 Island Operation
In this mode of operation, the Microgrid is isolated from the grid and the Microgrid Resources are managed to ensure a balance between generation and load while maintaining voltage and frequency within limits. Two approaches to the Microgrid island mode of operation were evaluated:

- Planned Island: The planned Island would occur during a planned outage of the circuit or for transmission line maintenance.
- Unplanned Island: The unplanned Island would occur after a fault that results in an extended outage. To operate in the unplanned island, a sequence of operation was developed to sectionalize the circuit for load management, cold start of the generator units, forecast of system load, and restoration of the customers within the Microgrid.

3.3.2 Control Methodology
Both a centralized control methodology and a distributed control methodology were considered. A distributed level of control has been successfully applied to managing operations
of the main grid. This same method was used as a starting point for evaluating the best control methodology for the Microgrid.

3.3.2.1 Centralized Control

All control actions for the Microgrid would be centralized under control of the Microgrid Controller as a component of the Distribution Management System (DMS). A centralized control methodology simplifies Microgrid operations and its integration with other distribution systems and processes. However, this strategy was deemed impractical for a number of reasons:

- The Team’s Microgrid research concluded that centralized control is not feasible due to the rapid response needed to address expected transients in real time.
- Centralized control is the control method of choice only for non-critical applications that can be applied over many seconds to minutes.
- Centralized control is vulnerable to single failures in communication or even loss of Microgrid Controller functionality. Communications require very high speed, low latency, and extremely high reliability to support the real time response to transients required by Microgrid resources.

3.3.2.2 Distributed Control

This scenario is a combination of centralized control and decentralized control. In this model, the Microgrid Controller is responsible for dispatching Microgrid resources and high level data collection and analysis. This model is similar to the approach used for the main grid with some exceptions:

- In parallel operation, the main grid maintains system frequency within limits. The main grid responds to Microgrid transients without action from the Microgrid control systems. Local controls at the Microgrid resources adjust voltage regulators and inverters to achieve Power Quality (PQ) and voltage set points. Centralized control from the Microgrid Controller adjusts set points of the Microgrid resources over a longer timeframe to optimize the performance.
- In island mode, the inertial response provided by the main grid is not available. The Microgrid is more sensitive to upsets and transients. Decentralized local controls at the Microgrid resources are useful in responding to changes in frequency and voltage. This action is analogous to the action provided by the governor and voltage regulator at the power plants connected to the main grid. The primary objectives are reliability, stability, and PQ within limits. Secondary objectives are efficiency, economics, and environmental metrics.
- The Microgrid Controller provides centralized control in parallel and island modes of Microgrid operation. It operates over a longer time horizon and dispatches Microgrid resources by adjusting their operating set points to achieve operating and optimization objectives.
- The Microgrid resources have their own local controls for distributed control including system operation and protection. These specific systems provide for individual control
to turn the equipment on and off, set the mode of operation, accept changes to operating set points, and trigger operational events.

3.3.3 Microgrid Resources – Specifications

3.3.3.1 Distributed Generation (Diesel Generators)

Two Caterpillar XQ-2000 Power Modules with CAT 3516TA Diesel Engine Generators were used as the Distributed Generation (DG) component of the Microgrid resources. Each generator has a nominal generation capacity of 1,800 kW. These units can be controlled locally at the substation or by using a secure remote interface. The design includes a Microgrid Controller that can provide commands and set points to the DG units. The DG units parallel with the grid through the Generator breaker.

The DG units provide the following modes of operation:

- **Base Load (Constant Output)** – This operational mode of the generator(s) is applicable when the generator(s) are running in parallel with the main grid. The generator(s) in base-load operates at set points to produce real power (kW) at a given power factor setting.
- **Import Control (Peak Shaving)** – This operational mode of the generator(s) is applicable when the generator(s) are running in parallel with the main grid. In this mode, the generators maintain power flow (kW) through the Microgrid Circuit breaker at or below the specified Import Control set point.
- **Island Operating Mode** – In this operational mode, the generator(s) are loaded to meet the demand (kW) on the Microgrid Circuit. The generator controller manages the frequency and reactive power of the circuit.

3.3.3.2 Advanced Energy Storage

The AES component of the Distributed Energy Resources (DERs) for the Microgrid Demonstration Project is a 500 kW /1,500 kWh lithium ion battery system. Since the AES system was deployed in the Microgrid substation, it is also referred to as the Substation Energy Storage (SES). The SES was procured through a competitive solicitation based on a set of specifications included in a RFP. Approximately 12 qualified vendors were invited to submit a bid. Ten vendors submitted proposals, which were evaluated, based on the required specifications and the evaluation criteria.
The SES is capable of serving multiple purposes, each represented by a control mode. These modes are user selectable from a remote operator interface provided by the SES vendor and function as directed by the AES internal controller using external inputs as required to define particular grid control conditions, such as grid element currents and voltages. The SES manages all functionality within equipment ratings capabilities and self-protection requirements. The SES operates in the following modes:

- Constant Power Charge and Discharge Mode
- Peak Load Management Mode
- PV Intermittency Smoothing Mode
- Self-Maintenance Mode
- Standby Mode
- Shutdown Mode

Unique specifications for the SES are as follows:

- The SES controls are configured to require a target state of charge (SOC) prior to initiating operations in the programmed mode of operation
- The PCS is configured to interface and accept commands from a remote third party control system using a Modbus protocol
- The SES needed to have air conditioning units for each container to address the high outdoor temperatures of the desert climate
- The SES containers had to be installed three feet off the ground due flood plain issues
- The SES inverters are required to be capable of four quadrant operation
3.3.3.3 Fault Location Isolation and Service Restoration (FLISR)

The FLISR system allows for semi-autonomous centralized control implemented with switch controllers. The implementation and demonstration of the FLISR system that resides within the OMS/DMS system included leveraging the existing OMS/DMS integration with the distribution network SCADA system. The Microgrid Circuit was one of the initial circuits used to test and validate the operation of the system. Among the DMS functions are the capabilities of using SCADA telemetry and status values to recognize a fault location (“FL”) in the distribution network, determine suggested switching alternatives with a recommend a plan to isolate (“I”) the fault, and execute the steps necessary for service restoration (“SR”); FLISR.

It can be a complex task to determine the optimal switch plan balancing all the objectives. The operator must determine what configurations are available, analyze the customer impact of each configuration, consider the circuit capacity available to carry additional loads, and balance the power requirements to device limitations to deliver power for partial restoration. In these situations, there are multiple variables, engineering and human, that can challenge the best operators. Their actions at times may take longer than five minutes as they are processing the available data. The FLISR tool is looking at the same SCADA data and maps for that outage to generate a recommended switch plan that can quickly be evaluated and executed by the operator thereby reducing the time required for the process.

3.3.3.4 Price Driven Load Management

The Price Driven Load Management dispatches the customer-side of the meter resources. The PDLM system interfaces with SDG&E’s existing AMI smart meter system, project supplied Home Area Network systems, and the Residential Energy Storage systems through the PDLM controller. Customer-side technologies that integrate into the PDLM system were:

- Gateway
- Programmable Communicating Thermostat (PCT)
- Load Control Switch (LCS)
- Plugged Load Controller (PLC)
- In-Home Display (IHD)
- Residential Energy Storage
- Customer Web Portal
3.3.3.5 PDLM Controller

The PDLM controller is the system of record to forecast demand response capacity, schedule DR events and present price signals to meet the load reduction objectives within the Microgrid. The PDLM architecture deployed in the Microgrid demonstration project is presented in Figure 4.

The PDLM controller functionality includes:

- Automated Demand Response with Direct Load Control and Dynamic Pricing programs
- Forecasting Demand Response capacity on a rolling 48-hour basis
- Monitor and execute automated Demand Response events
- Post-event measurement & verification (M&V)
- Analyze historical Demand Response data

The PDLM system enables operators to:

- Create and manage various types of Demand Response programs (i.e. Direct Load Control programs, Dynamic Pricing Program, etc.)
- Facilitate customer enrollment and notification of DR events, through its interface with the HAN System
- Initiate DR signals to be sent to the HAN devices through the HAN Network Operations Center (NOC)
- Capture post event information for analysis (although not suitable for billing purposes), feedback loop to the customer, and forecasting DR capacity
- Monitor and control the Residential Energy Storage system

Figure 5 provides a screenshot of the utility portal that operators use to perform the required demand response functions.

**Figure 5: PDLM System Utility Portal**

HAN System - The HAN NOC manages HAN devices installed in customer premises. The devices are configured to control loads based on event-based, demand response signals and price-driven response. The HAN system consists of a gateway that communicates with the in-home devices (via Zigbee wireless control signals) such as the in-home display, programmable communicating thermostats, load control switches, and plugged load controllers. The IHD is commissioned to the AMI smart meter via Zigbee so that it can receive whole house energy consumption data. Figure 6 shows a typical system configuration with the HAN devices installed in customer homes.
Microgrid Controller – The Microgrid Controller determines the preferred operating state of the Microgrid based on the assessed state and operational constraints of the system. The Microgrid Controller optimizes the behavior based on objective functions that evaluate the relative values of economic, environmental, and reliability factors. It dynamically weighs Microgrid objectives and implements multiple objectives in parallel (e.g. VAr optimization and Reduce Load Shaving and Fault Control). It provides the Distribution System Operator with the ability to change the dynamic objective weights and direct Microgrid operations.

During the Microgrid design stage, it was envisioned that an external vendor would be added to the Project Team to develop the Microgrid Controller. The team worked with a third party vendor to develop system functional requirements and an integration plan for a Microgrid Controller until it became clear that the planned approach was not able to be executed in the required time frame. The Project Team decided to use in-house tools to develop a system (Microgrid Visualizer) that could support the Microgrid operations required to execute the Project Demonstration Plans. This tool was used as the integration point that provides the interface between the Microgrid resources, various SDG&E systems (DMS, SCADA, and Microgrid Database) and external systems (NOAA for weather and CAISO for wholesale nodal pricing).

The Microgrid Visualizer is a custom developed solution deployed on an OSI PI Asset Framework. Figure 7 presents a high level architecture for the Visualizer identifying infrastructure required at the Microgrid Site, a utility data center and the Microgrid Operator’s office. The system communicates with the Microgrid Resources via a pair of gateways; one located in the data center and the other located in the Microgrid Yard with all resources within the Utility’s secure network.
The Microgrid Visualizer was created using PI Process Book to act as the user interface. The Microgrid Operator can access the Visualizer from the Control Van located within the Microgrid Yard or remotely from SDG&E’s offices in San Diego. The Visualizer user interface is presented in Figure 8 with key monitoring and control components for the critical SCADA switches, circuit load, each of the DG units, AES system, and system alarms.
The Microgrid Visualizer provides the Microgrid Operator the option of operating the equipment in a manual mode or in a scheduled mode. The system was configured to continuously collect system data and store it in a PI database. Data can be easily extracted for analysis and reporting using a PI add-in for Excel.

3.4 Task 6: Demonstration Plan

This task developed the Demonstration Plan to test the resources within the Microgrid. The testing strategy meets the desired outcome of the objectives defined in the scope of work of the DOE and Energy Commission grants. The objectives were to demonstrate a 15 percent or greater peak load reduction on the Microgrid Circuit, integration and coordinated operation of multiple DER systems, and operating the Microgrid as an Island.

The demonstration plan was based on a strategy of increasing complexity. The first step involved operating Microgrid component systems individually to validate control approaches, demonstrate the system’s contribution to the Microgrid operations, and collect data sufficient to quantify the benefits of the system. The next step of the plan was to operate the systems in combination. These combined operations provided opportunities to learn how the systems
interact and to evaluate how the benefits are altered. The final part of the strategy was to integrate the local controls of each system into a consolidated control platform (the Microgrid Visualizer) to support operations and control of the Microgrid as a system.

The initial operations for each system were simply to operate devices in a constant mode using local control. The next step in the progression was to operate the system in a Peak Shave mode. Peak Shave was defined as controlling the level of electricity being supplied by the grid while the Microgrid resources make up the difference through a load following type of operation. Systems were operated at various set points based on their capacities and the load profile of the Microgrid Circuit. To start gaining experience and confidence for the Island mode operation, a test called Virtual Island was developed where the resources operated in a manner that maintained zero energy flow across the Microgrid Grid Circuit Breaker. This is virtual because the circuit breaker is not opened. Additional demonstrations were planned that were specific to modes and attributes of the resources. Examples include energy arbitrage with the storage system and demand response programs with the PDLM system. The major Microgrid demonstrations are summarized in Table 2.

<table>
<thead>
<tr>
<th>Demonstration</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed Generation and VAr Management</td>
<td>Constant Output</td>
</tr>
<tr>
<td></td>
<td>Peak Shave</td>
</tr>
<tr>
<td></td>
<td>Zero Flow at the Breaker</td>
</tr>
<tr>
<td></td>
<td>VAr Control</td>
</tr>
<tr>
<td>Advanced Energy Storage</td>
<td>Constant Output</td>
</tr>
<tr>
<td></td>
<td>Peak Shave</td>
</tr>
<tr>
<td></td>
<td>VAr Control</td>
</tr>
<tr>
<td></td>
<td>Arbitrage</td>
</tr>
<tr>
<td></td>
<td>Four Quadrant Operation</td>
</tr>
<tr>
<td>Price-Driven Load Management</td>
<td>Event-based Demand Reduction (Direct Load Control)</td>
</tr>
<tr>
<td></td>
<td>Price Driven Demand Reduction (Pricing Event Control)</td>
</tr>
<tr>
<td></td>
<td>Peak Load Reduction (Load Following)</td>
</tr>
<tr>
<td></td>
<td>DR Capacity Forecasting</td>
</tr>
<tr>
<td></td>
<td>Customer Island Demonstrations</td>
</tr>
<tr>
<td>Optimized Operation with all Resources</td>
<td>Peak Load Reduction</td>
</tr>
<tr>
<td></td>
<td>Microgrid Monitoring and Control</td>
</tr>
<tr>
<td></td>
<td>Resource Control and Dispatch</td>
</tr>
<tr>
<td></td>
<td>Improved Reliability</td>
</tr>
<tr>
<td></td>
<td>Improved Economics</td>
</tr>
</tbody>
</table>

3.5 Task 7: Scoping

This task addressed the scoping and development of the PDLM component designed to manage customer loads. PDLM is the portion of the Microgrid project addressed through this contract.
with the CEC. PDLM addresses the customer-side of the meter resources that support Microgrid operations. Task 7 outlines steps to evaluate and integrate the PDLM system into the Microgrid circuit operation.

3.5.1 PDLM Concept of Operations and Requirements
The PDLM solution provides a systematic approach for demand response optimization and load control within the Microgrid. The system interfaces with various Microgrid resources including the Microgrid controller, HAN, AMI, NOAA Weather, and the CAISO's nodal pricing system. The PDLM system obtains data from the various systems to schedule and execute automated demand response programs. The PDLM system supports Microgrid operations through the following functions:

- DR capacity forecasting
- DR event configuration and execution
- Pricing event configuration and execution
- DR optimization
- Residential Energy Storage (RES) Control
- Analytics and Reporting

During the development of the Microgrid Use Cases, two use cases specifically addressed the role of managing customer loads within the Microgrid.

Table 3: PDLM Use Cases and Scenarios

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use Case 8: Microgrid Controller curtails customer load for grid management due to forecast</td>
<td>Scenario 1: Forecast load expected to be subject to curtailment and pass to DMS.</td>
</tr>
<tr>
<td></td>
<td>Scenario 2: Execute curtailment in response to pre-scheduled pricing event on system.</td>
</tr>
<tr>
<td></td>
<td>Scenario 3: Customer opts out of curtailment for pre-scheduled event</td>
</tr>
<tr>
<td></td>
<td>Scenario 4: Load at the customer site is already below threshold</td>
</tr>
<tr>
<td></td>
<td>Scenario 5: Forecast DR event incorporating 3rd party aggregators with localized control and measurement capabilities</td>
</tr>
<tr>
<td>Use Case 9: Microgrid Controller curtails customer load for grid management due to unforeseen events</td>
<td>Scenario 1: Execute emergency curtailment in response to load on system</td>
</tr>
<tr>
<td></td>
<td>Scenario 2: Customer opts out of curtailment for Grid Management</td>
</tr>
<tr>
<td></td>
<td>Scenario 3: Customer already operating at DR commitment level</td>
</tr>
</tbody>
</table>
3.5.2 PDLM System Components and Requirements

The use cases were used to develop the PDLM functional requirements that were in turn used to develop an RFP for a third party vendor to supply and install the PLDM system that included the following:

- PDLM Controller
- HAN System
- Residential Energy Storage System

A competitive bidding process was used to evaluate multiple vendors capable of delivering the PDLM solution. A team led by Lockheed Martin was selected for the project. The team consisted of:

- Lockheed Martin Smart Grid Solutions: PDLM Controller
- Tendril: Home Area Network (HAN) System
- Control 4: Home Area Network (HAN) System

Sunverge: Residential Energy Storage System

3.5.3 PDLM Program Operations

Two types of demand response programs were executed to meet the objectives of the demonstration 1) Traditional Demand Response and 2) Price Driven Demand Response:

1. **Traditional Demand Response (referred to as “Microgrid Reduce Your Use” (MRYU))**: These demonstrations were conducted as Direct Load Control Programs where the PDLM system sends commands to the customer HAN devices to control the customer load. After each event, PDLM Measurement and Verification relies on backend Meter Data Management System to estimate actual load reduction. The direct load control programs used for this project included:
   - PCT Program - The PDLM system sends a command to the program enrollee’s PCT to modify the temperature set point. It supports multiple levels of temperature offset, based on the program level configuration.
   - PLC Program- the PDLM system sends a command to the PLC, which is connected to consumer devices such as fans, lamps, televisions and other in-home devices. The PLC disconnects power to the consumer device during an event to reduce load.

2. **Price Driven Demand Response**: These demonstrations were conducted as Simulated Dynamic Pricing Programs (see Figure 9). A pricing model was used to calculate the simulated dynamic Real Time Price based on CAISO nodal day-ahead prices and the cost of operating the Microgrid resources for a given time period. The PDLM system sends the simulated retail prices to the customers’ HAN. Introduction of the simulated dynamic retail price into the HAN systems trigger a customers’ temperature setting to change for the PCTs and the on/off state of the PLCs based on the customer’s selected price threshold setting for each device. These dynamic retail prices are also presented on the customer’s In-Home Display (IHD) and the Customer Web Portal.
3.5.4 Customer Outreach and Recruiting

An important objective of the Microgrid demonstration was to integrate customer-side resources into the Microgrid. Since the resources identified were installed at customer premises, a Customer Recruitment and Outreach Plan were developed. Figure 10 presents an overview of the plan for customer recruitment.

The project objectives were to recruit 125 customers on the Microgrid Circuit. The ideal customers were high energy users, year-round single-family residences, having continuously accessible internet access, and willing to participate in DR events required to demonstrate the PDLM functions. Customers received incentives to enroll in the program, with additional incentives based on participation in DR events known as Microgrid Reduce Your Use events. The benefits provided included:

- Complimentary home-area network devices to participate in the program, valued up to $800.
- Gift cards valued at three stages of the program:
  1. Successful installation and programming of the HAN system
  2. Participation in the price driven demand response phase
  3. Ongoing participation in “Microgrid Reduce Your Use” events
In addition to the gift cards, customers received billing credits for participating in other utility DR programs such as “SDG&E Reduce Your Use”. The HAN devices, considered “enabling technology” qualified the participants for a higher credit of $1.25/kWh reduced during SDG&E Reduce Your Use days.

The key approaches and marketing collateral employed for customer recruiting are as follows:

- Microgrid Fact Sheet – Project overview with HAN device photos
- Recruitment Emails– Sent to Prioritized Customers
- Recruitment Letters– Sent to Prioritized Customers
- Microgrid Recruitment Web Portal https://www.sdgemicrogrid.com
- Customer application and qualification with detailed program information
- Customer access to utility accounts to view energy usage, and manage home devices, etc.

The Recruitment Web Portal and all collateral were provided in English and Spanish versions.

As part of the outreach effort, the SDG&E Microgrid team organized and participated in multiple events to engage the Borrego Springs community. These included:

- Energy Efficiency Reception at De Anza Springs Resort
- Microgrid Ice Cream Social at the Borrego Springs Chamber of Commerce Office
- Energy Connection Career Fair and Event at SDG&E’s Energy Innovation Center
- Microgrid Simulated Pricing Reception at Borrego Springs
- Arbor Day – Borrego Village Association
- Energy Day – Anza-Borrego Desert Natural History Association

Once the customers were selected from the pool of applicants, a HAN installation team contacted the customer and scheduled the installation of HAN devices in their homes. Upon selection, customers were provided with the following documentation, as part of the Welcome Package:

- Welcome Letter
- Getting Started Guide in English and Spanish
- Product Description & Troubleshooting Tools
- Product Benefit Guide
- Reduce Your Use Flyer
- Microgrid Fact Sheet

A dedicated customer service line was established to assist the customers with pre-installation, post-installation, and operational queries.
### 3.6 Task 8: Baseline

A performance baseline was established by identifying and collecting key Microgrid Circuit metrics. This baseline provided the basis for comparison with the data collected during the demonstrations. The existing system infrastructure on the Microgrid circuit included the following devices:

- SCADA enabled switches
- Voltage Regulators
- Capacitors
- Microwave Communication System

Historical data on the Microgrid Circuit, for each month from 2007–2009 shows a trend with higher peak demand in the summer with an average peak of 4.3 MW. The highest peak of 4.6 MW occurred in August 2009 (Table 4 and Figure 11).

<table>
<thead>
<tr>
<th>Month</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>4.12</td>
<td>3.38</td>
<td>4.21</td>
<td>3.90</td>
</tr>
<tr>
<td>Feb</td>
<td>3.58</td>
<td>3.29</td>
<td>3.50</td>
<td>3.46</td>
</tr>
<tr>
<td>Mar</td>
<td>3.75</td>
<td>3.48</td>
<td>3.70</td>
<td>3.64</td>
</tr>
<tr>
<td>Apr</td>
<td>3.7</td>
<td>3.62</td>
<td>3.54</td>
<td>3.62</td>
</tr>
<tr>
<td>May</td>
<td>4.03</td>
<td>3.76</td>
<td>3.89</td>
<td>3.89</td>
</tr>
<tr>
<td>Jun</td>
<td>4.11</td>
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<td>4.08</td>
<td>4.06</td>
</tr>
<tr>
<td>Jul</td>
<td>4.32</td>
<td>4.22</td>
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</tr>
<tr>
<td>Aug</td>
<td>4.12</td>
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<td>4.63</td>
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</tr>
<tr>
<td>Sep</td>
<td>3.84</td>
<td>3.86</td>
<td>4.48</td>
<td>4.06</td>
</tr>
<tr>
<td>Oct</td>
<td>3.05</td>
<td>3.69</td>
<td>3.94</td>
<td>3.56</td>
</tr>
<tr>
<td>Nov</td>
<td>2.63</td>
<td>3.59</td>
<td>3.23</td>
<td>3.15</td>
</tr>
<tr>
<td>Dec</td>
<td>3.45</td>
<td>3.45</td>
<td>2.66</td>
<td>3.19</td>
</tr>
</tbody>
</table>

**Table 4: Microgrid Circuit Historical Monthly Peak Demand**
Hourly data was analyzed to gain a better understanding of the load characteristics on the Microgrid Circuit. For each month, key day types were identified:

- Peak MW Day: The day of the month that the monthly peak occurs
- Maximum MWh Day: The day of the month that has the highest energy delivery for a 24 hour period
- Average MWh Day: The day of the month that has the statistical average energy delivery for a 24 hour period
- Minimum MWh Day: The day of the month that has the lowest energy delivery for a 24 hour period

Load profiles for July 2009 are representative of typical summer load profiles for the Microgrid Circuit with each colored line represents a daily load profile (Figure 12) and the key day types for July 2009 (Figure 13).
There are 26 customer-owned PV systems on the Microgrid Circuit with a total installed inverter capacity is 597 kW. The system sizes range from 225 kW down to 2 kW. There are two 225 kW customer-owned systems on the circuit. Detailed analysis was performed using NREL’s System Advisor Model to estimate the annual PV production for the PV systems on the Microgrid circuit. Figure 14 presents a graph of the daily AC output of the aggregated PV systems on the Microgrid Circuit for a typical July. Daily PV generation profiles are presented as different colors for each day of the month.
3.7 Task 9: Integrate Resources

This task addressed the installation and integration of the Microgrid resources used for demonstration as laid out in Task 5 (Microgrid Design) and Task 7 (Scoping).

3.7.1 Microgrid Yard

Microgrid resources (DG and AES units) were installed in a new Microgrid yard adjacent to the Substation. The Microgrid yard is a dedicated, fenced-in area. A SCADA controlled 5-Way switch was used as the electrical connection point for the DG and AES units. A portable Control Van built into an industrial shipping container was installed in the yard. The control van held the generator remote panels, network switches, the Microgrid gateway, and a PI database server. The Microgrid yard layout is presented in Figure 15.
3.7.2 Microgrid Resource Integration Approach

The demonstration involved the installation of various technologies, initial functional testing through a site acceptance and commissioning, followed by operational testing within the Microgrid environment. This process was completed in phases with individual resources integrated initially, and then tested with other resources. The phases included:

- Installation of DG
- Integration of DG
- Installation of AES
- Integration of AES
- Installation of FLISR
- Installation of PDLM
- Installation of Microgrid Visualizer
- Integration of DG + AES + FLISR + PDLM + Microgrid Visualizer

The systems used to support the Microgrid range from systems internal to the utility (i.e. Distribution Operations, OMS/DMS and SCADA), external systems (i.e. weather forecasts and nodal pricing), and Microgrid resource controls (i.e. generator controls, energy storage controls, and PDLM) (Figure 16). To support the operational activities for the project, a custom tool was developed to support the Microgrid Operator to plan, schedule and monitor Microgrid Resources. This system is referred to as the “Microgrid Visualizer”.

Figure 15: Microgrid Yard

![Microgrid Yard Diagram](image.png)
3.8 Task 10: Demonstration Testing

PDLM testing included Factory Acceptance Testing at the vendor’s location, Site Acceptance Testing at SDG&E’s HAN system test lab, and Demonstration Testing of field-installed devices. These tests covered all functional requirements of Demand Response, including:

- PDLM System Setup and Integration
- PDLM Program Definition and Management
- PDLM Operations (Standard Demand Reduction and Price Driven Dynamic Reduction)
- PDLM Analysis

3.8.1 Demonstration Testing Methodology

The PDLM demonstrations were planned as Standalone demonstrations that were carried out to support the overall objectives in support of Microgrid operations. The PDLM demonstrations were conducted in two phases 1) traditional demand response through the HAN systems and 2) price driven load management through the HAN systems.

Between December 2012 and February 2013, 42 Demand Response events were implemented. Each DR event was scheduled for one hour, while some days had multiple DR events. Out of the 42 DR events, 32 DR events registered a net reduction in total customer load, while 10 DR events registered a net increase in total customer load. This analysis shows that 76 percent of the
time a net reduction in total customer load was observed, while 24 percent of the time a net increase in total customer load was observed. During the 32 DR events in which a load reduction was observed, the average total load reduction was 7.0 kW. During the 10 DR events in which a load increase was observed, the average total load increase was 3.6 kW. The average total change in load across all 42 DR events was a total load reduction of 4.4 kW.

A summary of the event analysis for the DR events conducted between December 2012 and February 2012 is presented in Table 5.

### Table 5: DR Events Load Reduction Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of DR Event Days</td>
<td>16 Days</td>
</tr>
<tr>
<td>Number of DR event hours</td>
<td>42 Hours</td>
</tr>
<tr>
<td>DR events with Load Reduction</td>
<td>76%</td>
</tr>
<tr>
<td>DR events with Load Increase</td>
<td>24%</td>
</tr>
<tr>
<td>Average Total Load Reduction (when load reduced during DR events)</td>
<td>7.0 kW / event</td>
</tr>
<tr>
<td>Average Total Load Increase (when load increase during DR events)</td>
<td>3.6 kW / event</td>
</tr>
<tr>
<td>Average Total Load Change During all DR events</td>
<td>4.4 kW</td>
</tr>
</tbody>
</table>

Since the post event data represents the load impact of the aggregated customer base, further analysis was performed to understand the effect of DR events on individual customer load reduction. Hourly customer interval data was obtained from the AMI system for customers that participated in the DR demonstrations. This analysis identified several instances of actual load reduction in customer homes during the DR demonstrations. Figures 17 presents AMI data for a sample customer who participated in a DR event and had significant load reduction during the DR events. The chart below presents two load curves for comparison:

- Event Day Load Curve (red line), and
- Average Load for Days Prior to Event (black line)

A two hour DR event was executed between 14:00 and 16:00 (Figure 17). The load of the customer was significantly higher than the average load at the beginning of the event and was reduced to a level lower than the average during the second hour of the event (to less than 1.0 kW). The data shows that the customer had an overall load reduction of 4.6 kW during the event.
Between March 2012 and April 2013, 20 Pricing Events were implemented. Each Pricing event was scheduled for one hour, with some days having multiple pricing events. Out of the 20 Pricing Events, five events registered a net reduction in customer load, while 15 events registered a net increase in customer load. Thus, 25 percent of the time a net reduction in customer load was observed, while 75 percent of the time a net increase in customer load was observed. During the five Pricing Events in which a load reduction was observed, the average total load reduction was 2.25 kW. The average total change in load across all 20 Pricing Events was a total load increase of 4.8 kW.

A summary of the event analysis for the Pricing Events conducted in March 2013 and April 2013 is presented in Table 6.
Table 6: Pricing Events Load Reduction Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of RTP event days</td>
<td>14 Days</td>
</tr>
<tr>
<td>Number of RTP event hours</td>
<td>20 Hours</td>
</tr>
<tr>
<td>RTP events with Load Reduction</td>
<td>25%</td>
</tr>
<tr>
<td>RTP events with Load Increase</td>
<td>75%</td>
</tr>
<tr>
<td>Average Total Load Reduction (when load reduced during RTP events)</td>
<td>2.25 kW / event</td>
</tr>
<tr>
<td>Average Total Load Increase (when load increase during RTP events)</td>
<td>7.16 kW / event</td>
</tr>
<tr>
<td>Average Total Load Change During all RTP events</td>
<td>(4.8 kW)</td>
</tr>
</tbody>
</table>

Since many of the events have a measured net increase in load, secondary analysis was conducted to identify specific instances of customers who reduced their load during the events. Figure 18 presents an example of a customer load during two consecutive Pricing Events [Level 4 (PCT 2 °F Offset) and Level 5 (PCT 4 °F Offset)] that were executed between 14:00 and 16:00. The data shows a reduction in load during the first hour and then a further decline during the second hour when the PCT set point was adjusted an additional 20°F. This customer demonstrated a load reduction of 2.4 kW during the event.

**Figure 18: Example Customer Load Reduction during Pricing Event**

![AMI Data](image-url)
CHAPTER 4: Project Outcomes

The Microgrid demonstration involved operation of the Microgrid Resources under various scenarios. These demonstrations were planned to test the fundamental operation of the resources in standalone mode, as well as to operate the resources simultaneously to achieve specific project objectives. This section presents key findings and observations that illustrate the ability of the Microgrid to meet specific objectives outlined in Section 2 (Project Objectives).

4.1 Objective 1: Demonstrate the ability to achieve 15 percent or greater reduction in feeder peak load

Results: The Microgrid was designed to meet the operational objective of achieving 15 percent or greater reduction in feeder peak load. Through multiple demonstrations, the Microgrid was able to meet this objective. This section highlights two scenarios where the Microgrid resources operated at settings that reduced the load on the circuit by 15 percent or more.

Figure 19 presents the demonstration of the 15 percent peak load reduction during the nighttime peak of the circuit. The demonstration plan was to shave the peak load by reducing the load at the Microgrid Circuit Breaker by the 15 percent requirement of 695 kW. The load forecast predicted that the load would increase significantly at 11:00 PM due to the operation of the water district’s water pumps and the commercial customer irrigation pumps. The generators were started, warmed up, and synchronized to the circuit starting at 10:30 PM. As the load increased around 10:55 PM, the generator peak shave set point limit was set to 1,600 kW. The demonstration ended at 1:00 AM due to the noise and environmental permit requirements for the generators.
Figure 19: 15 percent Peak Reduction Demonstration

Peak Shave Demo C 2/19 - 2/20/2013 - Microgrid Circuit Load

Large increase in circuit demand due to pump operations by customers

Peak Shave Demo C 2/19 - 2/20/2013 - Microgrid Resources

Generator operations discontinued due to noise restrictions

Peak Shave Demo C 2/19 - 2/20/2013 - Grid Resource

Import Set Point @ 1,600 kW

38
Additionally, zero flow at the breaker demonstrations proved that the Microgrid resources were able to carry the entire load on the circuit (approximately 1,500 kW in this example). The ability to meet the 1,500 kW load on circuit using Microgrid resources represent more than a 15 percent reduction in peak load. Figure 20 shows the operation of one DG unit and the SES carrying the entire load of the Microgrid Circuit. Prior to the demonstration, the circuit load was a little more than 1,500 kW. The SES unit was operating in constant output at a rate of 250 kW. The DG was operating in load following mode to a set point of 0 kW at Microgrid Circuit Breaker. The combined operation of the DG and SES was able to carry the load on the circuit, thereby managing the power at the Microgrid Circuit breaker to near zero.
Figure 20: Zero Flow at the Breaker Demonstration (Virtual Island)

**DG-LF & SES-CO Virtual Island Demonstration: 01/24/2013 - Microgrid Resources**

- DG 1: Load Following Mode with set point = 0 kW
- SES: Constant Output Mode with set point = 250 kW

**DG-LF & SES-CO Virtual Island Demonstration: 01/24/2013 - Grid Resource**

- Zero Flow at the Microgrid Circuit Breaker

**DG-LF & SES-CO Virtual Island Demonstration: 01/24/2013 - SES State of Charge**

- State of Charge (%)

---

40
4.2 Objective 2: Demonstrate capability of Reactive power management

Results: The Microgrid was designed with optimal reactive power management controls provided by the operation of Microgrid resources (DG and SES). Multiple demonstrations were conducted using individual resources and a combination of resources to address the reactive power on the circuit. Figure 21 provides a summary of a demonstration that was conducted on January 8, 2013. The figure shows that during the first half of the operations the power factor was adjusted to various set points that lowered the reactive power on the Circuit. Generator #2 was brought on line and operated in parallel with Generator #1 to have enough VAr capacity to cancel the kVArs at the Microgrid Circuit Breaker.

![Figure 21: VAr Control Demonstration – Generators 1 and 2](image-url)

Figure 21: VAr Control Demonstration – Generators 1 and 2

![Diagram showing VAr Control Demonstration](image-url)
Figure 22 provides a summary of a demonstration that includes the operation of both generators and the energy storage unit. Both DG units operated at a constant output of 1,000 kW and power factor of 98, which contributed 180 kVar. The kVar setting on the storage unit was set at various negative outputs (0, -200, and -400) for 15 minutes at each level and then set at positive outputs (200, 400, and 0) during the operation of each generator. The demonstrations showed that the reactive power as measured at the Microgrid Circuit Breaker by the SCADA device could be controlled to specific levels with the DG units in combination with the SES unit.

**Figure 22: DG and SES VAR Mode Demonstration**

![Graph showing DG and SES VAR control demonstration](image)

4.3 Objective 3: Develop a strategy and demonstration of information integration and security

**Results:** The Microgrid demonstration involved integration of various resources with various utility systems. The Microgrid Visualizer was designed as the primary vehicle for information integration between the Microgrid resources and with other systems internal and external to the utility. Figure 23 is a high-level overview of the Microgrid information technology architecture.
This architecture leverages existing utility systems such as DMS, SCADA, and data warehouses and supports a scalable solution that is capable of integrating multiple Microgrids within the utility.

Figure 23: Microgrid Architecture

The Microgrid Visualizer provides centralized control in parallel and island modes of Microgrid operation. The Microgrid Visualizer, developed as part of this project, was utilized as a core tool for remote operation of the Microgrid Resources during a majority of the demonstrations. The Visualizer is an important integration point to various utility systems like the OMS/DMS, SCADA system and the PDLM system. This tool was effectively used by Microgrid Operators to monitor and schedule the resources for operation in various modes to support Microgrid operations. The Visualizer required several external inputs to be entered into the system manually. The Visualizer met the needs of the project to support planned demonstrations but is not sufficient to act as a standalone Microgrid Controller.

All components of the Microgrid IT infrastructure were secured behind multiple firewalls and included extensive intrusion protection controls and software (Figure 24). Each application was reviewed for compliance with extensive security requirements and company standards. Vendor hosted environments were reviewed to the extent that they expose utility assets to exploitation or intrusion.
Data security is provided by multiple internal and external firewalls and routers. The Microgrid assets are located in a security zone with restricted data access. All integration to internal and external systems includes 2-way SSL for authentication and authorization. Additional data security is provided to prevent access from unauthorized locations, systems, messages, or transactions.

All installed software is reviewed by Information Security for any security risks that must be mitigated and accepted by the business before implementation. Independent third party expert security consultants were engaged to provide additional detailed review of vendor software. This included installed software for the PDLM controller and embedded software included in HAN devices and residential batteries installed in the customer premise. Extensive reviews were conducted to identify any weaknesses that could expose the utility network and devices to intrusion or unauthorized access.

4.4 Objective 4: Develop a strategy and demonstrate the integration of Advanced Meter Infrastructure (AMI) into Microgrid operations

Results: The Microgrid integrated with the Advanced Metering Infrastructure to provide interval meter data from the Smart Meter for Demand Response forecasting. The meter data was also used for Measurement and Verification of event data after Demand Response events were executed. This information helped analyze the actual load reduction versus predicted load reduction. This section describes the demand response forecast and post event analysis processes that utilized the meter data from the AMI system.
Demand Response Forecast - The PDLM Controller develops a DR capacity forecast on a rolling 48-hour basis. The forecast is a learning algorithm that improves and converges over time. The baseline data initially utilized by the PDLM Controller vendor to develop the load forecast was based on typical Customer Baseline Load (CBL). The CBL data was developed by analyzing historical meter interval data, extracted from the AMI system. The forecast algorithm utilized the CBL to forecast DR Capacity on the Microgrid Circuit. The initial DR forecast did not converge for the expected Demand Response on the Microgrid Circuit. The PDLM Controller allowed for applying a correction factor that would reduce the CBL ratio, thereby reducing the DR Capacity Forecast. This resulted in the initial DR Capacity forecast that did not represent the true nature of DR on the Microgrid Circuit. The Microgrid team applied correction factors that provided a reasonable DR Capacity Forecast for the Microgrid Circuit (Figure 25).

**Figure 25 DR Capacity Forecast – After Correction Applied to CBL**
(PDLM software depicting forecasted load and forecasted available demand response)

---

Post Event Analysis- Once a Demand Response event was completed successfully; the PDLM system conducts a post event Measurement and Verification analysis. This provides a feedback loop to refine the DR capacity estimates for future events. It also allows the operator to develop a confidence level for specific programs so that more accurate DR capacity estimates are possible.

The PDLM system calculates the actual load reduction by comparing the forecasted load to the actual load as measured by the smart meter. Any difference is attributed to the devices participating in the DR event. The difference is considered the “actual load reduction.” The
actual load reduction is then compared to the forecasted load reduction. Any difference in these values is used to adjust the expected load reduction in future DR capacity estimates. The operator has the choice to accept and apply or reject the adjustments for future DR capacity estimates.

4.5 **Objective 5: Demonstrate the capability to use automated distribution control to intentionally island customers in response to system problems**

**Results:** The Microgrid was designed to have the capability to operate in island mode. Multiple demonstrations were performed that proved the Microgrid can seamlessly transition into island operation and seamlessly transition back to parallel mode of operation. This section provides information on the demonstrations that were conducted to island the Microgrid Circuit with real customers.

The key objectives of the island demonstrations are as follows:

- Operate the Microgrid Resources to a condition of zero power flow at the breaker and open the Microgrid Circuit Breaker while maintaining stability of the Microgrid Circuit
- Validate the isochronous operation of the DG units
- Validate stable operation of the islanded Microgrid Circuit while operating the DG and SES units together
- Quantify the level of reactive power support that the SES can provide to the DG units while in island operations
- Validate the seamless transition of the Microgrid from island mode back to the grid

Overall, there were seven Island demonstrations that were conducted as presented in Table 7. For the first two Island demonstrations, three separate sub-demonstrations were conducted that included:

- Island with Distributed Generators Only
- Island with Distributed Generators and Substation Energy Storage together
- Island with Distributed Generators and Substation Energy Storage for VAr Control

**Table 7: Island Operation Demonstrations**

<table>
<thead>
<tr>
<th>Mode of Operation</th>
<th>Microgrid Resources</th>
<th>Demo Description</th>
<th>Control Settings</th>
<th>Demo Date</th>
<th>Start Time</th>
<th>End Time</th>
<th>Control Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Island Test</td>
<td>Gen1 Gen2 SES</td>
<td>Island Demonstration w/DG Only</td>
<td>Gen 1 and Gen 2</td>
<td>2/13/2013</td>
<td>9:20</td>
<td>10:35</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>X X</td>
<td>Island Demonstration w/DG and SES</td>
<td>Gen 1, Gen 2 and SES (Real Power)</td>
<td>2/13/2013</td>
<td>10:45</td>
<td>11:40</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>X X</td>
<td>Island Demonstration w/DG and SES VAr</td>
<td>Gen 1, Gen 2 and SES (Real Power and Reactive Power)</td>
<td>2/13/2013</td>
<td>11:50</td>
<td>12:40</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>X X</td>
<td>Island Demonstration w/DG Only and VAr</td>
<td>Gen 1, Gen 2</td>
<td>2/27/2013</td>
<td>9:00</td>
<td>10:15</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>X X</td>
<td>Island Demonstration w/DG and SES VAr</td>
<td>Gen 1, Gen 2 and SES (Real Power)</td>
<td>2/27/2013</td>
<td>9:00</td>
<td>10:10</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>X X</td>
<td>Island Demonstration w/DG and SES VAr</td>
<td>Gen 1, Gen 2 and SES (Real Power and Reactive Power)</td>
<td>2/27/2013</td>
<td>10:15</td>
<td>11:45</td>
<td>Local</td>
</tr>
</tbody>
</table>
|                   | X X X               | Remote Island Demonstration                          | Gen 1, Gen 2 and SES (Real Power and Reactive Power)   | 3/13/2013       | 10:00      | 14:20    | Remote
Island with Distributed Generators Only - Island Operation with DG only was conducted as the first Island demonstration. The demonstrations were conducted at a time when the load on the Microgrid Circuit could be carried by the two 1.8 MW generator units. The specific objectives of this sub-demonstration included:

- Demonstrate Generator operation in Isochronous mode for
  - Load Control
  - Voltage Control
  - VAr Control
  - Frequency Control
- Demonstrate Stability of Operation of the Microgrid Circuit while in Island
- Demonstrate Seamless Transitions of the Microgrid Circuit for the following:
  - Generator synchronization to the grid
  - Separation of Microgrid from the Substation
  - Return of Microgrid back to the Substation

The Island Operations using only the generators were demonstrated successfully by locally controlling the generators using the Microgrid Visualizer. The first two times that the island mode was demonstrated, the Microgrid Operator controlled the equipment from the Control Van in the Microgrid Yard. The operations were coordinated with a line crew to manually turn off the fixed line capacitor at the beginning of the demonstration and to be available for other support if needed.

Figure 26 presents a summary of the island demonstration on February 13, 2013. For this demonstration, DG#1 was initially synchronized with the Microgrid Circuit with a load of approximately 1,600 kW. Then DG#2 was synchronized with the Microgrid Circuit and the load was shared equally by both generators. The two units operated in load following with a set point of 0 kW at the Microgrid Circuit Breaker from 9:27 AM to 9:40 AM when the Distribution Operator opened the Microgrid Circuit Breaker. The Microgrid operated as an island for 90 minutes. The Distribution Operator set the permission in the relay for the generators to synchronize back the grid. The synchronization took approximately 45 seconds. Once the Microgrid Circuit was closed, the two generators operated again in load following with a set point of 0 kW.
Figure 27 shows the DG #1 controls while operating in the island. The unit was operating at 970 kW, 479 volts, a power factor of 0.98 lagging, and a frequency of 60.02 Hz.

**Figure 27: Generator Control Display in Island Operations**

Figure 28 presents the generator synchroscope during the transition island to grid connected. The synchronization process took less than 45 seconds to complete. The breaker closes when the synchronization indicator is stable at the 12 o’clock position on the circle.

**Figure 28: Generator Synchroscope during Transition from Island**
Island with Distributed Generation and SES - With the successful Island Demonstration of the Microgrid Circuit with DG only, the next objective was to demonstrate Island Operation with simultaneous operation of the DG and SES units. Additional objectives of this demonstration include:

- Demonstrate Stability of Operation of the Microgrid Circuit while in Island
- Demonstrate ability to vary SES discharge rates in Island mode
- Demonstrate ability to transition the SES to charge mode in Island operation
- Demonstrate ability to vary charge rates in Island mode
- Demonstrate Seamless Transitions of the Microgrid Circuit for the following:
  - Generator synchronization to the grid
  - Separation of Microgrid from the Substation
  - Return of Microgrid back to the Substation

The Island Operations with DG and SES only were demonstrated successfully by controlling the generator and SES locally using the Microgrid Visualizer from the Control Van in the Microgrid yard. The control approach demonstrated that the DG and SES can be operated simultaneously to meet a forecasted load. The DG was operated in load following and while the SES was programmed to operate within specified constant mode set points. Figure 29 shows that the generators and SES were able to share and meet the load over the range of operation.

The SES was operated in both charge and discharge modes of operation and the set points were also altered during the demonstration. The point of adjusting the SES set points was to cause small rapid changes in the load seen by the DG units and observe if the stability of the island mode operation was affected by these changes.
Figure 29: Island Demonstration with DG and SES

Microgrid Circuit Load 02/13/2013 - Island Test w/DG & SES

Microgrid Resources 02/13/2013 - Island Test w/DG & SES

Grid Resource 02/13/2013 - Island Test w/DG & SES
Figure 30 presents a screen shot of the Microgrid Visualizer during island operation with both DG units and the SES operating.

**Figure 30: Microgrid Visualizer during Island Operations**

Microgrid Operating in Island Mode:
- Microgrid Circuit Breaker Open
- Island Operation Permission Granted
- Microgrid Resources:
  - SES: 100 kW
  - Gen#1: 677 kW / 99 kVAr
  - Gen #2: 656 kW / 277 kVAr

Island with Distributed Generation and SES (VAr Control) - The primary objective of this particular islanding demonstration is to evaluate how the Microgrid resources can effectively manage reactive power in island operation. This demonstration builds on the simultaneous operation of DG and SES in Island mode to evaluate options for VAr control during Island operation. In isochronous operation, the DG units supply the reactive power required by the circuit loads which can be high when the large pumps are operating. The goal of this scenario is to evaluate the ability to have the DG units provide a majority of the real power to the Microgrid and to have the SES unit provide a majority of the reactive power. This method of operation is expected to result in a lower cost of operation and provide the ability to potentially operate the generators longer since they will be consuming less fuel by operating more efficiently. Additional objectives of this demonstration include:

- Demonstrate Stability of Operation of the Microgrid Circuit while in Island
- Demonstrate ability to initiate SES operations (on/off) in Island mode
- Demonstrate ability to control VArS in Island mode

The Island Operation with DG and SES controlling VArS was demonstrated successfully by locally controlling the generator and SES from the Control Van in the Microgrid yard using the Microgrid Visualizer. The two DGs operated in isochronous mode and the SES operated in VAr mode to provide the required VArS on the circuit. The SES was not able to carry the full VAr load on the circuit, however, the use of SES for VAr control meant that the generators could be operated at a higher power factor of 0.95, thereby carrying more load on the circuit. The SES was initially operated in idle mode, then ramped up to discharge at 100 kW and was finally...
placed back in idle mode. This demonstrated the capability to operate the SES in Island mode without affecting the stability of the Microgrid Circuit. Finally, the Microgrid Circuit seamlessly transitioned from Island operation to grid parallel operation within 45 seconds.

Figure 31 shows that the generators are operating by themselves at a power factor of approximately 0.90. At 12:00 PM, the SES reactive power output was set to 100 kVAr, which allowed the generators to operate at a power factor of approximately 0.92. At 12:10 PM, the SES reactive power output was increased to 275 kVAr, which improved the generator power factor to 0.95. This demonstrated that the SES could manage VAr to the point where the generators could operate at improved power factors. The duration of the demonstration was from 11:40 AM to 12:45 AM. The Microgrid Circuit load ranged between 1,650 kW and 1,400 kW during the demonstration.

**Figure 31: Island Demonstration with DG using SES for VAr Control**

![Graph showing power factor and VAr output over time]

4.6 Objective 6: Develop information/tools addressing the impact of multiple DER technologies.

Results: The Microgrid was designed to operate multiple DER technologies that integrated with the Microgrid Visualizer. Various information tools and processes were developed that assisted in Microgrid operations.

Microgrid Visualizer –The Microgrid Visualizer interfaces with the various resources on the Microgrid Circuit, as well as various systems at SDG&E. Each individual resource in the Microgrid Circuit is equipped with its internal control system. Various systems at SDG&E like SCADA, OMS/DMS, and PDLM system have their own user interfaces that provide information on control functions available to the operator. With so many user interfaces to monitor, it would have been difficult for the Microgrid Operator to get an overall picture of the information flow across these systems.
The Microgrid Visualizer provides a consolidate user interface for the Microgrid Operator to dispatch resources and monitor equipment operation. When a desired set of operations are needed for the Microgrid, the Microgrid Operator selects, loads, and activates the appropriate schedule or profile. Figure 32 presents the Visualizer user interface when a scheduled operation is being executed. This interface provides the Microgrid Operator with the status and operating parameters of each of the Microgrid Resources as well as the scheduled operation. This provides feedback to the Operator whether or not the Microgrid is operating as anticipated.

Figure 32: Microgrid Visualizer User Interface

Load Forecast - A load forecast model was developed using August 2012 data to help support Microgrid operations and demonstration planning. The load forecast is based on a multivariable linear regression using the following variables:

- Time of day (military format with no colon)
- Outside ambient dry bulb air temperature forecast (°F)
- Pump schedule flag (1’s and 0’s, set to 1 from 11:00 PM to 5:00 AM)
- Average of three previous weekday’s load at the same time day (MW)
- Average of three previous weekday’s ambient dry bulb Air temperatures at the same time (°F)
Figure 33 presents a sample load forecast versus actual load that was observed for February 6, 2013.

Figure 33: Example Load Forecast

Microgrid Pricing - The Pricing Module is used to calculate the wholesale price of electricity ($/MWh) for electricity delivered to customers within the Microgrid. The wholesale price is dependent on the operation of Microgrid Resources along with the transmission grid. If the Microgrid resources are non-operational, the wholesale price is equal to the Locational Marginal Price at the Borrego node. This LMP nodal price is obtained through an interface with CAISO’s Nodal LMP system (referred to OASIS). If the Microgrid resources are operational, the wholesale price is established by calculating an average weighted price of energy obtained from the grid at the LMP nodal price and the price of energy produced by the operating Microgrid Resources.

The wholesale price consists of the following components:

- DG# 1 Price – Price associated with the operation of Distributed Generator # 1
- DG# 2 Price – Price associated with the operation of Distributed Generator # 2
- Grid Price - The Grid Price is equal to the CAISO DAM LMP price for the Borrego Node
- SES Price – Price associated with the charge/discharge operation of the Substation Energy Storage unit

The base formula to calculate the Total Weighted Average Price is:

\[ \text{Total Weighted Average Price} = \sum (\text{Price Component} \times \text{Weight}) \]
An exception to this calculation occurs when the SES is in the charging mode. The Total Weighted Average Price (Microgrid Prices$/MWh) during the charging interval is calculated by excluding the SES Aggregate Price component. The value of electricity in the SES unit is accounted for by using the LMP price at the time of the charging and the quantity of electricity added to the SES while charging. Prior to discharging the SES unit, the average cost of electricity for all the energy stored in the unit is calculated. This is used as the basis of the price of energy from the SES unit during the entire discharge cycle.

Table 8 presents the total weighted average price calculation for a simulation of Microgrid resources running on January 15, 2013. DG# 1 and DG# 2 were operating for two hours between 11:00 AM to 1:00 PM, while the SES was discharging between 10:00 AM to 12:00 noon. The CAISO wholesale price for that particular day is shown in the third column. The Table shows that at time periods when the DG unit or the SES is not operating, the Microgrid price is equal to the CAISO Price. During time periods when the DG units and SES were operated the associated Microgrid Price is calculated.

<table>
<thead>
<tr>
<th>Date</th>
<th>CAISO Price</th>
<th>DG 1</th>
<th>DG 2</th>
<th>SES Price</th>
<th>Grid</th>
<th>Microgrid Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/14/2013</td>
<td>37.63 $</td>
<td>35.80 $</td>
<td>36.23 $</td>
<td>37.63 $</td>
<td>35.80 $</td>
<td>36.23 $</td>
</tr>
<tr>
<td>1/15/2013</td>
<td>47.78 $</td>
<td>51.13 $</td>
<td>59.83 $</td>
<td>53.90 $</td>
<td>44.46 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/16/2013</td>
<td>69.73 $</td>
<td>81.47 $</td>
<td>76.82 $</td>
<td>69.73 $</td>
<td>44.46 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/17/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/18/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/19/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/20/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/21/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/22/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
<tr>
<td>1/23/2013</td>
<td>36.23 $</td>
<td>35.80 $</td>
<td>35.90 $</td>
<td>35.90 $</td>
<td>35.80 $</td>
<td>35.80 $</td>
</tr>
</tbody>
</table>
An example of the calculation is presented below for the system operations between 11:00 AM and 12:00 noon where DG# 1 was running at 823 kW and DG# 2 was running at 847 kW. The calculation used for DG1 and DG2 prices is as follows:

The components of the Total Weighted Average price associated with the operation of the Microgrid resources during the hour of 11:00 AM is:

- DG1 (823 kW x 293.80 $/MWh) = $241.79/Hour
- DG2 (847 kW x 314.03 $/MWh) = $265.98/Hour
- SES (293.8 kW x 40.25 $/MWh) = $11.82/Hour
- Grid (173 kW x 38.87 $/MWh) = $6.72/Hour
- Total Energy (kW) = 2,136.8

The Total Weighted Average Price = 246.31$/MWh

The Microgrid Price (Total Weighted Average Price) as shown in Table 7 is presented graphically in Figure 34.

Figure 34: Microgrid Wholesale Price Simulation 01/15/2013

This Total Weighted Average price was sent to the Price Driven Load Management system which translates the wholesale price to the retail price for presentment to the customers and their HAN systems. After a detailed quantitative analysis of historical CAISO wholesale prices, five pricing levels were developed to translate the Microgrid wholesale price to the customer retail price. The pricing model was developed to target a maximum of eight hours per week of prices that would trigger the HAN devices to alter operation of their connected equipment. The modeled distribution of pricing levels is 4 hours at Level 3, 2 hours at Level 4, and 2 hours at Level 5.
Table 9 presents pricing level methodology used to translate the wholesale price to retail price.

<table>
<thead>
<tr>
<th>Pricing Level</th>
<th>Wholesale Price Range ($/MWh)</th>
<th>Retail Price ($/KWh)</th>
<th>Hours of Occurrence per Week</th>
<th>Frequency of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>$00.00 to 29.00</td>
<td>$0.10</td>
<td>26</td>
<td>15.2%</td>
</tr>
<tr>
<td>Level 2</td>
<td>$29.01 to 59.49</td>
<td>$0.25</td>
<td>134</td>
<td>80.0%</td>
</tr>
<tr>
<td>Level 3</td>
<td>$59.50 to 66.99</td>
<td>$0.35</td>
<td>4</td>
<td>2.4%</td>
</tr>
<tr>
<td>Level 4</td>
<td>$67.00 to 74.99</td>
<td>$0.45</td>
<td>2</td>
<td>1.2%</td>
</tr>
<tr>
<td>Level 5</td>
<td>&gt;$75.00</td>
<td>$0.60</td>
<td>2</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

These pricing levels are designed such that the HAN devices will respond to price fluctuations based on the thresholds set by the customer through the PDLM Customer Portal. Default settings were programmed into the HAN devices at the time of installation. These programs were developed to respond at Level 3 and above with the device settings as follows:

- Level 3: Plug Load Controllers (PLC) activated
- Level 4: Programmable Communicating Thermostats (PCT) operate with a 2°F offset in cooling mode and PLCs are activated
- Level 5: PCT operates with a 4°F offset in cooling mode and PLCs are activated

Figure 35 presents an example of the how the hourly prices based on the Microgrid wholesale price was used to trigger the defined event Levels in the PDLM system. Note that the pricing model was implemented as a simulation for the purposes of this demonstration and that the customer bills were not affected by prices being passed to the devices.

In this example, Level 5 events would be executed at 8:00 AM, 11:00 AM and 12:00 noon that would adjust the PCT temperature by 4°F and switch off devices on the PLC. Level 4 events would be executed between 6:00 to 12:00 hours that adjusted the PCT temperature by 2°F and switch off devices on the PLC. In addition, Level 3 events would be executed between 6:00 AM to 12:00 noon and at 6:00 PM, when the devices on the PLCs would be switched off.
4.7 Objective 7: Demonstrate Programmable and Controllable Thermostats to achieve Demand Response goals within the Microgrid.

Results: The Microgrid was designed to integrate Programmable and Controllable Thermostats with the PDLM system to achieve Demand Response within the Microgrid. The HAN systems used in the Project consisted of a gateway that communicates with the in-home devices (through wireless control signals) such as the in-home display, programmable communicating thermostats, load control switches, and plug load controllers. The end devices were configured to control loads based on event-based activities (i.e. demand response events) or price-based activities. One of the key elements of the HAN systems was the Programmable Communicating Thermostats (PCT) as presented in Figure 36. The PCT provides the following features:

- Enables control of the home cooling system
- Customizes cooling usage to maximize in-home energy efficiency
- Receives set point signals from the PDLM system to offset temperature settings
Different types of demand response programs were developed (within the PDLM Controller) to meet the objectives of demonstrating Standard Demand Response and Real Time Pricing based Demand Response. The PCTs responds to signals from the HAN system and adjust the temperature settings which result in cycling of the air conditioning unit to a higher temperature, thereby reducing the load in customer homes.

PCT Participation in Standard DR Events - For the Traditional Demand Response activity, two PCT Programs were developed. Additionally, the PDLM Controller was configured with a PLC program. These programs were implemented through local control initiated by the PDLM Controller, and through triggers created with input from the Microgrid Visualizer. Multiple demonstrations were conducted on various days that included the following demand response programs:

- PCT program: 2 Degree Offset
- PCT program: 4 Degree Offset
- PLC only program
- All Devices (PCT 4 Degree and PLC combined)
Figure 37 presents information about the PCT operation during a two-hour Standard DR event. The PDLM Controller activates a PCT DR Program that is sent to the HAN systems in the Microgrid. Upon execution of the event, the PCT set point was increased by 4 °F for the cooling set point. The data shows that the room temperature gradually increased during the event as the operation of the cooling system was altered by the new thermostat setting at 14:00 (2:00 PM). During the event, the room temperature gradually increased from 76.0 °F to 81.5 °F. After the event, the PCT set point was reset back to its original value of 78.0 °F and the room temperature decreased to the set point in approximately half an hour.

Figure 37: Sample PCT Set Point – DR Event

PCT Participation in Pricing Events - For the Pricing Events, the primary objective was to demonstrate the use of pricing signals to impact customer load reduction. The demonstrations evaluated the ability to achieve the desired load reduction based on pricing signals communicated to the HAN devices (including PCTs) and in home displays.

Figure 38 presents information about the PCT operation during a one-hour Pricing event. The PDLM Controller converts the Microgrid Wholesale Price to the customer retail price and transmits the hourly prices to the HAN systems in the Microgrid. In the example presented in Figure 47, the PCT reacts to a price that triggers a set point offset of +2° F. The data shows that the room temperature gradually increased during the event as the operation of the cooling system has been altered by the new thermostat setting at 14:00. During the event, the room temperature gradually increased from 78.5° F to 80.5° F. After the event, the PCT set point was reset back to its original value of 78.0° F and the room temperature decreased back to the original set point temperature in approximately 30 minutes.
Figure 38: Sample PCT Set point – RTP Event

Sample PCT Setpoint - Pricing Event

- Pricing Event
- 2°F Offset

Room Temperature
Cooling setpoint
CHAPTER 5: Lessons Learned and Key Findings

5.1 Lessons Learned

The Microgrid demonstration proved to be a challenging project due to the complexity of integrating new systems to the distribution network that could impact customers, reliance on other projects for integration, the use of newly emerging technologies and systems, and environmental requirements.

The team first identified the complexities during the use case development phase of the project. The key stakeholders identified specific constraints with the existing systems and utility processes which drove some key elements of the system architecture for the demonstration. The use case process also demonstrated that Microgrids impact nearly all the departments within the utility. It became clear that the approach that would be implemented for the demonstration would be a first step toward the ability to integrate Microgrids but a more comprehensive enterprise strategy must be developed if Microgrids were to be employed as a common resource in the service territory.

The PDLM system integration and deployment was expected to be challenging at the beginning of the project and this proved to be the case as the project was executed. The use case results from the beginning of the project were used to develop an RFP for the system. A vendor that had formed a team to provide a turnkey solution was selected. The vendor had a base software solution for demand response that was modified to meet the pricing functional requirements for the Microgrid project. At first, this appeared to be a benefit to meeting the project schedule; however, the schedule was a challenge for the project. The implementation of the PDLM software required a security validation process before it could be approved to be operated along with the “production” systems operated by the utility. This process had a major impact on the schedule.

Another challenge to the PDLM implementation was the recruitment of customers. Many customer outreach and recruitment events were held in the community to entice residential customers to have the HAN systems installed in their homes and participate in non-tariff based demand response events over the course of a one year period. The target for the number of participants was 125; however, a total of 65 were enrolled and participated. By the time the system was installed and accepted for operation, the demonstration project schedule was near the end and many of the demand response events had to be conducted during a non-summer time period which significantly reduced the real demand response impact of weather based loads (i.e. air conditioning).

A major objective of the demonstration project was to discover how the PDLM resources could be managed in the Microgrid environment and if PDLM could be managed like the other DER resources. Ideally, PDLM could be managed in the Microgrid in a manner similar to the way that generators or storage systems are managed. PDLM does have some limitations and constraints. The capacity of PDLM to deliver load reduction depends on weather, time of day,
and customer behavior. PDLM operations must address the needs of customers as well and devices and systems. Agreements with customers limit the frequency and duration of PDLM events. Customers had the option to opt-out of events. The dependability of PDLM resources can vary with customer fatigue and other uncontrollable customer behavior.

Finally, the methodology for forecasting demand reduction is largely based on trial and error with incremental refinement of estimates based on experience. This means that early forecasts are unlikely to be reliable. It takes considerable refinement over multiple events to develop reliable estimates. Most of the issues that impact the PDLM forecasts would be eliminated by removing the customers' freedom of choice. However, for these demonstrations, that was not an option. Taken together, PLDM is very different from the other DER resources being managed within the Microgrid. While demand response can be dispatched as part of the overall Microgrid Optimized plan, benefiting from PLDM requires a wider variety of operational considerations and is far less reliable and predictable than other resources.

Another significant effort of the project was the development of a Microgrid Controller for Microgrid demonstration. The challenge for the Microgrid Controller was that there was not an existing product in the market that could easily be acquired and modified to meet the needs of the project. A decision was made to work with the vendor selected for the new Distribution Management System to leverage this work to provide a Microgrid Controller. While this initially appeared to be a benefit to the project, it became clear that the timeline for product development and controller objectives by the vendor did not align well with the demonstration project. Furthermore, the security testing requirements to place the controller into the utility’s “production” environment pushed the delivery schedule out further. It was finally decided to develop a project-specific application to provide a consolidated view of the Microgrid Resources referred to as the Microgrid Visualizer. The Microgrid Visualizer facilitated the planned Microgrid demonstrations by providing a method to easily operate the systems from a single screen, schedule equipment, monitor operations, and collect data. The Microgrid Visualizer was successfully used to support the demonstrations, including islanding operations, but is not a standalone and fully-automated control system.

5.2 Key Findings

The aspects of the project considered to be unique and to potentially advance the knowledgebase of Microgrids were:

- Develop an architecture and operational processes for utility-based Microgrids
  
  The Microgrid demonstration provided key lessons about the architecture that was suitable for this Microgrid demonstration. However, the demonstration did not produce an architecture that is easily scalable for deployment for the entire service territory. A scaled up deployment in the service territory will require a comprehensive enterprise strategy and additional automation capabilities through the distribution management system, distributed Microgrid Controllers, or a distributed energy resource management system.
• Develop and implement a pricing-based strategy to affect the operation of resources within a Microgrid

The team successfully developed a pricing model that was used by multiple Microgrid resources to influence and affect operations, particularly reducing demand to provide demand management resources to support the Microgrid circuit load. The idea to implement pricing was to have a market-based trigger that can be used to influence Microgrid operations. In the Microgrid demonstration, pricing signals influenced demand response with the objective of reducing the customer load. Demonstrations were conducted where a wholesale price was calculated based on a weighted average of Microgrid resource contributions to the planned energy supply of the Microgrid for each hour of the day. These prices where then converted to a “simulated” retail price that was presented to customer’s in home display units and HAN devices. The HAN devices responded as programmed during these pricing event demonstrations. As discussed in the storage system findings, the cost of energy was taken into account when charging the storage system. This allowed for the cost of energy being provided to the Microgrid when the storage unit was discharging to be accurately accounted. Thus, during times of high whole costs, a storage unit that had been charged during the off-peak low cost time periods could be used to reduce the cost of energy delivered to the Microgrid during peak time periods. The demonstration showed that this pricing-based strategy could effectively be used as a control signal for Microgrid Operations.

• Determine if there are approaches to using demand response resources in a manner similar to generation with dispatchability, reliability, and localization

The team envisioned that the use of home area networks combined with a central demand response control system could be used in a Microgrid to manage the demand response resource in a manner similar to the generators or the storage system. In order to accomplish this, demand response needs to be controllable, predictable, and repeatable. This proved to be challenging for the demonstration due to the resource load forecast model used, the post event estimating approached employed, the small loads being managed (mainly plug load controllers), and the small population of customers in the program. The project did successfully implement a demand response model that could execute demand response events for a targeted area of the service territory down to a section of a specific circuit. The demand response was not a major factor in Microgrid resource planning during the Microgrid Optimization Phase of the project due to its low capacity impact. Demand response has been identified as an area of further work that has the potential to be improved for both Microgrid applications and overall demand response activities.

• Demonstrate the ability to routinely operate multiple Microgrid Resources through a consolidated monitoring and control interface

Routinely operating utility-owned generation and energy storage systems on the distribution network is a new concept for utility distribution system operators. In
addition, these devices do not currently have a communication standard such as DNP3 that allows for a more straight forward integration to a typical SCADA system. The units integrated to the Microgrid offered a Modbus protocol for communications and control. In addition, these types of resources have unique operating characteristics and control sequences can be vendor-specific. In order to effectively operate these systems, a Microgrid Visualizer was developed and implemented that provided a consolidated interface to the equipment controls and monitoring. The Visualizer allowed for control of the Microgrid resource both from within the Microgrid yard (control van) and remotely from SDG&E offices in San Diego. This system also provided the function of data collection and archiving for project reporting and analysis.

- **Demonstrate seamless planned island operations on a circuit without affecting customers**

One of the highlights of the Demonstration project was the ability to effectively island the entire Microgrid supporting more than 600 customers. The islanding demonstrations transitioned into and out of the island mode without affecting the quality of service to the customers (seamless transitions without an outage or flicker). The island demonstrations evaluated the island operations with the DG units only, the DG units operating with the SES in both charge and discharge modes, and the DG units operating with the SES unit providing a majority of the reactive power requirements. All demonstrations were successful and demonstrated the stated operational objectives.

Additionally, the Microgrid was operated in island operation twice during the contract period to provide service to customers who would have otherwise had an extend loss of service.

- The first event took place on June 6, 2012 for a planned outage for the Borrego Springs community so that a new NRG Solar 26 MW solar project could be safely interconnected to SDG&E’s system. The outage began at 10:00 PM and lasted for approximately 5 ½ hours supplying energy to a total of 2,128 customers. This was a pre-planned operation in which the Microgrid was temporarily re-configured to service all three of the circuits at the substation.
The second event took place on September 6, 2013 when severe weather of high winds, heavy rain, and a lighting storm caused an unplanned outage of service to the entire substation. This manual black start operation primarily used the generators which were operated continuously on September 6 from 16:48 PM to 3:10 PM on September 7. As sections of the circuits were cleared or repaired, additional customers were energized as presented in the following table:

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Customers with Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/6/2013</td>
<td>2:20 PM</td>
<td>0 – Start of outage</td>
</tr>
<tr>
<td>9/6/2013</td>
<td>6:50 PM</td>
<td>162 – Powered by Microgrid</td>
</tr>
<tr>
<td>9/6/2013</td>
<td>7:50 PM</td>
<td>529 – Powered by Microgrid</td>
</tr>
<tr>
<td>9/7/2013</td>
<td>7:25 AM</td>
<td>754 – Powered by Microgrid</td>
</tr>
<tr>
<td>9/7/2013</td>
<td>8:33 AM</td>
<td>1,056 – Powered by Microgrid</td>
</tr>
<tr>
<td>9/7/2013</td>
<td>2:00 PM</td>
<td>All – All repairs complete and grid service resumes</td>
</tr>
</tbody>
</table>
CHAPTER 6: Public Benefits to California

The lessons learned and key findings of this proof-of-concept Microgrid demonstration are expected to produce benefits for California’s electricity ratepayers. Microgrids may provide benefits associated with the use of Distributed Energy Resources and their Control Strategies that include:

- **Reliability**
  - Reduce the impact of power interruptions for both planned and unplanned events
  - Improved power quality with local Distributed Energy Resources

- **Economics**
  - Peak load management at a local level
  - Leverage customer-side of the meter resources for grid operations
  - Execution of demand response programs based on near real-time pricing signals presented to customers

- **Environmental**
  - Support grid operations in areas of high renewable energy generation

With prolific deployment of PV, EV, and Energy Storage systems being installed at the distribution level of the electric infrastructure, Microgrids provide a locally controlled resource to address issues of new electric usage characteristics of customers, bi-directional power flow on the network, power quality issues, and reliability of service.

This project demonstrated specific scenarios for operating Microgrid resources under real operating situations while serving actual utility customers. This work helps advance future deployment of Microgrids by both California utilities and electric customers. Given proper design, integration, and controls, Microgrids can be part of a portfolio of energy solutions that help advance renewable energy standards in the state. With subsequent deployment and standardization of Microgrids, a competitive market for supply and demand management can be developed where both smaller and larger customers may be market participants. The demonstration of Dynamic Pricing advances the concept of market-based electric tariffs where customers are empowered to make informed decisions on electric purchases based on their willingness to pay at various price points throughout the day. Customers may be rewarded for adoption of enabling technologies through participation in the dynamic pricing market and incentives.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ADO</td>
<td>Advanced Distribution Operation</td>
</tr>
<tr>
<td>AES</td>
<td>Advanced Energy Storage</td>
</tr>
<tr>
<td>AMI</td>
<td>Advanced Metering Infrastructure</td>
</tr>
<tr>
<td>BAU</td>
<td>Business as Usual</td>
</tr>
<tr>
<td>C&amp;I</td>
<td>Commercial and Industrial</td>
</tr>
<tr>
<td>CAISO</td>
<td>California Independent System Operator</td>
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<tr>
<td>CB</td>
<td>Circuit Breaker</td>
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<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<tr>
<td>CBL</td>
<td>Customer Baseline Load</td>
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<tr>
<td>CES</td>
<td>Community Energy Storage</td>
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<td>CO</td>
<td>Constant Output</td>
</tr>
<tr>
<td>DEM</td>
<td>Distributed Energy Manager</td>
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<td>DER</td>
<td>Distributed Energy Resources</td>
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<td>DG</td>
<td>Distributed Generation</td>
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<tr>
<td>DMS</td>
<td>Distribution Management System</td>
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<td>DNP</td>
<td>Distributed Network Protocol</td>
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<td>DOE</td>
<td>Department of Energy</td>
</tr>
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<td>DR</td>
<td>Demand Response</td>
</tr>
<tr>
<td>EDW</td>
<td>Engineering Data Warehouse</td>
</tr>
<tr>
<td>EOC</td>
<td>End of Circuit</td>
</tr>
<tr>
<td>FAST</td>
<td>Feeder Automation System Technology</td>
</tr>
<tr>
<td>FLISR</td>
<td>Fault Location Isolation and Service Restoration</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>HAN</td>
<td>Home Area Network</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>HHV</td>
<td>Higher Heating Value</td>
</tr>
<tr>
<td>HPV</td>
<td>High Penetration Photovoltaic</td>
</tr>
<tr>
<td>IHD</td>
<td>In Home Display</td>
</tr>
<tr>
<td>ITC</td>
<td>Investment Tax Credit</td>
</tr>
<tr>
<td>kBTU</td>
<td>Kilo British Thermal Unit</td>
</tr>
<tr>
<td>kVAr</td>
<td>Kilo Volt Ampere Reactive</td>
</tr>
<tr>
<td>kW</td>
<td>Kilo Watt</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilo Watt Hour</td>
</tr>
<tr>
<td>LCS</td>
<td>Load Control Switch</td>
</tr>
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<td>LDAP</td>
<td>Lightweight Directory Access Protocol</td>
</tr>
<tr>
<td>LF</td>
<td>Load Following</td>
</tr>
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<td>LMP</td>
<td>Locational Marginal Pricing</td>
</tr>
<tr>
<td>M&amp;V</td>
<td>Measurement and Verification</td>
</tr>
<tr>
<td>MDMS</td>
<td>Meter Data Management System</td>
</tr>
<tr>
<td>MMC</td>
<td>Microgrid Master Controller</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>NMS</td>
<td>Network Management System</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>NOC</td>
<td>Network Operations Center</td>
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<tr>
<td>NPV</td>
<td>Net Present Value</td>
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<tr>
<td>O</td>
<td>Other</td>
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<td>O&amp;M</td>
<td>Operations and Maintenance</td>
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<td>OASIS</td>
<td>Open Access Same-time Information System</td>
</tr>
<tr>
<td>OMS</td>
<td>Outage Management System</td>
</tr>
<tr>
<td>OpEx</td>
<td>Operational Excellence</td>
</tr>
<tr>
<td>PCS</td>
<td>Power Conversion System</td>
</tr>
<tr>
<td>PCT</td>
<td>Programmable Communicating Thermostat</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>PDLM</td>
<td>Price Driven Load Management</td>
</tr>
<tr>
<td>PIER</td>
<td>Public Interest Energy Research</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
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<td>PQ</td>
<td>Power Quality</td>
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<td>PS</td>
<td>Peak Shaving</td>
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<td>PV</td>
<td>Photovoltaic</td>
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<td>RDO</td>
<td>Real Device Outage</td>
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<td>RES</td>
<td>Residential Energy Storage</td>
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<td>RFP</td>
<td>Request for Proposal</td>
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<td>SANDAG</td>
<td>San Diego Association of Governments</td>
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<td>Substation Energy Storage</td>
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<td>State of Charge</td>
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<td>US</td>
<td>United States</td>
</tr>
<tr>
<td>VAr</td>
<td>Volt Ampere Reactive</td>
</tr>
<tr>
<td>WP</td>
<td>Weak Point</td>
</tr>
</tbody>
</table>
APPENDIX A:  
Development Status Questionnaire

California Energy Commission  

PROJECT DEVELOPMENT STATUS

Answer each question below and provide brief comments where appropriate to clarify status. If you are filling out this form in MS Word, the comment block will expand to accommodate inserted text.

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<thead>
<tr>
<th>PI Name</th>
<th>Thomas Bialek</th>
<th>Grant #</th>
<th>CEC-500-08-025</th>
</tr>
</thead>
</table>

**Overall Status**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you consider that this research project proved the feasibility of your concept?</td>
<td>Briefly state why.</td>
</tr>
<tr>
<td>Yes, this project demonstrated some of the benefits microgrids can potentially provide to the distribution system and customers.</td>
<td></td>
</tr>
<tr>
<td>Do you intend to continue this development effort towards commercialization?</td>
<td>If NO, indicate why and answer only those questions below that are still relevant.</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

**Engineering/Technical**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the key remaining technical or engineering obstacles that prevent product demonstration?</td>
<td>Commercially available distributed microgrid control systems</td>
</tr>
<tr>
<td>Have you defined a development path from where you are to product demonstration?</td>
<td>SDG&amp;E is working with a vendor to complete the development path.</td>
</tr>
<tr>
<td>How many years are required to complete product development and demonstration?</td>
<td>It will take another 2 to 3 years to develop a more functional system</td>
</tr>
<tr>
<td>How much money is required to complete engineering development and demonstration?</td>
<td>Do not include commercialization costs such as tooling</td>
</tr>
<tr>
<td>$5 M to $10 M</td>
<td></td>
</tr>
<tr>
<td>Do you have an engineering requirements specification for your potential product?</td>
<td>This specification details engineering and manufacturing needs such as tolerances, materials, cost, stress etc. If NO indicate when you expect to have it completed.</td>
</tr>
<tr>
<td>Yes these have been developed for the DERMS product RFP.</td>
<td></td>
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</tbody>
</table>
## Marketing

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
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</thead>
<tbody>
<tr>
<td>What market does your concept serve?</td>
<td>Residential, commercial, industrial, other. All customer classes.</td>
</tr>
<tr>
<td>What is the market need?</td>
<td>Summarize the market need and identify any sources you referenced.</td>
</tr>
<tr>
<td></td>
<td>Customers wanting higher levels of reliability and an alternative service delivery model.</td>
</tr>
<tr>
<td>Have you surveyed potential customers for interest in your product?</td>
<td>If YES, the results of the survey should be discussed in the Final Report. No</td>
</tr>
<tr>
<td>Have you performed a market analysis that takes external factors into consideration?</td>
<td>External factors include potential actions by competitors, other new technologies, or changes in regulations or laws that can impact market acceptance of your product? No</td>
</tr>
<tr>
<td>Have you identified any regulatory, institutional or legal barriers to product acceptance?</td>
<td>If YES, how do you plan to overcome these barriers? Yes, significant patent activity in this area.</td>
</tr>
<tr>
<td>What is the size of the potential market in California for your proposed technology?</td>
<td>Identify the sources used to assess market size and any assumptions related to anticipated market penetration. A market assessment has not been completed</td>
</tr>
<tr>
<td>Have you clearly identified the technology that can be patented?</td>
<td>If NO, how do you propose to protect your intellectual property? Yes</td>
</tr>
<tr>
<td>Have you performed a patent search?</td>
<td>If YES, was it a self-search or professional search and did you determine if your product infringes or appears to infringe on any other active or expired patent? Yes it was a professional search and there is significant activity in this area.</td>
</tr>
<tr>
<td>Have you applied for patents?</td>
<td>If YES, provide the number of applications. No</td>
</tr>
<tr>
<td>Have you secured any patents?</td>
<td>If YES, provide the patent numbers assigned and indicate if they are generic or application patents. No</td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>8) Have you published any paper or publicly disclosed your concept in any way that would limit your ability to seek patent protection?</td>
<td>If YES, is it your intent to put the intellectual property into the public domain? No</td>
</tr>
<tr>
<td><strong>Commercialization Path</strong></td>
<td></td>
</tr>
<tr>
<td>9) Can your organization commercialize your product without partnering with another organization?</td>
<td>If YES, indicate how you would accomplish that. If NO, indicate who would be the logical partners for development and manufacture of the product. No, electrical equipment product vendors.</td>
</tr>
<tr>
<td>10) Has an industrial or commercial company expressed interest in helping you take your technology to the market?</td>
<td>If YES, are they a major player in the marketplace for your product? Yes, a number of large companies are very interested in the technology.</td>
</tr>
<tr>
<td>11) Have you developed a commercialization plan?</td>
<td>If yes, has it been updated since completing your grant work? No</td>
</tr>
<tr>
<td>12) What are the commercialization risks?</td>
<td>Risks are those factors particular to your concept that may delay or block commercialization. Acceptance of the technology need.</td>
</tr>
<tr>
<td><strong>Financial Plan</strong></td>
<td></td>
</tr>
<tr>
<td>13) If you plan to continue development of your concept, do you have a plan for the required funding?</td>
<td>Yes</td>
</tr>
<tr>
<td>14) Have you identified funding requirements for each of the development and commercialization phases?</td>
<td>Yes</td>
</tr>
<tr>
<td>15) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?</td>
<td>If YES, indicate the sources and the amount. If NO, indicate any potential sources of follow-on funding. No, DOE and CEC funding sources</td>
</tr>
<tr>
<td>16) What are the go/no-go milestones in your commercialization plan?</td>
<td>Not developed</td>
</tr>
<tr>
<td>17) How would you assess the financial risk of bringing this product/service to the market?</td>
<td>Not developed</td>
</tr>
<tr>
<td>18) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?</td>
<td>If YES, can you attach a non-proprietary version of that plan to your final report? No</td>
</tr>
<tr>
<td><strong>Public Benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>i) What sectors will receive the greatest benefits as a result of your concept?</td>
<td>Residential, commercial, industrial, the environment, other. Potential for all customer segments interested in grid resiliency.</td>
</tr>
<tr>
<td>j) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.</td>
<td>Show all assumptions used in calculations. Not performed.</td>
</tr>
<tr>
<td>k) Does the proposed technology reduce emissions from power generation?</td>
<td>If YES, calculate the quantity in total tons per year or tons per year per relevant unit. Show all assumptions used in calculations. Possibly but not performed.</td>
</tr>
<tr>
<td>l) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?</td>
<td>If YES, please specify. Local fossil generation resources.</td>
</tr>
</tbody>
</table>

**Competitive Analysis**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>i) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?</td>
<td>Identify top 3. Not performed.</td>
</tr>
<tr>
<td>j) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?</td>
<td>Identify top 3. Not performed.</td>
</tr>
</tbody>
</table>

**Development Assistance**

The Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.

<table>
<thead>
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<tbody>
<tr>
<td>i) If selected, would you be interested in receiving development assistance?</td>
<td>If YES, indicate the type of assistance that you believe would be most useful in attracting follow-on funding. Yes, letters of support or other funding.</td>
</tr>
</tbody>
</table>