ELECTRIC POWER RESEARCH INSTITUTE

Program on Technology Innovation: Microgrid Implementations: Literature Review

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ABSTRACT

Historically, power grids in the United States and Canada were built with a centralized structure with power generated at large plants and electricity transported across long distances to the end user. Now, the industry and governments are looking at a different approach in which electricity is generated and distributed locally, in many cases using renewable distributed generation (DG) resources and energy storage. For this report, a literature search was undertaken to describe the state of microgrid development and adoption across North America. The report lists a broad cross-section of the types of microgrid planned and in operation across the continent, from small test grids, used to assess new technologies and provide data, to large community microgrids built as part of an energy district. The report describes the benefits of microgrids, including reduced energy costs, lower greenhouse gas emissions, and greater reliability and flexibility. Several types of microgrids are discussed, including the virtual power plant (VPP), in which small DG resources are linked together and operated as a single unit.

Keywords
Distributed energy resources
Distributed generation
Islanding
Microgrid
Smart grid
Virtual power plant

CONTENTS

1 INTRODUCTION

Historically, power grids in the U.S. and Canada were built according to the traditional, centralized structure of generation, transmission, distribution, end user. Power is generated at large plants, usually located away from major population centers, with electricity transported across long distances to the end user. Although this worked well for over a century, the system is now under strain due to aging assets, an energy-hungry modern society that needs uninterrupted supplies, and changing climatic conditions that are instigating a rise in the frequency and ferocity of extreme weather events.

Utilities upgraded, modernized, strengthened and maintained the distribution grid, but largely kept the same structure and layout. Now, the industry and governments are looking at a different approach where electricity is generated and distributed locally, and in many cases using renewable distributed generation (DG) resources and energy storage. The answer to tackling many of the problems faced by electrical distribution systems may lie with the microgrid, which offers a way to integrate disparate resources, build resiliency into the system, and provide a number of economic and environmental benefits.

With this in mind, this literature research paper sets out to present the state of microgrid development and adoption across North America and list some of the major projects, whether they are still largely conceptual or full blown, operational microgrids. The paper lists a broad cross-section of the types of microgrid across the continent, from small test grids, used to assess new technologies and provide data, to large community microgrids built as part of an energy district.

What are Microgrids?

Although the idea of microgrids has been understood for many decades, with the term originally used to describe small distribution grids established in remote areas with no access to power, there is still some debate about the exact definition. Defining the concept is made difficult by the technological and conceptual overlap between microgrids, smart grids, and virtual power plants. As a result, the definition given by the U.S. Department of Energy (DOE) will be used in this paper:[1]

> A microgrid is a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island-mode [1].

[1] The CIGRÉ C6.22 Working Group definition is also useful: Berkeley Laboratory. *Microgrid Definitions*. Available at: http://building-microgrid.lbl.gov/microgrid-definitions

This definition covers remote systems that are permanently disconnected from utility grids, yet includes systems such as smart grids where sections can operate with and without connection to the main distribution network. Indeed, some smart grids can be considered a mesh of interconnecting microgrids that become integral building blocks or subsets of larger grids [1,2]. Both systems are designed to improve reliability, share the same technology, and incorporate non-traditional generation resources. Generally speaking, a microgrid:

- Includes distributed resources and load
- Can disconnect and parallel with the distribution system
- Has the ability to cope with intentional and planned islanding [3]

Of course, not every single installation covered by the DOE definition fulfills all of these points, but they act a useful guide. For example, many grids, especially campuses, are not intended to be true microgrids and are instead managed grids that allow the facility to manage resources and lower costs through DG while still connected to the grid. Remote grids may have no connection to a distribution system and operate in permanent island mode [4]. However, much of the same technology is used and data and ideas learned from a remote, community microgrid, for example, can still be applied to larger, urban projects [5].

Smart Grids and Microgrids

To further complicate the definition, there is an overlap between microgrids and smart grids. Both types may use the same technology, and often incorporating DG and energy storage, or include customer-focused technologies such as smart meters. Indeed, a microgrid can also be a smart grid and vice versa, and microgrids are often seen as an integral part of any self-healing smart grid [1]. The most important driver of microgrid research is learning how to integrate microgrids into traditional distribution systems and also into emerging advanced smart grid technology.[2]

Despite the similarity between microgrids and smart grids, both in terms of technology, DG, and building resilience into systems resources, smart grids are generally driven from the top down, by utilities or similar organizations. By contrast, microgrids are usually a bottom-up model driven by customers, businesses, organizations, and communities, with local control [2,5].

Rather than relying solely on utility-driven smart grid programs to improve reliability and power quality, microgrids embedded within utility transmission and distribution systems can increase flexibility and offer a number of economic, environmental, and reliability improvements.

The Benefits of Microgrids

Microgrids offer a number of benefits, and the business case for their development is becoming stronger.

[2] For an overview of some of the regulatory issues surrounding microgrids, see: Christopher Villareal, David Erickson, and Marzia Zafar. *Microgrids: A Regulatory Perspective*, CPUC Policy & Planning Division, 14 Apr. 2014, Available at: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M102/K036/102036703.pdf

Table 1-1
The benefits of microgrids

Benefits of Microgrids	
Reduces Energy Costs Decreases Greenhouse Gas Emissions Spurs Economic Activity (Development) Reduces Capital Costs of T&D Decreases Grid Congestion Prepares the Energy Infrastructure for the Future Contributes to Local Economies [6] Reduces the Economic Impacts of Extended Outages Enhances resiliency and Lowers O&M Costs Meets Environmental and Emissions Regulations May Cost Less than Upgrading Existing Distribution Infrastructure Offers Lower Cost Solution than Installing Transmission Lines [7]	Uses Smart Grid Technologies Allows Integration of DER and CHP Reduces Energy Losses by Co-locating Generation and Demand Could Reduce Peak Load Provides Power To Critical Facilities During Outages Controls Local Power Quality and Reliability Provides Demand Side Management and Leveling of Load Integrates DG and Renewable Resources Locally Provides Voltage Regulation and Overload Protection [8] Protects Consumers from Price Volatility in the Fossil Fuel Market

Microgrids can help to integrate local DG resources (e.g., solar and wind), allow regulation at the local level, and can help operators sell wholesale energy utilities. Rather than only operating as backup systems during outages, microgrids can operate in parallel with utility distribution systems, enhancing the benefits. Although the common perception of microgrids involves renewable energy (e.g., wind turbines and solar arrays), other distributed generation energy resources for a microgrid include combined heat and power (CHP) plants and energy storage devices, including electric vehicle batteries [2].

Microgrids can reduce the amount of fossil fuels needed by any networked generators, which is especially useful for remote communities with no grid connection [9]. Hawaii, for example, relies upon expensive fossil imports, and is pursuing the technology for this reason. Microgrids provide energy, in real time, to nearby small groups of end users, and allow supply to match demand.

Another advantage is that, while microgrid technology and installation can be expensive at the present time, they increase capacity without the need for large transmission installations. In addition, because they are often located in or close to urban areas, ancillary facilities such as natural gas for CHP generators or water are already nearby and accessible.

One additional aspect of microgrids that is particularly attractive to state and local governments is the idea that microgrids can contribute to the local economy. Construction jobs are created during system installation, and many states have set up initiatives to attract green technology manufacturers to the area. Although it can be argued that microgrids lose some of the benefits of economies of scale provided by traditional systems, their flexibility provides some compensation.

Microgrids will offer greater reliability, especially when integrated with smart grids, and will continue operation in islanded mode or even put power back into the wider grid during outages. The fact that installations can power critical facilities and emergency centers during emergencies, such as Superstorm Sandy, is another important aspect that has influenced legislation in a number of states.

Finally, microgrids can offer flexibility, because a variety of resources, including CHP and diesel backups can be integrated into the grid, providing reliability, using waste heat used for other purposes, and smoothing out supply/demand spikes [10].

Virtual Power Plants

Another development, common in Europe, is the use of virtual power plants (VPPs), which links small, DG resources together and operates them as a single, unified unit. Again, there is an overlap in the technologies used, with VPPs and microgrids both possessing the ability to incorporate demand response, renewable distributed energy generation (RDEG), and local storage. Both types of system require DG, advanced energy storage, and smart inverters [11].

However, there are some important differences. Firstly, VPPs are always tied to the grid and do not always offer islanding functionality. Secondly, VPPs do not always need local storage, while few microgrids can operate without energy storage. In addition, microgrids usually operate within defined geographical limits, whereas VPPs can operate over a wider area. Finally, microgrids generally operate DER at a local level, while VPPs can be linked with wholesale markets [2].

Types of Microgrid

Originally, the term microgrid originated a few decades ago, referring to isolated microgrids usually in remote areas operated by diesel. However, the modern definition usually involves IT, automation, and software whether they are isolated or connected to a wider grid. Although it is easy to think of microgrids only in terms of renewable energy, most include diesel or gas powered generators due to their ability to provide reliable power during outages [2].

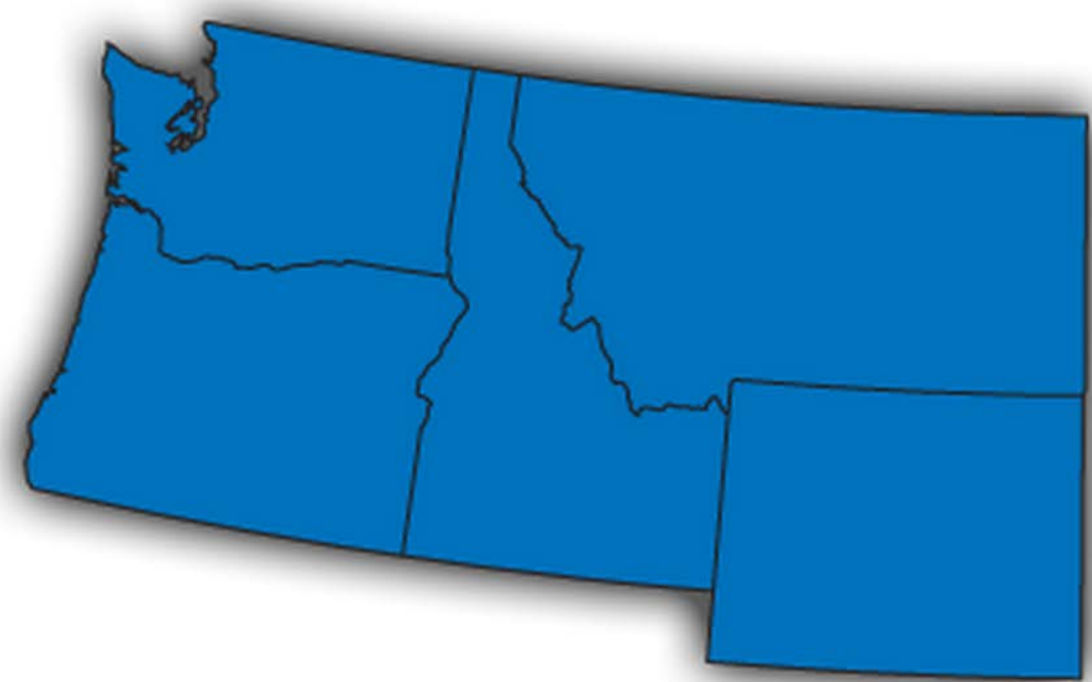
According to Navigant Consulting, there are five major types of microgrid project [2,12]:

- **Commercial/Industrial Microgrids**: These are generally built with the goal of reducing demand and costs during normal operation, although the operation of critical functions during outages is also important, especially for data centers.
- **Community/Utility Microgrids**: These are generally designed to improve reliability and also promote community participation.
- **Campus/Institutional Microgrids**: Most campuses already have DG resources, with microgrid technology linking them together. They are usually large and may be involved with selling excess power to the grid.
- **Military Microgrids**: Military microgrids focus on cyber and physical security, both for fixed bases and also for forward operating bases.

- **Remote Microgrids**: Remote microgrids are permanently disconnected from other grids, continuously operating in island mode. Many already use diesel generation, so microgrids offer a way to incorporate renewable energy.

These categorizations will be used for the purposes of this paper and, in addition, the U.S. is divided into regions according to the EPRI categorization [13].

2
NORTH WEST REGION



Oregon

Oregon is investing in energy storage solutions as part of an initiative to integrate renewable resources, such as hydro power, into the grid [14]. To promote local generation and distribution projects, the state exempts smaller providers from the regulations used for utilities [10].

Renewable Energy: Oregon has implemented several policies intended to encourage the development of renewable and clean energy resources. It is already home to one of the country's most sizeable wind farms, and is exploring power generation through wave energy.

Legislation and recent technological advancements prompted a number of projects, including solar, wind, geothermal, biomass/waste, and hydrokinetic energy, as part of a drive to promote sustainable energy. Tax credits have attracted a number of companies interested in installing alternative forms of energy production.

Renewable Standards Portfolio: By 2025, large utilities must produce 25% of their electricity through renewable resources, smaller utilities must produce 10%, and the smallest utilities must produce 5%. In addition, all utilities must generate 20 MW of energy through solar PV.

Net Metering: In terms of net metering, Oregon imposes a cap of 2 MW for non-residential Portland General Electric (PGE) and PacifiCorp customers. The level is set at 25 kW for municipal, co-operative and public utility districts (PUD), with a combined cap of 0.5% of the utility's historic single-hour peak load. Utilities will credit their customers any excess generation in the next billing cycle, while other providers can use their own methods for purchasing power.

Interconnection: Oregon, at present, has interconnection standards, with a maximum system capacity limit of 20 MW for large generators, 10 MW for small generators, 25 kW for residential net-metered, and 2 MW for non-residential net metered installations.

Tax Incentives: The state offers a number of tax incentives to encourage the growth of renewable and clean energy and related resources. These include Personal and Corporate Energy Conservation Tax Credits, Residential Energy Tax Credits, and Property Tax Incentives. Oregon also offers a Solar Volumetric Incentive Rate and low interest loans for small scale, local projects, typically providing between US $20,000 and $20 million over a timescale of between 5 and 15 years [15].

Microgrids: Oregon has proposed that any projects seeking funding must demonstrate how energy storage, especially batteries, can improve resiliency. The department has identified four main areas:

- Supporting transmission system devices such as static VAR compensators
- Co-location with renewable energy sources where transmission is restricted
- Stabilizing industrial facilities during outages
- Connecting distributed storage with DG sources

For example, the state is studying the feasibility of installing a pumped energy storage system around Swan Lake, Klamath Falls, using a closed loop facility with a capacity of up to 1000 MW. Importantly, the state is testing microgrid technology at the Salem Smart Power Center [16].

Pacific Northwest Smart Grid Demonstration Project (PNW-SGDP)

Another key element of Oregon's drive towards sustainability and resiliency is its membership of the PNW-SGDP. This project, covering five states, includes over 60,000 customers. Eleven utilities and six technology partners are involved in the program, with total energy responsive system assets of approximately 80 MW. Overall, the budget for the program is US $178 million, equally split between DOE funding and the project participants. The overall aims of the project are to:

- Develop and test command and control infrastructure and software.
- Develop methods for quantifying smart/microgrid costs and benefits.
- Integrate renewable DG resources.
- Develop standards for interoperability and cybersecurity.

Microgrids are a key element of this drive towards a smarter, more flexible grid [17].

South Salem Smart Power Center

Location: South Salem, Oregon

Type: Community Microgrid

Aims: Reliability improvement, smart grid integration, DG integration

Utility Involvement: PGE

Power Sources: 5 MW lithium-ion storage, 5.7 MW diesel generation, solar, diesel backup generators

Funding: DOE, Bonneville Power

Technology/Vendors: Bonneville Power Administration, Eaton, Battelle, Pacific Northwest National Laboratory, EnerDel

Status: Operational

Background

As part of the Pacific Northwest Smart Grid Demonstration Project, PGE is testing a microgrid in South Salem. This project involves 17 organizations from across five Northwest states, and the pilot will show how microgrids can form an integral part of a wider smart grid [18].

In South Salem, Portland General Electric has developed a localized power grid serving approximately 500 customers. The project received US $89 million from the U.S. Department of Energy and will allow the community to maintain power during blackouts [18,19].

Technology

At the heart of the microgrid is a 5 MW lithium-ion storage system, which is part of PGE's wider Pacific Northwest Smart Grid Demonstration Project [20]. [3] The system will be able to power the microgrid at the center for up to 30 minutes. In addition, the Center can call upon backup generators with 5.7 MW total capacity, and a solar array at Kettle Foods [16,21].

The energy storage system can react to conditions in the regional grid through transactive control, using technology developed by the DOE's Pacific Northwest National Laboratory, managed by Battelle. This technology allows consumers and producers to actively alter power usages, and will help to integrate DG and battery energy storage into the grid.[4] The transactive control includes commercial and residential demand response capability, including for heating water [18].

[3] For further details about the project, see: http://www.pnwsmartgrid.org/

[4] A full technical analysis of energy storage can be found at: Mark Osborn, Jil Heimensen, Ken Kaufmann, Jeff Lovinger, Erik Lovro, and Charles von Reis. *Opportunities and Challenges for Portland General Electric's Salem Smart Power Project (SSPP)*. LK Law. Jun. 2013. Available at: http://lklaw.com/wordpress_dev2/wp-content/uploads/2013/07/Battery-Storage-Salem-Smart-Power-Project-7-3-2013.pdf

A major component of the microgrid project is testing how the grid behaves when islanded, by creating a high reliability zone with two substations and using backup distributed generation on customer sites to maintain power during outages [18].

Business Case

At present, PGE is assessing how smart investments and microgrids can improve system operation and improve reliability, to discover which renewable investments will provide consumer value over the long term [21]. The Bonneville Power Association is trying to ensure that the needs of consumers and utilities are balanced, so provided US $10 million in funding for the project, which was matched by the DOE [22].

Idaho

Because Idaho has abundant hydroelectric, geothermal, and wind power potential, most of the state's renewable energy initiatives emphasize macro-scale generation projects. Although wind power generation projects generate 20% of its power needs, with Idaho exporting energy to other states, there is no overall target for generation by renewables. Although there is no specific legislation covering microgrids, much of the legislation could apply to microgrid projects.

Net Metering: Idaho has no policy for net metering, but the three state investor owned utilities (IOUs) have net metering tariffs filed with the PUC, including 100 kW for solar, biomass, wind, hydropower, and fuel cell systems, with Idaho Power and Rocky Mountain Power limiting smaller systems to 25 kW. In a baseline year, combined capacity cannot exceed 0.1% of peak demand, and no one customer can generate over 20% of peak production.

Tax Incentives: To promote renewable energy, the state includes income tax deductions for residential DG and property tax reductions, replacing them with a 3% tax on gross energy earnings.

Loans and Grants: For some renewable energy systems, the state offers 4% loans for a five year term of up to US $15,000 for residential developments and US $100,000 for commercial installations [15].

2012 Idaho Energy Plan

The 2012 Idaho Energy Plan was passed to develop a secure energy system while protecting public safety and promoting economic competitiveness. It has five core principles:

Ensure a stable and reliable energy system.

- Maintain energy supply at a low cost
- Preserve the environment and natural resources
- Promote growth in the economy, especially in rural areas
- Allow adaptation of energy policies to changing circumstances

The legislation emphasizes renewable resources and lays out a system to help local authorities make decisions for sites used for energy facilities, including microgrids [23,24,25].

Idaho National Laboratory Power Engineering and Microgrid Facility

Location: Idaho Falls, Idaho

Type: Test Microgrid

Aims: Microgrid research

Power Sources: Diesel generators, renewable resources

Technology/Vendors: SKM, PSS/E, RTDS, PSCAD, Matlab, Power World, PowerSim, and EMTP

Status: Operational

Background

The Idaho National Laboratory (INL), operated by Batelle Energy Alliance, has a full site utility test bed complete with the latest transmission, distribution, and SCADA technology. The main purpose of the laboratory is to assess the latest smart grid and microgrid technology before it is rolled out to larger microgrids.

Technology

The laboratory is equipped with technology designed to allow testing of grid layouts under a range of normal and abnormal operating conditions.

- **SCADA Assets**: The site contains test beds for SCADA cybersecurity, power systems, and wireless communications.
- **Distribution Assets**: The site includes diesel generators, renewable generation, power distribution and transfer systems, control and command technology, and storage batteries.
- **Battery Test Lab**
- **Power Systems Modeling Tools**: Suites include SKM, PSS/E, RTDS, PSCAD, Matlab, Power World, PowerSim, and EMTP.
- **GIS and Mapping**
- **Communications**: Fiber optic.

The secure power distribution system is 13.8 kV, with seven substations, three commercial feeds, three-phase transmission, and an H-type construction. The systems can be monitored in real time by SCADA at the operations center, and sections of the grid can be isolated for detailed testing [26].

This project's objective is to establish a testing facility at the INL that will assess a range of hardware and software to show how renewable distributed generation resources can integrate with traditional generation methods in the context of a microgrid. This will provide a database of historical data than can be used to promote future microgrid integration. The INL has a number of aims:

- **INL Smartgrid Energy Management System (iSEMS)**: Develop an open-source smartgrid platform that will allow integration, metering, and control for a microgrid, including during islanded mode.
- **Modeling**: Use the iSEMS load characteristics from DG to shape models of larger systems, and include weather and geographical simulations.
- **Collaboration**: Promote collaboration within the industry for converters and smartgrid energy management, operation, and control software.
- **Hardware Component Testing**: Provide a test bed for assessing interactions between hardware components for larger DG resources [27].

Washington

Hydroelectric power makes up the largest proportion of the Washington's electricity generation, but the state wants to develop a more diverse portfolio of renewable resources. To do this, Washington has developed supportive polices for renewable generation and a number of tax incentives. There is no specific legislation singling out microgrids, but the legislative environment emphasizes small scale initiatives.

As an example, the Clean Energy Fund awarded three grants in July 2014, totaling US $14.3 million, to three utilities wanting to develop grid-scale energy storage solutions for DG resources. The Pacific Northwest National Laboratory (PNNL) will lead this initiative.

Renewable Resources: By 2020, all utilities with over 25,000 customers must produce at least 15% of their power from renewable resources, with DG from sources producing less than 5 MW counted as double for compliance purposes.

Net Metering: Net metering is set at a system capacity limit of 100 kW, with an aggregate capacity limit of 0.5% of a utility's 1996 peak demand. Customers will receive credit for excess generation.

Interconnection: For IOUs, there is a system cap of 20 MW, and systems up to 300 kW must include an external disconnect switch.

Tax Incentives: For solar systems of between 1 and 10 kW, and solar thermal systems, there is a 100% sales and use tax exemption covering labor, services, and sale of equipment. For residential and commercial systems of less than 1 kW, the exemption level is 75% [15].

Washington State University/Schweitzer Engineering Laboratories

Location: Pullman, Washington

Type: Community Microgrid/Campus Microgrid

Aims: Demonstration project

Utility Involvement: Avista, Seattle City Light

Power Sources: Diesel/gas generators; backup diesel generators; 1 MW, 4 MWh vanadium redox flow battery

Funding: DOE via ARRA, Avista, SCL

Technology/Vendors: Schweitzer Engineering, Itron, Hewlett Packard, UniEnergy Technologies, FacNet, and Spirae.

Status: Operational

Background

In the city of Pullman, Washington State University (WSU) has partnered with Avista to create a smart grid community as part of the DOE Pacific Northwest Smart Grid Demonstration Project. The grid will test devices, command/control systems, and analytical software designed to enhance grid reliability and system performance. Overall, the demonstration will cost US $38 million, with the DOE funding one half via the American Recovery and Reinvestment Act. Seattle City Light (SCL) contributed US $600,000 to the project [28].

Technology

The project involves distribution automation with advanced metering, communication, and other smart grid technologies. Within the wider smart grid project, WSU and Schweitzer Engineering Laboratories will serve as microgrids. WSU already operates a generating plant using natural gas and diesel, which produces steam to heat campus buildings. The system also includes backup diesel generators to provide power to critical facilities during utility power outages.

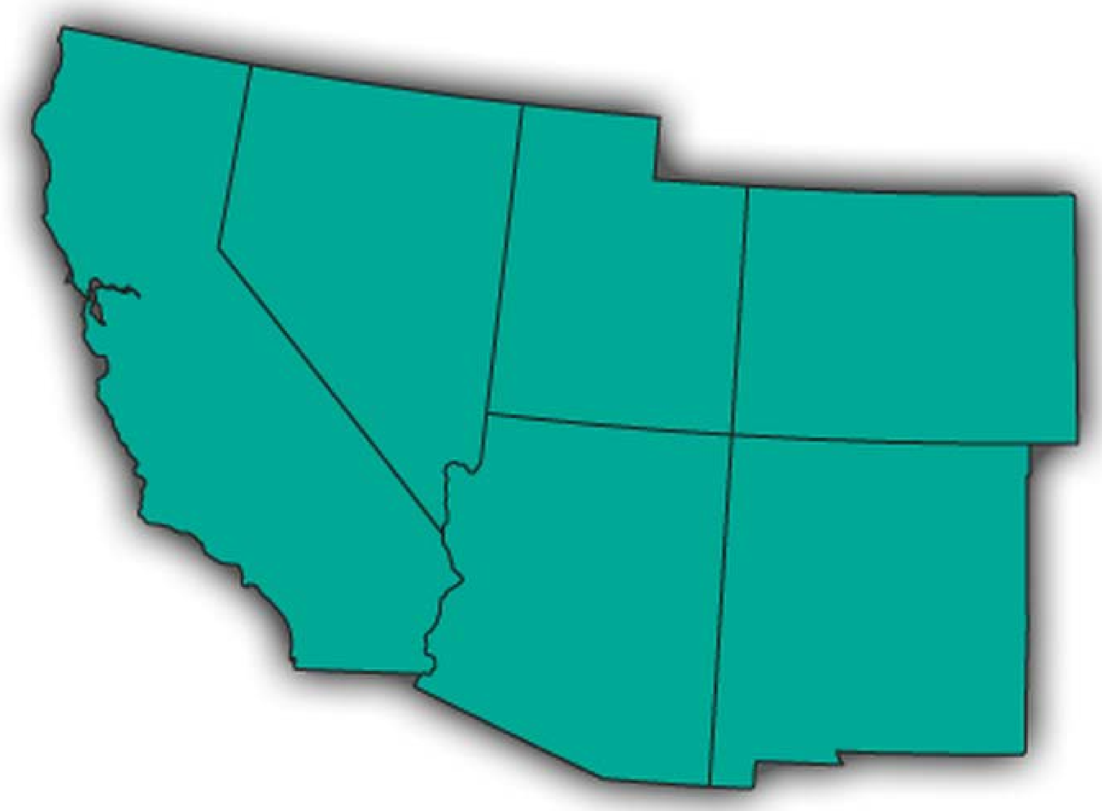
WSU will liaise with Avista, allowing campus generating facilities to provide energy to the wider distribution grid in cases of overloading or instability, including power shedding. Within the university, the Electrical Engineering and Computer Science department will be involved in research, development, design, testing, and data analysis [29].

Some of the technology tested includes distribution management system (DMS), three substations, regulators, reclosers/relays, and line switches. Conservation voltage reduction (CVR) may reduce energy demand by 3%, and automatic and remote switching will be tested to see how it improves reliability. Load control may provide extra efficiency on the campus [30].[5]

For energy storage, the system will include a 4 MWh battery manufactured by UniEnergy Technologies. With SCL, the campus installed 235 smart meters. In July 2012, these meters started to collect data; the meters use FacNet (facility network, a secure network), to collect and warehouse meter data [28].

[5] Details of the WSU microgrid plan and its use for simulation and tests can be found at: Kevin Schneider and Chen-Ching Liu. 2014 *Microgrids as a Resiliency Resource*. Smart Grid R&D Program Peer Review Meeting, 11 Jun. 2014. Available at: http://e2rg.com/workshops/docs/PNNL%20Pres%20Schneider.pdf

3
SOUTH WEST REGION



California

California is a strong proponent of microgrids, and the California Energy Commission (CEC) is providing funding for a number of projects with the aim of improving resiliency and cutting greenhouse gas emissions. The CEC has divided projects into two groups:

Microgrids for Critical Facilities: The first group of microgrids will allow crucial structures such as hospitals, emergency services, water and sewage treatment plants, schools, retailers, and transportation hubs to retain functionality during a power outage. These grids should enhance reliability and also reduce costs and emissions.

Microgrids with High Penetration Renewables: The second group will show how well microgrids can manage renewable energy resources providing between 50% and 100% of the total load for a facility or community. They will also be used to demonstrate that there are no negative impacts on the wider grid from using a microgrid controller or energy management system. Finally, the microgrid should be able to export power during periods of high production or low demand.

Overall, the commission wants to assess the various microgrid configurations for value to owners, ratepayers, and utilities, and also identify any potential difficulties during deployment. The systems should show how it is possible to shift from a closed system with a single goal of providing power, to a flexible platform that can accept power from a variety of resources, allow DER integration, and leave scope for future technological developments. Establishing which configurations are viable will remove the need for a lengthy application process for each microgrid, and it will allow the state to move towards a multi-cellular, multi-node system created from interconnected microgrids [31].

Public Interest Energy Research Program: The California State Legislature created the Public Interest Energy Research (PIER) Program in 1996. This law requires collection of US $62.5 million per year from California's three investor-owned utilities for energy-related research. Overall, this is intended to promote the integration between utility and non-utility resources [32].

Beach Cities

Location: Beach Cities, California

Type: Community Microgrid

Aims: Reliability, community participation, smart grid integration

Utility Involvement: SDG&E

Power Sources: Solar PV, natural gas CHP

Funding: U.S. Department of Energy, CEC

Technology/Vendors: SDG&E, Horizon Energy Group, Pacific Northwest National Labs, University of San Diego, Advanced Control Systems, Motorola, Lockheed Martin, IBM, Xanthus

Status: Operational

Background

The Beach Cities project was intended to show how smart technologies can be integrated into microgrids. It is assessing how existing infrastructure can increase its power delivery, and whether reliability is improved by making the grid more stable and reconfigurable. Over time, the project will also assess if microgrid technology can significantly reduce energy consumption.

The project was one of nine selected by the DOE, in 2008, to receive federal funding under the Renewable and Distributed Systems Integration (RDSI) program. In addition, SDG&E was awarded funding from the California Energy Commission (CEC) to deploy a sustainable community microgrid [33].

Aims

The initiative has a number of objectives, such as reducing feeder peak load by more than 15%, demonstrating the capability of VAR management, and integrating AMI, OMS, and DMS into microgrid operations. The project will also assess how microgrids can become part of a self-healing network through the integration of Feeder Automation System Technologies (FAST).

As part of assessing the integration of DER, the initiative aims to refine the information requirements and tools used for assessing the impact of multiple DER technologies. It is also evaluating control algorithms for autonomous DER operation and automation that can work with a range of DER types. Finally, SDG&E is testing a number of systems and processes that facilitate the control and use of customer-owned DG resources [34].

SDG&E is also investigating how to island customers intentionally if system problems arise. The utility will develop models to optimize circuits for microgrid operation with DG resources, demand response, and other advanced tools.

For the Beach Cities project, the utility is working with a number of partners:

- **Itron**: OpenWay AMI technology
- **SDG&E**: Project Management, facilities, customers, AMI, implementation
- **Horizon Energy Group**: Project coordination, design, and testing
- **Pacific Northwest National Labs**: DER design
- **University of San Diego**: Regulatory design
- **Advanced Control Systems**: Software and modeling
- **Motorola**: Communications and security
- **Lockheed Martin**: System architecture and facilities)
- **IBM**: DER automation and security
- **Xanthus**: Protocol standards, security, and integration [32]

Business Case

Because the project has received significant funding, it is not expected to become subject to cost recovery because the overall cost to ratepayers will be low. If the project is successful, SDG&E may use this as a basis for seeking cost recovery for future microgrid projects [33].

Borrego Springs Substation

Location: Borrego Springs Substation, California

Type: Community Microgrid, Remote Microgrid

Aims: Resiliency, remote service, smart grid integration

Utility Involvement: SDG&E

Power Sources: 26 MW solar installation, two 1.8 MW Caterpillar diesel generators, 500 kW/1500 kWh storage battery located at the substation, three 50 kWh batteries, six 4 kW/8 kWh home energy storage units, 700 kW solar PV

Funding: Federal, SDG&E, CEC, other partners

Technology/Vendors: In-house, Oracle, Lockheed, IBM, Horizon Energy, Advanced Energy Storage, Pacific Northwest National Laboratories, Caterpillar, Motorola, and University of California San Diego.

Status: Operational

Background

The Borrego Springs substation microgrid, developed at an overall cost of US $18 million, was established in 2013 to test technology and protocols for safe islanding at the substation, circuit, and transformer level. After testing various configurations and technologies, SDG&E is going to incorporate a fully functioning microgrid into normal commercial operations for 2,800 customers. The project received US $7.5 million federal funding, US $4.1 million from SDG&E, US $2.8 million from the California Energy Commission (CEC), and US $0.8 million from other partners.

Aims

The project was initiated to assess how microgrids can enhance grid resiliency in the face of storms, and connect with a wider, smart grid-based distribution system. The area is prone to outages from bad weather and from wildfires, and its existing substation and PV capability made it a good choice for a test project [35]. Overall, the project intends to show a 15% reduction in peak load demand.

Borrego was originally established as a remote microgrid to serve 500 residential, commercial, and industrial customers in a remote desert region, allowing the utility to assess if microgrids cost less than creating grid line extensions [3]. The utility is assessing the feasibility of "graceful degradation", a practice originally developed in telecommunications, where functions are diverted to critical needs customers [36]. Finally, SDG&E is testing price driven response systems using in-home storage, plug-in electric vehicles (PEVs), smart appliances, smart meters, and home area network (HAN).

Technology

The Borrego Substation project integrates five main technologies [2]:

- Distributed renewable resources, including solar PV and energy storage, with a technological configuration that provides VAR management
- A feeder automation system
- Microgrid controller developed by the utility and an OMS developed by Oracle
- Price-driven load management developed by Lockheed Martin
- Advanced substation storage totaling 500 kW/1500 kWh to provide real and reactive power
- SCADA

- Itron OpenWay Smart Meters [33]

The total 4 MW capacity of the microgrid includes:

- Two 1.8 MW Caterpillar diesel generators
- A 500 kW/1500 kWh storage battery located at the substation
- 3 50 kWh batteries
- Six 4 kW/8 kWh units for home energy storage
- 700 kW solar PV
- 125 residential systems (home area networks)

The project incorporates SCADA on all capacitors and capacitor banks, Feeder Automation System Technologies (FAST), OMS, and load management driven by price at the customer level. To assess the costs and benefits, SDG&E used EPRI methodology developed for the DOE to assess smart grid projects.

Results

SDG&E wanted to show that energy storage would mitigate the intermittent nature of energy from solar PV installations. They found that the energy storage exceeded predicted capabilities and proved able to cope with rapid fluctuations. The substation was designed to used energy storage and the onsite generators to address islanding, but SDG&E discovered some challenges with re-synchronizing frequencies after grid isolation.

However, the microgrid proved useful during a thunderstorm when power to the community was cut. As crews repaired utility poles, the local power generation restored power to 1,060 customers, including the prioritized business district and local library. Finally, the study suggested that microgrids could be used to energize the wider distribution system in cases of grid disruptions [37,38].

Civita Smart Community Project

Location: Civita Community, Mission Valley, California

Type: Community Microgrid

Aims: Smart grid support, islanding, energy efficiency, new construction template

Utility Involvement: SDG&E

Power Sources: 100 kW solar PV, six 5 kW fuel cells, 100 kW/100 kWh energy storage

Technology/Vendors: Pecan Street Research Institute, ECOtality

Status: Proposed

Background

After successful trials of microgrids during the Borrego Substation project, SDG&E is developing a number of new, smaller scale microgrid projects. One of these is the 100 kW Civita project, a smart community project located in Mission Valley, California with over 4,700 homes and apartments [2]. Civita is a planned community project conceived by Sudberry Properties, Inc. The apartment part of the project was completed in early 2015.

Aims

The developer and SDG&E are partnering to form a smart energy community that will act as a template for similar communities, and the project will include a microgrid. Civita will include six electric vehicle charging stations in both the commercial and residential sectors, which will be installed by ECOtality. Although the project is largely smart-grid based, SDG&E will explore the possibility of allowing critical buildings to island during outages.

As the community grows, the utility plans to add energy storage and automated switches. The utility is also building a "smart home" to test home area networking and smart appliances.

Technology

SDG&E's DER will support the project, including refrigeration, lighting, HVAC, or plug load. Planned resources include:

- Six 5-kW fuel cells
- 100-kW solar photovoltaics (one half SDG&E-owned, one half customer owned)
- 100 kW/100 kWh energy storage

The utility's DER will be interconnected on the utility's side of the meter; customers' bills will not be affected. In addition, heat from the fuel cells will be used to warm the swimming pool. Finally, the Pecan Street Research Institute will install devices to monitor energy and customer responses to data and messaging at 50 homes [38].

UC San Diego

Location: University of San Diego, San Diego, California

Type: Campus Microgrid

Aims: Energy efficiency, resiliency

Utility Involvement: SDG&E

Power Sources: Two 13.5 MW gas turbines, 3 MW steam turbine, 2.8 MW molten-carbonate fuel cell, and 1.2 MW solar array, 3.8 million gallon (14 million liter) thermal energy storage

Funding: UCSD, CEC, California Solar Initiative (proposed), DOE

Technology/Vendors: Johnson Controls, Schneider Electric, EDSA, Viridity Energy, UCSD Microelectric Embedded Systems Lab

Status: Operational

Background

To make use of its existing campus system and improve reliability and efficiency, UCSD is upgrading its campus microgrid. The US $2 million cost was split between UCSD and the CEC. Additional funding of US $1.2 million may come from a grant from the California Solar Initiative.

Technology

Generation: The University of California at San Diego possesses a microgrid that includes its own power generation, security, and monitoring systems. The campus has a daily population of approximately 45,000 and already operates:

- 3 MW steam turbine
- Two 13.5 MW combustion turbines
- 1.2 MW solar array
- 3.8 million gallon (14 million liter) tank for thermal energy storage

Together, these satisfied approximately 80% of the campus' power demands, with the remaining demand, up to 10 MW, provided by SDG&E through a 69 kV substation [39]. The system also provides 95% of the campus' heating and 95% of its cooling [2]. In addition, the campus entered into a power purchase agreement to power a 2.8 MW molten-carbonate fuel cell. The fuel cell uses methane from a nearby wastewater treatment plant.

To operate HVAC, the campus has a 40,000 ton per hour, 3.8 million gallon tank (14 million liter) for thermal energy storage. Five chillers are directly powered, and three chillers are driven by steam turbines.

Control and Automation: To control the microgrid, the campus uses a Johnson Controls SCADA for the facility control systems, and a Schneider Electric SCADA for the energy control systems. The university is installing a Paladin master controller from EDSA of San Diego, which will control and monitor power generation, storage, and loads. It will also use hourly computing to balance environment and economics. The system can handle up to 260,000 data inputs per second.

To help Paladin's decision making, UCSD will use VPower software developed by Viridity Energy, which integrates data from market pricing, weather forecasts, and resource availability. Together the systems will determine optimal power balance to determine how much power should be imported, when loads should be reduced, and whether energy storage systems should be charged or discharged.

200 power meters installed at circuit breakers and on the main lines track power usage on a minute by minute basis, and a website produced by UCSD Microelectric Embedded Systems Lab provides a graphic interface. The meters are three-phase models manufactured by Schneider Electric and send data several times per second to the central server via a wired network. The computer science building, housing servers and PCs, is monitored more intensively, with 15 circuits reporting according to power use type.

Importantly, the grid is being used as a potential model for larger feeders, with the DOE providing a grant to monitor PV output as clouds pass overhead, using Paladin to assist. The "sky imager" monitors the opacity of clouds over a 25 square mile (40 km^2) area, and makes predictions using image processing algorithms and a database with examples of cloud formation and behavior. This predictive ability might allow microgrids to know when to charge or recharge batteries.

Results

The campus participates in SDG&E's demand reduction program and can cut imports by up to 40%. Via use of chilled water from the tank to operate the HVAC system, the system shifts 7-14% of daily on-peak demand.

During the wildfires that struck San Diego in 2007, the campus moved from being a net 4 MW importer to a net 3 MW exporter in less than one-half hour, supporting the local grid when transmission supplies were under threat. The system can export power to the wider grid, although there are no plans to do so at present. Finally, the campus does not intend to become completely power independent due to growth and resulting increases in demand [2,40,41].

SmartSacramento - Sacramento Municipality Utility District (SMUD)

Location: Sacramento, California

Type: Community Microgrid

Aims: Demonstration project, smart grid integration, energy efficiency, resiliency, islanding

Utility Involvement: SMUD

Power Sources: Three 100 kW gas engines, 10 kW PV, 760,000 gallon (2.9 million liter) chilled water thermal energy storage tank, absorption chiller

Funding: Grant from California Energy Commission

Technology/Vendors: Landis+Gyr, Silver Spring Networks, National Renewable Energy Laboratory (NREL), Tecogen, CERTS

Status: Ongoing

Background

The Sacramento Municipal Utility District (SMUD) is a municipal utility that serves only electricity to a service territory of 600,000 customers in 900 square miles (1448 km^2). As part of a drive to introduce smart technology, the Sacramento Municipal Utility District is assessing various smart grid technologies, including microgrid islanding capability.

The company was awarded almost US $150 million of grants towards the US $360 million budget, and aims to test advanced metering infrastructure (AMI), cyber security technology, distribution automation, electric vehicle infrastructure, and demand response. The project will also assess energy storage and microgrid capability. The project, which is called "SmartSacramento," is the initial step in various SMUD smart grid features and projects.

Technology

SMUD has already installed AMI from Silver Spring Networks and Landis+Gyr meters, which will help to reduce demand at peak times. This has facilitated voltage reading, connection status, and transformer loading, and has helped reduce costs by making outages easier to locate and repair.

SmartSacramento includes 8 project areas and 50 subprojects, and has already tested the smart switch used to island the microgrid. The microgrid, installed at the company headquarters, is powered by:

- Three Tecogen InVerde 100 kW gas engines, which will produce 21 therms/hour waste heat in winter, and a 120 ton absorption chiller in summer
- 10 kW PV generation
- Thermal energy storage tank (760,000 gallons/2.9 million liters of chilled water)
- Battery energy storage
- Absorption chiller
- Central utility plant

The National Renewable Energy Laboratory tested a newly developed microgrid switch from Cyberex alongside the 100 kW Tecogen combined heat and power modules. The laboratory tested temperature stability, response to abnormal voltages and frequencies, synchronization, unintentional islanding/reverse power, and harmonics. This will allow SMUD to develop the most efficient microgrid configuration [42]. Tecogen also worked with Consortium for Electric Reliability Technology Solutions (CERTS) software to ensure that the engines could seamlessly transfer to and from the grid. SMUD was the initial demonstration of CERTS technology beyond the laboratory and will allow the Tecogen modules to operate in island mode [43].

SMUD is also testing a number of energy storage systems, although these, initially, will not be part of the microgrid. These will be tested in a solar subdivision of 280 homes with rooftop PV systems of 2-4 kW. Some homes are partially powered by 10 kW/8.8 kWh lithium-ion residential batteries, with others linked to one of three 30 kW/30 kWh community energy storage systems that are installed next to transformers. In addition, installation of a 500 kW flow battery is planned at the substation. Overall, the storage will smooth energy from DG, decrease peak load demand, and enhance reliability. Finally, SMUD may install a 1.2 MW "dairy digester" powered by biogas from cow waste [44].

Business Case

As a demonstration project, the aim is to help SMUD assess the costs and benefits of microgrids and smart grids, especially technology, effectiveness, and reliability. Plans for implementation of projects in the future can use the results of this project [44].

Catalina Island

Location: Catalina Island, California

Type: Remote Microgrid

Aims: Remote operation, energy efficiency, emissions reduction

Utility Involvement: SCE

Power Sources: Diesel generators, 1.4 MW microturbines, 1 MW NaS (sodium-sulfur)batteries

Technology/Vendors: S&C, NGK Insulators, Ltd (Japan)

Status: Operational

Background

Catalina Island, with 3,000 permanent residents and thousands of tourists during the summer, relies on diesel generators because it is too remote to connect to SCE's distribution grid. These have been designated high emitters of NOx gases by the South Coast Air Quality Management District. SCE installed emission control systems, but these were only partially effective and operated only when load was over 80% of peak.

To lower costs, improve reliability, and reduce reductions, SCE installed a fully-functioning microgrid on the island. The project was completed in July 2012.

Technology

The system has to manage fluctuating power demands and has a peak load of 5 MW, served by:

- Six diesel generators
- Microturbines providing 1.4 MW
- 1 MW sodium-sulfur batteries

To reduce fluctuations and help the diesel generators operate more efficiently, SCE installed an energy storage system using sodium-sulfur batteries. This system used S&C's PureWave SMS to control the recharging and discharging of the batteries, allowing them to act as a load and as a generator, depending upon overall grid conditions. The system allows Catalina's remote microgrid to meet peak demand and smooth fluctuations by allowing the generators to adjust output [45,46].

Hunters Point, San Francisco

Location: Hunters Point, San Francisco, California

Type: Community Microgrid

Aims: Testing technology, islanding, economic regeneration

Utility Involvement: Pacific Gas & Electric

Power Sources: Up to 50 MW of local DG resources

Technology/Vendors: Clean Coalition

Status: Ongoing

Background

The Clean Coalition, based in San Francisco, was set up to find a model that could help communities develop their own microgrids. The coalition is setting up a test bed at Hunters Point, a community in San Francisco that has been targeted for economic regeneration.

The planned microgrid will be connected to the distribution grid but will generate up to 50 MW of power, mostly from rooftop solar arrays. Overall, the grid is planned to serve 20,000 residential and commercial customers in the community [7]. For the project, the Clean Coalition will be working with Pacific Gas and Electric.

Phase I: Phase I of the project, due to be completed in early 2015, will create a modeling platform that can be used by any community wishing to test the viability of a potential microgrid. The platform will simulate local renewable resources and intelligent grid technology to assess the balance of power, voltage, and frequency in the local grid. The Phase I activities include:

- Modeling and simulating the existing distribution grid
- Modeling optimal scenarios for DG resources
- Assessing environmental, economic, and resiliency benefits
- Engaging community stakeholders in the process
- Providing cost-benefit recommendations

The group has been gathering and validating baseline data about the operation of the local distribution grid and modeling what happens to voltage and other functions when DG is added. The model can be reconfigured with advanced inverters, storage, demand response, and other smart grid technologies, as well as assessing how the grid operates under island conditions [47].

Phase II: Phase II, due to begin in late 2015, will see the actual deployment of the community microgrid according to the recommendations of Phase I. Key activities include:

- Adding up to 50 MW of local DG resources
- Lowering transmission-related costs
- Reducing CHG emissions
- Showing that the business case for microgrids is sound and that it will boost local economies [47,48]

Business Case

The projected benefits include US $200 million in added regional economic output, US $70 million in local wages during construction and installation, US $5.8 million in construction-related tax revenue, and US $10 million site leasing income for property owners. Environmental benefits include significant GHG emission reductions, water savings, and land preservation through the use of rooftop PV systems [48].

Alcatraz

Location: Alcatraz Island, California

Type: Remote Microgrid

Aims: Energy efficiency, emissions reduction, aesthetics

Power Sources: Diesel generators, 1,360 solar panels producing 400 kW

Technology/Vendors: Princeton Power

Status: Operational

Background

At Alcatraz, the island has long been energy independent since the 1960s, when a storm damaged the cable connecting the island to the main grid, prompting the installation of diesel generators. Now, the island has a 400 kW microgrid that includes 1,360 solar panels, which are disguised to avoid affecting the historical nature of the prison. The Alcatraz microgrid powers the main prison building and a number of smaller structures, including the media station. It is also used to charge the golf carts used for transportation around the island.

Technology

The new system is integrated with the existing diesel system and uses the pre-existing wiring. A master controller, the Princeton Power PPS GTIB-100, monitors the system to use as much solar energy as possible, while minimizing diesel use [49]. If the master controller is damaged, the eight inverters in the system are capable of autonomous operation.

Rather than using the solar panel to charge the batteries, which then release power to supply the load, the solar arrays are directly connected to the AC microgrid and release power, including to the batteries, via the grid. This is more efficient and also extends the lifecycle of the batteries.

The grid, designed by Princeton Power systems, could be connected to the main grid if another undersea cable is built, although this is not planned at present. Because of this autonomy, the grid contains inbuilt system redundancy. Due to the historical nature of the building, the Park Department had to add protective equipment to the panels to protect them from spray and salt. Inverters, batteries and other modern microgrid electronics also had to be hidden within existing enclosures to avoid affecting the aesthetics of the island. The project, due to these restrictions, was expensive, but could be replicated at a lower cost in a less demanding setting. Princeton Power now uses the grid as an example installation [49,50].

Santa Rita Jail, Dublin

Location: Santa Rita Jail, Dublin, California

Type: Institutional Microgrid

Aims: Energy efficiency, islanded operation

Power Sources: Diesel generators, fuel cells, 2 MW/4 MWh lithium-iron phosphate (lithium ion) batteries, 500 kW solar array, microturbines

Technology/Vendors: S&C, CERTS, Chevron, Lawrence Berkeley National Laboratory, BYD

Status: Operational

Background

Santa Rita Jail is one of the largest correctional facilities in the U.S., covering 113 acres near San Francisco. Recently the jail upgraded its power infrastructure to add microgrid functionality with its onsite generation, allowing the site to island indefinitely in case of loss of power. The grid was completed on March 22, 2012 [51].[6]

Technology

The onsite power sources include:

- Diesel generators
- Fuel cells
- 2 MW/4 MWh lithium-ion battery
- 1.5 MW solar array
- 1.0 MW molten carbonate fuel cell with heat recovery to provide hot water heating [52]
- Microturbines [52]

The facility has a daily power demand of at least 3 MW, so it required energy storage for excess power during outages and a mechanism for purchasing power during off-peak hours.

S&C developed a reliable solution by integrating a 2 MW PureWave Storage Management System (SMS) into the microgrid. The original system used a sodium-sulfur (NaS) battery, but S&C reengineered the system to use a 2 MW/4 MW lithium-ion battery, coordinating with the battery suppliers to ensure smooth operation. For this grid, the battery is the only controllable resource, so it must maintain energy balance [52].

The battery is fitted with CERTS capability to facilitate islanding for extended periods, with a static switch at the substation allowing rapid connection and disconnection from the main utility grid [52]. The grid's SMS controls charging and discharging, and when islanding occurs, the system will balance energy storage via the CERTS algorithm. The battery can provide power up for eight hours when islanded, with the diesel generators allowing further, indefinite operation.

Chevron Energy Solutions designed the microgrid and acts as the system integrator, overseeing power balance when the grid is connected and lowering costs by using and storing off-peak power [2,53]. To plan the microgrid, the facility used Distributed Energy Resources Customer Adoption Model (DER-CAM), developed by Lawrence Berkeley National Laboratory (LBNL), to arrive at the optimal configuration. DER-CAM can also predict battery schedule via weather forecasts and other data [9].

Business Case

Due to the historical trends showing DER performance, the jail is not likely to fulfill 100% of its own energy production, but the equipment and microgrid have shown great potential for reducing overall utility charges. Although the PV does not meet demand, it coincides with peak

[6] Photo gallery available at: http://building-microgrid.lbl.gov/gallery/1033

hour demand, allowing the jail to produce energy for steady power and hot water. Finally, the added energy storage allows the facility to alleviate inconsistent supply and outages, especially when used alongside DER-CAM to maximize savings [9].

Foothill College

Location: Foothill College, Los Altos, California

Type: Campus Microgrid

Aims: Energy efficiency, islanded operation

Power Sources: Solar PV, natural gas CHP

Status: Operational

Background

Like many educational campuses, Foothill College already had a form of proto-microgrid in the form of CHP generating capability, which provides additional thermal load for heating, and solar PV arrays. The college wanted to add additional microgrid technology to improve efficiency and allow the site to remain powered in case of outages.

Technology

The facility has 1.5 MW of solar PV, and 250 kW CHP using microturbines fired with natural gas to heat the swimming pool. Foothill College included an Integrated Demand Side Management (IDSM) energy strategy, intending to reduce power demand from the utility grid by up to 50%.

This system manages voltage, frequency, and phase. The facility does not yet have metering for every building and has no central application to manage and coordinate the grid. Adding these functionalities is planned, because the IDSM requires intelligent management to shift demand and maximize efficiency [54].

Marin County

Location: Marin County, California

Type: Community Microgrid

Aims: Reliability, community participation

Power Sources: Solar PV, natural gas CHP

Funding: U.S. Department of Energy, CEC

Technology/Vendors: ECN, Infotility, Xanthus Consulting, PlotWatt

Background:

In Marin County, there has been some public resistance to top-down utility smart grids, so microgrids are being explored at a variety of scales, including buildings, community centers, subdivisions, and remote areas. The project used the Marin County Sustainability Office and the Civic Center Campus for demonstrations.

The U.S. Department of Energy funded the three-year, three-phase project with US $1.6 million between 2008 and 2010, and the project involved collaboration with ECN, in the Netherlands, and the EU field testing center. The grid also received CEC funding. The contractors for the grid were Infotility, Inc. and Xanthus Consulting International.

Technology

All city halls in west Marin are already powered by solar energy, so they have the potential to be operated as microgrids during emergencies and act as control centers and emergency shelters. Infotility will provide “Grid Agent Intelligence”, which has access to EMS and will collect information from municipal PV and other distributed generation resources, before using this to develop grid strategies.

As part of the initiative, the Marin Agricultural Wind Cooperative has been trying to develop community driven wind projects at the community level. A new community, in Lucas Valley, will be a community of 85 to 1000 residents with homes equipped with “PlotWatt” technology, allowing consumers to look at energy usage on a device-by device basis [55].

University of California Irvine Campus (UCI)

Location: Irvine, California

Type: Campus Microgrid

Aims: Reliability, renewable resources

Power Sources: Amonix 113 kW and 836 kW solar PV arrays; 893 kW rooftop solar PV; eight chillers with TES; 15.8 MW gas turbine; 6.6 MW steam turbine; eight Level 2 EV chargers; absorption chiller; 180 kg/day hydrogen station

Technology/Vendors: ETAP, Amonix

Status: Operational

Background

Like many universities, UCI is faced with rising electricity costs and a demand for high-quality, uninterrupted power. To lower costs and improve reliability, the University of California partnered with ETAP Grid to develop a microgrid on its Irvine Campus.

Technology

The campus microgrid includes a number of distributed generation resources:

- Amonix 113 kW and 836 kW solar PV arrays
- 893 kW rooftop solar PV
- 8 chillers with TES
- 15.8 MW gas turbine

- 6.6 MW steam turbine
- 8 Level 2 EV chargers
- Absorption chiller
- 180 kg/day hydrogen station

ETAP used its Integrated Smart Grid 3.0 modeling tool to help plan the system, which assists with decision making when modeling microgrids. The system can emulate demand response and assess the dynamic and static behavior of all grid components. The tool can use historical, present, and predicted data to optimize operation.

For the UCI project, this included measuring kW and kVAR available capacity to monitor load growth while maintaining reliability. The tool also helped to find ways of maximizing generation usage and type, and maintain critical load when the grid becomes islanded. Other aspects studied include creating switching processes to balance feeders and loads [56].

Redwood Gate Ranch Microgrid

Location: Jenner, California

Type: Remote Island Microgrid

Aims: Reduced overall cost of electricity (verses diesel generation)

Power Sources: Three battery modules (54 kWh), 30 kW inverter, 40 each 270 W PV arrays, 30 kW backup diesel generator

Funding: Privately funded based on payback

Technology/Vendors: Battery supplier is Aquion Energy, power electronics vendor is Dynapower, and the Integrator is Real Goods Solar. The system interface and site controller were provided by Geli.

Status: Operational (2014)

Background

This project was for an off-grid ranch, and consists of a hybrid solar, battery and diesel generation system.

Technology

Photovoltaic array will be stored in the BESS in daylight hours, and used during night/cloudy periods. The battery technology is aqueous hybrid ion: manganese oxide cathode, activated carbon composite anode, and sodium sulfate in an aqueous solution electrolyte.

American Honda Motor Co. Microgrid

Location: Chino, California

Type: Industrial Microgrid

Aims: Demonstrate the viability of a DC Microgrid

Utility Involvement: Southern California Edison

Power Sources: Photovoltaic arrays and a battery energy storage system

Funding: California Energy Commission award is in the amount of US $2,817,566. Bosch and its partners have jointly provided US $1,790,095 matching funds.

Technology/Vendors: Robert Bosch LLC is the lead, Navigant Consulting, the California Lighting Technology Center (CLTC), Maxwell Technologies, and Imergy Power Systems

Status: Implementation in progress, scheduled to be completed by February 2018.

Background

This project is mainly intended to demonstrate the advantages of a DC microgrid. The efficiency of loads such as LED Lighting, Variable frequency drives can be improved by operating them on DC Power. Energy storage (batteries) efficiency is improved if they deliver DC Power, and the same applies to photovoltaic arrays.

Technology

The microgrid design will be powered by PV arrays and use DC lighting, DC ventilation and DC energy storage systems distributed on a 380-volt DC bus. Energy storage will include Imergy Power Systems' vanadium-flow batteries (long-term, high-energy) and Maxwell Technologies' ultra-capacitors (short-term, fast-responding).

Las Positas College Microgrid

Location: Livermore, California

Type: Campus Microgrid

Aims: Integrate renewable energy generation, reduce peak demand, and reduce overall energy cost

Utility Involvement: Pacific Gas & Electric

Power Sources: 2.35 MW solar array, 250 kW/1 MWh battery energy storage system (BESS)

Funding: US $1,500,000 CEC grant, Las Positas College’s on-going US $240 million bond-funded capital improvement program

Technology/Vendors: BESS from Imergy Power Systems, GELI: energy management function

Status: Implementation in progress

Background

An early analysis showed the College could reduce their annual energy cost by US $100,000 by using energy storage and energy management systems. This would be achieved by reducing peak demand charges and optimizing the value of energy.

Technology

The college has an existing 2.35 MW photovoltaic array and a 3200 ton/hour ice storage system. These will be combined with a new 250 kW, 1 MWh Vanadium Redox Flow Battery and related components from Imergy. These will be managed by GELI: energy management function to achieve the college's goal of overall energy cost reduction.

Santa Clara University Microgrid

Location: Santa Clara, California

Type: Campus Microgrid

Aims: Power resiliency, reduced energy costs

Utility Involvement: Silicon Valley Power

Power Sources: 1.1 MW PV, 1.5 MW backup generation and 3 MW of other combustion generation (in development in early 2014)

Funding: Grant from the CEC (pending)

Status: Proposed and unfunded

Background

This is a project that started in the 2010 time frame. In searching for information, there were many hits in the 2010 and 2011, then the project appeared to go dormant until recently.

In early 2014, the university applied for a grant under the CEC's 2015-2017 EPIC fund.

The university already has a strong energy infrastructure, including:

- 1.1 MW of installed solar power
- Advanced metering infrastructure
- 1.5 MW of standby generator capacity installed
- An additional 3 MW of state-of-the-art generation currently in development (in early 2014)

The on-site traditional and renewable generation can fully service the university's existing load.

Technology

The following is paraphrased from the above-referenced EPIC grant application. The university's microgrid would build a system using design elements from a number of existing military bases and island locations. The system would expand the time it would be able to operate when disconnected from the grid for several days, and allow solar generation to operate during disaster periods. During normal and islanded operations, the microgrid would monitor power systems and quality to assure maximum efficiency. The microgrid will turn loads and dispatchable generation on and off automatically to balance generation and load. The microgrid will island preemptively if an outage is expected or upon request by the distribution utility. The microgrid will provide cyber security protection by using techniques to encrypt and validate data, detect intrusions, and control user access.

New Mexico

Since the turn of the century, New Mexico has actively encouraged wind and solar power by introducing tax incentives that allow residential and commercial customers to invest in renewable resources. The state makes heavy use of solar and wind power, and is also the home of a number of algal biofuel and geothermal generating facilities. The state exports solar power to neighboring states, notably Texas. In Clovis, the Tres Amigas grid interconnection project will connect three major systems and also facilitate the integration of renewable resources.

Renewable Energy: Overall, New Mexico has mandated that IOUs, which produce just over two-thirds of the state's load, should produce 20% of their power through renewable resources by 2020. This includes a minimum of 20% through solar; 30% through wind; 5% through other sources such as biomass, geothermal, and hydropower; and 1.5% through distributed generation. Importantly for microgrids, the mandated DG percentage will rise to 3% in 2015. In addition, IOUs must invest 1.5% of their annual revenue in renewable resources.

Rural electric cooperatives, representing almost 21% of the state's load, must produce 10% of its energy using renewable resources by 2020.

Net Metering and Interconnection: For net metering, IOUs and cooperatives can impose a cap of 80 MW, with no specified aggregate limits. Interconnection limits are also 80 MW of system capacity, with insurance required for systems of over 250 kW and an external disconnect switch required for some systems of over 10 kW. Customers receive a credit on their next bill for net excess generation.

Tax Incentives: Personal or corporate Advanced Energy Tax Credits may be given for 6% of solar electric, geothermal, or energy storage project costs of over 1 MW capacity. Renewable Energy Production Tax Credit gives credit for systems of over 1 MW, with the amount depending upon the technology used. For personal solar PV or thermal arrays, 10% Solar Market Development Tax Credit is given, of up to US $9,000 per project with an aggregate level cap of US $2 million for solar thermal and US $3 million for PV [15].

New Mexico Green Grid Initiative

The New Mexico Green Grid Initiative (NMGG) is aiming to develop a distribution system built upon smart technology and microgrids. The NMGG systems integrate two-way communication into the grid, and involve a number of partners including customers, energy generators, national laboratories, and other collaborators, as part of planning a project with a national perspective. Overall, the NMGG initiative hopes to reduce peak power use by 25%, reduce overall consumption by 6%, and deliver a quarter of electricity from renewable resources [57]. It also hopes to see a 50% rise in the penetration of renewable resources and a 15-25% increase in reliability alongside a 25% reduction in New Mexico's carbon footprint [58].

To achieve this, the NMGG will partner with the Galvin Electricity Initiative to evaluate applicable technologies, and use Galvin's "Perfect Power" system [59]. In New Mexico, the Galvin Electricity Initiative has worked with the state to develop smart and microgrid technology that could revitalize the distribution grid, which suffers from a high frequency of power outages and shortages. The New Mexico Galvin Team is staffed by Energy Control Inc. In addition, the group is working with a number of Japanese technology companies, which make up part of the NEDO collaboration. By partnering with Japan, the state hopes to create the first fully green grid in the U.S., with microgrids forming the foundation of the project.

Aims

Some of the goals of the microgrid project include testing the interoperability of components and technologies, assessing cybersecurity, and commercializing proposed solutions. Through a series of test projects, the initiative will produce and analyze data to measure stability, reliability, and costs, and monitor how well consumers interact with energy management systems.

Real time data will also facilitate the development of models and algorithms to control and assess distributed generation resources. By using a number of different test sites, such as Los Alamos and Sandia, the initiative hopes to show how small scale projects can be scaled up to a regional level [58].

The initiative also aims to provide clean and secure energy for the state, as well as take advantage of its climate to develop solar resources that will underpin the export of renewable energy to other states. Finally, the NMGG also hopes to attract manufacturers of related technologies to the state, and encourage other businesses indirectly due to carbon taxes as a deciding factor [58].

Los Alamos

Location: Los Alamos, New Mexico

Type: Community Microgrid

Aims: Grid technology testing, smart grid integration

Power Sources: 1 MW PV array, 1.8 MW battery storage

Technology/Vendors: NEDO (Toshiba, Hitachi, Kyocera, NGK Insulators, Itochu Techno-Solutions, NEC, Toshiba USA), Los Alamos National Laboratory, Los Alamos Department of Public Utilities

Status: Operational

Background

At Los Alamos, a number of Japanese and U.S. companies have collaborated to create a smart grid project, which includes a microgrid demonstration. Overall, the project is designed to assess the addition of a variety of distributed energy resources to existing grids as part of the New Mexico Green Grid Initiative [59].

A number of companies are collaborating for this project, including Japanese solar panel manufacturer, Kyocera, and the New Energy and Industrial Technology Development Organization (NEDO) of Japan.[7] Overall, the project is intended to test and analyze solar PV arrays, energy storage, grid management technology, and communications, and provide real time analytical data. The project includes a power supply microgrid with a 910 kW Kyocera multi-crystalline silicon solar module array [60].

Technology

The circuit serves approximately 1,900 customers with a load of between 1.5 and 3.5 MW. At Los Alamos, one of two current projects is a microgrid with a 1 MW solar system and a battery system (1.8 MW/8.3 MWh). To test grid impact, the solar energy will be directed through a monitored distribution line [61]. The microgrid includes:

- 1 MW PV array
- 1.8 MW battery storage

Overall, the grid will show how well Japanese PV technology can integrate with micro EMS systems on U.S. distribution grid [61].

The grid will test PV at several penetrations and show that it can island for several hours [61]. The objective is to show the microgrid has the ability to integrate and schedule energy from batteries into the overall grid, and that it can manage PV and battery energy under a range of different scenarios. It will also show how real time pricing information can be used to charge the batteries when power is off peak.

Business Case

For NEDO, the project is part of the organization's programs to test microgrid and smart technologies that are not compatible with the Japanese electrical system, introduce smart Japanese technology to the U.S., and help develop international standards [61].

Albuquerque

Location: Albuquerque, New Mexico

Type: Community Microgrid

Aims: Grid technology testing, smart grid integration

Utility Involvement: Mesa del Sol, PNM (Public Service Company of New Mexico)

Power Sources: 50 kW solar PV array, 80 kW fuel cell, 240 kW natural gas generator, lead acid battery, hot and cold thermal storage

Technology/Vendors: NEDO (Toshiba Corporation, Hitachi, Kyocera, NGK Insulators, Itochu Techno-Solutions, NEC, Toshiba USA), Los Alamos National Laboratory, Los Alamos Department of Public Utilities, Shimizu Corporation, Tokyo Gas Company, Mitsubishi Heavy

[7] Further information available at: http://www.nedo.go.jp/english/introducing_mis_poli.html

Industries, Fuji Electric Company, Furukawa Electric Company, Meidensha Corporation, Sharp Corporation, Furukawa Battery Company

Status: Operational

Background

As part of the New Mexico Green Grid Initiative, a Perfect Power system has been built in Mesa Del Sol, a community covering a 20 square mile (32 km^2) territory on the edge of Albuquerque [59]. This residential development, by Forest City Covington, will include solar energy and EnergyStar sustainable homes. Using solar, energy efficiency, and demand response should reduce load by almost a third, to 60 MW.

Technology

The microgrid is fitted with a number of generating facilities and energy storage solutions:

- 50 kW parking lot canopy
- Solar PV array
- 80 kW fuel cell
- 240 kW generator (powered by natural gas)
- Lead acid battery banks
- Hot and cold thermal storage. (This will be turned over to the University of New Mexico at the end of April 2014) [62]

The Albuquerque microgrid incorporates energy storage, gas turbine generation, fuel cells, and solar cells. These contribute to grid operations by controlling power flow at the interconnection point and provide power when the grid is islanded, as well as canceling out any fluctuation of solar PV through smoothing [63].

The design includes PNM Perfect Power systems, including supply redundancy, advanced metering, demand response, fault detection automation and communication, solar-compatible components, DG, and energy storage.

Business Case

The system is projected to pay for itself within 30 years, and additional regulatory policy changes may unlock additional financing options, especially any state legislation that encourages utilities and the PRC to include carbon in cost considerations [64]. The system should also lower the cost of interruptions by improving reliability and reducing the number of manual operations. Finally, the community also hopes to attract new businesses by promoting itself as an energy efficient location [65].

Taos Pueblo

Location: Taos Pueblo, New Mexico

Type: Community/Remote Microgrid

Aims: Remote power

Utility Involvement: Kit Carson Electric Cooperative (KCEC)

Power Sources: 10 MW PV, energy storage

Technology/Vendors: NEDO

Status: Operational

Background

The remote Taos Pueblo is located in rugged, mountainous terrain, which makes it difficult to provide reliable electricity to the community through utility transmission/distribution systems. The community requires heat during the winter and cooling during the summer, so traditionally has relied upon fossil fuel generation for power [59].

In partnership with the New Mexico Green Grid Initiative and the Kit Carson Energy Cooperative, the community has developed a microgrid containing producing 30% of its load through a 10 MW solar power array, alongside associated storage technologies [66].[8] The microgrid is part of KCEC's program, with NEDO, to install AMI and demand management across New Mexico [67,68].

Roosevelt County

Location: Roosevelt, New Mexico

Type: Community/Remote Microgrid

Aims: Reliability

Power Sources: Wind, pumped water storage

Status: Ongoing

Background

Roosevelt County, an agricultural community, requires energy for water pumping and irrigation, for which it uses wind power and fossil fuel sources [59]. The community, as part of the New Mexico Green Grid Initiative, wants to develop a smart microgrid with 30% of power produced by wind and pumped water energy storage [67,68].

Colorado

Colorado already makes use of its abundant renewable energy potential, which includes wind, solar, biomass, and geothermal. To support this, the state has a wide ranging renewable program including rebates, generous net metering, and other incentives. In addition, DOE's National Renewable Energy Laboratory is in Colorado.

[8] The original renewable energy feasibility study performed for the Tribal Council can be found at: Richard Mason, Donovan Gomez, and Robert Palmer. *Taos Pueblo Renewable Energy Feasibility Study*, Tribal Energy Program and DOE. 2004-2006. Available at: http://apps1.eere.energy.gov/tribalenergy/pdfs/taos03final.pdf

Renewable Energy: By 2020, IOUs must generate 30% of their power from renewable resources, and DG must consist of 3% of retail sales. For municipal utilities and cooperatives serving fewer than 100,000 meters, 10% of power must come from renewable resources, with DG accounting for 0.75% of retail sales. For larger cooperatives serving more than 100,000 customers, DG must account for 1% of retail sales. To support the development of microgrids, 150% credit has been given to community-based projects installed before 2015.

Net Metering: With the exception of some small companies, limits for most utilities are 120% of a customer's consumption each year. For municipal utilities and coops, limits are 25 kW for non-residential customers and 10 kW for residential. Excess generation is credited to the next retail bill and, after 12 months, can be rolled over or purchased by the utility. For all utilities, excluding some smaller ones, interconnection limits are set at 10 MW.

Tax Incentives: Commercial PV and wind facilities of up to 2 MW are assessed locally for property taxes, with larger facilities assessed by the state. Property taxes and state sales taxes are not levied on use, sale, and storage of residential renewable energy.

Loans and Grants: Loans of over US $100,000 for DG technologies may be given to companies that find it difficult to receive funding from traditional sources. This is supported by the American Recovery and Reinvestment Act of 2009 [15].

Fort Collins

Location: Fort Collins, Colorado

Type: Community Microgrid

Aims: Outage mitigation, energy efficiency

Utility Involvement: Fort Collins Utilities

Power Sources: 345 kW of solar PV, 700 kW of CHP, 60 kW of microturbines, 5 kW of fuel cells. Private sources include 790 kW biogas, 200 kW from solar arrays, and backup diesel generation producing up to 2270 kW.

Funding: Colorado Clean Energy Cluster (CCEC), DOE, industry partners including Eaton, Advanced Energy, and Brendle

Technology/Vendors: UniverCity Connections, Johnson Controls, Trane.

Status: Operational

Background

Fort Collins, Colorado, has installed a microgrid to replace its aging distribution system. The old system suffered from a number of recurring problems, including limited consumer choice, lack of consumer involvement, slow response to power quality issues, and susceptibility to natural disasters [69]. To promote a unified approach using public and private expertise from across the community, the municipality has created a Zero Energy District, FortZED, which incorporates the Fort Collins microgrid [70].

The microgrid will help FortZED move towards its goal of producing as much energy as the community consumes. The integrated system includes distributed resources to reduce peak load by 20-30% across two feeders, and has already improved power quality and reliability. Eventually, the microgrid will be able to operate in islanded mode [70,71].

A number of customers are involved, including the New Belgium Brewery, InteGrid Laboratory, City of Fort Collins facilities, Larimer County facilities, and Colorado State University main campus facilities, as well as a number of DG resources and technologies. In addition to a US $6.3 million grant from the DOE, industry partners including Eaton, Advanced Energy, and Brendle have invested US $4.7 million [69].

Technology

The project incorporates a number of microgrid technologies, including solar PV, microturbines, fuel cells, thermal storage, and demand side management. The combined DG and load shedding capability is 5 MW, spread across five customer sites.

The project covers 10-15% of Fort Collins Utilities' entire distribution system, with a peak load of about 45.6 MW covering 7,257 customers. In terms of distributed generation and storage, the project will include:

- 345 kW of solar PV
- 60 kW of microturbines
- 700 kW of CHP
- 5 kW of fuel cells

In addition, the brewery produces 50% of its own power, with 790 kW drawn from biogas and 200 kW from solar arrays. Other facilities own diesel generators, which produce up to 2270 kW and are generally used for backup. Demand response uses heating, cooling, and ventilation scheduling, leveraging the pre-existing Johnson Controls and Trane building automation systems [72].

Business Case

Overall, it is hoped that the project will allow deferral of capital upgrades to sub-station and feeder infrastructure, and reduce the need for peak power purchases through peak generation technology [69,71].

Niobrara Data Center Energy Park

Location: Niobrara Data Energy Park, Northern Colorado

Type: Commercial/Remote Microgrid

Aims: Resiliency, islanding, cybersecurity

Power Sources: Wind, solar, natural gas

Status: Proposed

Background

The Colorado PUC has approved construction of the Niobrara Data Center Energy Park, a data storage site. Niobrara will be fully self-contained and supplied with onsite power, water, and communications. The site, located in the Rocky Mountains, will cover an area of 662 acres. Due to the award of a gas utility license, the site will be able to generate its own power.

Overall, this microgrid will give this data center, involved in cloud computing, high levels of energy security and cybersecurity. The project will use resources, such as wind, solar, and natural gas CHP, to create a microgrid that can operate when disconnected from the local transmission grid.

Business Case

Apart from the necessity for energy security for large data centers, which will attract customers with the need to protect sensitive data, it is estimated that the site will be able to significantly reduce operating costs, which usually make up to 30% of the annual operating costs for such centers [73].

Arizona

Because of its ideal location for solar generation, Arizona has the most installed PV per capita of any U.S. state. The state has set a standard of calling for renewable installations to account for approximately 15% of all generated power by 2025. However, in 2014, the state added a per-kilowatt charge for net-metered systems, which has slowed the adoption of DG.

In addition, some of the U.S. DOD's largest renewable projects are in Arizona, namely large solar installations at Davis-Monthan Air Force Base, near Tucson, and the Army's 18 MW Fort Huachuca solar project, near Sierra Vista.

Renewable Energy: For IOUs and electricity cooperatives, which produce 59% of the state's total electric load, 15% of power must be produced from renewable sources by 2025. Thirty percent of this target must come from DG, with 50% of this from residential applications and 50% of this from non-utility, non-residential resources.

Net Metering & Interconnection: For IOUs and cooperatives, net excess generation will be credited to customer bills, with no capacity or aggregate limit. However, there will be a US \$0.70/kW monthly fee charged to operators of net-metered solar PV systems. Interconnection standards vary according to utility.

Tax Incentives: Production Tax Credits will be given for wind, biomass, or solar system of over 5 MW capacity. Credits will last for ten years, with an individual cap of US \$2 million per year and a program cap of US \$20 million per year. Business Tax incentives include a 75% reduction on real and personal property taxes and/or a 10% refundable income tax credit. Finally, Non-Residential Tax Credits for Wind and Solar reimburse 10% of the cost of a solar or wind energy system, with an annual limit of US \$25,000 per building and US \$50,000 per business [15].

Arizona State University

Location: Arizona State University, Phoenix, Arizona

Type: Campus Microgrid

Aims: Emissions reductions

Power Sources: Renewable DG, CHP

Technology/Vendors: Ameresco, Rocky Mountain Institute

Status: Ongoing

Background

Arizona State University (ASU), as part of its drive to achieve carbon neutrality by 2025, has upgraded its campus microgrid to better incorporate DG, CHP, and modern technologies. Overall, the microgrid will improve reliability, resiliency, and flexibility, reduce energy costs, and promote the use of renewable energy. The university is working with a number of partners, including Ameresco and the Rocky Mountain Institute [74].

As part of the ongoing research, the university hopes to gain experience of designing, installing, and operating a microgrid, to benefit research and education. It will also assess the associated capital and O&M requirements and learn how microgrids can contribute to carbon reductions, especially when allied with energy conservation, building efficiency improvements, and renewable energy installations.

To test the microgrid during development, especially during off grid operations, the eLab Accelerator performed studies of any potential impacts to the campus and to the wider distribution grid. This allowed the university to refine the project and draft a proposal to the Arizona Commerce Commission suggesting that legislation to create a renewable-friendly environment should be enacted [75].

Nevada

Nevada already meets a significant proportion of its power needs through solar and geothermal resources, as well as wind and hydropower. The regulatory environment has seen sustained growth in the renewable energy industry, and the state is looking to fulfill a quarter of its needs through renewable energy by 2025.

To support this, Nevada has implemented net metering and interconnection policies that are favorable to DG resources and microgrids. Eventually, the state wants to shut down its coal fired generating facilities and use alternative clean energy resources to replace the generating capacity.

Renewable Energy: By 2025, IOUs and other retail suppliers, representing 88.2% of the state's present load, must generate 25% of their power through renewable resources. This includes a stipulation that solar energy must provide 5% of the minimum annual requirement, a figure that will rise to 6% in 2016. Utilities may use energy efficiency measures to offset some of this requirement. NV power must also install an additional 350 MW capacity from renewable resources by 2021.

The Temporary Renewable Energy Development (TRED) permits IOUs to seek extra payments from customers for energy derived from renewables, which must be reinvested in renewable projects.

Net Metering and Interconnection: For investor owned utilities, the system capacity limit is 1 MW or 100% a customer's annual requirements. The aggregate capacity limit is 3% of the combined peak capacity of all utilities operating in the state. Net excess generation will be credited to a customer's next bill. For IOUs, there is a 20 MW system cap for interconnection, and net metering is not required.

Tax Incentives: Property Tax Abatement for Large Scale Renewables, of 55% for a 20 period, applies to new or expanding businesses that meet certain investment criteria, and sales and use taxes may be reduced to 2.25%. Importantly, for microgrid-scale projects, renewable systems for residential, commercial, or industrial buildings are exempt from property taxes [15].

UNLV RDSI Demonstration Project

Location: Villa Trieste, Las Vegas, Nevada

Type: Community Microgrid

Aims: Energy efficiency

Utility Involvement: NV Power

Power Sources: Rooftop mounted PV panels of 1.76-2.43 kW, substation battery storage

Funding: DOE Smart Investment Grant, Pulte Homes

Technology/Vendors: SunPower PV system, Trilliant, OpenADR, ZigBee

Status: Proposed

Background

The University of Nevada microgrid project sets out a very aggressive goal for reducing peak energy demand by two thirds at the feeder/substation level, more than four times the recommended goal proposed by the DOE.

Technology

Partnering with NV Power, the university is building 180 energy efficient homes in the planned Villa Trieste community, which will include rooftop mounted PV panels of 1.76-2.43 kW, tankless water heaters, HAN, Energy Star rated appliances, thermostat controls, and other smart technologies.

The microgrid will also evaluate how well technologies integrate with the utility distribution grid, especially the command and control applications, and assess how customers actually use the in-home technology. Demand response will use Open Automated Demand Response (OpenADR), with the ZigBee protocol used in homes. Other aspects of the microgrid will include wireless mesh network and substation battery storage.

DOE Renewable and Distributed Systems Integration (RDSI) Awards: This project is part of a larger project that DOE recently awarded funding under the Smart Grid Investment Grant. In 2008, the DOE RDSI demonstration selected nine microgrids that would receive a total of US $55 million over five years. The goal of RDSI was to promote renewable DG and decrease peak loads for individual feeders by at least 15%. All selected grids should be able to operate in grid-connected and island modes.

The microgrids will also improve reliability, include cybersecurity, incorporate DER, and help customers manage their own energy usage [76].

Utah

Utah does not have a mandatory renewable portfolio goal, preferring to use voluntary targets to encourage utilities to produce 20% of their power from renewable resources by 2025. However, the state offers tax incentives to help residential and commercial customers invest in renewable energy.

Net Metering and Interconnection: In terms of net metering limits, which cover IOUs and cooperatives, there is a system capacity limit of 2 MW for non-residential resources and 25 kW for residential generation. Net excess generation will be credited to the customer's next bill.

Interconnection standards allow a system cap of 20 MW for IOUs and cooperatives, with an external disconnect switch mandated except for non-inverter systems with a capacity of less than 10 kW. Liability insurance may be required for systems of over 2 MW.

Tax Incentives: The state exempts from sales tax any equipment used to generate renewable energy, with all new systems of over 2 MW and existing facilities adding over 1 MW extra capacity eligible. For residential systems, customers may claim a Renewable Energy Systems Tax Credit, allowing them to claim income tax credit for a quarter of the costs, up to a maximum of US $2000.

For commercial customers, an investment tax credit for up to 10% of the installation costs can be claimed, to a maximum of US $50,000 for wind systems of less than 660 kW, and US $50,000 for solar installations of less than 2 MW. Other tax credits are available for installations meeting job creation and revenue stipulations [15].

EBay Facility

Location: Salt Lake City, Utah

Type: Commercial Microgrid

Aims: Reliability, cybersecurity

Utility Involvement: Ormat Technologies

Power Sources: 6 MW solid oxide fuel cells

Technology/Vendors: Bloom Energy

Status: Operational

Background and Technology

To protect its data centers, EBay has installed 6 MW of fuel cells at its Utah facility, as part of a shift towards developing power on-site and using the wider grid for backup. This is partly driven by EBay's corporate goal of using power derived from renewable resources. The main function of the microgrid is to regulate the fuel cells, with excess power diverted to the Topaz data center [77].

The Quicksilver data center, adjacent to the larger Topaz mega facility, uses 6 MW of solid oxide fuels cells developed by Bloom Energy, making this the U.S.'s largest non-utility fuel cell installation. To generate power, these fuel cells combine oxygen and natural gas. The Bloom cells are modular, to provide multiple redundancies and ensure that the failure of a single 40 kW cell will not compromise operation. The cells incorporate high-efficiency cooling systems, and the site has the potential for future expansion to 18 MW.

Business Case

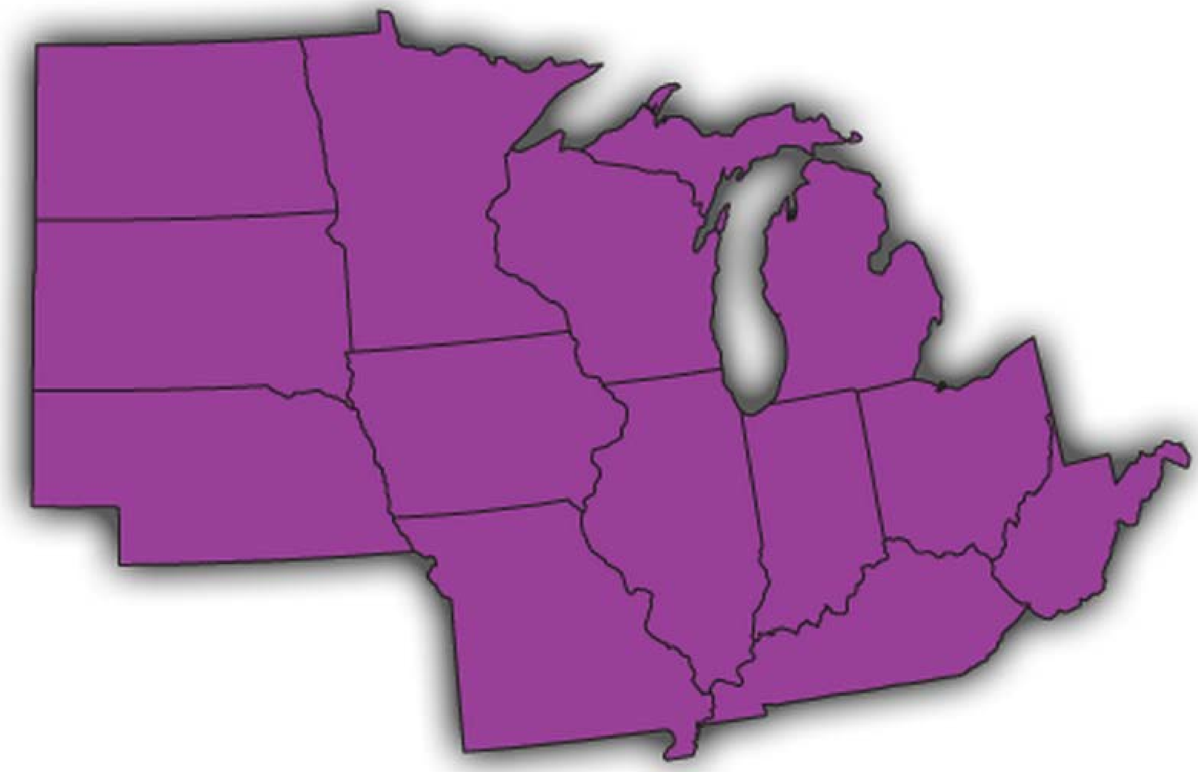
Although the upfront installation costs were high, some of this was offset by eliminating the need for uninterruptible power supply (UPS) and generators, alongside simplifications to the design of the building that lowered overall costs for the site. In addition, the fuel cells are powered by natural gas, which is less prone to potentially disastrous outages than electricity supplies.[9] Using gas also opens up the possibility of using biogas in the future, further shifting the site towards renewable power.

Although the cost of electricity produced per unit will be higher than with grid power, the cost of downtime for a data center can be huge. For the fuel cells, Bloom Energy has carried the upfront cost in return for a kWh power purchase agreement, and Bloom will also perform system maintenance [78].

In addition, because the cells only generate 6 MW of the 8 MW required by the facility, eBay has signed an agreement with Ormat Technologies, which will generate 5 MW from a natural gas pipeline facility near the data center using waste heat from the pipeline compression system. This power is sent to the wider grid rather than directly to the data center [79].

[9] EBay assessed a number of alternatives, which can be seen at: Alejandro D. Domınguez-Garcıa, George Gross, and Philip T. Krein. *Analysis of Design Alternatives for Supplying Electric Power to Mission-Critical Loads in Data Centers: Reliability, Environmental, and Efficiency Aspects*. University of Illinois Department of Electrical and Computer Engineering. Available at: http://tech.ebay.com/sites/default/files/publications/Analysis_of_Design_Alternatives.pdf

4
MID-WEST REGION



Illinois

As one of the top energy producing states in the U.S., Illinois exports power to other states, including electricity generated from wind, biomass, and other renewables. Illinois is the second highest in the Midwest for installed renewable energy capacity and fourth highest in the U.S. for installed wind power. The state promotes renewable energy and distributed generation, using legislation and incentives to create a supportive environment.

Renewable Power: By 2025-2026, IOUs and other retail suppliers, which supply 89% of the state's load, must produce a quarter of their power from renewable resources. IOUs must produce 75% of this from wind, while other retail suppliers must produce 60%. Photovoltaic generation must fulfill at least 6% of the annual requirement from 2015-2016 onwards, with distributed generation producing 1% of the annual requirement for IOUs from that date.

Net Metering: At present, the net metering limit is 40 kW, but this is set to rise to 2 MW under new legislation. The aggregate capacity limit is presently 1% of the utility's peak demand in the previous year, a figure that is set to rise to 5%. Excess energy is credited to the customer's next bill, but new rules covering non-competitive, non-hourly customers will see credits delivered on an hourly rather than flat retail rate.

Interconnection Standards: For all DG installations, an external disconnect switch is required, and the state has a number of insurance requirements that vary according to facility type and size.

Tax Incentives: Businesses investing in new wind power facilities in designated enterprise zones will be exempted from state and local sales taxes for any building materials used in the facility. The business must make a minimum investment of US $12 million and create at least 500 jobs to qualify.

Grants and Funding: The state supports the development of renewable resources through a system of grants and loans. The total fund for the years 1998-2015 was approximately US $100 million. Under the Solar and Wind Energy Rebate Program, residential developments may be given US $10,000; commercial enterprises US $20,000; and non-profit organizations and the government sector up to US $30,000. To qualify, wind systems must produce between 1-100 kW, solar PV arrays must produce over 1 kW, and solar thermal systems must produce over 0.5 therms per day or cover at least a 60 sq. ft (18 m^2) area.

For businesses, the Community Solar and Wind Grant Program may provide up to 30% of the cost of the project for solar thermal and wind, and 25% for solar PV. For government and non-profit organizations, the support rises to 40%, up to a maximum level of US $250,000. Finally, for renewable energy projects that provide a significant public benefit, the Illinois Finance Authority will issue tax exempt bonds.

Illinois Institute of Technology

Location: Chicago, Illinois

Type: Campus Microgrid

Aims: Outage mitigation, energy efficiency

Utility Involvement: Commonwealth Edison

Power Sources: Two 4 MW combined-cycle gas units, rooftop PV, wind turbine, 500 kWh zinc bromine flow battery

Funding: DOE, Industrial Funds, American Recovery and Reinvestment Act (ARRA)

Technology/Vendors: S&C Electric, Galvin Electric Institute, ZBB Energy Corporation

Status: Operational

Background

Partnering with S&C Electric and the Galvin Electricity Initiative (GEI), the Illinois Institute of Technology (IIT) developed a microgrid at a total cost of US $14 million. Federal funds (DOE) of US $7 million and industrial funds of US $5 million sponsored this microgrid over a five year period [80].

IIT had a number of reasons for wanting to establish a microgrid. Firstly, a number of extended outages, estimated at three every year, cost the institute an estimated US $500,000 per annum due to teaching and research disruptions. With demand for power on the campus growing, IIT felt that a microgrid would accommodate growth, improve energy efficiency, reduce disruption, and reduce consumption [81].

Technology

The campus microgrid includes renewable resources and flow batteries. To provide power, the campus uses:

- Two 4 MW combined cycle gas units
- Rooftop PV
- Wind turbine
- 500 kWh zinc bromine flow battery

Together, these resources provide 9 MW of the campus's 10 MW peak load requirement. The grid can operate when islanded, with a seamless transition, and the system, with the aid of smart metering, can shed 20% of load [82,83,84,85].

Business Case

The main aim of the project is to enhance reliability and power quality, because outages on the campus could jeopardize multimillion dollar research projects. University departments also wanted reliable power at night, and the microgrid includes provisions for future expansion of the campus. The Perfect Power system should avoid the need for future upgrades to the grid, and IIT believes that the project will pay for itself within five years [84].

With the microgrid, IIT hopes to offset the effects of potential future electricity price rises by producing their own power and building efficiency into the system. In addition, the system helps the institution to manage energy costs by allowing it to engage in real-time pricing and ancillary services markets. Additional savings will be made by eliminating the existing high pressure steam system, which requires oversight 24 hours per day [81].

Naperville

Location: Naperville, Illinois

Type: Community Microgrid

Aims: Outage mitigation, energy efficiency

Utility Involvement: City of Naperville Department of Public Utilities

Technology/Vendors: S&C Electric, Galvin Electric Institute, Siemens, S&C Electric, ACS, Cityworks Azteca, ESRI/Miner&Miner, SynerGEE Stoner, Microsoft

Status: Operational

Background

Galvin Initiative: Established in the aftermath of the 2003 Northeast Blackout event, the Galvin Initiative is developing a modern, flexible design for delivering power, based upon a microgrid and with a focus on the end consumer. For this, the initiative is developing open-source prototypes for smart microgrids.

The grids will improve reliability for consumers and also give them much more ability to alter their energy usage through access to pricing and usage data. The initiative will look at microgrid aggregation and energy districts, as well as exploring ways to finance microgrids and help local government build and operate new microgrids, or help utilities to make smart/microgrid improvements [86,87].

Naperville: The idea of installing a microgrid arose in response to the city's aging energy grid, rising population, and increasing demand for energy, which has led to frequent and often extended outages. Rather than attempting to patch up the existing infrastructure, the City of Naperville Department of Public Utilities is upgrading the grid, which should lead to savings over the long term.

Naperville's community-based smart microgrid design includes the latest smart technology, local power generation, and a flexible configuration that has dramatically decreased the number of outages. This was accomplished by undergrounding, installing automated switches, and installing communications. The smart microgrid is looped to offer redundancy and alternative routes. In addition, the grid is able to accept renewable resources and allows two way flows and metering.

Vendors

- Siemens: Substation Automation
- S&C Electric: Distribution Automation
- ACS: SCADA
- Cityworks Azteca: Service Request
- ESRI/Miner & Miner: Geographical Information System
- SynerGEE Stoner Engineering: Technical Analysis Software
- Microsoft: File and Application Servers [88]

Business Case

By giving consumers control over their power usage, it is hoped that the reduced demand will lower the cost of purchasing wholesale energy. Over the next 15 years, it is hoped that the city will save US $34 million directly, and US $52 million if societal benefits are included. The grid infrastructure will support the future addition of DG resources and is capable of supporting electric vehicles [88].

Commonwealth Edison's Bronzeville Microgrid

Location: Chicago, Illinois

Type: Utility Microgrid

Aims: Study a specific microgrid configuration

Utility Involvement: Commonwealth Edison

Power Sources: This project would include at least three of the following technologies: solar photovoltaic, fuel cells, natural gas generation (including CHP), electricity storage, geothermal generation, and wind turbines.

Funding: This will be funded by Commonwealth Edison from their rate base if approved by the legislature (HB 3328/SB1879)

Technology/Vendors: No vendors have been selected at this time

Status: Proposed and unfunded

Background

Commonwealth Edison is evaluating Chicago's Bronzeville neighborhood for implementation of a potential microgrid. This will be a 12 MW microgrid and include fault tolerance and self-healing.

The proposed location is next to the Illinois Institute of Technology microgrid. This would create the first clustered microgrid in the world.

Location is a great cross section of Chicago, with diverse critical loads:

- High tech manufacturing
- Educational facilities
- Police headquarters
- Healthcare and senior residences
- Other private residences

In addition to the above project, Commonwealth Edison has indicated (March 2015) that they are considering the following microgrid project sites, but the author could find no information on these:

- The Illinois Medical District
- An airport in Winnebago County
- Chicago Air Route Traffic Control Center
- DuPage County Courthouse and Administration Building
- Water pumping and treatment in Chicago Height

Technology

No technologies have been selected at this stage of the project.

Ohio

Although Ohio has a large potential for generating power from wind, it has not yet used this resource on the same scale as some of its neighboring states. However, the state has the number one ranked installed solar capacity in the Midwest, and has invested in ethanol production. At present, Ohio is actively seeking ways to expand its usage of renewable resources, especially solar PV.

Renewable Energy: By 2024, IOUs and other retail energy suppliers must generate at least 12.5% of their load from renewable resources and, by 2025, must produce an additional 12.5% from advanced energy systems, co-generation, and DG. Overall, by 2024, solar energy must account for 0.5% of the energy produced. Penalties will be imposed if these standards are not met.

Net Metering and Interconnection Standards: The customer will be credited net excess generation on their next bill at the unbundled generation rate. At present, the interconnection standards are a 20 MW system capacity limit.

Tax Incentives: Tax incentives include an Energy Conversion and Thermal Efficiency Sales and Use Tax Exemption for property used by certain energy projects. The Qualified Energy Property Tax Exemption, for projects over 250 kW, allows producers to make a payment in place of personal and real property taxes. Renewable projects may also qualify for an Air Improvement Tax incentive, with a reduction in corporate taxes and/or a sales and use tax exemption.

Loans and Grants:

In August 2013, The U.S. Department of Agriculture provided US $1.1 million in grants for rural agricultural businesses to increase their use of renewable energy. In addition, small businesses, manufacturers, non-profit organizations, and public organizations are eligible for loans at an interest rate equal to or less than the market rate.

Eligible projects are required to decrease energy consumption by 15% and yield a return on investment in fewer than 15 years. Through participating banks, residents of the state are eligible for financing at reduced rates for upgrades of home energy efficiency and renewable energy. The maximum reduced loan rate is for up to US $50,000 and lasts for seven years [15].

CERTS/American Electric Power Test Bed

Location: Columbus, Ohio

Type: Test Microgrid

Aims: Microgrid research and testing

Utility Involvement: American Electric Power (AEP)

Funding: California Energy Commission PIER Electric Transmission Research Program

Technology/Vendors: University of Wisconsin-Madison Power Systems Engineering Research Center (PSERC), Sandia National Laboratories, Northern Power Systems, Tecogen, and Lawrence Berkeley National Laboratory.

Status: Operational, moved to full scale demonstration

Background

The CERTS Microgrid Test Bed, set up in partnership with American Electric Power, was designed to examine how small, distributed generation resources could be integrated with a microgrid. To achieve this, the full-scale test bed microgrid was designed to fulfill a number of aims [89]:

1. Developing a method to allow automatic, seamless transitions between grid-connected and islanded mode.
2. Develop an electrical protection system that does not require high fault currents.
3. Develop microgrid controls that maintain voltage and frequency stability without high speed communications.
4. Use plug-and-play technology with no custom engineering.
5. Provide autonomous local control.
6. Use CERTS technology to develop a grid that can handle power from intermittent renewable resources.

The funding was provided by the California Energy Commission PIER Electric Transmission Research Program.

Presently, the test bed includes a PV emulator and inverter, a flexible energy management system, an energy storage device with CERTs control, and a CERTs compatible synchronous generator [8].

Results

The tests confirmed earlier pilot studies conducted in laboratory scale tests, and through factory tests of individual components. The islanding and synchronization techniques met the Institute of Electrical and Electronics Engineers 1547 standard and power quality requirements. The system distinguished between normal and faulted operation, and the controls worked under all conditions [89].

Overall, the microgrid required little custom engineering, due to the plug-and-play and peer-to-peer technology, and offered great reliability when integrated with the distributed generation resources in operation.

Business Case

Another function of the microgrid was to test the business case, using the DOE's Distributed Energy Resources Customer Adoption Model (DER-CAM) software to aid with project prioritization. CERTS and AEP enhanced the DER-CAM application to consider energy storage and thermal storage technologies, with flexibility to adjust equipment type and size and take seasonal fluctuations into account. They also adjusted the tool to take into account customer power quality and reliability, alongside the reliability of individual components. Overall, the study showed that microgrids are not economic in every situation, mainly due to the present high cost of energy storage [90].

Wisconsin

Wisconsin is developing its energy market to fulfill its goal of producing 10% of electricity from renewable resources by 2015. The state is one of the leading ethanol producers in the U.S., and incentives and proximity to clean energy supply chains make it attractive to manufacturers. In 2012, solar capacity doubled, with most of this increase derived from the addition of residential and commercial solar developments.

Net Metering and Interconnection Standards: For IOUs and municipal utilities, there is a 20 kW system capacity limit, rising to 100 kW for some utilities. Although the sale of excess power varies according to utility, it is generally credited to the customer’s next electricity bill at the retail rate. For IOUs and municipal utilities, the interconnection standard has a system capacity limit of 15 MW.

Public Benefit Fund: This fund, funded by state IOUs and by participating electricity cooperatives and municipal utilities, stipulates that utilities must invest 1.2% of their annual operating revenue in energy efficiency measures and renewable resources. This fund for 2014 stands at US $10 million, and is used to provide financial assistance, technical support, and information.

Tax Incentives and Funding: The Renewable Energy Competitive Incentive Program (RECIP) is a competitive award for businesses installing eligible renewable energy systems, with the amount ranging from US $5000 to US $500,000. Eligible renewable purchases are exempt from sales tax, and any additional value added by a solar or wind system is exempt from property taxes [15].

University of Wisconsin-Madison

Location: Madison, Wisconsin

Type: Test Microgrid

Aims: Energy efficiency, islanding

Background

The University of Wisconsin-Madison has a laboratory scale microgrid used for testing technologies and refining control algorithms. The system can produce a variety of loads and operating conditions to assess the behavior of microgrids under a wide range of scenarios.

Technology

Technology used for simulations at the center includes a DC power supply, a DC bus and inverter connected to the AC grid via an LC filter and transformer, and an inductor. These are sized to give a ten degree voltage angle. With this setup, the microgrid can emulate microturbines, fuel cell systems, and other equipment:

- Multiple DG sources

- Directly-interfaced and transformer-coupled DG systems
- Island operation
- Single phase loads
- Digital signal processing
- AC-side capacitor banks [91]

Minnesota

Due to its location in the path of severe weather systems, Minnesota is investing heavily in renewable energy as part of a drive to improve reliability and mitigate outages. Using financial incentives, Minnesota supports ethanol production, biomass, and wind power. In 2014, the state strengthened its renewable portfolio standard (RPS) by requiring IOUs to produce at least 1.5% of their energy from solar power by 2020.

Renewable Energy: By 2020, Xcel energy must produce 31.5% of its energy from renewable resources; other IOUs must produce 26.6% by 2025; and other utilities must produce 25% by 2025. IOUs must produce 1.5% of their total retail sales from solar, and the state is working towards a statewide goal of 10% by 2030. Importantly, for microgrid developers, 10% of this solar PV requirement must come from systems producing less than 20 kW. A fund of US $5 million will support this over the next five years.

Net Metering and System Interconnection: For all utilities, the net metering limit is 40 kW, a figure due to rise to 1 MW. Customers receive credit or payment at retail rate or avoided-cost rate for installations producing between 40 kW and 1 MW. Interconnection standards stipulate a maximum system capacity limit of 10 MW, and an external disconnect switch must be fitted. Insurance requirements vary according to installation type and size.

Tax Incentives: Solar and wind systems, and the components required to manufacture, install, and repair them are exempt from sales tax. Solar PV installations qualify for a reduction in real property taxes, and wind installations see real and personal property taxes replaced with a production tax.

Grid connected solar systems of less than 40 kW and manufactured in the state fall under the Made in Minnesota Solar Energy Production Incentive, granting a 25% rebate of the installed costs. The Sustainable Infrastructure Revolving Loan Program provides low interest loans for on-farm energy production, of up to US $40,000 for a single farm family and US $160,000 for joint projects. Home improvement loans at low, fixed interest rates are available for projects costing between US $2000 and US $50,000.

Finally, public utilities must create 20-year Power Purchase Agreements with community-owned renewable energy projects.

Microgrids

Recently, the Minnesota Department of Commerce commissioned a study into the viability of microgrids in the state. The research group set out to study:

- **Regulations & Policies**: This includes federal and regional laws for siting and permits, and identifying any relevant policy gaps.
- **Interconnection Standards & Practices**: The study will identify state standards for interconnection, interoperability, and control of DG, comparing them with federal and industry standards.
- **Contracting, Risk Assessment and Financing**
- **Prospective Microgrid Capacity**: Research and model the potential load available to microgrids, and assess infrastructural issues.
- **Renewable Microgrid** Prospects: Identify renewable resources that may be available to microgrids, including technological, economic, and operational factors.
- **Create Policy Roadmap**: Develop a roadmap that would capture the benefits of microgrids for the states and assist in safe integration into utility systems.

The plan will also look at microgrids in the context of reliability and providing emergency power during outages, operating in islanded mode, and protecting critical sites. Finally, the study will also assess how microgrids could contribute towards clean energy goals [92].

University of Minnesota

Location: Minnesota, Minnesota

Type: Campus Microgrid

Aims: Energy efficiency

Power Sources: DG, CHP, battery storage

Technology/Vendors: Lawrence Berkeley Laboratory

Status: Ongoing

Background

To test how smart grid features can be incorporated into a microgrid, the University of Minnesota has redesigned the system serving its Morris Campus. The university is also developing a new residential community that will incorporate a new smart microgrid and a mix of technologies.

The goal of the microgrids is to incorporate DG resources and allow the university to benefit from time-of-day pricing. Any savings and technological improvements learned from the two microgrids may be adopted as a larger project across the whole campus.

Technology

To make the campus a zero net-energy campus, the grid will include the ability to reconfigure the system to accommodate new construction and renovations. It will also allow the university to integrate new smart technologies, renewable resources, and energy storage, as well as use demand response applications. To facilitate demand response and allow power to be directed to critical facilities during outages, the project will include a system manufactured by Lawrence Berkeley Laboratory.

Plans also include phasing in electrified transportation and vehicles with reactive power support to minimize reliance on gasoline-powered cars and buses. The UMore Park community will include CHP, DG, and inverters. The homes will be equipped with smart meters and energy management tools, as well as backup battery storage and electric vehicle charging points.

To facilitate demand management and response, the system will include two-way wireless communication to allow two-way data flows. Finally, the project will include a newly developed cybersecurity detection system that is self-configuring and scalable [93].

5
SOUTH CENTRAL REGION

Texas

Texas is the only state in the U.S. that is a separate interconnection. It is also the leading state for wind power production. Recently, the state has started to upgrade its power grid to allow wider penetration of renewable energy, including microgrid and smart grid technologies. Texas exceeded its overall renewable energy goal 16 years early, although it has not yet achieved its target of 500 MW of new installations using non-wind resources. The state has not yet enacted legislation to create a favorable environment for solar resources.

Renewable Energy and Interconnection: The state already reached its 2025 goal of producing 10,000 MW of renewable power. By 2025, the state wants to produce an additional 500 MW from non-wind resources. At present, IOU systems enforce an interconnection standard of a 10 MW system capacity limit. Facilities must include an external disconnect switch, and insurance may be required for some installations.

Loans and Funding: The LoanSTAR Revolving Loan Program give low interest loans for cost-reduction retrofits in state, public school, college districts, and public hospitals. The maximum loan is US $7.5 million, with loans repaid from cost savings. The total budget for this program is US $190 million.

For wind, solar, or biomass energy, there is a property tax exemption according to the appraised value. Companies that manufacture, sell, or install solar or wind devices are exempt from business franchise taxes, and a corporation installing these devices can deduct some of the cost from franchise tax [94].

Colonias

Location: Border Colonias, Texas

Type: Remote Microgrids

Aims: Off-grid power

Power Sources: 40 kW from bio-diesel generators, Xtreme Powercell

Funding: Funding from Texas State Energy Conservation Office, Texas Commission on Environmental Quality, National Energy Technology Laboratory

Technology/Vendors: Xtreme Power Solutions

Status: Operational

Background

Texas Engineering Experiment Station (TEES) received a US $200,000 grant from the Texas State Energy Conservation Office (SECO) to develop and assess microgrids for communities in border colonias that are not connected to utility systems due to their remote location. Phase I of the project developed systems that could serve 10-20 households, with Phase II programs expecting to serve up to 100 customers [95].

TEES partnered with Xtreme Power Solutions, based in Texas, a company that specializes in providing portable generation technologies that provide power to communities at close to grid rates.

Technology

The Xtreme Powercell is the heart of the microgrid and can achieve storage efficiencies of 98% when coupled with an inverter to convert DC to AC [96]. The company integrated these power cells with high efficiency bio-diesel generators, delivering 40 KW of electric power to 10-20 customers for 6-8 hours. Solar panels and wind turbines may be used to increase this runtime. The cells have an extremely high cycle life, and the microgrid includes charge controllers, inverters, and system control [96].

The initial phase installed four microgrids in the La Presa community of Webb County, Texas and provides power to 43 customers who pre-purchase power. When power is purchased, the portable generator is updated via a computer system. As the project progresses, solar and wind power will be added, alongside a master control, to allow the system to differentiate between power sources. Phase II will add four additional generating units to allow a cost benefit analysis [97,98].

Presidio

Location: Presidio, Texas

Type: Remote Microgrid, Community Microgrid

Aims: Off-grid power, reliability

Utility Involvement: Electric Transmission Texas

Power Sources: 4 MW sodium sulfur storage battery system

Funding: ETT

Technology/Vendors: S&C, NGK Insulators, Ltd (Japan)

Status: Operational

Background

In Presidio, frequent electrical storms have negatively impacted reliability, a situation aggravated by the single, aging transmission line. This is difficult to access and repair, leading to frequent, extended power outages. It is one of the hottest cities in the U.S., so the loss of air conditioning is a major problem, and computer systems are affected by outages, which can be an issue for border enforcement authorities in the town. As a result, the local utility, Electric Transmission Texas (ETT), created a microgrid as part of a US $70 million investment in Presidio and the surrounding areas.

Technology

ETT has installed a 4 MW sodium-sulfur storage battery system to mitigate voltage fluctuations and provide backup power during shirt-term outages. The battery control is provided by an S&C PureWave SMS Storage Management System, which responds rapidly to fluctuating grid conditions. The SMS is an automatic power converter and controller that manages battery charging and discharging, allowing the grid to meet peak demand, usually during heat waves. The system can provide up to six hours backup, allowing power restoration or give enough time for the town to go through the process of sourcing additional power from Mexico [99].

The microgrid performs a number of functions:

- Quick response to address voltage fluctuations and momentary outages
- Can supply 4 MW of power or 8 hours if the system is islanded
- Will enable maintenance on the Marfa-Presidio transmission line without service interruptions [100]

Oncor System Operating Services Facility Microgrid

Location: Lancaster, Texas

Type: Utility Microgrid

Aims: Maintain power and maximize the use of renewables

Utility Involvement: Oncor

Power Sources: This microgrid uses ten different distributed power sources, including:

- 65-kW micro-turbine
- 210-kW diesel generator
- (2) 175-kW diesel generators
- 45-kW reciprocating natural gas generator
- 25-kW community energy storage
- 106-kW carport photovoltaic array
- 8-kW ground-mounted photovoltaic array
- 200-kW stationary battery storage
- Capability to add future wind generation

Technology/Vendors: S&C Electric Co. and Schneider Electric

Status: Operational

Background

There was no specific statement of why Oncor developed this microgrid, but Oncor frequently researches advanced technologies related to electric utilities. Thus it is believed that this project fulfills several needs, including (1) assuring resilient power at an important service center, (2) gaining hands-on experience in developing a microgrid, (3) evaluating microgrids elements of Oncor's distribution system, and (4) informing how Oncor should interact with private microgrids in the future.

Technology

The microgrid automates dispatch using pricing signals, determining when to buy, sell, or store power. The system looks at prices 15 minutes, an hour, and a day ahead, and also uses weather forecasts to optimize economics.

The project also is rich with "inverter-based resources" and is notable for its use of battery energy storage as the anchor resource it follows when it separates from the grid.

6
NORTH EAST REGION

New York

New York has significant wind and solar generation capacity and also uses hydropower, landfill gas, and solid waste generation. To increase this, the state is developing a “Green Bank” with the intent of using private sector capital to fund renewable projects. It may also establish a Clean Energy Fund with the intent of promoting investment to help the state reach its renewable portfolio standard target of 30% by 2015 [101].

New York Power Authority has announced that its new plans for grid expansion and retrofitting will focus in local generation and microgrids. Consolidated Edison has also agreed to review the technology. Together, utilities and NGOs will assess CHP power and microgrids that can island, isolate outages, and reduce system load [102].

Renewable Energy: The target for New York State is 30% by 2015, of which 8.4% must be derived from customer-sited systems. This target applies only to IOUs, which supply 84.7% of the state's capacity. New York State Energy Research and Development Authority (NYSERDA) also collects an RPS charge on customer bills, which is used to support projects and incentive programs.

Net Metering and Interconnection Standards: At present, IOUs have a net metering system capacity limit of:

- Residential wind, solar, or micro-hydro: 25 kW
- Non-residential wind, solar, or micro-hydro: 2 MW
- Biogas on farms: 1 MW
- Residential fuel cells or micro CHP: 10 kW
- Wind on farms: 500 kW
- Non-residential fuel cells: 1.5 MW

The aggregate capacity limit is 3% of the utility's 2005 demand for all renewables other than wind, which has a limit of 0.3%. In most cases, net excess generation is carried to the next bill at retail rate. For IOUs, the interconnection standard is a 2 MW system capacity limit.

Tax Incentives: In New York, the sale of residential and solar energy systems receives a tax incentive, and eligible energy conservation improvements receive a real property taxation exemption for the added value. In addition, homeowners may receive tax relief for 25% of the cost on solar energy systems, and may receive credit for leasing costs or PPA agreements made with a third party. To qualify, the system must be less than 25 kW, or 50 kW for multi-family homes.

For RPS resources on customer sites, NYSERDA may give an upfront rebate and performance-related incentive for customer-installed facilities, applying to non-residential projects of over 200 kW [101].

Reforming the Energy Vision: The Reform the Energy Vision Initiative was established to encourage distributed generation, microgrids and distributed system platform providers (DSPP). It was created, after the NY Commission 2100 Report of January 2013 in response to storms Irene and Sandy [103,104].

Under the control of the New York Department of Public Service, the plan will create a grid operator to manage distributed energy resources and develop a market for energy providers to buy and sell power, making it easier to monetize microgrids, demand response, energy storage, and other facilities through a system of tariffs. The plan highlights microgrids as an important element of the initiative.

The PSC is reviewing a number of community and microgrid-related issues:

- Potential changes in interconnection standards and standby rates

- Developing relationships between utilities and microgrids to clarify distribution line ownership and the regulatory status of microgrid operators
- The role of microgrids in planning for system needs and adding resilience to critical facilities [105]

Funding: As part of a US $17 billion storm preparedness plan, New York has created a US $40 million prize fund to support the development of community microgrids. To be eligible, a microgrid should support communities of approximately 40,000 residents. The microgrids will primarily operate in conjunction with the grid, but will be able to operate independently in case of grid disruption and power critical facilities [33].

Two projects, in Nassau and Suffolk counties, which suffered damage from Sandy, have already been given US $10 million as part of an US $815 million recovery package for Long Island [106].

Cornell University

Location: Cornell University, New York

Type: Campus Microgrid

Aims: Reliability, energy efficiency

Power Sources: Two 14.7 MW duel-fuel generators; 2 steam turbo-generators of 1.7 MW and 5.7 MW; 2 heat recovery steam generators; 2 1 MW emergency diesel generators; 2 hydroelectric generators of 800 kW and 1 MW; 2 coal fired boilers; 2 dual fuel package boilers; 1 natural gas package boiler

Technology/Vendors: Solar Titan, Turbodyne, Rentech, Ossberger

Status: Operational

Background

Like many universities, Cornell requires reliable power to ensure that critical research is not compromised by power outages. In addition, with 150 buildings across a 14 million square feet (4,267 km^2) campus, the university understood that upgrading its electrical distribution system to incorporate modern microgrid technologies could lead to huge cost savings. The new microgrid facilities allow for future expansion and increases in demand.

Technology

Although the campus already had its own generating facilities, these were outdated and were upgraded to:

- 2 Solar Titan Model 130 gas turbines producing 14.7 MW each
- 2 Turbodyne back-pressure steam turbo-generators, from 1986, producing 1.7 MW and 5.7 MW each
- 2 Rentech heat recovery steam generators that produce 58,000 lbs/hr
- 2 emergency diesel generators of producing 1 MW each

- 2 Ossberger run-of-river hydroelectric generators, installed in 1981, that produce 800 kW and 1 MW
- 2 coal fired stoker boilers of 170,000 lbs/hr and 90,000 lbs/hr respectively
- 2 dual fuel package boilers, capable of using natural gas or ultra low sulfur diesel, producing 100,000 lbs/hr each
- 1 natural gas fired package boiler (100,000 lbs/hr)

Overall, the peak electric capacity is 37.9 MW.

The cogeneration facility, called the Cornell Combined Heat and Power Project (CCHPP), will allow the campus microgrid to operate in parallel with the regional grid or in island mode. The system is islanded under normal conditions, with utility power serving as a backup. The microgrid is capable of black-start operation to restore service in island mode. In addition, the Solar Titan and Rentech Heat Recovery systems allow the campus to improve efficiency by recycling waste heat.

Business Case

Because the university spends over US $30 million per year on energy, two thirds of which was paid to utilities before the system upgrade, the potential for recovering the installation costs over time is huge. Studies suggest that the CCHPP alone will provide a net value of US $15 to $20 million over 25 years.

During a local or regional power outage, the University's microgrid will be able to operate in an islanded mode. Black-start support to the system from the diesel generators may in turn support the regional grid. Islanded operation will enable Cornell's sensitive research labs and essential facilities to continue to operate during the power loss. Cornell will also become a community haven in the event of a lengthy emergency in the region [33].

New York University

Location: New York, New York

Type: Campus Microgrid

Aims: Islanding, energy efficiency

Utility Involvement: ConEd

Power Sources: 13.4 MW CHP; Two 5.5 MW gas turbines with heat recovery steam generators, 2.4 MW steam turbine; seven Caterpillar D399 engines with waste heat boilers (895 kW each); one steam turbine (2.4 MW); three dual fuel high temperature hot water boilers (65 Mmbtu/hr each); three electric centrifugal chillers (1500 tons each); three absorption chillers (2500 tons each).

Funding: NYSERDA grant for feasibility study; tax exempt bonds

Technology/Vendors: SKM, PSS/E, RTDS, PSCAD, Matlab, Power World, PowerSim, and EMTP

Background

New York University has produced power onsite since the 1960s and installed an oil-fired generation plant in the 1980s. As the unit reached the end of its operational life, the university installed a natural gas fired CHP facility, with the idea of developing a microgrid to improve reliability and control energy expenditures. The project was financed by tax exempt bonds issued by the Dormitory Authority of the State of New York [33].

Technology

The CHP, operational since 2011, produces 13.4 MW and supplies power to 22 buildings, and heat to 37 buildings across the campus. Added to this, the university microgrid includes two 5.5 MW gas turbines, with heat recovery steam generators, and a 2.4 MW steam turbine. The university's power generating facilities include:

Pre-existing facilities are listed above. New facilities include the following:

- Two duct fired burners (70 MMBtu/hr each)
- Two dual-fuel Solar Taurus 60S series turbines (5.5 MWp each)

Thermo provides programmable logic controllers and SCADA, as well as control valves.

The NYU microgrid is connected to the 13.2 kV ConEd system by an interconnection switch at the Warren Weaver Hall substation, and will transition to the grid if one of the campus generators fails. Importantly, the NYU system can operate as an island, as successfully tested during Hurricane Sandy [107].

Business Case

Although the campus still uses gas delivered by Consolidated Edison, it will make savings through reducing total energy costs. It will also see significant reductions in emitted gases. The campus is saving between US $5 million and US $8 million per year and has seen a two-thirds decrease in NO_x, SO_2, and CO_2 emissions [33].

South Oaks Hospital

Location: Long Island, New York

Type: Campus Microgrid

Aims: Islanding, backup power, energy efficiency

Power Sources: 1.3 MW CHP system, five 250 kW IntelliGen engines, 400 ton hot water absorption chiller 1 MVA diesel generator

Status: Operational

Background

Due to the need to maintain operation during extended outages caused by extreme weather events, South Oaks Hospital has developed a full scale microgrid. During the blackout of August 2003, the hospital did not lose power, and during Superstorm Sandy, where the hospital remained isolated for 15 days, the system successful transitioned to island mode and provided full power and thermal energy to the hospital and nursing home [104]. This also allowed the facility to accept patients and refrigerated medications from other facilities, and house staff impacted by the storm.

Technology

The South Oaks microgrid includes:

- 1.3 MW CHP
- Five 250 kW Intelligen engines
- 400 ton hot water absorption chiller [104]

Griffiss Business and Technology Park

Location: Rome, New York

Type: Commercial Microgrid

Aims: Low cost energy

Power Sources: Steam and biomass generators

Status: Operational

Background

Griffiss Business and Technology Park, containing businesses that could lose significant amounts of money during outages, built a microgrid by developing its existing distribution system. The park intends to use biomass and steam generation to meet seasonal heating needs, and the use of low cost energy will be a selling point when inviting businesses to set up at the location. Griffiss works closely with local authorities to help businesses finance local energy programs [104].

Village of Potsdam Microgrid

Location: Potsdam, New York

Type: Community Microgrid

Aims: Power resiliency and integration of renewables

Utility Involvement: National Grid

Power Sources: Three MW CHP, 2 MW PV, 2 MW of batteries, and 900 kW of hydro

Funding: US $1,2000,000 from the Department of Energy OEDER and a US $300,000 investment from GE

Technology/Vendors: GE, NREL, National Grid, Clarkson University

Status: Implementation in progress – only 18 months of engineering and six months of testing at NREL is funded.

Background

The Village of Potsdam is located in a remote region in far northern New York near the Canadian border. Due to its location, power reliability is poor, particularly during severe winter storms. A 1998 storm left over 100,000 people in the Potsdam area without power for as long as three weeks.

The idea for a microgrid began in the Clarkson University engineering department. Clarkson is located in Potsdam. GE, Nova Energy Specialists, and National Grid analyzed how a community might maintain power in case of another catastrophe. The only way to integrate local conventional and renewable energy sources along with new energy storage and control elements to form a resilient system is via a microgrid.

Technology

A US $1.2 million grant from the DOE's Office of Electricity Delivery and Energy Reliability and a US $300,000 investment by GE will be used to develop an enhanced microgrid control system. By using the new control system, the microgrid will operate in as an island for and use energy storage to help power critical loads for as long as two weeks. The microgrid will also support National Grid integration of distributed energy resources. This microgrid will normally be connected to the grid. Existing distributed generation will be integrated into the microgrid.

ConEd / NYCEDC Brooklyn Army Terminal Microgrid

Location: New York, New York

Type: Community Microgrid

Aims: Reducing peak demand

Utility Involvement: Consolidated Edison

Power Sources: 720 kWh lead-acid battery, PV system, 100 kW inverter

Funding: Partially by the DOE

Technology/Vendors:

- Battery is a Hitachi lead-acid rated at 720 kWh
- Inverter is Princeton rates at 100 kW
- PV System is Suntech 100 kW with Advanced Energy Inverter
- Building Management Systems from Alerton and Viridity

Status: Operational

Background

The New York City Economic Development Corporation (NYCEDC) understands that New York City facilities can be improved through the use of microgrids. NYCEDC, and Consolidated Edison are implemented a microgrid in the Brooklyn Army Terminal (BAT). This industrial-facility has 4,000,000 sq. ft (1,219 km^2).

Technology

A 100 kW solar photovoltaic array in integrated with a 720 kWh battery using a building management system. This system can deliver 100 kW for four hours.

Business Case

The payback streams for this project are:

- NYISO Special Case Resources Program
- ConEd's Distribution Load Relief Program
- ConEd's Commercial System Relief Program

For each program, notice for a demand response event is given the day before the event. During the event the battery will furnish its rated output for four hours. Participants get a reservation payment per kW of energy available during their enrollment every month and payments for each kWh supplied during the events.

Freeport Microgrid Proposal

Location: Freeport Village, Town of Hempstead, New York

Type: Community Microgrid

Aims: Assure power resiliency in the event of a major storm

Utility Involvement: Long Island Power Authority

Funding: NYSERDA Prize (not awarded)

Technology/Vendors: These are currently not defined

Status: Proposed and unfunded

Background

As of March 2015, Freeport Village was seeking bids for design and engineering services to enable it compete for the US $40 million New York Microgrid Prize. Freeport is on Long Island and is susceptible to major outages from large storms.

Technology

No technologies are defined at this stage of the project.

Connecticut

Connecticut is one of the highest energy cost areas in the continental United States and is one of four most problematic areas for reliability, with brownouts very common. In addition to disruptions and weather-related events, the grid is afflicted with capacity issues, with supply unable to keep up with demand from growth.

The state estimates that it is at least 700 MW short of meeting peak demand, and it is difficult to build new power generation facilities due to air emission standards and local concerns. As a result, the state is looking at five areas for improvement, namely capacity, reliability, cost, quality, and an emphasis on green technology.

Renewable Energy: Overall, the state expects 27% of all power to be generated from renewable resources by 2020, with renewable resources divided into three classes with different requirements. In addition, the Clean Energy Finance and Investment Authority must develop an incentive program for residential solar that will yield at least 30 MW of extra capacity before 2023.

Net Metering and Interconnection: There is a system capacity limit of 2 MW and 3 MW, depending upon the resource class, with net excess generation given as a credit or paid after 12 months. Interconnection standards for IOUs are 20 MW, with external disconnect switches required. Insurance is required for some systems.

Tax Incentives: Equipment and labor are sales tax exempt for manufacture and installation, and certain renewable resources, including solar and wind, are exempt from property tax. Incentives are also given for performance for systems under 10 kW, and grants and loans are available for solar thermal systems [101].

Microgrids

The state of Connecticut has been very proactive in promoting microgrids, especially in the wake of Hurricanes Irene and Sandy, and has initiated a Microgrid Grant and Loan Pilot program. This program, administered by the Department of Energy and Environmental Protection (DEEP) Bureau of Energy and Technology, in conjunction with the state's two utilities, will provide state funding for a number of microgrid programs, and is estimated to be worth over US $45 million.

In most cases, grants are assigned to developing microgrid interconnection with utilities rather than generation or energy storage technologies. Overall, the project will assess the feasibility of using a distributed microgrid network to power critical facilities during widespread outages. Microgrids are seen as an integral part of hardening the distribution system and introducing a statewide microgrid network [108].

Integration: Unlike previous programs, which tended to favor asset owners, the new program includes robust standards for integration with utility systems. Thus, the program emphasizes the design, engineering, and interconnection of projects rather than the customer owned generation and storage functions. As an example, existing municipal steam systems and university campus grids could be interconnected to the wider grid and each other via this funding.

In addition, utilities will be required to maintain and own all non-private distribution grid assets interconnecting with customer-owned microgrids. Each microgrid must have sufficient fuel to operate for two weeks in isolation, and access to fuel for a further two weeks. As a result, this emphasizes clean generation over fossil fuel-operated microgrids, namely fuel-cell storage to support the state's fuel cell manufacturers, including FuelCell Energy, Proton Power, and ClearEdge [2].

Twenty-seven out of 36 proposals received funding, including hospitals, police stations, and other critical customers. Because DEEP wanted to learn as much as possible about an array of microgrid programs, there were no size constraints imposed. Nine proposals have received approval for full-scale deployment, receiving a total of US $18 million funding:

- Bridgeport: US $2.97 million
- Fairfield: US $1.16 million
- Groton Naval Submarine Base: US $3 million
- Hartford: US $2.27 million
- Middletown: US $694,000
- Storrs: US $2.14 million
- Windham: US $639,950 [109]
- Woodbridge: US $3 million [109,110]

Future Refinements: The state has proposed some ideas for future projects, including allowing more time for feasibility studies and design; helping municipalities source financing; and weighting the proposals toward renewables rather than fossil fuel projects. Legislation should be enacted to allow the sale of electricity without compromising utility franchise agreements [111].

In addition to existing requirements, proposals should serve at least two critical facilities, including a mix of public and private facilities; and emphasize clean generation, with no more than a quarter of power from diesel. Renewables must use energy storage and be available for at least 7000 hours per year [112].

Wesleyan University

Location: Wesleyan University, Middletown, Connecticut

Type: Campus Microgrid

Aims: Energy Efficiency, Islanding, Critical Facilities

Power Sources: CHP plant, 200 kW PV, 3 MW reciprocating engines

Funding: DEEP

Technology/Vendors: A/Z

Status: Operational

Background

Wesleyan University was recently selected as a grant recipient for a new microgrid solution on its Middletown campus. This was part of a drive to become energy independent and allow the

Freeman Athletic Center to act as an emergency shelter for up to 48,000 people, and a Federal Emergency Management Agency (FEMA) operations center during emergencies. The microgrid should reduce carbon emissions and will reduce energy costs by up to US $300,000 per year [113].

Technology

The campus already had a CHP plant and a 13 kV underground electric distribution system. Because of the athletic center's function as an emergency shelter, natural gas rather than renewable resources form the backbone of the microgrid, to offer better reliability. The campus has 3076 kW of reciprocating engines, with a further 676 kW to be added. The university operates 200 kW of photovoltaic cells and can operate in islanded mode [110].

University of Connecticut

Location: Storrs, Connecticut

Type: Campus Microgrid

Aims: Energy efficiency, islanding, critical facilities

Power Sources: 400 kW fuel cell and 6.6 kW of solar PV

Funding: DEEP

Technology/Vendors: Schneider Electric, ClearEdge Power, A/Z Corporation, and Connecticut Center for Advanced Technology

Status: Operational

Background

The University of Connecticut (UCONN) received US $2.14 million funding from DEEP to create a microgrid integrating renewable resources and a fuel cell. Apart from improving energy efficiency and helping the university reach its clean energy goals, the grid will support critical facilities on the campus, enhancing its ability to act as a shelter and operations center during emergencies. The microgrid will also help the university become an academic leader in electric system reliability and energy efficiency, through developing industry partnerships that focus on microgrids and smart grids.

UCONN will develop its microgrid in partnership with the U.S. Department of Energy's National Renewable Energy Laboratory, ClearEdge Power (formerly UTC Power), and Schneider Electric [114].

Technology

To its existing generation resources, the campus will add a 400 kW fuel cell and 6.6 kW of solar PV [115]. Overall, the grid will support:

- Intentional and unintentional islanding during normal and abnormal conditions
- Synchronizing during reconnection automatically

- Volt/Var and frequency control during island transitions and normal functions
- Frequency control
- Island transitioning
- Grid protection with and without communications [116,117,118]

Fairfield

Location: Fairfield, Connecticut

Type: Community Microgrid

Aims: Energy efficiency, islanding, critical facilities

Utility Involvement: United Illuminating

Power Sources: Two natural gas generators of 60 kW and 50 kW, 47 kW solar PV

Funding: DEEP

Technology/Vendors: Schneider Electric

Status: Operational

Background

The City of Fairfield was awarded a US $1.16 million to develop a microgrid with two natural-gas-fired engines and 47 kW of solar to power the police station, emergency operations center, fire headquarters, cell tower, and public shelter during extended grid outages. Power is also provided to the wastewater treatment plant and the waste treatment center. Schneider Electric developed the microgrid design and implemented the microgrid.

Technology

The program involved:

- Upgrading the existing 50 kW natural gas generator to 60 kW capacity through computer adjustment
- Replacing the 50 kW diesel generator at the police headquarters with a gas generator installed above the flood plain. This provides approximately 50% of the required power for the building
- Interconnecting the critical facilities
- Installing 20 kW and 27 kW rooftop PV systems
- Installing a control system at the police headquarters to monitor power and emphasize renewable power sources [119]
- Allowing the facilities to operate in island mode

The facilities provide sufficient power is planned to fulfill 120% of peak load, and diesel generation is still be used to improve reliability. During normal operation, the control system for the microgrid will reduce demand and consumption by 250,000 kWh over two years. During islanding, this reduction also means that less diesel storage is required to provide 120% of power needs for the required four weeks [120].

Windham

Location: Windham Connecticut

Type: Community Microgrid

Aims: Energy efficiency, islanding, critical facilities

Power Sources: Natural gas, diesel, solar, and energy storage technologies; 200 kW solar PV and a 200 kWh battery

Funding: DEEP

Technology/Vendors: DERP Technologies

Status: Ongoing

Background

The town of Windham has been awarded a grant of US $639,950 to develop a small scale microgrid that will supply two schools, used for emergency shelter and operations, ensuring that they remain operational in the event of extended outages [109]. The schools already have an existing 18 kW solar system and two oil-fueled Burnham boilers, and offer refuge to between 500 and 1500 residents during outages [104]. DERP Technologies designed and will develop the microgrid.

Technology

The grid will include a mixture of

- Natural gas generator
- Diesel generators
- Energy storage
- 200 kW solar PV
- 200 kWh battery

The DG resources will provide 100% of the annual power required by one of the schools, and the system can operate while islanded for at least four weeks. In addition, there is scope for expanding the grid to include other critical facilities, including the hospital. The grid will lower energy costs for at least 20 years and will reduce the carbon footprint of the community, as well as improve reliability. Finally, excess energy released through demand management could be sold back to CL&P [121,122].

Stamford Energy Improvement District

Location: Stamford, Connecticut

Type: Community Microgrid

Aims: Energy efficiency, islanding, critical facilities, reducing costs

Utility Involvement: CL&P

Power Sources: 400 kW natural gas-powered fuel cell, 600 kW reciprocating natural gas-powered engine, 300 kW diesel engine

Funding: DEEP

Technology/Vendors: Pareto Energy, General Electric, United Technologies, EnerNOC

Status: Ongoing

Background

Because Connecticut is one of the highest energy cost areas in the U.S., the City of Stamford, with a population of over 100,000, is establishing an Energy Improvement District (EID). There are a number of drivers for this, namely the high electricity costs, the lack of renewable resources, and system unreliability, which are all barriers to attracting new businesses.

The advantage of an EID is that off-peak power can be stored and discharged to meet peak demand, and an integrated microgrid will be able to incorporate new technologies such as using waste from biosolids, wood waste and, in the future, gasified solid waste. At the same time, Connecticut Light and Power (CL&P) is improving and rebuilding the grid in the city.

In addition, the city was an early member of the International Council for Local Environmental Initiatives (ICLEI), and a founding member of the Climate Communities organization. In line with this, a recent mayoral initiative has promoted clean energy, fleet efficiency, and similar initiatives.

Energy Improvement District

The city is working with Pareto Energy consultants and the United States Conference of Mayors to set up an Energy Improvement District (EID). The plan, which was finalized in 2008, includes creating microgrids around buildings as part of the wider EID. Overall, the privately-funded initiative will encourage green energy initiatives and power decentralization. This will allow the use of the grid as a backup, and reduce disruptions and overall demand.

The city has set up a demonstration grid around city hall, using fuel cell technology and CHP. The building will to be able to operate when islanded and act as a base for emergency operations, storm management, and homeland security. The overall goal is to show that interconnecting a large microgrid to a utility distribution system will not cause power to feed into the main grid and endanger line workers.

The city is planning to extend the project to nearby housing complexes, across a utility right of way, and attract other property owners with different demand cycles and peaks. Rather than using the grid only for backup functionality, Stamford is looking to develop a true, semi-independent microgrid that incorporates much of the functionality of a smart grid.

Technology

The Government Center includes a single fuel cell powered by natural gas, with a series of reciprocating engines designed to supplement peak demand. The microgrid also incorporates GE backup motors with UTC power cells, and Stamford hopes to incorporate demand response, load balancing, voltage control, dispatching, and metering/billing. Resources include:

- United Technologies natural gas-powered fuel cell (400 kW) with heat recovery and absorption chilling
- GE reciprocating natural gas-powered engine (600 kW), with heat recovery and absorption chilling (CHP)
- A 300 kW diesel engine at the Government Center will remain

The system includes GridLink, a program that using power converters to allow the grid to operate independently or in parallel with the grid, and connect or disconnect without service interruption. The device coverts AC to DC power and DC back to clean AC via a common microgrid bus. This offers high reliability and also provides the excellent power quality required by the city's high tech industries. The microgrid can switch, change, and balance multiple power resources in microseconds. To the utility grid control systems, the power converters appear as a load management device with synchronous interconnection via fast switches [104,123].

The facility will be able to generate 100% of its power demands at all times, with the backup generator supplying power during outages. Because the Government Center already uses EnerNOC, as part of the ISO New England demand response program, it operates an advanced energy management system with the ability to shed load quickly during abnormal grid conditions. This gives the backup generators enough time to start without interrupting service [33].

Business Case

Under a power purchase agreement (PPA) agreement with Pareto, the Government Center's annual costs will be the same, with Pareto recovering costs from avoided energy costs. Pareto expects that payback for the project will take between five and eight years. In addition, indirect savings will be made through reduced outages, and the building will be able to act as an emergency center.

Ansonia

Location: Ansonia, Connecticut

Type: Community Microgrid

Aims: Energy improvement district, islanding, critical facilities, reducing costs

Power Sources: 700 kW biogas, 1.05 kW natural gas generator, 58.4 MW generator

Funding: DEEP

Technology/Vendors: Pareto Energy, Ansonia Copper and Brass

Status: Ongoing

Background

Ansonia is another community that has established an Energy Improvement District (EID) to mitigate the problems caused by the state's energy shortfall and irregular supply. Like Stamford, Ansonia is partnering with Pareto Energy, which is presently negotiating with private investors [124,125].

The Ansonia project would place a wastewater treatment plant, a Water Pollution Control Authority facility, a transfer station, a Department of Public Works facility, and a grocery store on a microgrid powered by a 700 kW anaerobic digester and a 1.05 MW natural gas generator [126]. A local company, Ansonia Copper and Brass, is participating in the program by installing a 58.4 MW generator at its factory.

Milford Connecticut Microgrid

Location: Milford, Connecticut

Type: Community Microgrid

Aims: Power critical loads during outages, reduce energy costs

Utility Involvement: United Illuminating Company

Power Sources: Two 148 kW natural gas CHP units, a 120 kW solar array, and a 100 kW battery energy storage system (BESS)

Funding: Connecticut Department of Energy and Environmental Protection

Technology/Vendors: Schneider Electric, Green Energy Corp. and ZHP Systems

Status: Implementation in progress

Background

Milford, Connecticut is a coastal community that has been challenged by major storms in the northeast. With 14 miles (23 km) of coastline along Long Island Sound, Milford accounted for more than one half of the homes damaged in New Haven County during Superstorm Sandy. With this history Milford is pushing hard to develop a hardened infrastructure. As part of this effort Milford recently received a grant that will provide US $2. million for eligible initial costs.

This microgrid is planned to power the Parsons Center, Harborside School, a senior center/housing, and the civic center.

Technology

Other than as described above, there were no details on the technology that will be used in this project.

Massachusetts

In Massachusetts, the commonwealth has made US $40 million available for a municipal resilience grant program funded by the Department of Energy Resources (DOER), as part of a US $50 million package aimed at improving overall climate resiliency. Funding for this is drawn from Renewable Portfolio Standard Alternative Compliance Payments, which consists of penalty payments from retail electricity providers who fail to meet the State's renewable and alternative energy quotas [112,127].

With the grant, Massachusetts will fund clean energy and storage solutions, including fuel cells, CHP, solar power, wind power, and air thermal energy storage, alongside load shedding and critical load isolation for demand side management. It will also cover microgrids and "nanogrids", which build extra resiliency into structures [108]. To support this, the DPU-12-76 – MA Grid Modernization Act, July 2013, actively calls for investment in microgrids [103].

Examples of projects eligible for funding include adding storage to existing solar arrays or enhancing existing CHP systems to cope with islanding, as well as enhancing inbuilt black start functionality. This would eventually allow microgrids to enhance macrogrid peak demand response and contribute to grid stability, by integrating them into the wider smart metering/smart grid program presently under development.

With the funding and initiatives, co-generation and backup systems are being supplemented by renewable generation, energy storage, and demand-side management hybrids, which will contribute during normal operations when a microgrid is not islanded or isolated from the grid [128]. As part of the initiative, utilities must prepare 10-year-plans showing how they will modernize their systems to decrease power outages, integrate distributed resources, reduce peak demand, and enhance workforce and asset management [47,129].

Renewable Energy: By 2020, 15% of power must be sourced from renewables, with a subsequent 1% increase per year. IOUs and retail suppliers, which provide 86% of the load in the state, must produce 400 MW of this requirement from solar resources, with at least 50 MW of solar systems installed on landfill and brown fields. Overall, by 2020, the state hopes to produce 2 GW of wind power and 1.6 GW of solar power.

Net Metering: At present, IOUs have a 10 MW system capacity limit for government systems and 2 MW for other systems, with an aggregate capacity of 6% of the utility load. For IOUs, there is no specified system capacity limit for interconnections, and the external disconnect switch and insurance requirements vary according to system type and size.

Rebates and Grants: Massachusetts Clean Energy Center (MassCEC) provides various programs for residents, nonprofits, businesses, and government agencies to develop renewable programs, including microgrids. The Commonwealth Solar Hot Water Financing Program offers incentives for solar thermal installation, with a US $10 million fund through 2016.

Solarize Mass. provides a pricing structure that is tiered to increases savings for communities installing small-scale solar electricity systems. The Public Benefit Fund, funded by a surcharge on bills, provides grants and loans to support renewable energy. Finally, the state gives income tax credits for residential systems and sales tax exemptions for residential installations [101].

Vermont

Because the state believes that every dollar spent on protection saves four dollars after a storm, it initiated the Vermont Project for Resilient Microgrids, recognizing that almost one half of the backup generators across the state failed to start during Superstorm Sandy [130]. At present, Vermont generates 30% of its power from renewable resources, and has recently initiated state-wide "feed-in tariff" legislation to encourage renewable energy to make up 20% of all retail sales of electricity. The program actively encourages communities to develop microgrids and promote energy independence [131].

In 2014, the state expanded its net metering program, quadrupling the cap, and is offering incentives for small scale solar developments, such as a 150 kW community solar project covering 50 homes. Vermont has stringent renewable requirements, stipulating that 55% of annual sales during 2017 must be from renewable energy, a level that will increase to 75% by 2032. By 2050, 90% of all heating, electric, and transportation power should be derived from renewable resources.

Net Metering: The present limits are 2.2 MW for military facilities, 20 kW for CHP, and 500 kW for other systems, with an aggregate capacity limit of 15% of a utility's peak demand, whichever is greater. Net excess capacity is credited to the next customer bill at retail rate. For all utilities, an external disconnection switch is required, with special standards in place for systems under 150 kW.

The state operates a Small-Scale Renewable Energy Incentive Program, giving rebates to eligible solar electric, solar hot water, and micro-hydro systems. The Renewable Energy Systems Sales Tax Exemption is applicable to CHP systems (up to 20 kW), renewable energy systems (up to 250 kW), and solar water heating systems. Finally, solar equipment with a capacity of up to 10 kW is exempt from property tax, with larger installations paying US $4 per kW. Finally, commercial energy installations receive a rebate equivalent to 24% of the "Vermont-property portion" of federal business energy tax credit [101].

Rutland

Location: Rutland, Vermont

Type: Community Microgrid

Aims: Microgrid testing

Utility Involvement: Green Mountain Power, NRG

Power Sources: Solar PV

Technology/Vendors: NRG, Dynapower

Status: Ongoing

Background

In Vermont, the state's largest power company, Green Mountain Power (GMP), has partnered with NRG Energy to develop distributed energy solutions. The partnership hopes to develop new solutions rather than continuing to make huge investments in aging infrastructure. As part of the initiative, the utilities will develop a microgrid in Rutland, to test new technology and interconnection equipment.

Technology

The microgrid will include solar PV arrays, including NRG's 2 MW community solar array and a number of micro-generation solutions, including NRG's Beacon 10 technology. These units produce up to 10 kW of electricity, provide heat for water and central heating, and offer solar integration and battery storage. The microgrid will also include 4 MW/3.4 MW of energy storage, allowing peak shaving during periods of high load, and ensure that the grid can operate in islanded mode and send power to critical facilities. Grid integration will be overseen by Dynapower [130].

Maryland

Maryland has created a task force to study the implementation of microgrids across the state, which will assess statutory, financial, regulatory, and technical barriers to microgrids and will look for suitable sites where demand is high. This initiative followed a report produced in Sep. 2012, which recognized that microgrids should be a major element of a sustainable, resilient energy grid [108].

Renewable Energy, Net Metering, and Interconnection: The state has a renewable portfolio standard of 20% by 2022, and wants to increase solar output to 1.2 GW over the next six years. Present net metering limits are 2 MW system capacity, or 30 kW for micro CHP, with an aggregate limit of 1.5 GW. Excess energy is credited to the next bill at retail rate. For all utilities, the interconnection limit is 10 MW, with an external disconnection switch required and insurance requirements varying according to size and type of installation.

Tax Incentives: The state offers a property tax exemption for solar and wind property, with solar and geothermal energy and cooling systems assessed for property tax at no more than the value of an equivalent conventional system. Sales and use tax exemptions are available for the purchase of geothermal, wind, and solar systems, and for the sale of electricity produced by eligible systems.

Grants and Funding: Under the Clean Energy Grant Program, commercial projects will be supported with US $30-$60 per kW for PV systems not exceeding 200 kW, and US $10-$20 per square foot (0.3 m^2) for solar water heating. Businesses, non-profit customers, and residential customers installing wind energy systems of up to 750 kW will be given a grant of up to US $3000 per kW, to a maximum of US $100,000 for individuals and 50% of the cost for community grants [101].

Microgrids

After a series of discussions that resulted in the publication of the *Resiliency through Microgrids Task Force Report*, Maryland developed a future pathway for integrating microgrids into the distribution system. The discussions included representatives from nearby states, project developers, utilities, non-profit organizations, and ratepayer representatives. Maryland proposed a number of technological and regulatory solutions and set up a task force.

The task force proposed that Maryland should pursue public purpose microgrids, over the short term, to provide uninterrupted service to critical assets when the wider grid is compromised. This would also allow local governments and private initiatives to develop their own programs while protecting consumers. Finally, the group recommended a Grid Transformation Program to facilitate the recommendations and initiate grant programs for microgrid projects, advanced controls, and energy storage solutions [132].

The group argued that microgrids offer benefits when the macrogrid is down and facilitate the integration of DG and energy storage during normal operations, so proposed that the state should adjust existing protocols and regulations to allow for the successful integration of microgrids and DGs. The state also recommended that utilities should incorporate microgrids into existing grid upgrades and planning, and liaise with local governments and local planners to establish how microgrids will be leveraged during emergency situations.

The task force recommended that the PSC and Maryland energy Commission should focus on:

- Reviewing interconnection procedures to ensure safe interconnection with the macrogrid, enabling islanding and smart control technologies
- Ensuring that utilities provide project developers with information about the prime locations for microgrid development [133]

The state is in the process of initiating a Microgrid Research, Development, and System Design grant, and the Maryland Energy Administration's Game Changer Awards have supported a number of projects, including a PV microgrid [112].

Konterra Headquarters

Location: Laurel, Maryland

Type: Commercial Microgrid

Aims: Reducing costs, energy efficiency, islanding

Power Sources: 402 kW solar array, 500 kW PowerFactor Advanced Storage System, 300 kW AllCell lithium-ion battery

Funding: Konterra, PNC Bank, Solar Grid Storage (private funding), Maryland Energy Administration (MEA) Grant

Technology/Vendors: Standard Solar, Solar Grid Storage, AllCell, Solaire

Status: Operational

Background

In July 2014, Standard Solar, a company specializing in solar electric system development, financing, and installation, and Solar Grid Storage, installed one of the largest U.S. microgrids at the corporate headquarters of Konterra, a property developer.

Technology

The microgrid is an interactive energy storage system integrated with a 1,386 panel Solaire solar PV array. The 402 kW system will provide 20% of the building's annual power demand, and includes two electric vehicle charging stations, with the possibility of adding another four. The grid can provide backup power, via two Solar Grid Storage PowerFactor 250 advanced energy storage units, providing 500 kW capacity, and a 300 kW AllCell lithium-ion battery.

The microgrid supports peak shaving and demand reduction, and will enhance grid reliability through frequency regulation, demand response, and VAR compensation services. As well as reducing the use of non-renewable resources and lowering costs, the microgrid will be capable of islanding and will add stability to power supplies [134,135].

Olney Town Center Microgrid Project

Location: Olney, Maryland

Type: Community Microgrid

Aims: Reduce outage times, reduce emissions, and improve efficiency

Utility Involvement: Pepco Holdings Inc.

Funding: DOE NETL, US $1.2 million in funding assistance for design and study only

Technology/Vendors: Burr Energy is the prime contractor; Schneider Electric provides power engineering, and modeling; Green Energy provides the microgrid management system as well as leads R&D, planning, design, and analysis; North Carolina State University provides microgrid management systems tests.

Status: Proposed and unfunded (partially funded)

Background

This project will design a microgrid control system capable of integrating distributed renewable energy resources, natural gas CHP units, energy storage, and demand-side management technologies in near-real-time optimization schemes.

Olney Town Center provides primary services to a community of 33,000 residents. The town center has a 7 MW load, and contains a hospital, police station, two fire stations, two schools, grocery stores and gas stations, the community's water tower, and many commercial businesses

Olney Town Center expects long-term: significant growth in photovoltaic arrays and electric vehicle charging, and steady growth in residential communities around the Olney Town Center

The goals of this project are:

- Obtain average reliability (SAIDI) of under two minutes for critical loads
- Reduce Olney Town Center CO_2 footprint by 20% from current baseline
- Improve Olney Town Center average system energy efficiency by more than 20%

Technology

The only element of the technology that is currently defined is the Green Energy Corp. GreenBus® Microgrid controls platform.

Montgomery County Microgrids

Location: Montgomery County, Maryland

Type: Community Microgrid

Aims: Maintain operations of critical facilities in the event of an extended failure of the electric grid

Power Sources: The only mention in the request for proposal (RFP) was a system of controls, generators (e.g., gas turbines, fuel cells), storage devices (e.g., batteries), and other technologies.

Funding: The county prefers to finance the system and necessary support infrastructure through a long term energy purchase agreement where the county would purchase the generated electricity and other energy resources, with the vendor using associated incentives to finance the system.

Status: Proposed and unfunded

Background

Montgomery County would like to improve the energy infrastructure reliability and continue operations of critical facilities in the event of an extended electric outage. This includes facilities which are used as emergency shelters, cooling stations, and provide direct and ongoing social services [136].

The county asked for proposals to install, own, operate, and finance microgrids for Montgomery County.

The county identified three critical projects and issued a request for proposals in April 2014. Fourteen responses were received and the county selected six vendors to submit a final proposal, final cost and price proposals should be received April, 23, 2015. The successful vendor will be awarded in selected in May with contract negotiations occurring over the summer. The county expects construction to require 12-18 months after the conclusion of negotiations.

Technology

No technologies identified at this time.

District of Columbia

At present, the District of Columbia (DC) imports most of its renewable power from neighboring states, and allows utilities to use credits to offset requirements. The district is in the process of encouraging wider support for distributed generation, including a solar rebate encouraging residential and commercial customers to make use of the extensive roof space available in the capital. As an example, the DC Department of General Services recently installed 10 MW of solar PV in 49 city buildings in March 2014, with power sold to local utilities via power purchase agreements.

Renewable Portfolio Standard: By 2020, all utilities should source 20% of the power form renewable resources, with a 2.5% solar requirement by 2023. Qualifying facilities must produce less than 5 MW and must be located in DC or on a distribution feeder serving DC. Solar thermal energy is included in this figure.

Net Metering: At present, the system capacity for IOUs is 1 MW, with excess generation credited to the customer's next bill. Interconnection standards are 10 MW system capacity for connection to an IOU grid. An external disconnection switch and insurance are required for some systems.

Tax Incentives and Rebates: Under the Renewable Energy Incentive Program (REIP), the state will reimburse 20% of the cost of non-residential solar systems, to a maximum of US $6000. In addition, the program offers 20% of the cost for non-residential solar thermal systems, to a maximum of US $5000 for water heating and combination systems and US $2000 for space heating systems. For non-residential PV systems, the grant will give US $0.50 per watt, with maximum level of US $10,000; for residential PV systems, the rebate will give US $3.00 per watt, to a maximum of US $10,000.

In terms of tax incentives, solar and cogeneration systems are exempt from property tax. Through the Public Benefit Fund, DC collects approximately US $20 million per year to support energy efficiency and renewable energy programs [101].

New Jersey

In New Jersey, 146 government agencies have been allocated a total of US $25 million to develop microgrids and improve system residency in the distribution grid, through the Energy Resilience Bank. These funds will be used to develop DG and energy storage solutions, including fuels cells and CHP, and promote the use of diesel, solar, or natural gas powered generators to backup normal electricity supplies.

After the extensive damage caused by Superstorm Sandy, this funding will emphasize protecting critical facilities. It is part of an ongoing partnership between New Jersey, the Department of Energy's National Renewable Energy Laboratory, and the Federal Emergency Management Agency [137].

In 2013, New Jersey achieved 1.23 GW of solar capacity, and the 236 MW installed accounted for all of the new generating capacity installed that year.

Renewable Portfolio Standards: By 2020-2021, Class I and II resources must account for 20.38% of a utility's power generation, with solar generation reaching 4.1% by 2027-2028.

Net Metering: New Jersey does not specify any net metering limits, with interconnection standards dependent upon individual IOUs. External disconnect switches are not required, with liability insurance not needed for installations meeting certain technical requirements.

Grants and Incentives: For single family homes, US $1200 will be given for new solar water heating systems, alongside US $500 for geothermal heat pumps installed in residences.

Technology companies producing Class I products or other emerging technologies can apply for a loan at 2% interest of up to US $2 million for five years, as long as they meet employment requirements. Finally, all solar equipment is exempt from state sales taxes [101].

At present, the state is discussing regulatory requirements for renewable energy resources with utilities seeking rate recovery [138].

New Jersey Energy Storage Program

With this program, New Jersey hopes to promote energy storage facilities, which must be powered by clean energy rather than grid power or traditional diesel generators. This program, part of a US $10 million state incentive, is intended to create a sustainable energy storage market. NJ has also proposed a US $210 million Resilience Bank that will support resilient power projects [130].

NJ Transitgrid

Location: New Jersey

Type: Commercial Microgrid

Aims: Outage mitigation

Funding: DOE, NJ TRANSIT, BPU

Technology/Vendors: Sandia National Laboratories

Status: Proposed

Background

After the ravages of recent hurricanes, which severely damaged New Jersey's transit system, the state and the DOE are developing a microgrid that will integrate distribution and generation assets into the transport system. This project, NJ Transitgrid, will use an arrangement developed by Sandia National Laboratories, which has developed 25 microgrids for military installations. The microgrid would power the transportation system between Newark, Hoboken, and Jersey City, along with maintenance facilities and critical stations [137].

At present, NJ TRANSIT and Sandia have a number of goals that they intend to fulfill with the microgrid:

- Develop self-generation power facilities
- Build a new, dedicated power grid
- Distribute self-generated power to the overhead wire network
- Distribute of self-generated power to key NJ TRANSIT facilities [139]

Technology

Sandia's Energy Surety Microgrid (ESM) methodology is a quantitative risk assessment tool built around real data derived from microgrid performance on military bases. ESM integrates existing resources, including PV arrays, wind turbines, storage and backup generators, and allows the development of grid tied and islanded microgrids. The project will use existing rights of way for train lines between transit stations [140].

The first phase will look at the critical power needs of the transit system, before integrating over 50 MW generating capacity into the system, mainly through solar arrays [141,142].

Princeton University

Location: Princeton, New Jersey

Type: Campus Microgrid

Aims: Reducing costs, energy efficiency

Utility Involvement: PSG&E

Power Sources: 15 MW co-generating natural gas CHP, 5 MW backup diesel generator, 5.4 MW solar PV array, 40,000 ton-hours thermal energy storage

Technology/Vendors: General Electric, Sofame

Status: Operational

Background

Because of the high price of power generation in Massachusetts, Princeton has developed its own microgrid system for its research facilities, dining facilities, and housing. Overall, the microgrid serves approximately 12,000 people across 150 buildings.

With the microgrid, the institution plans to reduce costs, cut emissions, and lower its huge demand for heating and cooling. Although island operation is a driver for the grid, Princeton works closely with Public Service Gas and Electric (PSG&E) and uses the main grid as a backup if its own equipment fails. The university can also purchase power if prices are low and sell peak generation back to the PJM ancillary markets [143].

Technology

The distributed generation assets on the microgrid include [144]:

- 15 MW GE LM1600 natural gas CHP with Sofame heat recovery stack
- 5 MW backup diesel generator
- 5.4 MW solar PV array
- 40,000 ton-hours thermal energy storage, with heat recovery boilers and auxiliary boilers, steam-driven power, and electric chillers

In future, the microgrid will be able to operate via PV arrays and a battery system during islanded operation [103]. The microgrid continued to provide power in October 2012 when Superstorm Sandy devastated the eastern U.S. Before the storm made landfall, the microgrid disconnected from the local utility grid, which protected it from damage.

Hoboken

Location: Hoboken, New Jersey

Type: Community Microgrid

Aims: Resiliency, islanding

Utility Involvement: PSE&G

Power Sources: Solar, wind, fuel cells

Technology/Vendors: Sandia National Laboratories

Status: Proposed

Background

The community of Hoboken is developing a microgrid that will provide the city with a power supply in case of widespread power outages or during peak periods. The planned microgrid, a partnership between the state, Sandia National Laboratories, and PSE&G, will include diverse DG resources and combine clean burning fossil fuel generation with solar PV, wind turbines, and hydrogen fuel cells. The grid, estimated to cost between US $30 million to over US $50 million, will be able to operate in parallel with the utility grid or when islanded [138].

Pennsylvania

As a major exporter of coal and natural gas, Pennsylvania has always relied upon fossil fuel electricity generation. Recently, the state has incentivized renewable resources and established an 18% alternative energy portfolio standard, with renewable energy accounting for one half of this figure.

At least 8% of the standard will be derived from Tier I sources, namely coal-mine methane, fuel cells, and any new or existing systems not counted in Tier II. Five percent of this allowance must be generated from solar PV. Ten percent will come from Tier II resources, which include DG and demand side management. This stipulation applies to IOUs and retail suppliers, which produce 97.3% of the state's load.

Net Metering: For IOUs, the system capacity limits is 5 MW for microgrids and emergency systems, 3 MW for non-residential systems, and 50 kW for residential systems. Net excess generation will be credited to the customer's next bill. In February 2014, the PUC issued proposals to limit the types of system that could benefit from net metering. For all interconnections, net metering and external disconnect switches are mandatory.

Tax Incentives and Grants: Commercial wind farms, turbines, and related equipment are not counted when setting property values. A keystone help loan provides low rate loans for many home energy improvements, including geothermal and solar energy installations, to a maximum of US $35,000. The High Performance Building Program will give loans to small businesses of up to US $2 million, and US $100,000 for individual residences. Grants may be given for high performance buildings of up to US $500,000 or 10% of the cost, whichever is lower [101].

Penn State GridSTAR Net Zero Energy Demonstration Project

Location: Philadelphia, Pennsylvania

Type: Campus Microgrid

Aims: Demonstrate electrical systems technologies, education, training, and provide an infrastructure for research

Utility Involvement: PJM, PECO, DTE, and Viridity are listed as partners

Power Sources: Photovoltaic panels for electricity generation, photo-thermal absorption system for hot water heating, solar-canopied electric vehicle charging station with integrated community energy storage, grid-scale battery system

Funding: US $5 million contractual award by DOE to Penn State, US $5 million in matching funds

Technology/Vendors: ELECTRI International, CertainTeed Corporation, Eaton, Lutron, Solar-Grid Storage, Unirac, Isofoton, Dynapower, Sequentric, U-Go, Pacific Data and Electric, Scitor

Status: Implementation in progress

Background

The DOE GridSTAR Center is a microgrid education and research facility that is managed by the Penn State University Architecture Department.

The Center will offer several for-credit and non-credit courses at various colleges and other educational facilities.

Much of the research will occur at an existing microgrid at the Navy Yard in Philadelphia. Part of this microgrid will be a subgrid being designed for the testing of smart grid components and system configurations. After components are shown to be robust and have an acceptable value proposition, they should be installed through the balance of The Navy Yard.

Technology

Since this is an educational facility, there are few details on the technology. The one exception is the GridSTAR Net Zero Energy Demonstration Structure. This uses leading edge construction, energy generation, and management / coordination within the host microgrid. Included in this structure are:

- Photovoltaic roofing
- Designed for island-mode operation with LED lighting
- Efficient inverter and battery

Philadelphia Industrial Development Corporation is The Navy Yard developer. The Navy Yard's Smart Energy Campus was created by various organizations that wish to make The Navy Yard an energy research, commercialization, and education canter.

7
SOUTH EAST REGION

North Carolina

In North Carolina, recent developments in renewable power have mainly focused on the solar energy, with some biogas and waste energy installations. As of October 2013, the state had 800 MW of solar capability already installed or under construction.

Renewable Portfolio Standards: By 2021, IOUs must source 12.5% of their power from renewable resources, and cooperatives and municipalities must produce 10%. By 2018, 0.2% of power must derive from solar resources. Energy efficiency technology and reduced electricity demand may be used to provide up to 25% of the IOU target and 100% of coop/municipal targets. For IOUs, no net system capacity limit is set for interconnections.

Tax Incentives: North Carolina offers personal or corporate energy tax credits of up to "35% of the cost of purchasing, leasing, or constructing renewable facilities." Eligible renewable property may claim a maximum of US $2.5 million for a business installation or US $1400-$10,500 for a residential installation, depending upon the technology used [94].

McAlpine Microgrid Project

Location: Charlotte, North Carolina

Type: Commercial Microgrid

Aims: Outage mitigation

Utility Involvement: Duke Energy

Power Sources: Battery storage, solar PV

Status: Operational

Background

As part of a project to assess the feasibility of virtual power plants, which will aggregate resources across a service territory, Duke Energy has created the MacAlpine microgrid, which will assess the ability of the system to operate in island mode when isolated from the main grid.

Technology

The project includes:

- Solar DG
- Smart grid
- Battery storage at substation scale
- Technology behind the meter
- An optimization engine [145]

Dominion, Kitty Hawk

Location: Kitty Hawk, North Carolina

Type: Commercial Microgrid

Aims: Energy efficiency, microgrid research

Utility Involvement: Dominion

Power Sources: Four wind turbines producing 13 kV; 6 kW solar panels, 75 kW storage battery

Status: Operational

Background

To act as a demonstration project and reduce electricity costs, Dominion Power has created a microgrid research project that incorporates renewable distributed generation.

Technology

The project incorporates four wind turbines capable of generating 13 kV, and solar panels mounted on the ground that can generate an additional 6 kW. The microgrid also includes a 75 kWh storage battery with protective equipment and battery management [146].

8
OTHER MICROGRIDS

Canada

One of the major drivers of microgrid research in Canada is the number of remote communities. The country has initiated a number of programs designed to assess how microgrids could bring reliable, cost effective power to these communities, which generally rely on expensive diesel imports[10]. As part of a long term energy plan, Ontario has called for the federal government to assist with remote microgrids [108].

In June 2013, Canada hosted a Renewables in Remote Microgrids conference to discuss how microgrid technology and regulations can help remote communities utilize off-grid generating resources. The conference discussed the technical, social, economic, and financial implications for communities, military installations, and mines, and showcased projects incorporating smart microgrid technology, wind, and solar distributed generation resources.

The Natural Sciences and Engineering Research Council of Canada (NSERC) Smart Microgrid Network, established in 2010, is a five-year collaboration between academic institutions, industry, and the Canadian government. The program is running programs designed to assess microgrid operation and control, protection, planning, legislation, and communications technologies[11]. Some of the projects include grid control and energy management systems, and frameworks for monetizing the costs and benefits of microgrids. In addition, sensor nodes for communicating environmental data in real time have been developed [147].

British Columbia

British Columbia Institute of Technology

Location: British Columbia Institute of Technology, Burnaby Campus, British Columbia

Type: Campus Microgrid

Aims: Microgrid testing

Utility Involvement: BC Hydro

Power Sources: Solar, thermal generating

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[10] Canada has many remote communities served by microgrids. A paper discussing these can be found at: Government of Canada. *Status of Remote/Off-Grid Communities in Canada*. Aug. 2011. Available at: http://www.bullfrogpower.com/remotemicrogrids/presentations/status_of_remote_off_grid_communities_in_canada_2013-118_en.pdf

[11] More information available at: http://www.smart-microgrid.ca/

Funding: BC Hydro, British Columbia Innovative Clean Energy (ICE) fund, and the Canadian government's Western Diversification Fund

Technology/Vendors: BCIT's Internet Engineering Lab. Non-vendor specific smart meters, RF and BPL, data aggregation units, smart appliances, data aggregation software

Status: Operational

Background

With the support of the British Columbia government's Innovative Clean Energy fund and the Canadian government's Western Diversification Fund, BC Hydro and BCIT have developed a microgrid on the Barnaby campus. The project will collaborate with the international GridWise initiative and provide education opportunities for BCIT students.

Technology

The BCIT microgrid is designed to test a number of communication technologies, including wired and wireless RF, and broadband over power line (BPL). As part of testing how smart technologies can integrate with microgrids, the test bed will also assess smart metering for one- and three-phase power [148].

The grid incorporates diverse distribution generation resources, including a thermal turbine, photovoltaic arrays, and wind power [149]. Finally, to further test the integration of smart resources, the grid will show how smart appliances can be integrated into microgrids as part of BC Hydro's drive to develop a flexible, intelligent Grid.

Smart meters and other control components, alongside communication modules linked to data aggregation units in substations, allow the utility to monitor consumption and demand, energy use profiles, and distributed generation yields.

Other technologies installed include smart metering, load control devices, a communications network incorporating ZigBee, WiMax and fiber backhaul, and protection devices allowing islanded operation. The custom EMS system will allow annual savings of 10% [149].

The complex networking of these components will rely upon BCIT's Internet Engineering Lab, which can test the resiliency and operation of different network layouts, and assess different topographies, system architectures, and protocols. The utility and BCIT are ensuring that they develop solutions that are open source, and non-utility and non-vendor specific [150].

Business Case

The university will be able to save money through use of renewables and demand reduction/peak shaving, and local stakeholders will be able to advertise their expertise to a global audience. The grid and any commercial expansion, alongside the sale of technology and expertise, will benefit the economy of the local area. For the next ten years, in the U.S. alone, microgrids may develop into a US $60 billion market, with BC Hydro keen to capitalize on this. The global market is potentially four times larger.

For BC Hydro, the combination of microgrid technology with smart technology will help to reduce operational costs in the longer term and also improve reliability. Finally, for both BCIT and BC Hydro, reduced emissions will prepare the organizations for potential future emissions legislation and avoid high, future costs [149,150].

Hartley Bay

Location: Hartley Bay, British Columbia

Type: Remote Microgrid

Aims: Reducing costs, energy efficiency

Utility Involvement:

Power Sources: Two 420 kW diesel generators, 210 kW diesel generator, 900 kW hydro (planned)

Technology/Vendors: Pulse Energy

Status: Operational

Background

Hartley Bay is a remote community only accessible by air or water, so the 170-strong community uses a remote microgrid for its power needs. The community is looking to add the latest microgrid technology to improve efficiency and reliability.

Technology

To provide power for 62 residential and 20 commercial buildings, the community has two 420 KW generators and one 210 KW generator. Annual energy consumption is approximately 2 GWh [151].

In 2008 and 2009, the community installed smart meters to monitor usage, and precision flow meters on the generators to assess efficiency. The 210 KW generator proved to be very inefficient, so has been retrofitted with a demand response system to ensure that it is used as little as possible. DR has been installed in 12 commercial buildings, using 20 variable thermostats and twelve load controllers, and this has reduced maximum demand by 15% [152].

The remote microgrid uses an energy management system developed by Pulse Energy. The DR components include 30A load controllers, a building automation system, smart meters, a paging system, antenna, GPS, and transmitter. In the future, the community plans to add a hydro plant with a capacity of 900 kW [153].

Bella Coola

Location: Bella Coola, British Columbia

Type: Remote Microgrid

Aims: Energy efficiency

Utility Involvement: BC Hydro

Power Sources: Ballard fuel cell, run-of-river hydro

Funding: Bella Coola Province, Sustainable Development Technology Canada (SDTC)

Technology/Vendors: Powertech, GE, Ballard

Status: Operational

Background

Powertech Labs, which is part of BC Hydro, has been developing a fuel cell project based on converting electricity from a run-of-river hydro plant into hydrogen. Ballard fuel cells then convert the hydrogen back into electricity.

This Hydrogen Assisted Renewable Power (HARP) project is a partnership between Powertech, BC Hydro, and GE, with support from the province of Bella Coola and Sustainable Development Technology Canada (SDTC).

Overall, the project is intended to provide power to a remote community, helping them to rely less upon diesel generation. By using GE's microgrid controller, the energy storage will be able to address fluctuations in supply and demand, and efficiently manage energy [154].

This pilot project is also being used to look at utility-scale energy storage solutions, with Hydrogenics and Enbridge collaborating on the Power-to-Gas program. Here, hydrogen would be produced when renewable generation is higher than needed and would be added to the natural gas pipeline, bridging the divide between electricity and natural gas [154].

Field/Yoho National Park

Location: Field, Yoho National Park, British Columbia

Type: Remote Microgrid

Aims: Outage mitigation

Utility Involvement: BC Hydro

Power Sources: 1 MW NaS battery

Funding: National Resources Canada

Technology/Vendors: NGK, S&C, IntelliRupter

Status: Operational

Background

As a remote community, often suffering power outages, the 300-strong community of Field was a prime location for installing and testing new microgrid technology.

Technology

BC Hydro partnered with S&C to install a 1 MW sodium-sulfur battery bank, which includes NGK batteries, S&C's PureWave storage management system, and IntelliRupter automated switches for the distribution grid.

The project received $6.5 million from the Natural Resources Canada's Clean Energy Fund, covering one half of the budget. Since July 2013, the system has operated during six major disruptions, where it automatically disconnected from the grid [155].

Ontario

Ontario aims to reduce coal use to zero by the end of 2014, with much of the generating capacity taken up by renewable resources and reduced demand due to economic circumstances and energy efficiency programs. The territory's Long-Term Energy Plan (LTEP) advocates "cost-effectiveness, reliability, clean energy, community engagement and an emphasis on conservation and demand management before building new generating capacity."

In Ontario, by 2025, 10% of the peak demand will use demand response (DR). This is equivalent to 2400 MW. By 2025, the state will incorporate 20,000 MW of renewable resources, and by 2021, solar, wind, and bioenergy will contribute 10,700 MW. Targets for renewable energy will be subject to annual reviews as part of the Ontario Energy Report.

In addition, Ontario will assess the possibility of allowing its microFIT program to evolve from a generation purchasing agreement to a net metering program, with energy storage becoming part of the procurement process [156].

PowerStream Utility Distribution Microgrid

Location: Vaughan, Ontario

Type: Commercial

Aims: Demonstration grid

Utility Involvement: PowerStream

Power Sources: 17 kW solar PV, 1.8 kW wind, 35 kW natural gas generation, 23 kWh lead-acid battery, 5 kWh lithium-ion battery, 12 kWh sodium nickel chloride battery, 5 kW solar carport, and a 14.4 kW EV charger

Technology/Vendors: GE Digital Energy, Navigant Consulting, Enbridge Gas Distribution, Enviro-Energy Technologies, renewz sustainable solutions, Rosewater Energy Group, SMA Canada, SunPower, Southwest Windpower, Eaton, Caterpillar, Surette, China Aviation, Silfab Ontario, Renewz

Background

PowerStream Inc. of Ontario has developed a small demonstration microgrid of 15 kW capacity at its head office, in Vaughan. The microgrid is part of PowerStream's wider smart grid project, built upon the idea that microgrids could play an important role during asset renewal for larger scale energy electricity delivery systems.

To develop the grid, PowerStream sought input from a variety of consultants and vendors, including GE Digital Energy, Navigant Consulting, Enbridge Gas Distribution, Enviro-Energy Technologies, renewz sustainable solutions, Rosewater Energy Group, and SMA Canada. The grid is being phased in over a two year period [2].

Technology

Phase I: For Phase I, the company will use a solar PV array, a wind turbine, a natural gas generator, a lead-acid battery, a lithium-ion battery and a sodium nickel chloride battery. Together, these sources will provide electricity for loads including lighting, air-conditioning, and refrigeration at the company's head office. Power from these sources will also be used to power electric vehicle charging.

Phase II: For phase 2, CHP, fuel cells, and vehicle to home technologies will be added to the microgrid resources.

The resources used include:

- 17 kW of SunPower solar PV modules and 1.8 kW of wind utilizing a single Southwest WindPower turbine. Both systems will be integrated into the microgrid by Enviro-Energy Technologies
- 35 kW of natural gas-fired generation from a Caterpillar engine, integrated into the microgrid via an Eaton manufactured automatic transfer switch
- 23 kWh lead-acid battery manufactured by Surrette
- 5 kWh lithium-ion battery manufactured by China Aviation
- 12 kWh Durathon sodium nickel chloride battery manufactured by GE
- 5 kW solar carport developed by renewz with Silfab Ontario solar PV panels
- 14.4 kW EV charger manufactured by Eaton and integrated by renewz

Control for the microgrid will be provided by GE Digital Energy's D400 microgrid controller. This is built around a supervisory control architecture that monitors loads, generation, and energy storage when the microgrid is connected to the wider grid and when in island mode.

The SMA inverter/battery set and integrated smart panel ensure that the microgrid is synchronized to the wider PowerStream grid. The GE D400 system sends signals to these devices, instructing them to connect or disconnect and determining how the integrated system will handle a range of different operating systems and synchronize.

Together, the control technologies will address and phase, voltage, frequency, or phase angle issues that may arise from a diverse array of resources that provide a significant share of overall system capacity [157].

Quebec

Glencore Raglan Mine

Location: Glencore Raglan Mine, Nunavik, Quebec

Type: Remote/commercial microgrid

Aims: Pilot study

Power Sources: 3 MW wind turbine (potential upgrade to 9-12 MW), three energy storage devices, flywheel, battery storage, hydrogen storage loop

Technology/Vendors: Enercon

Status: Ongoing

Background

In 2009, Raglan assessed its mining operations at the remote facility on the Ungave Peninsula, Nunavik, which is too remote to receive natural gas or connect to the hydroelectric grid. The company wanted to reduce costs by integrating renewable resources and, because the mine is located at an area of high, consistent winds, wind turbines were proposed as the best solution.

Technology

The Glencore Raglan mine already operated an isolated microgrid that traditionally relied upon diesel generation. After five years of study, the company decided to replace 5% of its diesel consumption with a 3 MW wind turbine and three energy storage devices, a flywheel, a battery energy storage system, and a hydrogen storage loop including electrolyzing fuel cells. The project is intended to act as a five year demonstration for the storage technologies.

The wind turbine was built by Enercon, a German company specializing in building turbines able to handle arctic conditions. The company will add the energy storage components in 2014/early 2015. If the pilot study is successful, Raglan intends to add additional turbines that will generate between 9 and 12 MW, replacing 40% of the mine's diesel requirements. The turbine has been placed at a location where it can be isolated from the microgrid.

Without energy storage, potential penetration for wind would be only 15-20%, but with energy storage, this could rise to 35-50%. The flywheel will be used to smooth the energy production curve and improve the wind energy available to the internal power grid. The hydrogen produced for storage may be siphoned off for fueling vehicles, reducing the need for the importing hydrocarbon fuels.

One interesting challenge for this microgrid, which could apply to other remote areas, is the relatively short window for delivering the components, by ship, and installing the technology. The project must be planned thoroughly and be simple to install. Raglan believes that the pilot was crucial not only for testing the technology but for training personnel [158].

Department of Defense

Traditionally, most military installations use backup diesel generators to provide power in case of outage. Although this system is generally sound, there have been cases of generators failing to start, with Sandia National Laboratories reporting that military generators only start 60% of the time due to lack of maintenance or poor system understanding [159].

As a result, the DOD is developing microgrids to provide reliable, secure power, include a higher level of cybersecurity, and fulfill its goal of reducing emissions. As part of this initiative, the DOD established the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program, designed to improve the overall cyber security of the power grid and develop islanding functionality. As a result, military research into inverters, switching, control and protection technology, system design and integration, and economic analysis tools is at a very advanced stage [160].

The DOE and DOD have jointly funded projects with Sandia National Laboratory to work with military bases and develop microgrids.

SPIDERS

With the SPIDERS program, the DOD embarked on a program that scales up over time, with each step improving the technology and demonstrating increased security and threat mitigation. SPIDERS, encompassing three separate military bases, integrates legacy systems and new technology, and will help create a DOD microgrid protocol to secure power and allow islanding for mission-critical loads. SPIDERS has a number of main goals [161]:

- Cyber security
- Integrate Smart Grid technology
- Islanding capability
- Use distributed resources
- Demand-side
- Redundant backup power systems [8]

The three bases selected for SPIDERS are:

- Fort Carson, Colorado
- Camp Smith, Hawaii
- Pearl Harbor-Hickham Air force Base, Hawaii

Commercial Technology

Importantly, the DOD is ensuring that its microgrid approach can be transferred to the commercial sectors with, for example, a smart switch being rolled out to the commercial market. Partners in the program include the DOD, DOE, U.S. Department of Homeland Security, the National Defense University, and agency laboratories [2].

Vendors

Vendors used by the military include SAIC, Lockheed Martin, Power Analytics (formerly EDSA), and General Electric [162]. Power Analytics recently received a Department of Defense's Environmental Security Technology Certification Program (ESTCP) contract to manage a secure cluster of microgrids at three U.S. Navy facilities in the San Diego area. Project participants include the following:

- Conner Networks: Providing cyber security
- OSISoft: Data network management and historical data storage
- Spirae: Control mechanisms
- Viridity Energy's: VPower software will forecast generation capability, electrical loads, and market price

Project consultants include the University of California, San Diego (UCSD) and San Diego Gas & Electric (SDG&E) [163].

Fort Bliss

Location: Fort Bliss, Texas

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG

Utility Involvement: El Paso Electric

Power Sources: Three solar arrays producing 120 kW, 1.4 MW, and 13.4 MW, backup generator, 300 kW energy storage system

Technology/Vendors: Lockheed Martin

Status: Operational

Background

Fort Bliss is the U.S. Army's first microgrid project and will act as a model for other military microgrids. The system incorporates renewable energy resources, energy storage solutions, and load management to ensure normal operation during emergencies. The microgrid was installed by Lockheed Martin, using the Intelligent Microgrid Control System [164].

Although the army has long made use of microgrids and backups, this is the first installation that will be connected to a utility distribution grid [162]. At present, the microgrid covers the dining facility, but will be gradually expanded to cover the whole base. The military hopes to reduce its US $16 million per annum energy bill by at least 20%, and the system will guarantee power if the wider distribution grid becomes inoperative due to natural disasters or attacks.

Technology

The microgrid includes a 120 kW solar array, a backup generator, a 300 kW energy storage system, and interconnection with the utility grid. El Paso Electric is installing a 20 MW solar array, to be completed in 2015, which will power the eastern sector of the base, to add to the 1.4 MW solar array and the 13.4 MW solar array installed on rooftops. The military is also working with the city of El Paso to develop a center for converting waste into energy [162,165].

29 Palms

Location: 29 Palms, California

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG

Utility Involvement: SCE

Power Sources: 7.2 MW natural gas CHP, 4.8 MW solar PV

Technology/Vendors: S&C, Johnson Controls, General Electric

Status: Operational

Background

As part of installing a microgrid, 29 Palms military base has installed extra generation capability and technology alongside modernizing the existing grid infrastructure. The overall aim is to allow the base to be powered without external support for over 12 hours, using the two CHP plants and solar PV, and generate over 90% of its own power during normal operation.

Technology

The base already had a 7.2 MW CHP cogeneration gas turbine and 4.8 MW of solar PV. Further improvements included the addition of a new natural gas supply line, modernization of the control infrastructure, adding 60 S&C SCADAMATE switches, and improving communications to switches and substations [166]. The base has recently added 2.5 MW of solar capacity and 564 kW of battery storage, as well as a new plant that combines generation and thermal capture.

The system will match output from the generators and solar to produce power as needed, and potentially export power to the wider grid, although thus is not yet possible due to an agreement with SCE. Recently, the base managed to operate under its own power during a 14 hour outage. The existing plant is operated by Johnson Controls Inc., based in Milwaukee [167].

General Electric has developed new software and microgrid controllers to manage DG and energy storage, with the software operating in parallel with the SCE grid and allowing it to operate when islanded [168].

Fort Carson

Location: Colorado Springs, Colorado

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG

Power Sources: 1 MW PV array, 3 diesel generators with 3 MW total capacity; wind, geothermal heat pumps, biomass, and solar water heating (planned)

Status: Operational

Background

As part of the SPIDERS project, Fort Carson intends to become a Net Zero facility through the use of distributed energy resources and storage. The present microgrid incorporates a 1 MW PV array, three diesel generators with a total capacity of 3 MW, and 5 electric vehicles. There will be no modifications to PV inverters other than installing on/off functionality.

The base wants to add extra PV power and wind power, biomass generation, ground source heat pumps, and solar water heating. The electric vehicles are being assessed for potential use as a source of energy storage for home and forward bases, as well as peak shaving and demand response [161,169,170].

Fort Hunter Liggett

Location: Monterey County, California

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG, energy market partiucipation

Power Sources: 8 MW PV, 5 MWh energy storage

Technology/Vendors: OpenADR, Lawrence Berkeley National Laboratory (LBNL), Alstom, Siemens, SAFT, One cycle controls, Microgrid Labs, Customized energy solutions,Tri-Technic,

Status: Ongoing

Background

Fort Hunter Liggett is implementing a commercial-scale microgrid project designed to demonstrate PV intensive islanded operation, the use of day-ahead predictive optimization and real-time control. This system will plan charging and discharging schedules for a system incorporating 8 MW PV generation and 5 MWh lithium-ion electric storage. This project has a number of objectives:

- Allow islanded operation with significant PV penetration
- Store excess energy from the PV arrays for night use
- Demand management
- Energy market participation
- Add technology, such as OpenADR, to create a microgrid with diverse DG resources

To achieve these goals, the microgrid requires supervisory control to control and schedule PV storage. Tri-Technic is liaising with the Lawrence Berkeley National Laboratory (LBNL) to develop this functionality and create software that will optimize and control DG resources, collect data, communicate with local SCADA, and incorporate servers [171]. Technologies used include SAFT/other batteries, Siemens/OCC inverters, and LBNL DER-CAM microgrid control [172].

San Nicolas Island

Location: San Nicolas, California

Type: Military Microgrid/Remote Grid

Aims: Backup power, security and cybersecurity, integrating DG, remote

Power Sources: Wind turbines, diesel generators, 1 MWh storage battery

Technology/Vendors: ZBB Energy Corporation

Status: Operational

Background

Due to its relatively isolated location, San Nicolas Island military base has been assessing ways to create a microgrid that lowers dependence on imported fossil fuels.

Technology

At the heart of system is a 1000 kWh energy storage system built by ZBB Energy Corporation. This system includes the ZBB EnerSystem Power and Energy Control Center, and 20 ZBB EnerStore zinc-bromide flow battery modules. The storage system will be assessed to see if it can maintain power quality and provide load management for the existing wind turbines and diesel generators on the island. Where possible, the system will emphasize renewable resources over generators [173].

Francis E. Warren Air Force Base

Location: Cheyenne, Wyoming

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG

Power Sources: Wind turbines, diesel generators, 1 MWh storage battery

Status: Operational

Background

In 2010, the Francis E. Warren Air Force Base tested a microgrid configuration powered by diesel generators and a wind farm, using one-third of normal base load to simulate power loss from the grid. The test was successful and directed power to the most critical facilities, with mission equipment remaining online. The microgrid provided stable system voltages and frequencies, and total loads supplied varied between 2.1 and 3.1 MW. In addition, over time, the microgrid reduced fuel consumption by a quarter [26].

Fort Sill

Location: Lawton, Oklahoma

Type: Military Microgrid

Aims: Backup power, security and cybersecurity, integrating DG

Power Sources: Two 210 kW natural gas generators, 30 kW PV, 2.4 kW wind turbines, 500 kWh/250 kW zinc bromide battery

Technology/Vendors: Eaton, Encorp

Status: Operational

Background

The Fort Sill microgrid, developed with the aid of CERTS Modeling and Simulation, includes two 210 kW natural gas generators, 30 kW PV, 2.4 kW wind turbines, and a 500 kWh/250 kW zinc bromide battery. The system also includes adjustable trip-curve breakers and a microgrid interface switch. Demonstrations have shown that the microgrid can operate when islanded, via a seamless transition [161,174].

The microgrid also includes:

- Microgrid interconnection switch (MIS)
- Adaptable trip curve breakers
- Converters for renewable energy microgrids with enhanced CERTS
- Energy efficient variable frequency drives for variable torque loads
- Static transfer switch [175]

Camp Williams Wind Turbine Microgrid

Location: Bluffdale, Utah

Type: Military

Aims: Islanding

Power Sources: Wind, diesel

Funding: State of Utah Division of Facilities Construction and Management

Technology/Vendors: Sunrise

Status: Operational

Background

This project, under the auspices of State of Utah Division of Facilities Construction and Management, included the development of a new microgrid that integrated existing wind generation with a new diesel generator. The generator supplies backup power if utility power is disrupted.

Technology

Developed with Sunrise, the project integrated a diesel generator into a 12.47 kV electrical distribution grid, alongside a load management system to provide start-up power to wind turbines if utility supplies are disrupted. Using existing relays fitted to five feeders, the control system monitors load, allowing load management software to match available power to the highest priority loads. The microgrid includes provisions for adding extra generators, and utilized a remote tie switch and reprogramming of existing relays to allow switching via the master control [176].

Marine Corps Air Station Miramar Microgrid

Location: San Diego, California

Type: Military Microgrid

Aims: Reduce electric power costs, solely powered by on-site generation by 2017

Utility Involvement: San Diego Gas & Electric

Power Sources: 1.5 MW of photovoltaics, 250-kW, 1 MWh battery energy storage system (BESS), 3.2 MW methane gas electricity generating equipment, providing roughly 25,000 MWh per year

Funding: Department of Defense, EPA's Green Power Partnership, based on future payback

Technology/Vendors: BESS from Primus Power, control system from Raytheon, power electronics from Advanced Energy

Status: Implementation in progress

Background

Marine Corps Air Station Miramar is a relatively compact base in San Diego. The facility increased its renewable energy by 2.5 times in 2013. The base now provides one half of it electricity and 35% of its overall energy via renewables. These include PV, and methane-fueled generators.

This latest initiative will fully power the base with on-site generation by 2017.

Technology

This system has been tested via a simulator in the DOE's National Renewable Energy Laboratory.

Camp Pendleton FractalGrid Demonstration

Location: Northwestern San Diego County, California

Type: Military Microgrid

Aims: Electric power resiliency, integrating renewables, reduced overall electric power costs

Power Sources: Concentrating photovoltaic arrays, 225 kW; flat panel high efficiency photovoltaic system, 300 kW; diesel generator, 200 kW; battery energy storage system (BESS), 240 kWh; deep cycle batteries, 60 kWh; electric vehicle (EV) with vehicle to grid (V2G) for additional storage

Funding: California Energy Commission US $1.7 million award, US $1.1 million in match funding from vendors

Technology/Vendors: Harper Construction, general contractor; CleanSpark, designer, integrator and installer; Quantum Energy Storage Corporation, BESS

Status: Proposed and unfunded (not fully funded)

Background

The California Energy Commission (CEC) appears to be the primary promoter of this project currently, although the project was probably initiated by the above “Technology/Vendors” and the Marine Corps. The project goals are to integrate ‘best-of-breed’ advanced energy storage technology using the following criteria:

- Flexibility – the microgrid must provide reactive power able to sustain critical loads in a seamless manner in the event of an outage
- Longevity – the microgrid components should offer a life span of 25 years, and the BESS should have a minimum full charge/discharge cycle life of 25,000 cycles
- Affordability – the microgrid should be cost competitive with current alternative technologies

Technology

This project is currently in the earliest stages, and there are few details on most elements of the microgrid, including technologies.

Alaska

Because the state has extremely high electricity and gasoline prices, the state is increasingly looking to use renewable resources to meet its power needs. Through hydroelectric and wind projects, the state already derives over a fifth of its electricity generation from renewable resources.

State initiatives traditionally support smaller scale projects, with Alaska home to over 150 grids serving remote village and commercial installations. This includes many small scale hydroelectric projects aimed at small, remote communities, which receive funding from Alaska Energy Authority (AEA) and the DOE.

Renewable Portfolio Standards: At present, there is a system cap of 25 kW and aggregate cap of 1.5% of average retail demand for utilities with annual retail sales of over 5 GW. For interconnection, net metering is mandatory, with other requirements varying according to utility.

Tax Incentives: In terms of incentives, municipalities may exempt residential systems from property tax. In addition, the Renewable Energy Fund provides grants for utilities, power producers, and local and tribal governments to perform feasibility studies, funded by the Alaska Energy Authority.

The Emerging Technology Fund supports demonstration projects that have a reasonable chance of becoming commercially viable within five years, with a maximum funding level of US $500,000. Finally, a loan fund is available for the development of facilities under 10 MW [15].

St Paul Island

Location: St Paul Island, Alaska

Type: Remote Microgrid

Aims: Lowering costs

Utility Involvement: Tanadgusix (TDX) Corporation

Power Sources: Two 150 Volvo diesel generators, 225 kW Vestas wind turbine, flywheel

Funding: TDX Corporation, Alaska Native Village Corporation (ANC)

Technology/Vendors: Beacon Power

Status: Operational

Background

St Paul Island, in the Bering Sea, is the type of remote, isolated community that needs the ability to manage electricity supply with no connection to an external grid. With an existing grid built around diesel generation, the community is testing flywheel energy storage as part of its wind and diesel microgrid. This technology is predicted to stabilize the grid and increase diesel generator downtime by 10-15%.

The present grid, built and financed by the TDX Corporation[12] and the ANC, is a hybrid microgrid system with a 225 kW Vestas wind turbine and two 150 kW Volvo diesel generators. The system incorporates smart switch technology and a synchronizing condenser. The plant was commissioned in 1999 and has reduced costs by 40%.

Using technology developed by Beacon Power, TDX is hoping to improve the utilization of wind and deliver further fuel savings of up to 30%. This demonstration project is designed to use natural resources and wind energy, reducing the need for expensive diesel fuel imports [177].

[12] More details about the corporation available at: http://www.tdxpower.com/

Kodiak Island

Location: Kodiak Island, Alaska

Type: Remote Microgrid

Aims: Lowering costs

Utility Involvement: Kodiak Electric Association (KEA)

Power Sources: Hydropower, 9 MW wind, two 1 MW flywheels, two 1.5 MW storage batteries

Technology/Vendors: ABB PowerStore

Status: Operational

Background

On behalf of Kodiak Electric Association (KEA), an electrical cooperative, ABB is installing a commercial flywheel, PowerStore, on Kodiak Island, Alaska. This technology will be integrated alongside existing renewable generation resources and a battery system. The technology is designed to provide the extra stability required after the installation of an upgraded crane at the port facilities, which will see a diesel crane replaced with an electric crane.

The island already has a microgrid that generates virtually all of its power from hydropower and wind. The flywheel will allow the grid to shave peak loads from the crane, smoothing destabilizing power fluctuations, extending the lifecycle of storage batteries, and reducing the need for additional diesel generation. The ABB system will also provide extra grid control and power management capability [178].

Hawaii

Hawaii, due to the difficulty of energy transmission across the archipelago, is investing in its abundant geothermal, biomass, wave, hydropower, solar and wind resources. Due to high electricity rates and the expense of importing oil, the state has developed policies built on encouraging distributed generation technology to the state. Presently, the island relies upon imported fossil fuels for 90% of its energy demands, so hopes to increase renewable portfolio standards to 70% by 2030, made up of 40% renewable generation and 30% through energy efficiency.

Renewable Energy: Total solar penetration increased by 75% in 2013, of which 92% was from distributed generation, and Hawaiian IOUs recently announced plans to increase the amount of solar PV by a factor of three and cut electricity bills by 20%. In addition, the U.S. Pacific Command announced an US $8 million scheme to install a microgrid with PV arrays (that can operate in island mode) at its headquarters.

All electric utilities must produce 40% of power from renewable resources by 2030, and all utilities must install net metering, with a 100 kW system capacity limit and an aggregate capacity limit of 15% per distribution circuit feeder. For IOUs, no interconnection limit is specified, and an external disconnect switch is required for all installations.

Tax Incentives: Personal or corporate tax incentives will be given as Solar and Wind Energy Credit, for 20% of the cost of equipment and installation of a wind system, and 35% of the cost of equipment and installation of a solar system. Most renewable resources will benefit from a feed-in tariff over a twenty year contractual period by three utilities, the Hawaiian Electric Company (HECO), Maui Electric Company (MECO), and the Hawaii Electric Light Company (HELCO).

At present, all utilities, excluding Kauai Island Utility Cooperative (KIUC), collect a surcharge on bills that is reinvested in renewable energy, with the 2013-2014 budget standing at US $21.9 million. In addition, The Department of Business, Economic Development, and Tourism can issue green infrastructure bonds providing low cost financing for renewable energy measures.

Finally, the Farm and Aquaculture Alternative Energy Loan provides up to 85% of the cost of PV, hydro, biogas, wind, or biofuel projects, with a maximum of US $1.5 million, for up to a loan term of 40 years [8,15].

Hawaii Ocean Science and Technology (HOST)

Location: Hawaii

Type: Campus Microgrid

Aims: Microgrid testing

Utility Involvement: Hawaii Electric Light Co.

Power Sources: Solar, biofuels

Funding: State of Hawaii, Hawaii County

Technology/Vendors: NRG

Status: Proposed

Background

By 2050, Hawaii wishes to generate 100% of all energy from renewable resources, and 40% by 2040, which is crucial for an island wishing to avoid the high cost of importing fossil fuels. Because this will include a large number of disparate distributed generation resources, with many customers electing to disconnect from the main grid and generate their own power, the state utility is aware that it needs to develop robust energy storage solutions and microgrid capability. At present, the shortage of commercially viable energy storage solutions has been a major bottleneck in the development of microgrids [179].

To overcome this, The State of Hawaii, the Hawaii Electric Light Co., and Hawaii County are developing a microgrid test bed for companies wishing to test and assess commercial energy storage solutions.

Technology

The Hawaii Ocean Science and Technology (HOST) Park, at Kailua Kona on the Big Island, is managed by the Natural Energy Laboratory of Hawaii Authority (NELHA) and hosts a number of technologies for producing energy, including algal biofuels and solar technology.

HOST is working towards the development of a microgrid on the campus that will be used to test emergent technologies, allowing companies to test technology, such as energy storage devices, under real world conditions and validation. The site will include testing sites, power sensors, and real time monitoring of devices.

Bakken Hale Estate Microgrid

Location: Kona Coast, Hawaii Island, Hawaii

Type: Remote Island Microgrid

Aims: Reduction of fossil-fuel usage by approximately 97%

Power Sources: 176 kW Photovoltaic array, 1 MWh battery energy storage system (BESS), propane-fueled generator

Funding: Privately funded by Medtronic, owner of Bakken Hale estate

Technology/Vendors: Aquion Energy BESS, Renewable Energy Services, Inc. system integration

Status: Operational (scheduled for end of June 2015)

Background

Earl Bakken invented the pacemaker and founded Medtronic Inc. At his estate on the Big Island of Hawaii, Bakken will power his estate, Bakken Hale at Kiholo Bay, entirely on solar power.

The project will use 512 solar panels to power the estate. The work should be completed by the end of June 2015. Energy will be stored by a battery made by Aquion Energy, which specializes in remote island systems.

Technology

Excess energy from the PV array is stored in the BESS when the PVs are producing energy, and used during non-productive periods. The battery technology for the BESS is aqueous hybrid ion: manganese oxide cathode, activated carbon composite anode, and sodium sulfate in an aqueous solution electrolyte.

Australia

Hydro Tasmania King Island System

Location: King Island, Tasmania, Australia

Type: Remote Island Microgrid

Aims: Reduced diesel generation, increased renewable generation, reduced carbon emissions, reduced cost of electric power

Utility Involvement: Hydro Tasmania

Power Sources: 6 MW diesel, 390 kW photovoltaic, 2.45 MW total wind capacity, 3 MW, 1.6 MWh battery energy storage system (see comments on the BESS under Technology below) [180]

Funding: Funded by the Tasmanian government and Hydro Tasmania based on a positive business case.

Technology/Vendors: Hydro Tasmania, Ecoult

Status: Operational

Background

Hydro Tasmania has several remote island utilities. These primarily used diesel generation prior to the year 2000. In 1998 Hydro Tasmania started deploying wind turbines on King Island, its largest remote island. In 2003 it added a second wind project and also added an 800 kWh Vanadium Redox Flow Battery energy storage system (since retired). In 2008 photovoltaic arrays were added. Between 2010 and 2013 additional components were added to complete the integration of a full microgrid.

Technology

The power sources include:

- 6 MW diesel generator fleet, partially fueled by biodiesel
- 390 kW photovoltaic array
- 5 wind turbines with 2.45 MW total capacity
- 3 MW, 1.6 MWh Battery Energy Storage System (BESS)

Apparently Hydro Tasmania engineered and integrated the microgrid control system themselves.

The original BESS was an 800 kWh Vanadium Redox Flow Battery installed in 2003. This was unreliable and was retired after a few years. Its replacement, described above, was ordered from Ecoult Energy Storage in late 2012. It is unclear whether this has been delivered and/or commissioned as of this writing (2015). Ecoult is an Australian company, and its battery design uses lead acid plus an asymmetrical super-capacitor.

Business Case

This project was made possible by a reasonable payback, which can be attributed to:

- Extremely expensive cost of delivering diesel fuel
- Rapid reductions in the cost of power generated by wind and photovoltaic generation
- Relatively mature supporting technologies, including BESS, power electronics, and control systems

The final enabling factor was government support through policy and funding.

India

Gram Power Khareda Lakshmipura Microgrid

Location: Various small villages in India

Type: Remote Island

Aims: Provide power to remote villages in India

Power Sources: Photovoltaic array, internal combustion generator, battery storage

Funding: Privately funded by Gram Power with payback by electric sales

Technology/Vendors: Gram Power

Status: Operational (Khareda Lakshmipura village)

Background

Gram Power was selected as a finalist at the LAUNCH energy forum in 2011, LAUNCH is a partnership of government agencies and NIKE. LAUNCH identifies and develops solutions to important global problems.

Gram Power's first microgrid installation electrified the Khareda Lakshmipura village. This village has 25 homes.

Technology

Khareda Lakshmipura's system powers homes within 2 km (1.2 mi). This system can be expanded for clusters of several thousand homes. Gram Power's design can interface with any type of generation, including wind, solar, or combustion generation.

Business Case

Each home has a pre-paid meter. Consumers can choose from several contract types. Consumers can operate electrical appliance. Larger appliances, like water pumps, can be operated through community meters.

Gram Power uses an entrepreneur model to sell power. An entrepreneur buys large amounts of energy at a discount. The entrepreneur sells power to customers in small increments. The pre-paid meter loads this credit and monitors use.

Italy

University of Genoa Microgrid

Location: Savona, Italy

Type: Campus Microgrid

Aims: Reduced energy costs, reduced carbon emissions, demonstrate campus microgrid

Utility Involvement: ENEL Distribuzione

Power Sources: CHP gas turbines with combined ratings of 160 kW electrical and 284 kW thermal. Roof-mounted PV of 80 kWp, CSPs equipped with Sterling engines (3 kWe, 9 kWth), which were installed primarily for research purposes, storage batteries with 100 kWh capacity.

Funding: Italian Ministry for Environment

Technology/Vendors: Siemens Microgrid Manager

Status: Operational, commissioned February 2014

Background

More renewable generation and improved energy efficiency will reduce energy consumption and carbon emissions.

On-site electrical and thermal energy production improves energy efficiency. An efficient method to integrate this generation into a facility is by forming a microgrid. A microgrid can operate to reduce demand when the facility is connected to the utility grid. If grid power is lost, the microgrid can operate as an independent grid.

Using waste-heat from electrical generation and other source also increases efficiency.

University of Genoa Microgrid is called the Smart Polygeneration Microgrid (SPM). The SPM efficiently generates energy for the facility and provides a testing facility for research and development.

Technology

The Siemens Microgrid Manager includes an electrical SCADA, a thermal SCADA and a centralized energy management system for the microgrid. These systems receive data from the field and communicate with installed devices.

The control system dispatches thermal and electrical generation resources as well as energy exchange with external grid. Planned dispatch uses forecasts of renewable resources and weather. Forecasting is done daily as well as for three days in advance. On the day of operations the control system optimally adjusts the dispatch every 15 seconds per actual weather conditions and demand.

Energy resources that are connected to the microgrid include:

- Three combined heat and power (CHP) gas turbines with combined ratings of 160 kW electrical and 284 kW thermal. In the winter the thermal output is used for environmental heating. In the summer the thermal output is routed to an absorption chiller for cooling the library.
- Roof-mounted photovoltaic arrays of 80 kW
- Three generators equipped with Sterling engines (3 kWe, 9 kWth), which are primarily for research

- Na-NiCl (ZEBRA) storage batteries with 100 kWh capacity
- Charging stations for two EVs

The microgrid has a single intertie to the main grid via a MV/LV transformer. The distribution network comprises a ring approximately 500 m (1640 ft) in length, with four main substations.

Japan

Niijima Island Microgrid Project

Location: Niijima Island, Japan

Type: Remote Island Microgrid

Aims: Addition of renewable generation to diesel power source

Utility Involvement: Takaoka Toko Co., Ltd., subsidiary of Tokyo Electric Power

Power Sources: Wind turbines and other renewable power, battery energy storage system (BESS) with capacity of 520 kWh and 1 MW peak power output

Funding: Japanese government

Technology/Vendors: Saft BESS, Takaoka-Toko's control systems

Status: Operational (early 2015)

Background

This microgrid is on the remote Japanese island of Niijima in Tokyo prefecture. This project will demonstrate diesel generators, solar panels and wind turbines working together.

This demonstration project is scheduled to run for five years.

Technology

The Saft Intensium Max 20 M Medium Power lithium-ion BESS is rated 520 kWh (nominal) and 1 MW peak power output. The BESS will be used with the Takaoka-Toko control system to maximize the use of renewable power.

Netherlands

SOPRA HAN University Microgrid

Location: Province of Gelderland, the Netherlands

Type: Remote Island Microgrid

Aims: Develop an off-the-grid microgrid for remote villages

Power Sources: 30 kW photovoltaic panels, a 30 kW wind turbine (simulated), a biodiesel generator, 60 kW, 50 kWh battery

Funding: European Regional Development Fund

Technology/Vendors: The following are listed as project partners: Exendis, Bredenoord, Wind Energy Solutions (WES), PFIXX Solar, Alliander DSO, HAN University and Delft University of Technology. The batteries are apparently made by Alfen Netherlands per a DOE database.

Status: Implementation in progress

Background

The SOPRA project (Sustainable Off-grid Power Station for Rural Applications) is developing a modular island microgrid for rural applications. The SOPRA system consists of wind, solar, and/or hydropower, electricity storage and backup diesel power. Together, they will provide power to the consumers connected to the microgrid in a remote village.

Technology

The core of the SOPRA system is a multi-source hybrid inverter (MHI) that connects all of the generators and electrical storage together in an optimal manner and thus defines the microgrid. The project focuses on the design and development of this MHI and demonstration of the system in multiple locations.

Spain

CENER / Jofemar Factory Microgrid

Location: Peralta, Navarre, Spain

Type: Industrial Microgrid

Aims: Minimize environmental impact of factory

Utility Involvement: National Renewable Energy Centre (CENER), Navarre, Spain

Power Sources: 100 kW wind turbines of 40 kW photovoltaic array, zinc bromine flow batteries capable of storing up to 500 kWh

Funding: Microgrid requires a total investment of approximately 2 million euros (approximately US $2.8 million). Approximately 50% of the total will be financed by the LIFE + program, the European financial program for the environment.

Technology/Vendors: Jofemar will provide the zinc bromine flow batteries. No other details on technology are available.

Status: Implementation in progress (scheduled for completion in 2017)

Background

This microgrid is part of the LIFE + 2013 program. The primary goal is to demonstrate, an industrial microgrid. It is hoped that microgrids will be shown to efficiently generate power while reducing their impact to the environment. Project partners are the Corporation Jofemar and the National Renewable Energy Centre, CENER.

During this project the partners will design and implement a microgrid at Jofemar's industrial facilities in Peralta (Navarra). The Factory Microgrid smart grid will meet the specific energy needs of the Jofemar plant, demonstrating the feasibility and technical suitability, and economic viability of the microgrid.

Technology

Jofemar will provide the zinc bromine flow batteries. No other details on technology are available.

9
CONCLUSION

At present, the research and development of microgrids is at a formative stage, making it difficult to draw conclusions or predict which social, environmental, economic, technological, and legislative solutions will prove valuable as the market matures. However, it is tentatively possible to highlight the following general trends:

Extreme Weather and the Legislative Environment: Overall, the trend for promoting microgrids has largely been developed as a response to extreme weather events and the need for improved reliability and resiliency. For example, many states on the east coast, such as Connecticut, New Jersey, and New York, created a legislative environment that supports microgrids due after the widespread outages caused by Superstorm Sandy.

Technological Compatibility: Because the U.S. military and educational institutions are heavily involved in developing microgrid technology, many of the solutions use open-source or simple plug-and-play technology. This will help the industry develop “standardized layouts” for microgrids and produce valid data for comparison between different projects.

Flexibility: Although the common perception of microgrids often sees them as a way to integrate renewable resources, most try to balance the benefits of using green energy with the judicious use of fossil fuels. For example, many projects use renewables as a source of emissions-free power, with natural gas and diesel used to balance loads and provide backup. In many ways, microgrids, rather than completely get rid of fossil fuels, emphasize using them more efficiently, through CHP, load balancing, and peak shaving.

The Energy Storage Barrier: The major barrier to a wholesale adoption of microgrids is the present expense of energy storage solutions, which are a necessity when integrating sporadic DG resources into a grid. As the technology matures, efficiency and lower prices should see more microgrid projects become economically and technically feasible.

Corporate Goals as a Driver: Businesses are becoming much more receptive to microgrids, with many using access to renewable power as a factor when deciding to locate to an area. This is partly because they are aware that future emissions regulations may become a future business cost, and partly because many businesses now rely upon high quality, uninterrupted power.

Balancing the Needs of Communities and Utilities: There are distinct signs that states are finding innovative ways to balance the needs of communities and utilities. For example, many states are developing electricity wholesale markets that emphasize distributed generation resources, and encouraging utilities to adopt a broad approach. The overlap between smart grids and microgrids is a particularly ripe area for integrating the needs of the communities and utilities by aligning goals and technology.

In addition, the successful operation of many microgrids during outages, notably during Sandy, suggests that the technology for interconnection and islanding works well and will help utilities improve reliability.

The Importance of Remote, Campus, and Military Microgrids: The importance of remote microgrids in terms of microgrid development should not be underestimated. They provide data and act as test beds for new technologies, especially for the integration of renewable resources, operation in islanded mode, energy storage, and smart technology. This importance can also be extended to military and campus microgrids, which are serving as useful models and test-beds for community microgrids.

The Collaborative Approach: Overall, although many technological, legislative, economic, and social barriers to the development of microgrids remain, there are signs that these are being overcome. At the heart of this is a collaborative approach that incorporates a number of stakeholders, including businesses, government, utilities, non-profits, communities, and institutions. In addition, across North America, communities and businesses are willingly becoming more proactive and seizing opportunities to develop energy independence.

Market Leaders: Because the U.S. and Canada will provide a huge market for microgrid development, alongside the research performed by private and public bodies, there is a huge potential for U.S. and Canadian companies to become world leaders and participate in the growing national and international market for microgrid technologies.

Economics and Quantifying the Intangible: It is important to remember that microgrids may not be the solution for every situation, and the economic arguments, such as balancing installation costs against future O&M and reliability savings, are still under development. Asset management software and predictive models such as DER-CAM may prove useful, but these rely upon developing methodologies for quantifying intangible benefits, such as the indirect cost of avoided outages to businesses and communities. Further research into intangible benefits is crucial.

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A
ABBREVIATIONS AND ACRONYMS

ACORE	American Council on Renewable Energy
AEA	Alaska Energy Authority
AEP	American Electric Power
AMI	Advanced Metering Infrastructure
ANC	Alaska Native Village Corporation
ARRA	American Recovery and Reinvestment Act
ASU	Arizona State University
BAT	Brooklyn Army Terminal
BCIT	British Columbia Institute of Technology
BESS	battery energy storage system
BPL	broadband over power line
CCEC	Colorado Clean Energy Cluster
CCHPP	Cornell Combined Heat and Power Project
CEC	California Energy Commission
CENER	National Renewable Energy Centre (Spain)
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	combined heat and power
CL&P	Connecticut Light and Power
CLTC	California Lighting Technology Center
ConEd	Consolidated Edison
CVR	conservation voltage reduction
DC	District of Columbia
DEEP	Department of Energy and Environmental Protection (CT)
DER	distributed energy resources

DER-CAM	Distributed Energy Resources Customer Adoption Model
DG	distributed generation
DMS	distribution management system
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOER	U.S. Department of Energy Resources
DR	demand response
DSPP	distributed system platform providers
EID	energy improvement district
ESM	Energy Surety Microgrid
ESTCP	Environmental Security Technology Certification Program
ETT	Electric Transmission Texas
EV	electric vehicle
FAST	Feeder Automation System Technologies
FEMA	Federal Emergency Management Agency
GEI	Galvin Electricity Initiative
GMP	Green Mountain Power
HAN	home area network
HARP	Hydrogen Assisted Renewable Power
HECO	Hawaiian Electric Company
HELCO	Hawaii Electric Light Company
HOST	Hawaii Ocean Science and Technology
ICE	Innovative Clean Energy
ICLEI	International Council for Local Environmental Initiatives
IDSM	Integrated Demand Side Management
IIT	Illinois Institute of Technology
INL	Idaho National Laboratory
IOU	investor owned utility

ISO	independent system operator
iSEMS	INL Smartgrid Energy Management System
KCEC	Kit Carson Electric Cooperative
KEA	Kodiak Electric Association
KUC	Kauai Island Utility Cooperative
LBNL	Lawrence Berkeley National Laboratory
LTEP	Long-Term Energy Plan
MassCEC	Massachusetts Clean Energy Center
MEA	Maryland Energy Administration
MHI	multi-source hybrid inverter
MIS	Microgrid Interconnection Switch
NEDO	New Energy and Industrial Technology Development Organization
NELHA	Natural Energy Laboratory of Hawaii Authority
NETL	National Energy Technology Laboratory
MECO	Maui Electric Company
NMGG	New Mexico Green Grid Initiative
NREL	National Renewable Energy Laboratory
NSERC	Natural Sciences and Engineering Research Council of Canada
NYCEDC	New York City Economic Development Corporation
NYSERDA	New York State Energy Research and Development Authority
OMS	outage management system
PEV	plug-in electric vehicle
PGE	Portland Gas and Electric
PIER	Public Interest Energy Research
PNM	Public Service Company, New Mexico
PNNL	Pacific Northwest National Laboratory
PNW-SGDP	Pacific Northwest Smart Grid Demonstration Project
PPA	power purchase agreement

PSC	Public Service Commission
PSERC	Power Systems Engineering Research Center
PSG&E	Public Service Gas and Electric
PUC	Public Utilities Commission
PUD	public utility districts
PV	photovoltaic
RDEG	renewable distributed energy generation
RDSI	renewable and distributed systems integration
RECIP	Renewable Energy Competitive Incentive Program
REIP	Renewable Energy Incentive Program
RFP	request for proposal
RPS	renewable portfolio standard
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory Control And Data Acquisition
SCE	Southern California Edison
SCL	Seattle City Light
SDG&E	San Diego Gas and Electric
SDTC	Sustainable Development Technology Canada
SECO	Texas State Energy Conservation Office
SMS	Storage Management System
SMUD	Sacramento Municipal Utility District
SOPRA	Sustainable Off-grid Power Station for Rural Applications
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
SPM	Smart Polygeneration Microgrid
TDX	Tanadgusix Corporation
TEES	Texas Engineering Experiment Station
TRED	Temporary Renewable Energy Development
UCONN	University of Connecticut

UI	United Illuminating
UPS	uninterruptible power supply
V2G	vehicle to grid
VPP	virtual power plant
WES	Wind Energy Solutions
WSU	Washington State University

B
SUMMARY TABLES

North West Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Oregon							
South Salem Smart Power Center	South Salem, OR	Community	PGE	5 MW Na Ion Storage, 5.7 MW Diesel Generation, Solar , Diesel Backup	DOE Bonneville Power	Battelle, PNNL, Bonneville Power, Eaton, Enerdel, PNW-SGDP	Operational

Idaho							
Idaho National Laboratory Power Engineering and Microgrid Facility	Idaho Falls, ID	Test				Battelle Energy Alliance, SKM, PSS/E , RTDS, PSCAD Matlab, Power World, PowerSim, EMTP	Operational

Washington							
Washington State University/ Schweitzer Engineering Laboratories	Pullman, WA	Campus Community	Avista SCL	Diesel/Gas Generators, Backup Diesel, 3.2 MWh Battery	DOE – ARRA SCL Avista	Schweitzer Engineering, Itron, Hewlett Packard, UniEnergy Technologies, UniEnergy, FacNet and Spirae	Operational

South West Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
California							
Beach Cities	Beach Cities, CA	Community	SDG&E	Solar PV, Natural Gas CHP	DOE CEC	SDG&E, Horizon Energy Group, Pacific Northwest National Labs, University of San Diego, Advanced Control Systems, Motorola, Lockheed Martin, IBM, Xanthus	Operational
Borrego Springs Substation	Borrego Springs, CA	Community Remote	SDG&E	26 MW Solar Installation, Two 1.8 MW Caterpillar Diesel Generators, 500 kW/1500 kWh Storage Battery, Three 50 kWh batteries, Six 4 kW/8 kWh Home Energy Storage Units, 700 kW solar PV DG	Federal, SDG&E, CEC, Other Partners	Oracle, Lockheed, IBM, Advanced Energy Storage, Horizon Energy, Motorola, Pacific Northwest National Laboratories, Caterpillar, and UCSD	Operational
Civita Smart Community Project	Civita Community, Mission Valley, CA	Community	SDG&E	100 kW Solar PV, Six 5 kW Fuel Cells, 100 kW/100 kWh Energy Storage		Pecan Street Research Institute, ECOtality	Proposed
UC San Diego	San Diego, CA	Campus	SDG&E	Two 13.5 MW Gas Turbines, 3 MW Steam Turbine, 2.8 MW Molten-Carbonate Fuel Cell, 1.2 MW Solar Array, 3.8 Million Gallon (14.4 Million Liter) Thermal Energy Storage	UCSD, CEC, California Solar Initiative, DOE	Johnson Controls, Schneider Electric, EDSA, Viridity Energy, UCSD Microelectric Embedded Systems Lab	Operational

SmartSacramento - Sacramento Municipality Utility District (SMUD)	Sacramento, CA	Community	SMUD	Three 100 kW Gas Engines, 10 kW PV, 760,000 Gallon (2.9 Million Liter) Chilled Water Thermal Energy Storage Tank, Absorption Chiller	CEC	Cyberex, Landis+Gyr, Silver Spring Networks, NREL, Tecogen, CERTS	Ongoing
Catalina Island	Catalina Island, CA	Remote	SCE	Diesel Generators, 1.4 MW Microturbines, NaS Batteries		S&C	Operational
Hunters Point, San Francisco	San Francisco, CA	Community	PG&E	Up to 50 MW of local DG resources		Clean Coalition	Ongoing
Alcatraz	Alcatraz Island, CA	Remote		Diesel Generators, 1,360 solar panels, producing 400 kW		Princeton Power	Operational
Santa Rita Jail,	Santa Rita Jail, Dublin, CA	Institutional		Diesel Generators, Fuel Cells, Lithium-Ion Batteries, 500 kW Solar Array, Microturbines		S&C, CERTS, Chevron, LBNL	Operational
Foothill College	Palo Alto, CA	Campus		Solar PV, Natural Gas CHP			Operational
Marin County	Marin County, CA	Community		Solar PV, Natural Gas CHP	DOE CEC	ECN, Infotility, Xanthus Consulting, PlotWatt	Operational
University of California Irvine Campus	Irvine, CA	Campus		113 kW and 836 kW Solar PV Arrays; 893 kW Rooftop Solar PV; 8 Chillers with TES; 15.8 MW Gas Turbine; 6.6 MW Steam Turbine; 8 Level 2 EV Chargers; Absorption Chiller; 180 kg/Day Hydrogen Station		ETAP, Amonix	Operational
Redwood Gate Ranch Microgrid	Jenner, CA	Remote		Three Battery Modules (54 Kwh); 30 Kw Inverter; 40 each 270 W Photovoltaic Arrays; 30 Kw Backup Diesel Generator	Private	Aquion Energy, Dynapower, Real Goods Solar, GELI	Operational

American Honda Motor Co. Microgrid	Chino, CA	Industrial	SCE	Solar PV, Battery Storage	CEC Bosch	Robert Bosch LLC, Navigant Consulting, the California Lighting Technology Center (CLTC), Maxwell Technologies, Imergy Power Systems	Implementation in Progress
Las Positas College Microgrid	Livermore, CA	Campus	PGE	2.35 MW Solar Array, 250 kW/1 MWh Battery Energy Storage System (Bess)	CEC Las Positas College	Imergy Power Systems, GELI	Implementation in Progress
Santa Clara University Microgrid	Santa Clara, CA	Campus	Silicon Valley Power	1.1 MW PV, 1.5 MW Backup Generation, and 3 MW Other Combustion Generation	CEC (pending)		Proposed

New Mexico							
Los Alamos	Los Alamos, NM	Community		1 MW PV Array, 1.8 MW Battery Storage		NEDO, Los Alamos National Laboratory, Los Alamos Department of Public Utilities, NMGG	Operational
Albuquerque	Albuquerque, NM	Community	Mesa del Sol, PNM	50 kW Solar PV array, 80 kW Fuel Cell, 240 kW Natural Gas Generator, Lead Acid Battery, Hot and Cold Thermal Storage		Los Alamos National Laboratory, Los Alamos Department of Public Utilities, NMGG, Shimizu, Tokyo Gas, Mitsubishi, Fuji Electric, Furukawa Battery	Operational
Taos Pueblo	Taos Pueblo, NM	Remote, Community	KCEC	10 MW PV, Energy Storage		NEDO, NMGG	Operational
Roosevelt County	Roosevelt County, NM	Remote, Community		Wind, Pumped Water Storage		NMGG	Ongoing

Colorado							
Fort Collins	Fort Collins, CO	Community	Fort Collins Utilities	345 kW Solar PV, 700 kW CHP, 60 kW Microturbines, 5 kW Fuel Cells. Private Sources Include: 790 kW Biogas, 200 kW Solar Arrays, Backup Diesel Generation Producing 2,270 kW	Colorado Clean Energy Cluster (CCEC), DOE, Eaton, Advanced Energy, Brendle	UniverCity Connections, Johnson Controls, Trane	Operational
Niobrara Data Center Energy Park	Niobrara Data Energy Park, Northern CO.	Commercial, Remote		Wind, Solar, Natural Gas			Proposed

Arizona							
Arizona State University	Phoenix, AZ	Campus		Renewable DG, CHP		Ameresco, Rocky Mountain Institute	Ongoing

Utah							
EBay Facility	Salt Lake City, UT	Commercial	Ormat	6 MW Solid Oxide Fuel Cells		Bloom Energy	Operational

Mid-West Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Illinois							
Illinois Institute of Technology	Chicago, IL	Campus	ConEd	Two 4 MW Combined Cycle Gas Units, Small Wind Turbine, Rooftop PV, 500 kW Battery	DOE, Industrial Funds, ARRA	S&C Electric, Galvin Electric Institute	Operational
Naperville	Naperville, IL	Community	City of Naperville Dept. of Public Utilities			S&C Electric, Galvin Electric Institute, Siemens, S&C Electric, ACS, Cityworks Azteca, ESRI/Miner&Miner, SynerGEE Stoner, Microsoft	Operational
Commonwealth Edison's Bronzeville Microgrid	Chicago, IL	Utility	Common-wealth Edison	Solar PV, Fuel Cells, Natural Gas Generation (Including CHP), Electricity Storage, Geothermal Generation, Wind Turbines	Commonwealth Edison		Proposed

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Ohio							
CERTS/American Electric Power Test Bed	Columbus, OH	Test	AEP		California Energy Commission PIER Electric Transmission Research Program	University of Wisconsin-Madison (PSERC), Sandia National Laboratories, Northern Power Systems, Tecogen, CERTS, DER-CAM, and Lawrence Berkeley National Laboratory	Operational

Wisconsin							
University of Wisconsin-Madison	Wisconsin, MI	Campus					Operational

Minnesota							
University of Minnesota	Minneapolis and St. Paul	Campus Community		DG, CHP, Battery Storage		Lawrence Berkeley Laboratory	Proposed

South Central Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Texas							
Colonias	Border Colonias, TX	Remote		40 kW from Bio-Diesel Generators, Xtreme Powercell	Texas State Energy Conservation Office, Texas Commission on Environmental Quality, NETL	Xtreme Power Solutions	Operational
Presidio	Presidio, TX	Remote, Community	ETT	4 MW Sodium Sulfur Storage Battery System	ETT	S&C	Ongoing
Oncor System Operating Services Facility Microgrid	Lancaster, TX	Utility	Oncor	65 Kw Micro-Turbine, 210 Kw Diesel Generator, (2) 175 Kw Diesel Generators, 45 Kw Reciprocating Natural Gas Generator, 25 Kw Community Energy Storage, 106 Kw Carport Photovoltaic Array, 8 Kw Ground-Mounted Photovoltaic Array, 200 Kw Stationary Battery Storage, Capability to Add Future Wind Generation		S&C, Schneider Electric	Operational

North East Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
New York							
Cornell University	Ithaca, NY	Campus		Two 14.7 MW Duel-Fuel Generators; 2 Steam Turbo-Generators of 1.7 MW and 5.7 MW; 2 Heat Recovery Steam Generators; Two 1 MW Emergency Diesel Generators; 2 Hydroelectric Generators of 800 kW and 1 MW; 2 Coal Fired Boilers; 2 Dual Fuel Package Boilers; 1 Natural Gas Package Boiler		Solar Titan, Turbodyne, Rentech, Ossberger	Operational
New York University	New York, NY	Campus	ConEd	13.4 MW CHP; Two 5.5 MW Gas Turbines with Heat Recovery, 2. 4 MW Steam Turbine; 7 895 kW Caterpillar D399 Engines; 1 2.4 MW Steam Turbine; 3 Dual Fuel Hot Water Boilers Rated at 65 MMBtu/hr each; 3 Electric Centrifugal Chillers of 1500 tons each; 3 Absorption Chillers of 2500 tons each	NYSERDA grant for feasibility study; Tax Exempt Bonds	SKM, PSS/E, RTDS, PSCAD, Matlab, Power World, PowerSim, and EMTP	Operational
South Oaks Hospital	Long Island, NY	Campus		1.3 MW CHP, Five 250 kW IntelliGen Engines, 400-ton Hot Water Absorption Chiller, 1 MVA Diesel Generator			Operational
Griffiss Business and Technology Park	Rome, NY	Commercial		Steam and Biomass Generators			Operational

Village of Potsdam Microgrid	Potsdam, NY	Community	National Grid	3 MW CHP, 2 MW PV, 2 MW Batteries, 900 kW Hydro	DOE OEDER, GE	GE, NREL, National Grid, Clarkson University	Implemen-tation in Progress
ConEd / NYCEDC Brooklyn Army Terminal Microgrid	New York, NY	Community	ConEd	720 kWh Battery, 100 kW Inverter, 100 kW PV	DOE	Hitachi, Princeton, Suntech, Alerton, Viridity	Operational
Freeport Microgrid	Freeport Village, Town of Hempstead, NY	Community	Long Island Power Authority		NYSERDA Prize (not awarded)		Proposed

Connecticut							
Wesleyan University	Middletown, CT	Campus		CHP Plant, 200 kW PV, 3 MW Reciprocating Engines	DEEP	A/Z Corporation	Ongoing
University of Connecticut	Storrs, CT	Campus		400 kW Fuel Cell and 6.6 kW of Solar PV (New Capacity)	DEEP	Schneider Electric, ClearEdge Power, A/Z Corporation, and Connecticut Center for Advanced Technology	Ongoing
Fairfield	Fairfield, CT	Community	UI	Two Natural Gas Generators of 60 kW and 50 kW, 47 kW Solar PV	DEEP	Schneider Electric	Ongoing
Windham	Windham, CT	Community		Natural Gas, Diesel, 200 Kw Solar PV, Energy Storage Technologies, 200 Kwh Battery	DEEP	DERP Technologies	Ongoing
Stamford Energy Improvement District	Stamford, CT	Community	CL&P	400 kW Natural Gas Fuel Cell, 600 kW Reciprocating Natural Gas-Powered Engine, 300 kW Diesel Engine	DEEP	Pareto Energy, General Electric, United Technologies, EnerNOC	Ongoing
Ansonia	Ansonia, CT	Community		700 kW Biogas, 1.05 kW Natural Gas Generator, 58.4 MW Generator	DEEP	Pareto Energy	Ongoing

Milford Connecticut Microgrid	Milford, CT	Community	UI	Two 148 Kw Natural Gas CHP Units, 120 Kw Solar Array, 100 Kw Battery Energy Storage System (BESS)	Connecticut Department of Energy, EPA	Schneider Electric, Green Energy Corp., ZHP Systems	Implement ation in Progress
Massachusetts							
Vermont							
Rutland	Rutland, VT	Community	GMP, NRG	Solar PV		NRG, Dynapower	Ongoing
Maryland							
Konterra Headquarters	Laurel, MD	Commercial		402 kW Solar Array, PowerFactor Advanced Storage System, 300 kW AllCell Lithium-Ion Battery	Konterra, PNC Bank, Solar Grid Storage, MEA Grant	Standard Solar, Solar Grid Storage, AllCell, Solaire	Operational
Olney Town Center Microgrid Project	Olney, Maryland	Community	Pepco Holdings Inc.		DOE NETL	Burr Energy, Schneider Electric, Green Energy, North Carolina State University	Proposed
Montgomery County Microgrids	Montgomery County, MD	Community		Generators (e.g., Gas Turbines, Fuel Cells), Storage Devices (e.g., Batteries)			Proposed
District of Columbia							

New Jersey							
NJ Transitgrid	New Jersey	Community			DOE, NJ TRANSIT, BPU	Sandia National Laboratories	Proposed
Princeton University	Princeton, NJ	Campus	PSG&E	15 MW Co-Generating Natural Gas CHP, 5 MW Backup Diesel Generator, 5.4 MW Solar PV Array, 40,000 ton-hours Thermal Energy Storage		General Electric, Sofame	Ongoing
Hoboken	Hoboken, NJ	Community	PSE&G	Solar, Wind, Fuel Cells		Sandia National Laboratories	Proposed

Pennsylvania							
Penn State GridSTAR Net Zero Energy Demonstration Project	Philadelphia, PA	Campus	PJM, PECO, DTE, Viridity	PV, Photo-Thermal Absorption System, Solar-Canopied Electric Vehicle Charging Station with Integrated Community Energy Storage, Grid-Scale Battery System	DOE	ELECTRI International, CertainTeed Corporation, Eaton, Lutron, Solar-Grid Storage, Unirac, Isofoton, , Dynapower, Sequentric, U-Go, Pacific Data and Electric, Scitor	Implemen-tation in Progress

South East Region

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
North Carolina							
McAlpine Microgrid Project	Charlotte, NC	Commercial	Duke	Battery Storage, Solar PV			Operational
Dominion, Kitty Hawk	Kitty Hawk, NC	Commercial	Dominion	Four Wind Turbines Producing 13 kV; 6 kW Solar Panels, 75 kW Storage Battery			Operational

Canada

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
British Columbia Institute of Technology	Burnaby, BC	Campus	BC Hydro	Solar, Thermal Generating	BC Hydro, British Columbia Innovative Clean Energy (ICE) Fund, Western Diversification Fund	BCIT's Internet Engineering Lab. GridWise	Operational
Hartley Bay	Hartley Bay, BC	Remote		Two 420 kW Diesel Generators, 210 kW diesel Generator, 900 kW Hydro (Planned)		Pulse Energy	Operational
Bella Coola	Bella Coola, BC	Remote	BC Hydro	Fuel Cell, Hydro	Bella Coola Province, SDTC	Powertech, GE, Ballard	Ongoing
Field/Yoho National Park	Field, Yoho National Park, BC	Remote	BC Hydro	1 MW NaS Battery	National Resources Canada	NGK, S&C, IntelliRupter	Operational

PowerStream Utility Distribution Microgrid	Vaughan, Ontario	Commercial		17 kW Solar PV, 1.8 kW Wind, 35 kW Natural Gas Generation, 23 kWh Lead-Acid Battery, 5 kWh Li-ion Battery, 12 kWh Sodium Nickel Chloride battery, 5 kW Solar Carport, and a 14.4 kW EV charger		GE Digital Energy, Navigant Consulting, Enbridge Gas Distribution, Enviro-Energy Technologies, renewz sustainable solutions, Rosewater Energy Group, SMA Canada, SunPower, Southwest Windpower, Eaton, Caterpillar, Surette, China Aviation, Silfab Ontario, Renewz	Operational
Glencore Raglan Mine	Nunavik, Quebec	Commercial		3 MW wind turbine (Potential Upgrade to 9-12 MW), Three Energy Storage Devices, Flywheel, Battery Storage, Hydrogen Storage Loop		Enercon	Ongoing

Department of Defense

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Fort Bliss	Fort Bliss, TX	Military	El Paso Electric	3 Solar Arrays producing 120 kW, 1.4 MW, and 13.4 MW, Backup Generator, 300 kW Energy Storage System		Lockheed Martin	Operational
29 Palms	29 Palms	Military	SCE	7.2 MW natural gas CHP, 4.8 MW Solar PV		S&C, Johnson Controls, General Electric	Ongoing

Fort Carson	Colorado Springs, CO	Military		1 MW PV array, 3 Diesel Generators with 3 MW Total Capacity. Wind, Geothermal Heat Pumps, Biomass, and Solar Water Heating (Planned)			Operational
Fort Hunter Liggett	Monterey County, CA	Military		3 MW PV, 1 MWh Energy Storage		OpenADR, Tri-Technic, LBNL, SAFT, Siemens	Ongoing
San Nicolas Island	San Nicolas, CA	Military, Remote		Wind Turbines, Diesel Generators, 1 MWh Storage Battery		ZBB Energy Corporation	Operational
Francis E. Warren Air Force Base	Cheyenne, WY	Military		Wind Turbines, Diesel Generators, 1 MWh Storage Battery			Operational
Fort Sill	Lawton, OK	Military		Two 210 kW Natural Gas Generators, 30 kW PV, 2.4 kW Wind turbines, 500 kWh/250 kW Zinc Bromide Battery		Eaton, Encorp	Operational
Camp Williams Wind Turbine Microgrid	Bluffdale, UT	Military		Wind, Diesel	State of Utah Division of Facilities Construction and Management	Sunrise	Operational
Marine Corps Air Station Miramar Microgrid	San Diego, CA	Military	SDG&E	1.5 MW of Photovoltaics, 250 Kw, 1 MWh Battery Energy Storage System (BESS), 3.2 MW Methane Gas Electricity Generating Equipment	DOE, EPA's Green Power Partnership	Primus Power, Raytheon, Advanced Energy	Implemen-tation in Progress

Camp Pendleton FractalGrid Demonstration	Northwestern San Diego County, CA	Military		225 kW Concentrating PV Arrays, 300 kW Flat Panel High Efficiency PV System, 200 kW Diesel Generator, 240 kWh Battery Energy Storage System (BESS), 60 kWh Deep Cycle Batteries, Electric Vehicle (EV) with Vehicle to Grid (V2G)	California Energy Commission	Harper Construction, CleanSpark, Quantum Energy Storage Corporation	Proposed

Alaska and Hawaii

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Alaska							
St Paul Island	St. Paul Island, AK	Remote	TDX	Two Diesel Generators, 225 kW Wind Turbine, Flywheel	TDX Corporation, Alaska Native Village Corporation (ANC)	Beacon Power	Operational
Kodiak Island	Kodiak Island, AK	Remote	KEA	Hydropower, 9 MW Wind, Two 1 MW Flywheels, Two 1.5 MW Storage Batteries		ABB PowerStore	Ongoing

Hawaii							
Hawaii Ocean Science and Technology (HOST)	Hawaii	Commercial	HELCO	Solar, Biofuels	State of Hawaii, Hawaii County	NRG	Ongoing
Bakken Hale Estate Microgrid	Hawaii	Remote		176 kW PV Array, 1 MWh Battery Energy Storage System (BESS), Propane-Fueled Generator		Aquion Energy, Renewable Energy Services, Inc.	Operational

Australia

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Hydro Tasmania King Island System	King Island, Tasmania, Australia	Remote	Hydro Tasmania	6 MW Diesel, 390 kW Photovoltaic, 2.45 MW Total Wind Capacity, 3 MW 1.6 MWh Battery Energy Storage System	Tasmania, Hydro Tasmania	Hydro Tasmania, Ecoult	Operational

India

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Gram Power Khareda Lakshmipura Microgrid	Various small villages in India	Remote		PV Array, Internal Combustion Generator, Battery Storage	Gram Power	Gram Power	Operational

Italy

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
University of Genoa Microgrid	Savona, Italy	Campus Microgrid	ENEL Distribuzi one	160 kW Electrical and 284 kW Thermal CHP Gas Turbines. 80 kWp PV, 3 kWe, 9 kWth CSPs, 100 kW Battery Storage	Italian Ministry for Environment	Siemens Microgrid Manager	Operational

Japan

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
Niijima Island Microgrid Project	Niijima Island, Japan	Remote	Takaoka Toko Co., Ltd.	Wind; 520 kWh, 1 MW Battery Energy Storage System (BESS)	Japanese government	Saft, Takaoka-Toko	Operational

Netherlands

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
SOPRA HAN University Microgrid	Province of Gelderland, the Netherlands	Remote		PV Array; Internal Combustion Generator; Battery Storage; 30 kW PV Panels, 30 kW Wind Turbine (Simulated); Biodiesel Generator; 60 kW, 50 kWh Battery	European Regional Development Fund	Exendis, Bredenoord, Wind Energy Solutions (WES), PFIXX Solar, Alliander DSO, HAN University and Delft University of Technology, Alfen Netherlands per a DOE database.	Implemen-tation in Progress

Spain

Name	Location	Type	Utility	Power Sources	Funding	Vendors and Partners	Status
CENER / Jofemar Factory Microgrid	Peralta, Navarre, Spain	Industrial	CENER	100 kW Wind Turbines, 40 kW PV Array, 500 kWh Zinc Bromine Flow Batteries	LIFE +	Jofemar	Implemen-tation in Progress

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