76 - City of Rochester
(Rochester District Heating)

September 2016

Notice

NY Prize Task 5 Milestone Deliverable: Rochester District Heating Final Report

Table of Contents

Executive Summary

Rochester District Heating Cooperative (RDH) is proposing a feasibility study for implementing a Community Microgrid located in the City of Rochester downtown central business district that is interconnected with Rochester Gas and Electric's (RG&E) electric system. In addition to RDH, the participants in the feasibility study include RG&E, which satisfies the required participation of the Local Electric and Fuel Distribution Company, and the City of Rochester, which satisfies the required participation of the Local Government.

RDH has a bulk heat load requirement every hour of the year. While summer thermal loads are significantly smaller than winter, RDH's primary boilers must still maintain operation year-round to meet the load. Additional heat generation from a centrally located CHP plant would allow RDH to meet its summer heat load without the expense of operating its main boilers, resulting in a potential savings of over $1.5 million per year. These savings would then be passed along to RDH's customers and members in the form of lower energy bills and membership costs. In addition, at peak winter thermal loads, additional capacity and resiliency via a Community Microgrid would promote growth for RDH and increase its redundancy in its thermal generation capacity. Willdan Energy Solutions (Willdan) recommends a Community Microgrid for the City of Rochester, which include the City of Rochester, RG&E/IUSA, Rochester Downtown Development Corporation, and Rochester District Heating, by providing a master controller which has the ability to perform, in real-time, reconfiguration of the Microgrid functions, seamless islanding for economic, reliability, or resilience reasons, and optimization of storage and generation resources.

Unfortunately, due to the technical constraints of the downtown Rochester electric system, as well as the lack of viable sites for this project, the primary team members agreed to close the project early without completing Tasks 3 and 4. The work completed up to the time the decision to close was made is included in the following report, as well as a final section outlining the process by which the project was closed and concluding thoughts and future projects for each team member.

Task 1 – Development of Microgrid Capabilities

Rochester Community Microgrid Existing and Proposed Overview			
Category	Existing Resources	Proposed/Suggested Improvement	Justification
Load	• Residential Electric Heat • 13.37 MW NYPA allocation • 22 MW Winter Peak	• Building Energy Efficiency • LED Street lighting • Load Curtailment • Winter Peak Shaving	• Resilience • Reduced winter load • Reduce inefficiency
Distributed Energy Resources (DERs)	• Backup Generators	• Combined Heat and Power (CHP) • Energy Storage • Solar	• Demand Response • Resilience • Renewable Sources • Reduced winter load
Electrical and Thermal Infrastructure	• Radial Path 4.16kV & 12.45kV	• High Reliability Distribution System • Self-Healing	• Resilience • Reliability
Master Controller and Building Controls	• Some Building Controls	• Connected Master controller • Upgraded building controls • Smart Charger/Inverter for Batteries/Solar	• Resilience • Optimal utilization of Microgrid Assets
IT/Communication Infrastructure	• Manual Meters • Some System Level Load metering	• Advanced Metering Infrastructure (AMI) • 900 MHz mesh network • Fiber optic backbone • Control interface for DER	• Resilience • Reliable real time information • Remote Control

Task 1 Introduction

The existing technologies that support smart grid and microgrid capabilities were screened for their application to the Rochester Community Microgrid. This involves appropriating the benefits to the specific wants and needs of the stakeholders as well as thinning the list to the reasonable and applicable technologies for the region. The remaining technologies, applications, and revenue streams are then evaluated based on financial and technical feasibility in their application to the Rochester Community Microgrid. This primarily consists of detailed research into the existing infrastructure available and compatibility of the proposed technology with this infrastructure and with the other resources available in the Microgrid. Finally, the passing technologies are studied in detail, with tools such as the Distributed Energy Resources Customer Adoption Model ("DER-CAM"), to determine the range of acceptable capacity as well as the rough costs and cost savings.

Community Microgrid

Willdan recommends a Community Microgrid for the City of Rochester, which will enhance the overall operational reliability of the electrical distribution system. By providing a master controller, the Rochester Community Microgrid would be capable of seamless islanding and resynchronization for economic, reliability, or resilience purposes. Seamless islanding and resynchronization is defined as automatic separation from the grid on loss of utility power and automatic restoration of grid power after an outage on the grid side is cleared.

Normal operating conditions would see reliability improvements, through infrastructure reconfiguration, such as a High Reliability Distribution System (HRDS) which senses and clears faults with virtually no impact on building loads, to a self-healing and more fault tolerant grid, by reducing the number of single points of failure by adding redundancy to the electrical and communications networks, and by adding alternate sources of generation to serve critical and non-critical loads. In addition to increased reliability, the Rochester Community Microgrid would reap economic benefits in the form of added revenue streams from demand response, alternate generation sources, and energy efficiency measures to reduce overall energy costs, as well as participating in ancillary service markets such as fast regulation and operating reserve markets. Based on the price of electricity and availability of Distributed Energy Resources (DERs), the master controller will optimally dispatch the units, while maintaining 24x7x365 operation of the main CHP plant, to provide the cheapest, cleanest, and most reliable energy possible to the critical and non-critical microgrid facilities.

During emergency operating conditions, the Rochester Community Microgrid master controller would optimize generation and load to provide uninterrupted power to critical loads, through the use of DERs and load shedding schemes that ensure safe and reliable operation of the buildings that matter most in emergency situations. Long term outages will be mitigated by large natural gas fed combined heat and power (CHP) plant, which will maintain a black-start capability in the event the outage occurs when the CHP facility is not active. These plant or plants will rely on robust natural gas pipelines and produce enough power to serve all of the critical facilities, public street and security lighting, and some residential loads. This added resiliency will keep emergency responders and residents safe and provide the Rochester Community Microgrid with heat and power when it needs it most.

A key consideration in the development of the proposed Microgrid will be the purchase and ownership model of any installed system. Although several models were explored, preference was given to models that include developer owned/operated projects, and energy performance contracts that limit the upfront capital investment required by RDH.

Load

Existing Resources

There are currently six major thermal customers of RDH, with a peak load of 4 MW. Due to the high population density in the City of Rochester and harsh winter conditions, any bulk system disruption has the potential of creating hardship that endangers the safety of the community. A CHP driven microgrid will also introduce additional redundancy into the existing RDH thermal system, allowing the main boilers to be shut down in the summer for regular maintenance, which will improve the operability the overall system. Figure 1 shows the monthly load in Rochester for the recent years.

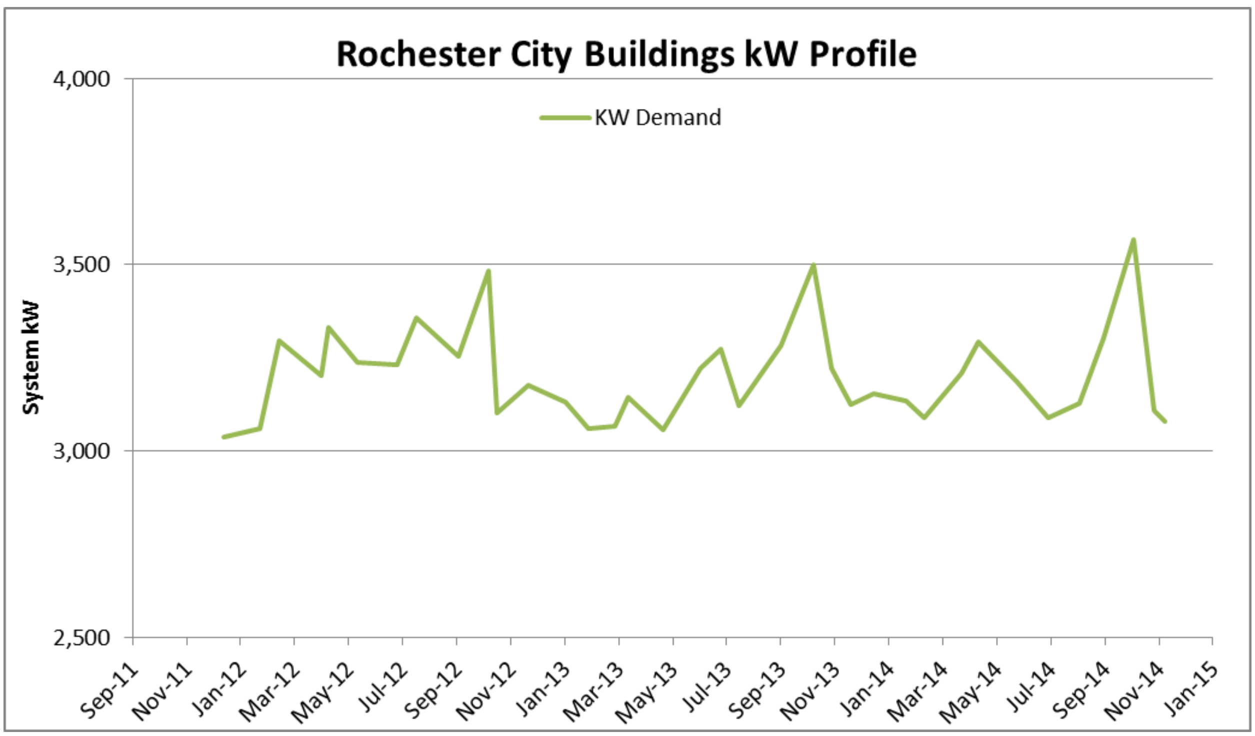


Figure 1 Load Demand Load Profile in Rochester

The City of Rochester's loads can be separated into the broad load categories, critical and non-critical, with critical facilities including the City Hall, the Public Safety Building, the Bausch and Lomb Library, and the Rundel Library, and non-critical facilities including the Convention Center and the Blue Cross Arena. The total critical load demand is about 4 MW. The load demand in each facility can be further separated into the following load categories as shown in Table 1 to describe the unique nature of, and opportunities available for, the different load types. The thermal loads that are not fed by electric heaters are also considered separately.

Table 1 - Electrical Load Type

Type	Description	Opportunities
Lighting	General, task, exits, and stairwells, decorative, parking lot, security, normal, and emergency.	Load curtailment
Transportation	Elevators, dumbwaiters, conveyors, escalators, and moving walkways.	Critical Load
Appliances	Business and copying machines, receptacles for vending machines, and general use	Load curtailment
Data processing	Desktop computers, central processing and peripheral equipment, and uninterruptible power supply (UPS) systems, including related cooling	Critical Load
Space conditioning	Heating, cooling, cleaning, pumping, and air-handling units	Short term Load curtailment and shifting
Food preparation	Cooling, cooking, special exhausts, dishwashing, disposing, and so forth	Load curtailment
Plumbing and sanitation	Water pumps, hot water heaters, sump and sewage pumps, incinerators, and waste handling	Short term load curtailment
Special loads	For equipment and facilities in mercantile buildings, restaurants, theaters, recreation and sports complexes, religious buildings, health care facilities, laboratories, broad casting stations, and so forth	Critical loads, Short term load curtailment, load curtailment
Fire protection	Fire detection, alarms, and pumps	Critical Load
Miscellaneous loads	Security, central control systems, communications; audio-visual, snow-melting, recreational, or fitness equipment	Critical load

Consequences

Summer thermal load requirements require RDH to maintain operation of its primary boilers year round. Maintenance and Operations tasks can be improved in terms of efficiency and cost by installing a smaller CHP system to serve the much lower summer heating load.

Opportunities

RDH explored placing the Microgrid's CHP and distributed generation resources in available land around RDH, including the unused RG&E station 6 and other vacant lands, unfortunately this space was removed at the recommendation of RG&E and the city and became a major roadblock to project success. The thermal output would eliminate the need to operate the main boilers during the summer months, potentially saving RDH over $1.5 million per year, as well as adding necessary redundancy to the overall RDH thermal system. In any case, the heat load from the CHP would be utilized year round, capitalizing on RDH's existing piping and distribution infrastructure to deliver thermal loads, and the extra capacity could be turned into electricity as an additional value stream. Electrical and Thermal Demand Response programs can also be implemented to add to the overall resiliency of the Rochester Community Microgrid.

Proposed/Suggested Improvements

A community microgrid would be helpful for solving these constraints existing in Rochester's system by providing additional capacity and resiliency. New CHP plants and demand response would help in mitigating the reliance on RDH's main boilers and electric power from utility grid. Willdan recommends to replace all the existing lighting with high efficient LED (Light Emitting Diode) fixtures. By applying the latest building control technology in each building, RG&E would be able to have the direct control capability on the curtailable and shift-able loads. Willdan recommends educating the customers to participate in peak-load demand response program.

Benefits

With a Community Microgrid, Rochester would be able to provide more reliable electricity to its electric customers. The critical facilities would remain powered on even in emergency situation when the power supply from the utility grid is lost. With the capability of direct control on the loads, RDH would not only be able to improve the reliability of the community distribution system, but have the potential to participate in ancillary service market such as, frequency regulation, demand response, etc. For the electric customer, they can get the better quality of thermal and electricity service while cutting their customer's bills at the same time. In addition, the operational requirements of a new CHP plant and microgrid system in the City of Rochester is expected to require the creation of new professional-level jobs in the Downtown area. Current evaluations estimate that 10 new jobs may be required to operate the CHP and microgrid systems proposed in this application. These estimates are based on current RDH employment at their existing steam plant, and represent long-term jobs that would be created through this project.

Barriers

Implementing the Community Microgrid would require new investment in generation resources. A greater review of the exact equipment installed must be done to determine any necessary reconfiguration of the existing distribution network and communication system. It would also be necessary to educate the electric customer to be involved in the demand response program.

DERs

Existing Resources

Currently, there are no permanent generation resources anywhere in the proposed Microgrid system. Within the next year, 800 kW of natural gas generation at City Hall and 260 kW of CHP at RDH's headquarters are expected to come on line, but are not sufficient to support the City's four (4) critical electric loads. Aside from these planned resources, only 800 kW of backup diesel generation exists in the proposed system

Consequences

The critical loads have an average demand of about 3,000 kW and the DERs total just over 1,800 kW of generation, indicating that there is not enough generation to provide critical loads with power in the event of an emergency. In addition, most of the generation is concentrated on the west side of the river. This means that a number of vital critical facilities, including the Rundel Library and the Bausch and Lomb Library, would be out of power in the event of an emergency, putting the entire City of Rochester in a dangerous position if these locations needed to be utilized as emergency shelters. In addition, the community pays to maintain and test the backup generators, or runs risk of the generators not working when needed, and doesn't see any value added beyond emergency situations. Finally, it is worth noting that half of the generation runs off of diesel fuel, which is a relatively dirty fuel source that reduces the quality of the air, increases the carbon footprint of the community, and must be stored or shipped into the city in the event of an outage.

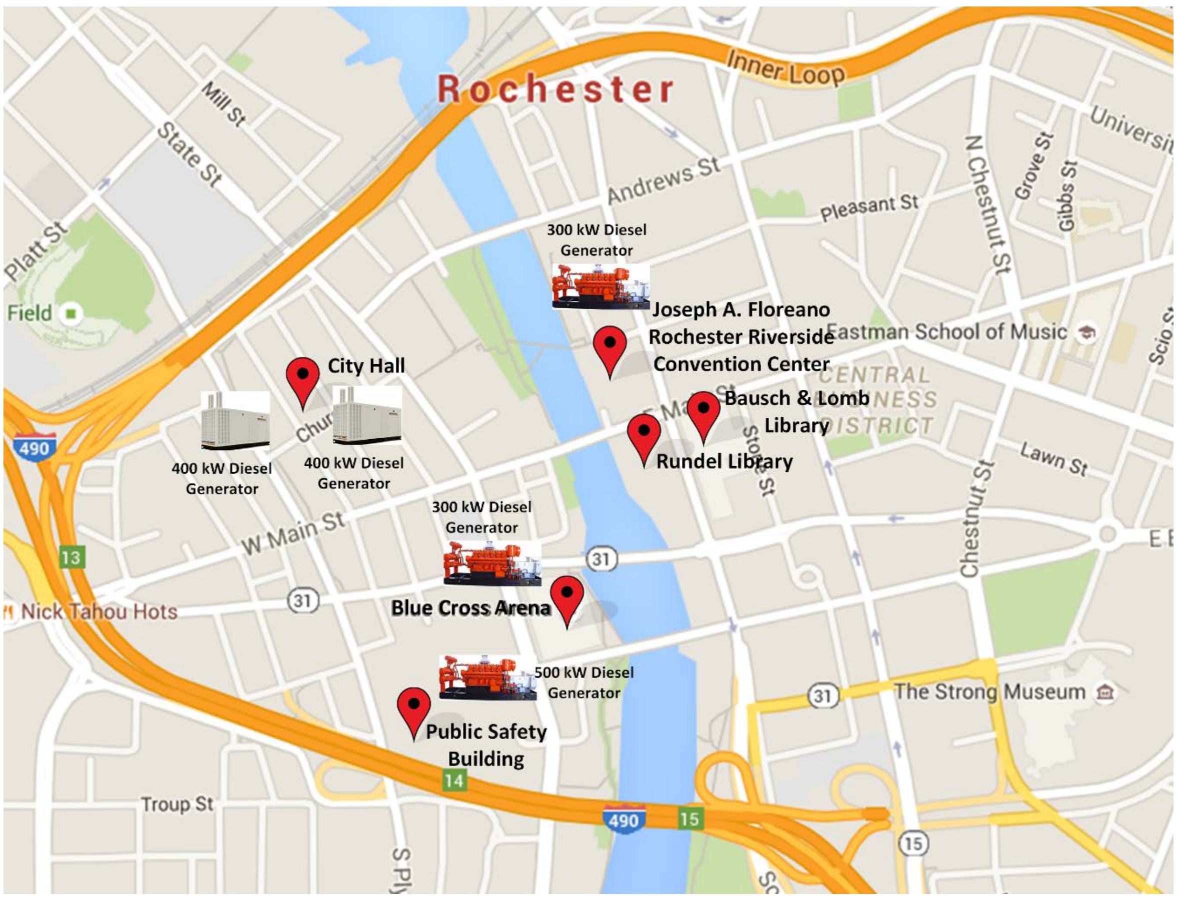


Figure 2 Critical Load and Existing DER Map of Rochester

Opportunities

The location of new generation assets in the form of large-scale CHP and the primary potential locations are illustrated in Figure 2. Vacant City land and underutilized City parking lots had potential for siting new generation assets, although unused RG&E Station 6 is ideally located for the proposed microgrid, and includes distribution infrastructure and existing RDH heating infrastructure on site. Unfortunately this space was removed as a possible location by the recommendation of RG&E and the city. Station 6 is also located adjacent to the aqueduct and a parking lot, allowing for the provision of heat and power to both sides of the Genesee River and additional space to expand if necessary. This expansion would allow Rochester to participate in Demand Response programs and reduce its dependency on its bulk electric power purchases.

Proposed/Suggested Improvements

DER Technology

The following table includes the screened technologies and their barriers and opportunities specific to the City of Rochester.

Table 2 - Distributed Energy Resources

Type	Description	Barriers	Opportunities
Combined Heat and Power (CHP)	Natural Gas fired turbines used to generate electricity and provide heat to nearby buildings	Space, Capital Cost, Cost of NG, Heating Infrastructure	Clean and Reliable, Reduce winter peak load, Resiliency, Thermal energy into RDH's infrastructure
Solar	Renewable energy source powered by the sun	$/kW of solar is greater than electricity price	Clean, Reduce daytime peak load
Electric Storage	Converts electrical energy to chemical or mechanical for rapid dispatch when needed	Space, Capital Cost	Fast Regulation, Provides power during NG spool up
ICE Distributed Generation (ICE DG)	Internal Combustion Engine Backup generation	Cost, Range of use, Maintenance	Black Start for CHP, Provides power during NG spool up
Wind	Renewable energy source powered by the wind	Space, Capital Cost, maintenance, zoning	Clean Source
Hydro	Renewable energy source powered by the flow of water	Location, Cost, maintenance	Clean Source
Alternative Fuel Sources	Production of fuel from local processes (Biomass, garbage dump, Waste Water Treatment Plant)	Supply	Converts waste into electricity

A screening of the available DER technology available to the Rochester Community Microgrid favors CHP, Batteries as Energy Storage, Solar as an Alternate Fuel Source, and ICE DG as black start generators for CHP. Based on initial analyses, Wind and Hydro potential, along with space required and maintenance/expertise needed, Wind and Hydro are not justified economically or in terms of resiliency and do not merit further consideration.

Benefits

The addition of a range of DERs, including long term sources like CHP, short term sources like Batteries, ICE DG, and renewables like solar would allow the City of Rochester to operate as a microgrid, take advantage of new revenue streams such as Demand Response and Fast Regulation Markets, increase resiliency through on-site generation, provide new growth potential for electric and heating service for new developments, and reduce charges associated with summer heating loads from the main boilers by utilizing CHP to take the boilers offline. Distribution of these additional resources close to the Rundel and Bausch and Lomb Libraries will ensure that critical facilities will remain powered on in emergencies, providing the City of Rochester with peace of mind.

Barriers

Additional modeling was performed to determine exact size and capacity of the proposed units, to ensure feasibility from financial and space requirements. Plant Operating Engineers for CHP will have to be hired internally or externally and training will be required for maintenance and operators of the proposed DERs.

Electrical and Thermal Infrastructure

Existing Resources

RG&E owns the electric and gas distribution infrastructures in the City of Rochester. These resources include substations, transformers, switchgear, underground transmission lines, and communications equipment in unknown quantities. A further investigation into the existing configuration of these resources must be done in subsequent phases to determine final system configuration possibilities for the Rochester Community Microgrid.

RDH operates a central boiler plant that produces and distributes steam through their installed heating infrastructure including over 9 miles of steam distribution pipelines, which is used throughout the downtown loop of Rochester to provide heat to as many as 46 customers[1].

RDH has completed numerous efficiency projects on their existing thermal distribution system, including:

- Complete plant Controls and Automation upgrades
- Plant and Distribution system insulation
- Condensate return from the distribution system
- Intra-plant condensate return
- Improved boiler combustion curves and excess air management
- Additional flue gas heat recovery
- System pressure reductions

The biggest drawbacks to the current RDH thermal distribution system are summer inefficiencies and winter capacities. The existing RDH boilers need to be operated in the summer to meet the

[1] NYSERDA NY Prize RDH Willdan 042815.docx – NY Prize Proposal for Rochester

minimum heating requirements of their customers. The summer loads are low and the boiler plant operates less efficiently and there are also higher thermal loses as a percentage of use than during higher thermal demand seasons. During the winter months RDH operates near capacity (while maintaining redundancy) when heating demand is high.

Consequences

As much of RDH's thermal infrastructure operates near capacity during the winter months, expansion of its customer base or of the current customer base's heating load presents a risk to the overall operational reliability of the RDH system. In addition, running the main boilers during the summer months adds complexity and costs to RDH for performing the critical yearly maintenance, raising the risk of failure of their systems during peak winter months.

Opportunities

A CHP-driven microgrid will also introduce additional redundancy into the existing RDH thermal system, allowing the main boilers to be shut down in the summer for regular maintenance, which will improve the safety of the overall system. Additional heat generation from a centrally located CHP plant would allow RDH to meet its summer heat load without the expense of operating its main boilers, resulting in a potential savings of over $1.5 Million per year. This savings would then be passed along to RDH's customers and members in the form of lower energy bills and membership costs. For the City of Rochester as a whole, this development would increase the propensity of economic development by providing affordable, reliable and resilient energy resources to a growing and revitalized business and residential district in the City.

Proposed/Suggested

Willdan recommends a centrally located CHP plant to add to the overall steam production capacity of RDH, as well as to potentially supply the critical facilities with electricity in the event that extra steam is not needed or that the RDH customers are without power and in need of electricity. Additional simulation and modeling is required, and was performed during Task 2 as well as the design phase, to determine the exact quantity of CHP that would benefit RDH and potentially allow the Rochester Community Microgrid to island from RG&E for economic or reliability purposes or during an outage.

Benefits

The Rochester Community Microgrid can operate in either grid-connected mode or island mode. The distribution network can be easily reconfigured for reliability purpose and minimizing the system loss to 3 to 4 cycles (~40ms). The critical loads can be served by multiple feeders. With the Automatic Transfer Switch (ATS), the Community Microgrid would be able to automatically isolate those buildings or distribution cables affected by outage, instead of spreading the outage to the whole distribution system. RDH would also be able to shut down its main boilers in the summer due to added CHP steam capacity as well as provide resiliency through a greater redundancy if any part of the RDH thermal distribution fails.

Barriers

The existing or future distribution network will need further upgrades which may incur extra investment costs. Also, automatic smart switches are needed for fast automatic switching.

Master Controller and Building Controls

Proposed/Suggested Improvements

A major element of the Rochester Community Microgrid is its master controller. The master controller applies hierarchical control via Supervisory Control and Data Acquisition (SCADA) software to ensure reliable and economic operation of the Rochester Community Microgrid. It also coordinates the operation of on-site generation, storage, and individual building controllers. Intelligent switching and advanced coordination technologies of master controller through communication systems facilitates rapid fault assessments and isolations.

Figure 4 shows the community microgrid elements, functions, and control tasks associated with each criterion. In order to achieve the optimal economics, microgrids apply coordination with the utility grid and economic demand response in island mode. The short-term reliability at load points would consider microgrid islanding and resynchronization and apply emergency demand response and self-healing in the case of outages. Functionally, three control levels are applied to the Rochester Community Microgrid:

- Primary control which is based on droop control for sharing the Microgrid load among DER units.
- Secondary control which performs corrective action to mitigate steady-state errors introduced by droop control and procures the optimal dispatch of DER units in the Microgrid.
- Tertiary control which manages the power flow between the Microgrid and the utility grid for optimizing the grid-coordinated operation scheme.

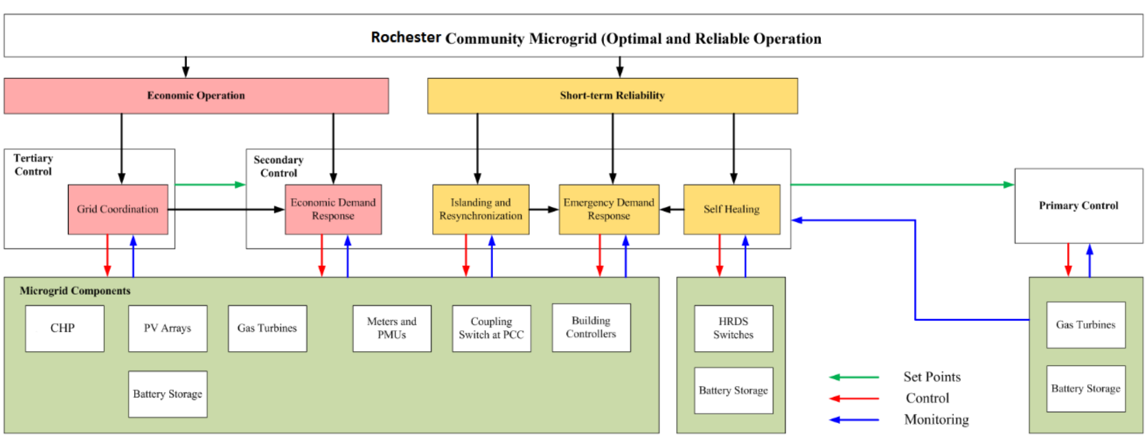
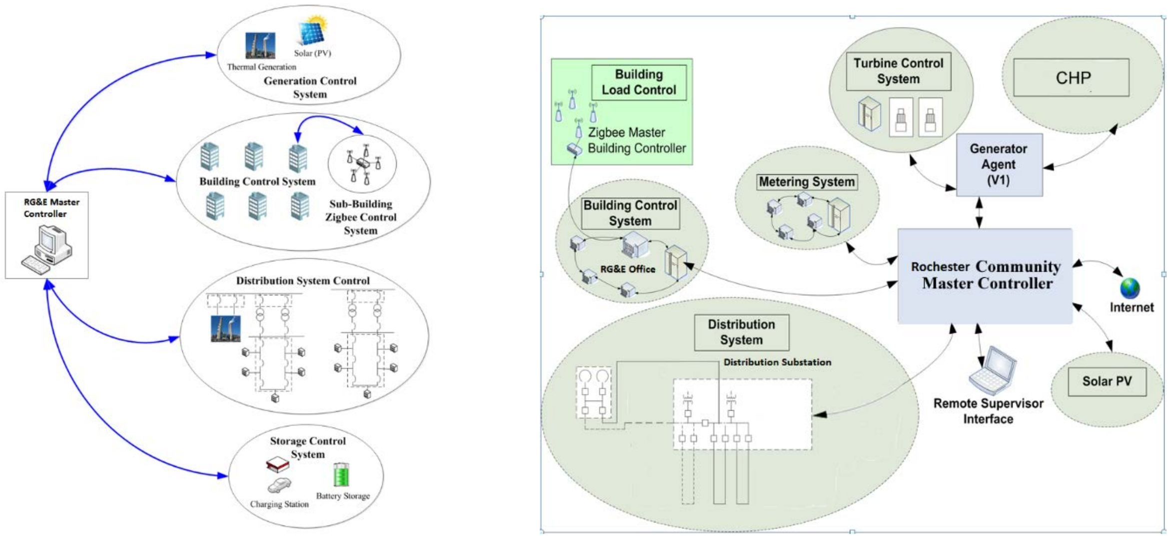


Figure 4 Objectives and functions for the control and operation of the Rochester Community Microgrid



(a) (b)

Figure 5 Architecture of master controller for Rochester Community Microgrid

The hierarchical secondary control approach would receive the information from loads and power supply entities as well as the information on the status of distribution network and procure the optimal solution via an hourly unit commitment and real-time economic dispatch for serving the load in the normal operation mode and contingencies. Figure 5 shows the hierarchical framework of the Master Controller proposed for Rochester's Community Microgrid project. In Figure 5, the monitoring signals provided to the master controller indicate the status of DER and distribution components, while the master controller signals provide set points for DER units and building controllers. Building controllers will communicate with sub-building controllers and monitoring systems to achieve a device level rapid load management.

The hierarchical protection configuration strategy for the Community Microgrid mainly contains four-level protection: load way, loop way, loop feeder way and microgrid level.

Benefits

Rochester Community Microgrid master controller offers the opportunity to eliminate costly outages and power disturbances, supply the hourly load profile, reduce daily peak loads, and mitigate greenhouse gas production. Master controller will include the implementation of additional functions for load shedding and coordinating demand response signals with the other controllers for peak demand reduction. In demand response mode, the utility master controller will shutoff loads according to predetermined load priorities. Part of the load shedding will be accomplished by shutting off power to entire building through smart switches and the rest will be accomplished by communicating directly with specific loads distributed across the community via the SCADA network and building controllers.

Barriers

In order to implement the proposed Community Microgrid in Rochester, the existing or future distribution network would need a further upgrade which may incur extra investment cost, automatic smart switches are needed for fast automatic switching. The functions of the Community Microgrid would depend a lot on the implementation of a reliable communication system.

IT/Communication Infrastructure

Any modern utility or system operator relies heavily on their communication infrastructure to monitor and control their grid assets. For a microgrid master controller and microgrid operators, this architecture enables real time control, rapid digestion of critical grid information, and historical data for analysis and reporting. As part of a feasible microgrid, assessment and upgrade of the equipment and protocols used in the Microgrid area was performed.

Existing Resources

RG&E owns and operates the electric distribution system that serves the Microgrid customers. A large majority of those customers are individually metered; however, these meters are read manually every month by a meter reader. At this stage, RG&E has submitted limited information on their communications and control architecture. They have provided building level load information, but not feeder level, distribution map, or three phase data from their distribution system or their substations.

Consequences

A limited communications architecture can lead to increased frequency and duration of outages if problems must occur and be reported rather than having symptoms trigger notifications to grid operators of location and scope of the issue. Limited information and delay in this information leads to man hours wasted and longer duration of customers without power, putting strain on residential customers and potentially costing commercial customers significant amounts of money. Systems could have telltale signs of issues for weeks, but operators may not discover these until they have caused damage and outages to the electric grid or substations, costing the utility money and potentially endangering employees and customers.

Opportunities

The Microgrid should consider an expansion to industrial smart meters for their customers. The key advantage of this expansion would be the network addition, which often utilizes the 900 MHz ISM band and relies on communication between integrated Network Interface Cards ("NIC"s) that form a mesh network, allowing signals to hop between any installed meters to reach their ultimate destination and increases the propagation range of the signal in proportion to the number and dispersion of integrated NIC Smart Meters. The integrated NICs are connected to a local Access Point (AP) that transmits the metering and control signals for the streetlights over a cellular wireless network back to the utility data center, where it can be fed into a SCADA platform for use in billing or monitoring the overall grid.

RG&E-controlled Advanced Metering Infrastructure (AMI) would also provide opportunity for community demand response aggregation, in which RG&E will be able to remotely control non-critical loads at the customer level to maximize economic benefit and/or reduce strain on the grid.

Proposed/Suggested Improvements

The Rochester Community Microgrid would be connected efficiently and productively, through the use of modern communication architectures and equipment, enabling a master controller to optimize the Microgrid control and giving operators the tools they need to perform their daily duties. This network would leverage the AMI network and seek to strengthen it through the use of connected LED streetlights, which shorten the overall payback of a street lighting upgrade through the implementation of smart photocells or integrated NICs that individually meter and control each streetlight, seen in figure 6. The switch from existing LED streetlights to intelligent LED streetlights is as simple as adding a plug and play smart photocell into the existing photocell socket located on every new streetlight. This provides a low effort low cost solution for drop in network architecture that provides the above benefits.

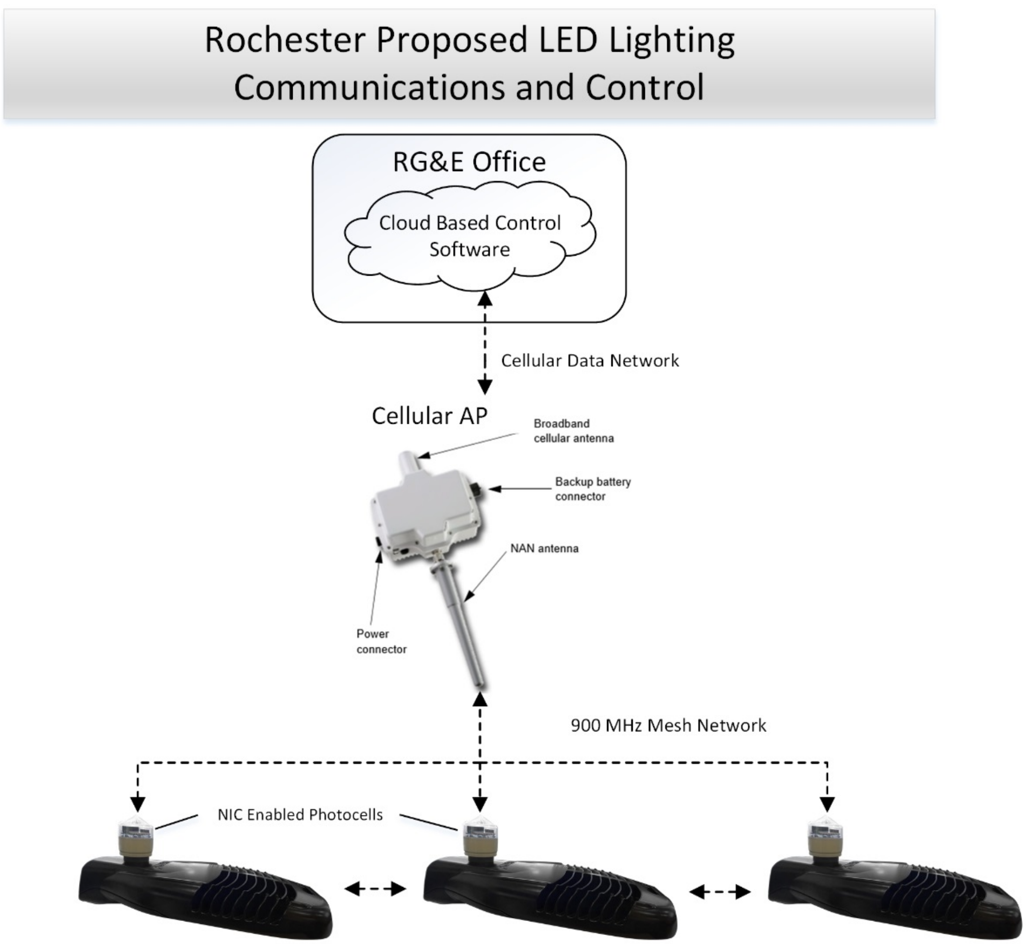


Figure 6 Rochester Proposed LED Lighting Communications and Control Diagram

In addition to meters and streetlights, circuit breakers, relays, re-closers and other switchgear are vital to the control of the Rochester Community Microgrid. While some distributed switchgear can utilize a similar wireless infrastructure, with data being fed through substations instead of through a cloud network, the control equipment is more vital to the safe operation of the Microgrid and would ideally use a fiber optic backbone between the RG&E data center and the local distribution substation. The substation relays may have to be upgraded to communicate using the DNP3 protocol over TCP/IP, the de facto standard for modern utility communications, which will be used to monitor and control the proposed DER as well.

Once in the data center, the data will be fed into an upgraded or added SCADA system to allow operators to access, visualize, and control, all of the Microgrid assets.

Benefits

Utilizing a fully connected microgrid, with every vital piece of equipment monitored and controlled remotely, the master controller will be able to optimize load and generation automatically and in real time, the Microgrid operators will be able to view the status, create reports, and plan future developments, and maintenance will be able to quickly assess and address any issues.

Barriers

A more extensive review of existing communications and control equipment needs to be performed to determine the exact quantity and specification of the upgrade, RF testing will need to be performed to determine the layout of the wireless network proposed. Training would have to be done on the SCADA system and the newly implemented relays, and personal may need to be hired to maintain the network and communications equipment. A review of costs of the current system, including streetlight usage and maintenance data, current metering system costs and inaccuracies, and outage information will have to be performed to determine exact cost savings of upgrading to the new system.

Task 2 – Develop Preliminary Design Costs and Configuration

Rochester Community Microgrid Existing and Proposed Overview			
Category	**Existing Resources**	**Proposed/Suggested Improvement**	**Justification**
Load	• Central Steam Heating Plants (Natural Gas Fired Boilers) • 6 Critical Facilities (Non-Coincident 3.7 MW Peak, 2.2 MW Average)	• Building Energy Efficiency • LED Street Lighting • Load Curtailment	• Resilience • Reduce Generator Size
Distributed Energy Resources (DERs)	• 1,100 kW Diesel Backup Generators • 800 kW Natural Gas Backup Generators	• 2.5-4 MW Combined Heat and Power (CHP) • 0-1 MW Solar and 0-250 kWh Energy Storage	• Resilience • Demand Response • Renewable Sources • Turn off Main Boilers During Summer Months
Electrical and Thermal Infrastructure	• Radial Path • Mostly overhead distributed cable	• High Reliability Distribution System • Self-Healing	• Resilience • Reliability
Master Controller and Building Controls	• Some Building Controls	• Connected Master controller • Upgraded building controls • Smart Charger/Inverter for Batteries/Solar	• Resilience • Optimal utilization of Microgrid Assets
IT/ Communication Infrastructure	• Manual Meters • Building Level Electric Load Metering	• Advanced Metering Infrastructure (AMI) • 900 MHz mesh network • Fiber optic backbone • Control interface for DER	• Resilience • Reliable real time information • Remote Control

Serving Critical Loads with Islanding in Peak Load Season (January)					
Islanding Days	**Load Curtailment**	**Resilience Weight (%)***	**Proposed DER Capacity(kW)**	**Operation Cost (K$)**	**Investment Cost (K$)**
7	0-40%	100% - 89.41%	2,916-1,700	4,686 –3,984	8,645 –4,971
6	0-40%	86.76% -76.18%	2,889-1,700	4,680-3,983	8,578 – 4,971
5	0-40%	73.53% - 62.94%	2,889-1,700	4,680-3,984	8,578 – 4,971
4	0-40%	49.71% - 73.53%	2,889-1,700	4,680-3,972	8,578 – 4,971
3	0-40%	47.06% - 36.47%	2,889-1,700	4,680-3,971	8,578 – 4,971

2	0-40%	33.82% - 23.24%	2,889-1,700	4,680-3,969	8,578 – 4,971
1	0-40%	20.59% - 10%	2,889-1,700	4,680-3,968	8,578 – 4,971

*Resiliency weight is introduced based on the maximum number of days that critical load capacity is powered on during the grid outage duration and maximum level of critical load which can be served. We define that the capability of serving critical load with no curtailment for seven days (as customer's requirement) is 100% resiliency and the capability of serving 60% critical load for one day is 10% resiliency

Task 2 Introduction

Rochester District Heating Cooperative (RDH) is proposing a feasibility study for implementing a Community Microgrid located in the City of Rochester downtown central business district that is interconnected with Rochester Gas and Electric's (RG&E) electric system. In addition to RDH, the participants in the feasibility study include Rochester Gas and Electric, which satisfies the required participation of the Local Electric and Fuel Distribution Company, and the City of Rochester, which satisfies the required participation of the Local Government.

Rochester District Heating Cooperative has a bulk heat load requirement every hour of the year. While summer thermal loads are significantly smaller than winter, RDH's primary boilers must still maintain operation year-round to meet the load. Additional heat generation from a centrally located CHP plant would allow RDH to meet its summer heat load without the expense of operating its main boilers, resulting in a savings of over $1.5 million per year. These savings would then be passed along to RDH's customers and members in the form of lower energy bills and membership costs. Additional capacity and resiliency via a community microgrid would promote growth for RDH and increase its redundancy in its thermal generation capacity. Willdan Energy Solutions (Willdan) recommends a community microgrid for the City of Rochester, which include the City of Rochester, RG&E/IUSA, Rochester Downtown Development Corporation, and Rochester District Heating, by providing a master controller which has the ability to perform, in real-time, reconfiguration of the microgrid functions, seamless islanding for economic, reliability, or resilience reasons, and optimization of storage and generation resources.

The City of Rochester's critical loads, which include the City Hall, the Public Safety Building, the Bausch+Lomb Library, and the Rundel Library, will remain powered on while the microgrid is islanded. In addition to providing resiliency for critical loads, Willdan's proposed Rochester Community Microgrid could provide power for the Cooperative's 4 MW peak load[2], which includes the Convention Center and the Blue Cross Arena, when the microgrid is islanded.

[2] Rochester Energy Profile.xlsx

Sub Task 2.1 Proposed Microgrid Infrastructure and Operations

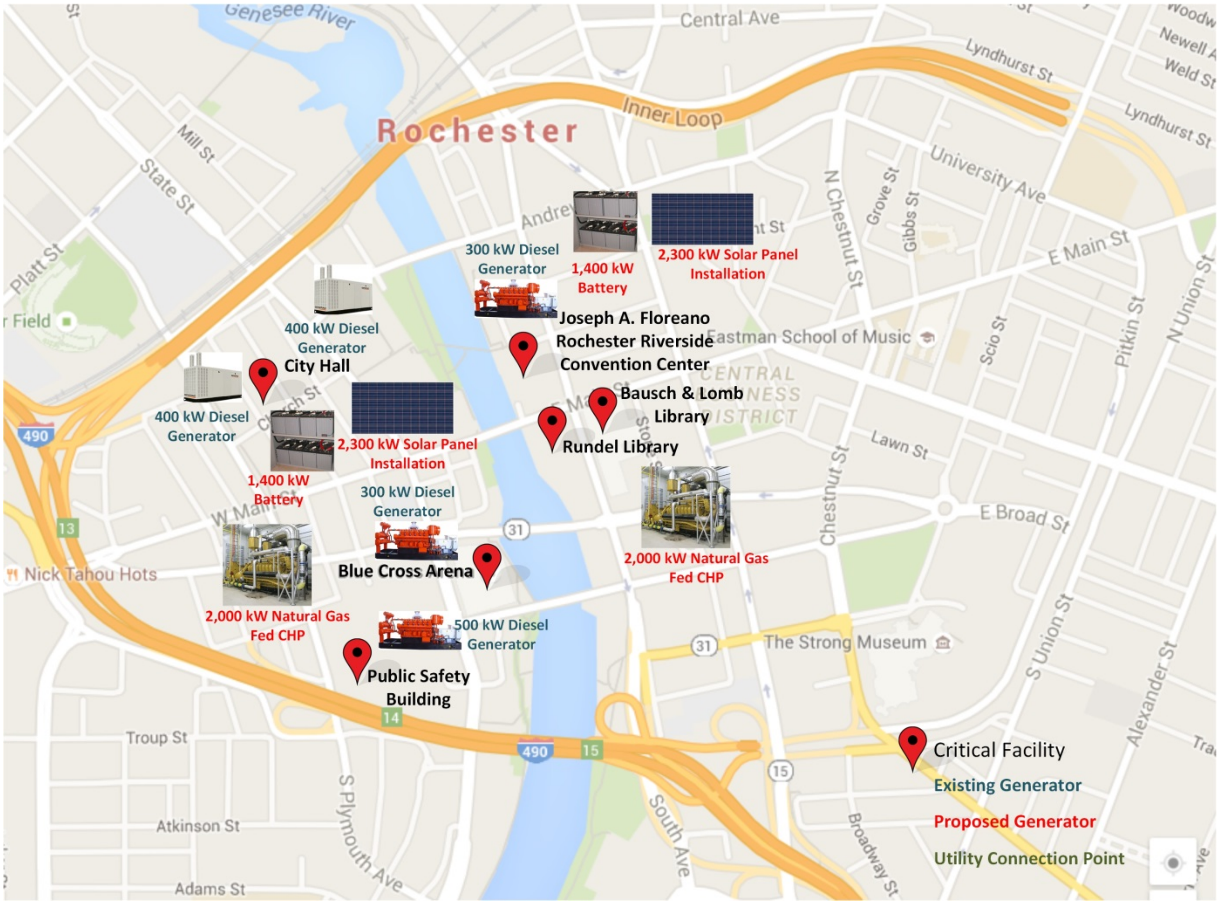


Figure 2.1.1 Generation simplified equipment layout diagram

Willdan recommends a community microgrid for the City of Rochester, which will enhance the overall operational reliability of the electrical distribution system. By providing a master controller, the Rochester community microgrid would be capable of seamless islanding and resynchronization for economic, reliability, or resilience purposes. Seamless islanding and resynchronization is defined as automatic separation from the grid on loss of utility power and automatic restoration of grid power after an outage on the grid side is cleared.

Normal operating conditions would see reliability improvements, through infrastructure reconfiguration, such as a High Reliability Distribution System (HRDS) which senses and clears faults with virtually no impact on building loads, to a self-healing and more fault tolerant grid, by reducing the number of single points of failure by adding redundancy to the electrical and communications networks, and by adding alternate sources of generation to serve critical and non-critical loads. In addition to increased reliability, the Rochester Community Microgrid would reap economic benefits in the form of added revenue streams from demand response, alternate generation sources, and energy efficiency measures to reduce overall energy costs, as well as participating in ancillary service markets such as fast regulation and operating reserve markets. Based on the price of electricity and availability of Distributed Energy Resources (DERs), the master controller will optimally dispatch the units to provide the cheapest, cleanest, and most reliable energy possible to the critical and non-critical microgrid facilities.

During emergency operating conditions, the Rochester Community Microgrid master controller would optimize generation and load to provide uninterrupted power to critical loads, through the use of DERs and load shedding schemes that ensure safe and reliable operation of the buildings that matter most in emergency situations. Long term outages will be mitigated by Solar Installations and by large natural gas fed combined heat and power (CHP) plant, which will maintain a black-start capability in the event the outage occurs when the CHP facility is not active. These plant or plants will rely on robust natural gas pipelines and produce enough power to serve all of the critical facilities, public street and security lighting, and some residential load. This added resiliency will keep emergency responders and residents safe and provide the Rochester Community Microgrid with heat and power when it needs it most.

Sub Task 2.2 Load Characterization

There are currently six major customers of the RDH, with a peak load of 4 MW. Due to the high population density in the City of Rochester and potentially harsh winter conditions, any bulk system disruption has the potential of creating hardship that can affect the safety of the community. A CHP-driven microgrid will also introduce additional redundancy into the existing RDH thermal system, allowing the main boilers to be shut down in the summer for regular maintenance, which will improve the safety of the overall system. Figure 2.2.1 shows the locations of critical facilities within Rochester. Figure 2.2.2 shows the monthly load demand in Rochester for the recent years. Figures 2.2.3 and 2.2.4 illustrate monthly kWh consumption profile of the Rochester system. The shape of the monthly kWh usage matches the Heating-Degree-Days (HDD) of the locality.

The City of Rochester's loads can be separated into the broad load categories, critical and non-critical, with critical facilities including the Bausch+Lomb Library, the Rundel Library, the City Hall Building, and the Public Safety Building, and non-critical facilities including the Convention Center and the Blue Cross Arena. The total non-coincident peak critical load demand is about 3.7 MW. The detailed load information for all the critical loads is shown in Table 2.2.2. The load demand in each facility can be further separated into the following load categories as shown in Table 2.2.1 to describe the unique nature of, and opportunities available for, the different load types. The Rochester District Heating Cooperative serves the summer and winter heating load of its customers through a central heating plant. The types of Heating and Cooling loads for each facility are seen in Table 2.2.3.

Table 2.2.1 - Electrical Load Type		
Type	**Description**	**Opportunities**
Lighting	General, task, exits, and stairwells, decorative, parking lot,	Load

	security, normal, and emergency.	curtailment
Transportation	Elevators, dumbwaiters, conveyors, escalators, and moving walkways.	Critical Load
Appliances	Business and copying machines, receptacles for vending machines, and general use	Load curtailment
Data processing	Desktop computers, central processing and peripheral equipment, and uninterruptible power supply (UPS) systems, including related cooling	Critical Load
Space conditioning	Heating, cooling, cleaning, pumping, and air-handling units	Short term Load curtailment and shifting
Food preparation	Cooling, cooking, special exhausts, dishwashing, disposing, and so forth	Load curtailment
Plumbing and sanitation	Water pumps, hot water heaters, sump and sewage pumps, incinerators, and waste handling	Short term load curtailment
Special loads	For equipment and facilities in mercantile buildings, restaurants, theaters, recreation and sports complexes, religious buildings, health care facilities, laboratories, broad casting stations, and so forth	Critical load
Fire protection	Fire detection, alarms, and pumps	Critical Load
Miscellaneous loads	Security, central control systems, communications; audio-visual, snow-melting, recreational, or fitness equipment	Critical load

Table 2.2.2 Critical Loads

Critical Facilities	**Peak kW**	**Average kW**
Joseph A. Floreano Rochester Riverside Convention Center	865	525
Bausch+Lomb Library	451	238
Rundel Library	250	121
Blue Cross Arena	1119	680
City Hall	521	253
Public Safety Building	570	455
Total	**3,776**	**2,272**

Table 2.2.3Heating and Cooling Source for Facilities		
Facility	**Heating**	**Cooling**
Joseph A. Floreano Rochester Riverside Convention Center	Boilers, Hot Water	Chillers
Bausch+Lomb Library	RDH, Steam	Heat Pumps
Rundel Library	RDH, Steam	Chiller
Blue Cross Arena	RDH, Steam	Monroe County Chilled Water
City Hall	RDH, Steam	Heat Pumps and Chiller
Public Safety Building	RDH, Steam	Heat Pumps

Consequences

Due to a minimum heating demand during the summer months, RDH is currently required to operate their main boilers at a fraction of their capacity all throughout the summer. This inefficient operation results in a significantly higher cost of operation than would be necessary if there was another way to meet the summer heating load. In addition, due to the summer heating load there is no way to shut down the boilers for necessary maintenance.

Opportunities

Rochester will explore placing the microgrid's CHP on the steam loop and adding distributed generation resources such as solar panels on the available roof space of critical facilities. This will allow the RDH to shut down its main boilers for maintenance in the summer, saving them significant time, energy, and money. As most of the facilities are commercial buildings, solar installations will help mitigate peak demands that occur during the middle of the day, when solar is most effective, and can serve to power the facilities in the event of a system outage. By applying an Advanced Metering Infrastructure (AMI), it would help consumers by providing real-time monitoring of their utility usage. Energy consumers would be encouraged with variable pricing to shift their use from high demand periods to low demand periods. By decreasing peak demand surges the entire energy infrastructure could be run more efficiently.

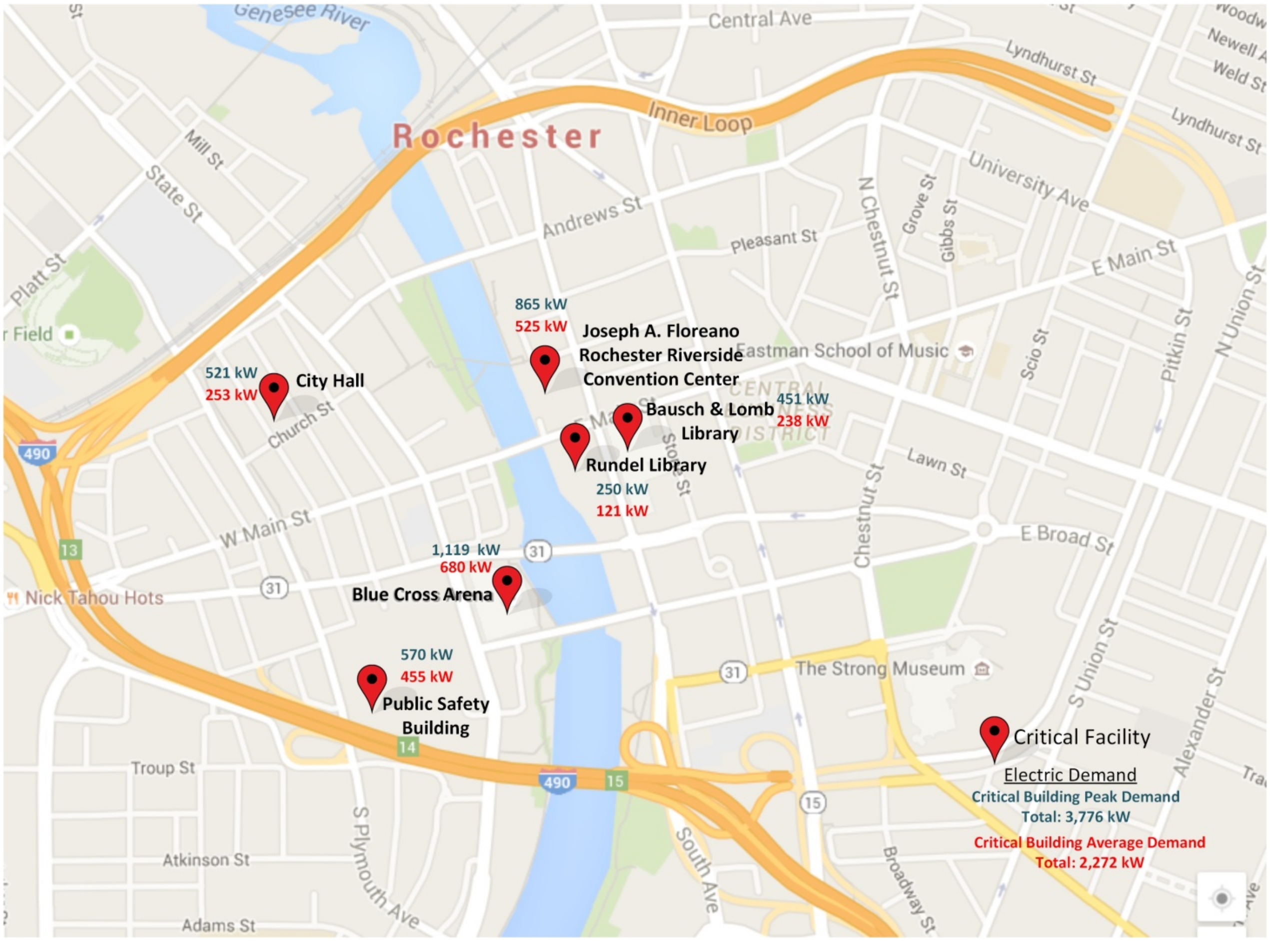


Figure 2.2.1 Load simplified equipment layout diagram

Table 2.2.4 Electric Demand for Rochester (2014)		
Source	**Summer Peak**	**Winter Peak**
Coincident	3.1 MW	3.3 MW
Non-Coincident	3.5 MW	3.8 MW
Average	2.0 MW	2.5 MW

Table 2.2.5 Electricity Usage	
Month	**Energy (MWh)**
January, 2014	649.4
February, 2014	655.9
March, 2014	631.3
April, 2014	635.9
May, 2014	606.2
June, 2014	650.3
July, 2014	679.4
August, 2014	620.5
September, 2014	618.0
October, 2014	654.6
November, 2014	678.2
December, 2014	641.7

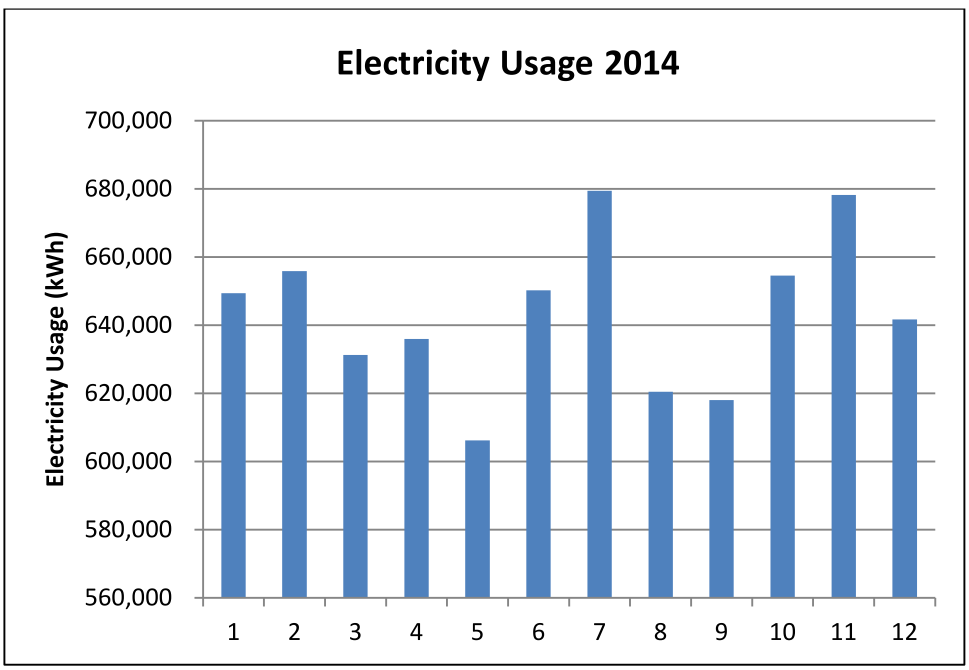


Figure 2.2.2 Electricity Usage 2014

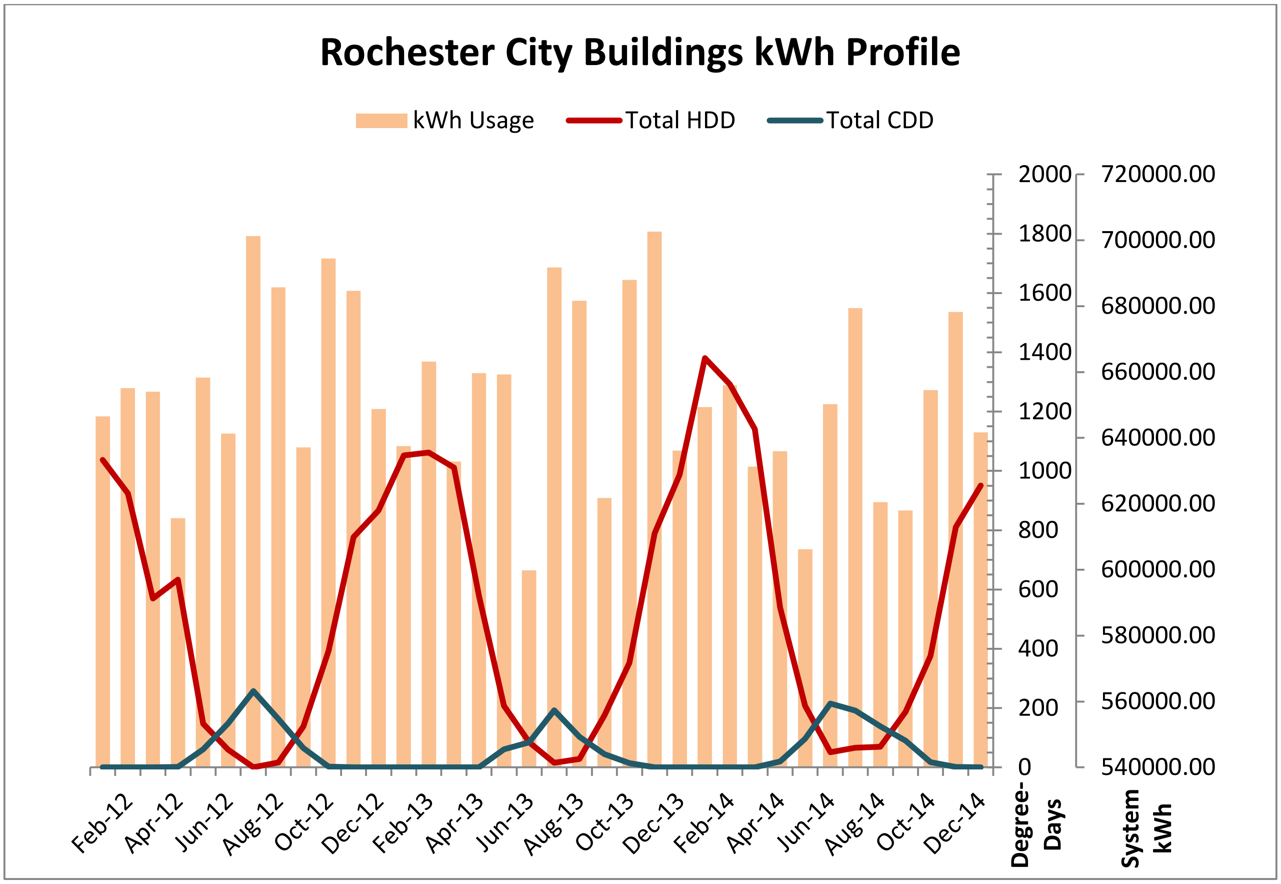


Figure 2.2.3 Rochester Monthly Energy Profile

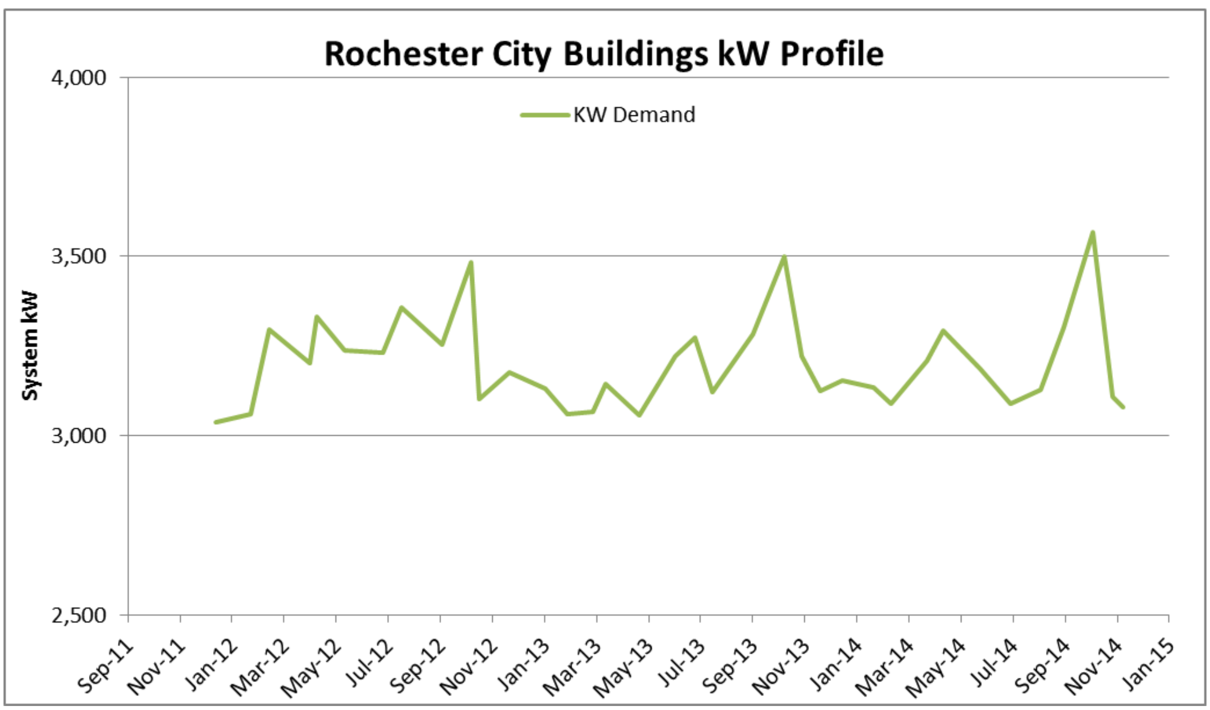


Figure 2.2.4 Rochester Monthly Demand Profile

Proposed/Suggested Improvements

A community microgrid would be helpful for solving the existing limitations in the RDH system by providing additional steam capacity and electric resiliency. Willdan recommends supporting critical facilities with distributed generation resources including CHP generators, locating between 2.5-4 MW of generation resources on the RDH Steam loop, which will operate in inter-connected and island modes to automatically supply electricity to facilities in the event of an outage while maintaining steam and electricity production during normal operating conditions. The proposed generators will be primarily fueled by natural gas. Solar installations totaling between 0 and 1 MW combined with an energy storage system of between 0 and 250 kWh, distributed among the critical facilities, will provide a renewable source of power while lowering the overall cost of electricity in interconnected mode and outage in island mode. Willdan recommends replacing all the existing lighting with high efficient LED (Light Emitting Diode) fixtures. By applying the latest building control technology in each building, building owners would be able to have the direct control capability on the curtailable and shift-able loads.

Benefits

With a community microgrid, Rochester would be able to provide more reliable electricity to its facilities. The critical facilities could remain powered on even in emergency situation when the power supply from the utility grid is lost. The community microgrid would also help RDH avoid a large cost by shutting down its main boilers in the summer. By using the more efficient and safe LEDs for public street lighting and residential lighting, both the community and residential customers can reduce maintenance cost and electricity bills. With the capability of direct control on the generation and loads, Rochester would not only be able to improve the reliability of the community distribution system, but have the potential to participate in ancillary service market such as, frequency regulation, demand response, etc. the included facilities would have better quality of electricity service while cutting their electricity bills at the same time.

Barriers

Implementing the community microgrid would require new investment in generation resources. A greater review of the exact equipment installed must be done to determine any necessary reconfiguration of the existing distribution network and communication system. The previously indicated available space for any added generation resources has been taken back by the city and by the RG&E. RG&E has no capacity constraints in downtown Rochester and overall would not benefit from the microgrid project. Available roof space and building space would be needed for solar panel installations, for the panels themselves and for the necessary inverters.

Data Visualization

Figure 2.2.5 shows the average hourly load profile of the total system load that is served by the Rochester Community Microgrid. The hourly load is broken down by month to reflect the different usage by month seen in Figures 2.2.5, 2.2.4, and 2.2.2 as well as in Table 2.2.4. It can be seen that the load is mostly commercial, with some base load at night and most of the load occurring during the daytime hours.

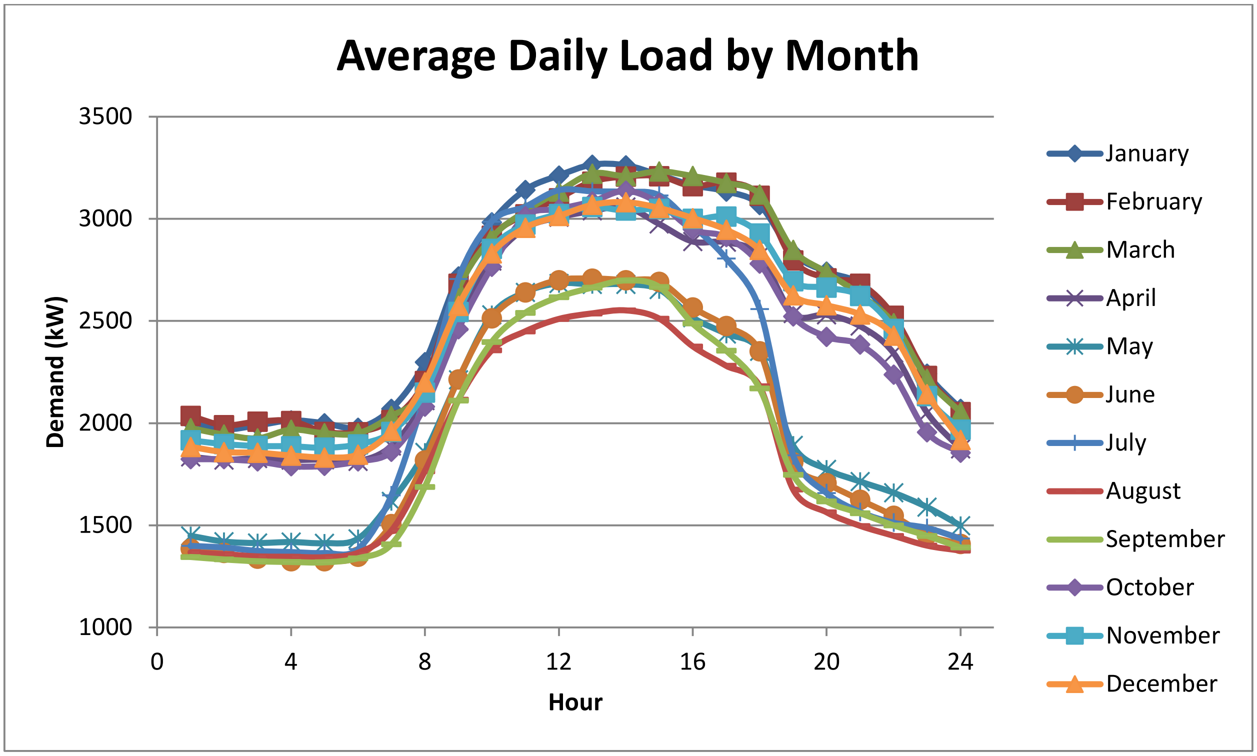


Figure 2.2.5 Rochester Average Daily Load by Month[3]

The proposed Rochester Community Microgrid focuses on providing electricity for the critical buildings while meeting the summer heating load. The installation of 2.5-4 MW of generation would be able to adequately serve the entire load, depending on the amount of roof space available for solar panels and the level of load shedding implemented.

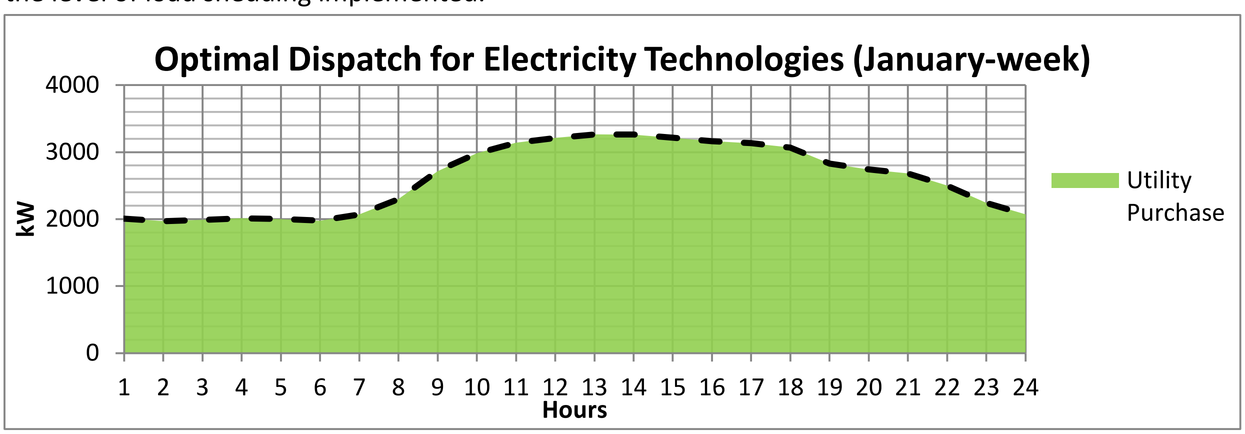


Figure 2.2.6 Pre Investment Average Electricity Dispatch

[3] From Rochester Hourly Data

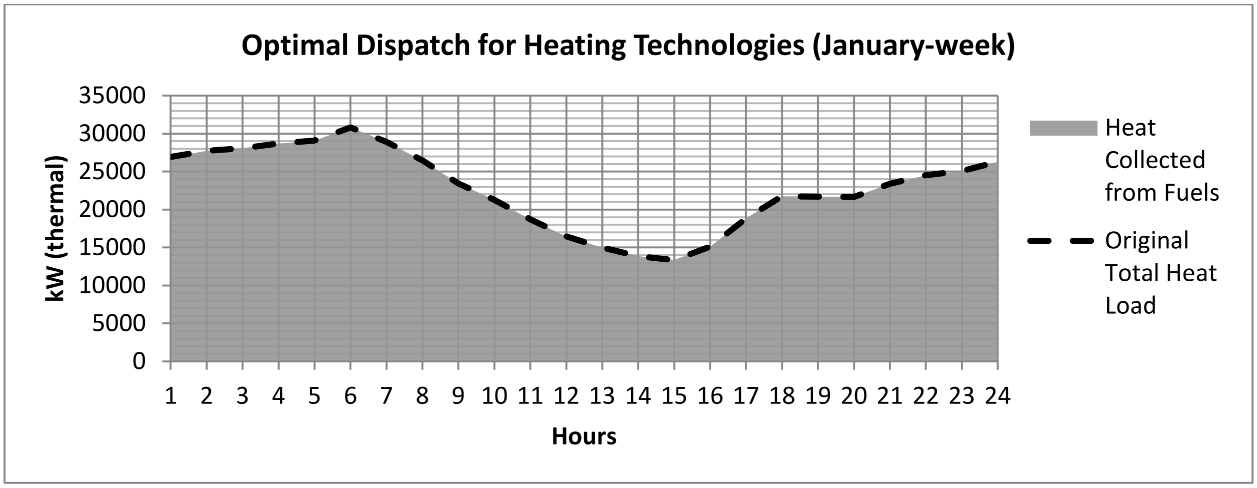


Figure 2.2.7 Pre Investment Average Heating Dispatch

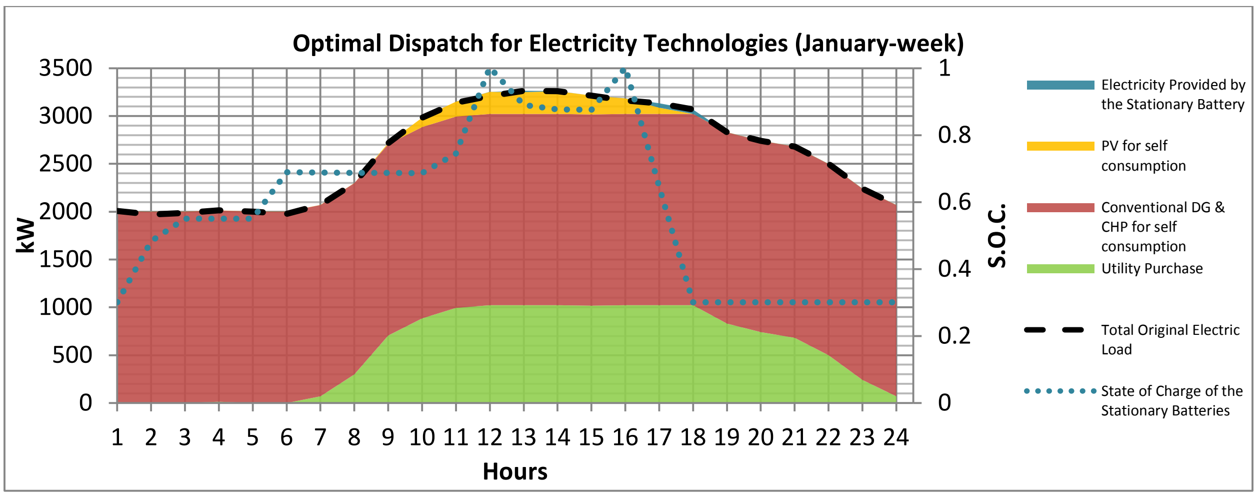


Figure 2.2.8 Example Post Investment Average Electricity Dispatch

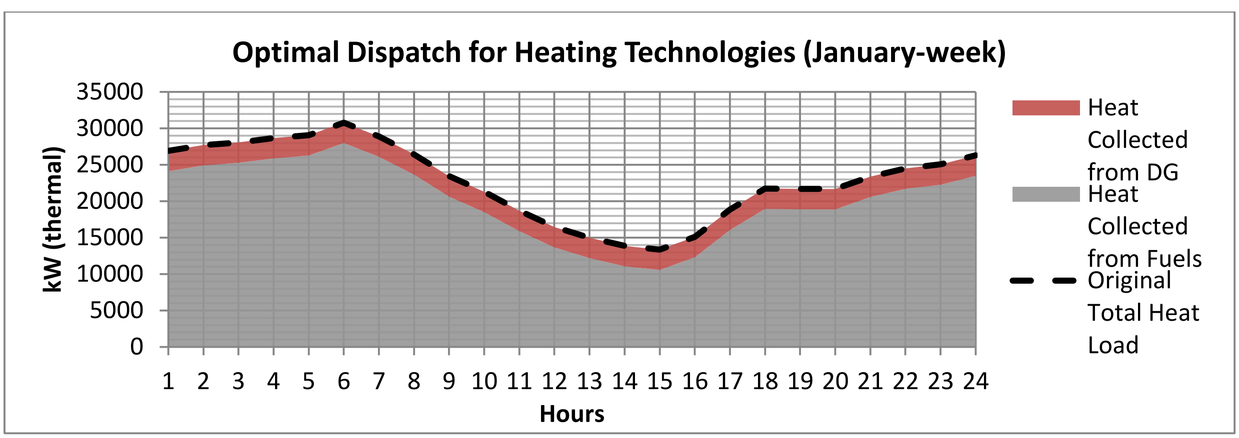


Figure 2.2.9 Example Post Investment Average Heating Dispatch

Figures 2.2.6 and 2.2.7 show DER-CAM simulation results for the critical buildings in the Rochester Community Microgrid under normal base conditions with no added generation. It can be seen that the electric load peaks around noon and the facilities have a relatively high base load at night. Figures 2.2.8 and 2.2.9 show the same time period and load being served, but includes the proposed CHP and solar panel installation being optimally dispatched throughout the day. It can be seen that the heat generated is a small portion of the January heating load and is only enough to meet the summer heating demand, which was determined to be around 5.6 MW, and that the electricity purchased from the utility is lowered to nearly nothing due to the dispatch of Solar and CHP.

Proposed Energy Efficiency Improvements

Willdan recommends an energy efficiency program for Rochester community for the purpose of economics and reliability. In addition to standard EEMs, Willdan recommends considering a time of use (TOU) electricity price mechanism. By applying TOU within Rochester community, the customers can save both on energy cost and peak-demand charge by curtailing energy usage or shifting their energy usage from peak load hours to off-peak load hours, and then reduce the amount of energy bill. By shifting the energy usage from peak load hours to off-peak load hours, the overload on the distribution cables and substations would be mitigated and the reliability of Rochester's distribution system would be improved.

Sub Task 2.3 Distributed Energy Resources Characterization

Existing Resources

Existing DERs located in the proposed Rochester Community Microgrid are used primarily as backup generators in the event that utility power is interrupted. Most of the backup generators are diesel generators, with only one facility having natural gas generators, and are distributed among the critical facilities and retain about a week of fuel. Existing DER respective to critical load compared the building peak demand and are shown in Table 2.3.1 and the DER location and capacity are also shown in Figure 2.1.1.

Consequences

While the critical loads have an average demand of about 2.2 MW and the DERs total 1.9 MW of generation, indicating that there is enough generation to provide critical loads with power with only minor load shedding in the event of an emergency. However, due to the location of the generators, this means that only the City Hall Building and the Public Safety Building would be able to meet most of their load in the event of an emergency. Both the Convention Center and the Blue Cross Arena would be able to meet a fraction of their load, while the two libraries would be completely in the dark. Any ability to utilize the libraries as emergency shelters would be lost if they remain without backup generation or without power. In addition, the community pays to maintain and test the backup generators, or runs risk of the generators not working when needed, and doesn't see any value added beyond emergency situations. Finally, it is worth noting that most of the generation runs off of diesel fuel, which is a relatively dirty fuel source compared to natural gas, contributes to the reduction of the the quality of the air, increases the carbon footprint of the City of Rochester, and must be stored or shipped into the City in the event of an outage.

Table 2.3.1. Existing Backup Generators and Critical Facilities

Location	Capacity (kW)	Fuel Type	Peak Demand (kW)
Joseph A. Floreano Rochester Riverside Convention Center	300	Diesel	865
Bausch+Lomb Library	0	-	451
Rundel Library	0	-	250
Blue Cross Arena	300	Diesel	1119
City Hall	800	Natural Gas	521
Public Safety Building	500	Diesel	570
Total	**1,100 kW Diesel, 800 kW Natural Gas**		**3,776**

Opportunities

Rochester is exploring innovative projects and smart grid circuit isolation to meet its demand and consumption needs such as using combined heat and power (CHP) generation and solar panel installations. The additional heat capacity provided by CHP will be utilized to improve the year-round efficiency of the RDH cooperative. This expansion would also allow Rochester facilities to participate in Demand Response programs and reduce its dependency on electric power purchases.

Proposed/Suggested Improvements

A screening of the available DER technology (Table 2.3.2) available to the Rochester Community Microgrid favors CHP, Batteries as Energy Storage, Solar, and ICE DG as black start generators for CHP.

At this point, there are no existing generators in either of the two large libraries. These libraries could act as critical emergency shelters in a number of different emergency situations if they had backup power. Willdan recommends that a potential 2 MW CHP be located along the RDH steam loop but close to these facilities to serve them in the event of an emergency. The additional 2 MW of CHP could be located in the same facility, or across the river at the Public Safety office or the City Hall, as these are also critical facilities.

The proposed generation listed above would provide Rochester with the eligibility to participate in NY Demand Response Program and to earn up to $309,280 per year or more in addition to the resilience and economic benefits. Assuming that a total of 2.5MW DERs are able to participate in the capacity market ($298.67/MW per day[4]), regulation market ($12.87/MWh[5]) and demand

[4] http://www.nyiso.com/public/markets_operations/market_data/icap/index.jsp

[5] http://www.nyiso.com/public/webdocs/markets_operations/documents/Studies_and_Reports/Reports/Market_Monitoring_Unit_Reports/2014/NYISO2014SOMReport__5-13-2015_Final.pdf (Page 12)

response market ($500/MWh[6]), the annual demand response period is assumed as 20 hour, so the income would be $309,280=2.5*365*298.67+365*2.5*12.87+20*2.5*500.

Table 2.3.2 - Distributed Energy Resources

Type	**Description**	**Barriers**	**Opportunities**
Combined Heat and Power (CHP)	Natural Gas fired turbines used to generate electricity and provide heat to nearby buildings	Space, Capital Cost, Cost of NG, Heating Infrastructure	Clean and Reliable, Reduce winter peak load, Resiliency
Solar	Renewable energy source powered by the sun	$/kW of solar is greater than electricity price	Clean, Reduce daytime peak load
Electric Storage	Converts electrical energy to chemical or mechanical for rapid dispatch when needed	Space, Capital Cost	Fast Regulation, Provides power during NG spool up
ICE Distributed Generation (ICE DG)	Backup generation	Cost, Range of use, Maintenance	Black Start for CHP, Provides power during NG spool up
Wind	Renewable energy source powered by the wind	Space, Capital Cost, maintenance	Clean Source
Hydro	Renewable energy source powered by the flow of water	Location, Cost, maintenance	Clean Source
Alternative Fuel Sources	Production of fuel from local processes (garbage dump, WWTP)	Supply	Converts waste into electricity

Benefits

The addition of a range of DERs, including long term sources like CHP, short term sources like Batteries and ICE DG, and renewables like solar would allow the Rochester facilities to operate as a microgrid, take advantage of new revenue streams such as Demand Response and Fast Regulation Markets, increase resiliency through on-site generation, and reduce charges associated with summer heating loads by allowing the RDH to shut down its main boilers. Distribution of these additional resources close to the libraries, and the public safety building or city hall will ensure that critical facilities will remain powered on in emergencies, providing the City of Rochester with peace of mind.

Barriers

Additional modeling will be performed to determine exact size and capacity of the proposed units, to ensure feasibility from financial and space requirements. Plant managers for CHP will have to be hired internally or externally and training will be required for maintenance and operators of the proposed DERs.

[6]http://www.nyiso.com/public/webdocs/markets_operations/services/market_training/workshops_courses/Training_Course_Materials/NYMOC_MT_ALL_201/Demand_Response.pdf, Page 45-46

As Natural Gas fed CHP is the most feasible option for the Rochester Community Microgrid, the microgrid will rely heavily on Natural gas pipelines to power the facilities. Pipelines are highly resilient to inclement weather, but do have the potential to break down or be damaged. This would have to be monitored closely by Rochester to prevent any small issues from becoming major problems if there is an interruption in natural gas supply.

Furthermore, based on preliminary sensitivity analysis for the critical facilities, the Rochester Community Microgrid is sensitive to the increases of Electricity price (Figure 2.3.1). When Electricity price fluctuates, Rochester may need to consider further diversification of their DERs to include renewables or other forms of generation. In addition, the Rochester Community Microgrid would be highly sensitive to natural gas price increase, with a large portion of its power and heating load being served by natural gas, Figure 2.3.2. As natural Gas price increases slightly, more Solar Generation is recommended to offset the higher cost of generating electricity through CHP. Around 6 c/kWh natural gas, CHP is no longer recommended as the most cost effective option, without considering the significant benefits from shutting down the main boiler or participation in Demand Response.

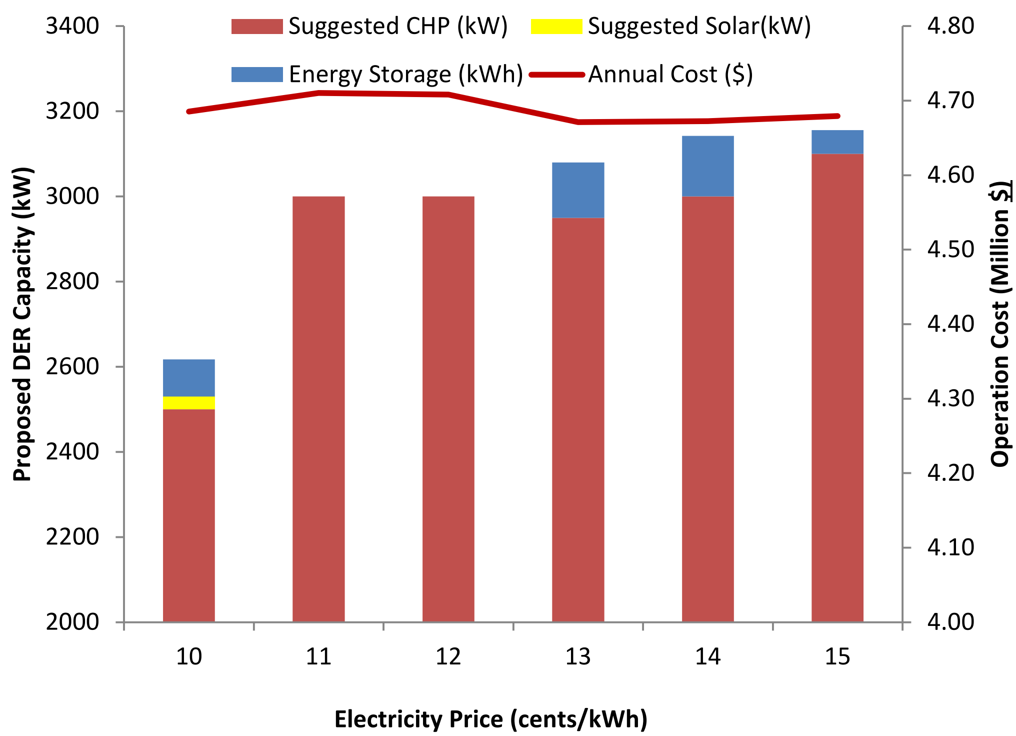


Figure 2.3.1 Sensitivity Analysis Results for Electricity Price

The Rochester Community Microgrid master controller would determine the optimal and reliable operation of microgrid through optimal generation dispatch and load signals. The generation dispatch signals are sent to dispatchable distributed energy resource (DER) units and the load signals are sent to building controllers. An interactive grid-forming control would be used either in island or grid-connected mode. In island mode, DERs apply this control scheme to share the load while in the grid-connected mode. DERs apply this control scheme to regulate the power exchange between the microgrid and the utility grid. In the grid-connected mode, the DER unit with grid-following control follows the microgrid voltage and frequency, which is set by the utility grid in grid-connected mode and other DER units in island mode.

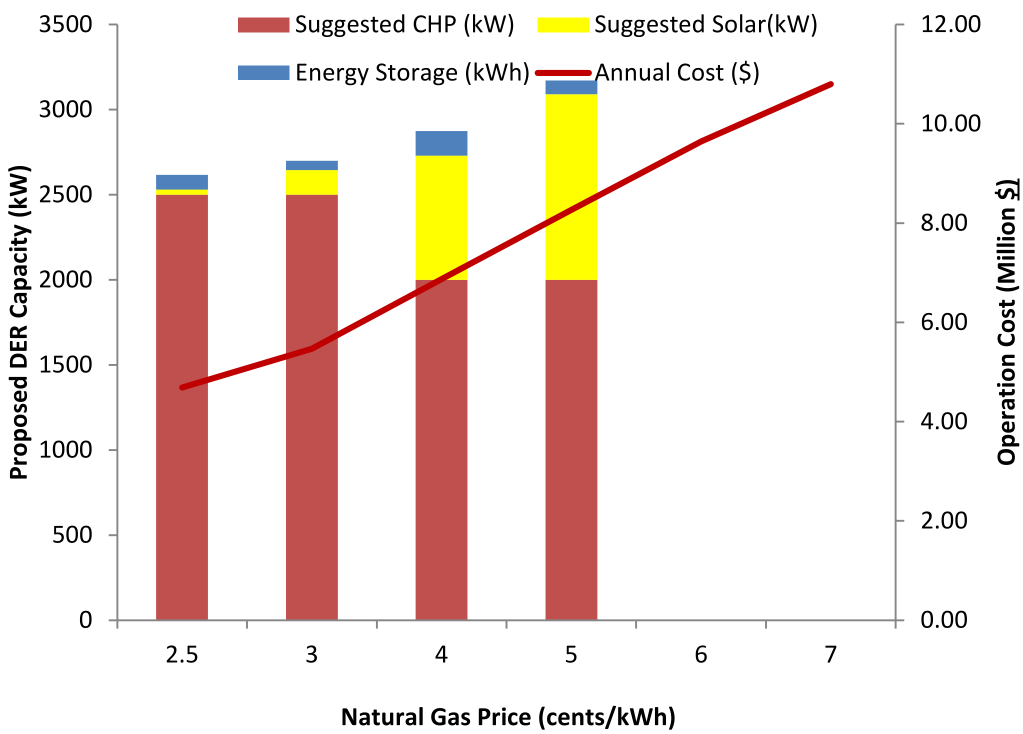


Figure 2.3.2 Sensitivity Analysis Results for Natural Gas Price

DOE TAP Findings

As part of the Department of Energy (DOE)'s Northeast CHP Technical Assistance Program (TAP), CHP has been studied for the Rochester District Heating Cooperative in Rochester, NY. It was determined that the annual thermal demand for the district heating system is 511,000 MMBtu, with an average demand of 58.33 MMBtu/hr. The annual steam production is 270,000 Mlb, with an average steam flow of 30,830 pph. It was determined that the average steam flow in the summer base load period (May 1st – September 30th) is approximately 15,000 pph (19.48 MMBtu/hr). Thus, the proposed CHP system was sized to meet the varying thermal demand in this summer base load period. It is assumed that the CHP system will maintain a constant thermal output of 19.48 MMBtu/hr the rest of the year (October 1st to April 30th); where the thermal output from the CHP system will offset the overall thermal demand of the RDH system. This corresponds to an annual base load thermal demand of 201,995 MMBtu, with an average annual demand of 23 MMBtu/hr. Based on collected utility information, the average electricity and thermal fuel costs are $0.10/kWh and $3.27/MMBtu, respectively[7].

Four main configurations were tested with option one and option 2 being the best options, Figure 2.3.3 and 2.3.4.

	Option #1	Option #2
CHP Configuration	Recip. engine	Recip. engine
Number Prime Movers	3	3
Total Output (MW)	3.9	4.278

Figure 2.3.3 CHP Configurations

	Base Case	Option #1	Option #2
Thermal Fuel Price ($/MMbtu)	$3.27	$3.27	$3.27
CHP Natural Gas Price ($/MMbtu)	$3.27	$3.27	$3.27
Base Electric Rate ($/kWh)	$0.10	$0.10	$0.10
CHP Fuel Costs ($)	N/A	$1,151,900	$1,084,267
Total Electric Cost ($)	$1,449,019	-$918,482	-$1,089,913
Incremental O&M Costs ($)	N/A	$657,197	$725,769
Total Annual Costs ($)	$2,297,804	$1,063,400	$966,626
Annual Operating Savings ($)	N/A	$1,234,403	$1,331,178
CHP Capital Costs ($)	N/A	$11,700,900	$12,834,000
Simple Payback (years)	N/A	9.48	9.64

Figure 2.3.4 CHP Operating Savings and Simple Payback[8]

These findings mirror Willdan's except that DER-CAM, the simulation software used to determine the exact capacity of the DERs, limited the amount of CHP by the average electrical load. This resulted in a lower simulated suggestion of 2.5 MW to prevent over generation. The owner will have to take this as a design configuration question moving forward; however, both

[7] RDH Feasibility Report.pdf

[8] Option 2 has a larger capacity generator than option 1, 4.3 MW to 3.9 MW, but uses less fuel, $67,633 less annually, due to the greater rated efficiency of the larger unit meeting the same load under both simulations

Willdan and the DOE findings support the financial and technical feasibility of combined heat and power systems.

Sub Task 2.4 Electrical and Thermal Infrastructure Characterization

Electrical and Thermal Infrastructure

Rochester Gas and Electric (RG&E) owns the electric and gas distribution infrastructures in the City of Rochester. These resources include substations, transformers, switchgear, underground transmission lines, and communications equipment in unknown quantities. There are two substations located within Rochester community. The distribution system in Rochester, which connects the two substations (SUB 6 and SUB 26), is shown in Figure 2.4.1.

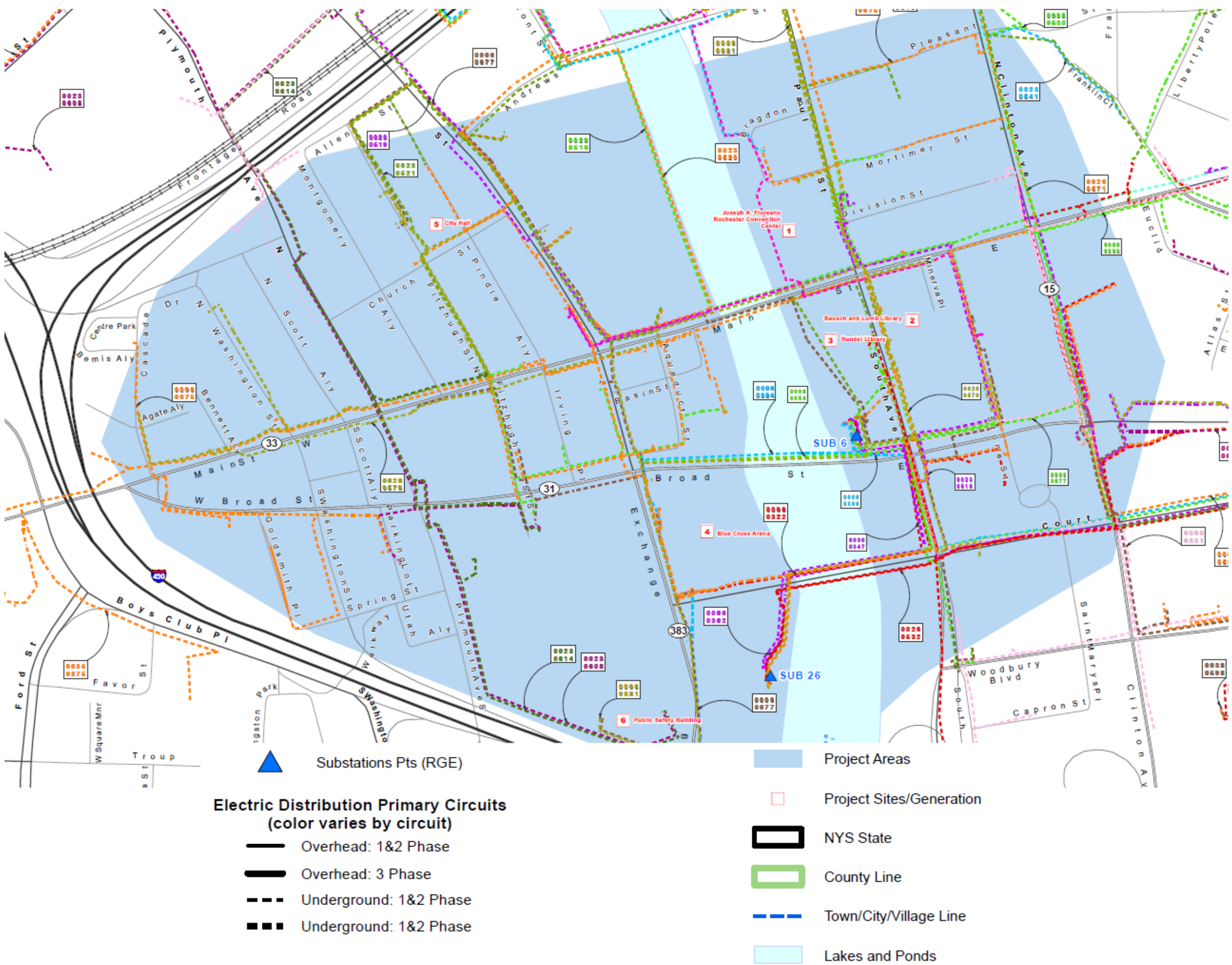


Figure 2.4.1 Distribution system in Rochester

Currently, there are no permanent generation resources anywhere in the proposed microgrid system. 800 kW of natural gas generation at City Hall and 300 kW of CHP at RDH's headquarters are expected to come on line, but are not sufficient to support the City's six (6) critical electric loads. Aside from these planned resources, only 800 kW of backup diesel generation exists in the proposed system.

Existing DERs located in Rochester Community are used primarily as backup generators in the event that utility power is interrupted. Willdan recommends 2.5-4 MW CHP, 0-250 kWh battery and 0-1 MW solar PV in order to supply power to critical facilities in case of grid outage and improve the reliability and resiliency of the Rochester's distribution system. The total generation capacity would be enough to supply power for critical electrical loads in peak hours.

Willdan recommends a Loop-based community microgrid for Rochester. This new distribution network has a meshed structure which can operate as loop or radial, though it would normally operate as radial (i.e., with no loop) so as to make the protection coordination easier (upstream to downstream) and to make the distribution design easier. Also, Automatic Transfer Switches (ATS) are proposed to be deployed within the community microgrid, which have the capability of network reconfiguration in case of emergency or outage. The conceptual design of the Rochester's distribution network for supplying power to the critical loads is shown in Figure 2.4.1, the square represents the ATS which can operate in three ways to reconfigure the network or isolate the loads. Once the existing distribution system network is available, a more detailed design will be presented for Rochester community microgrid.

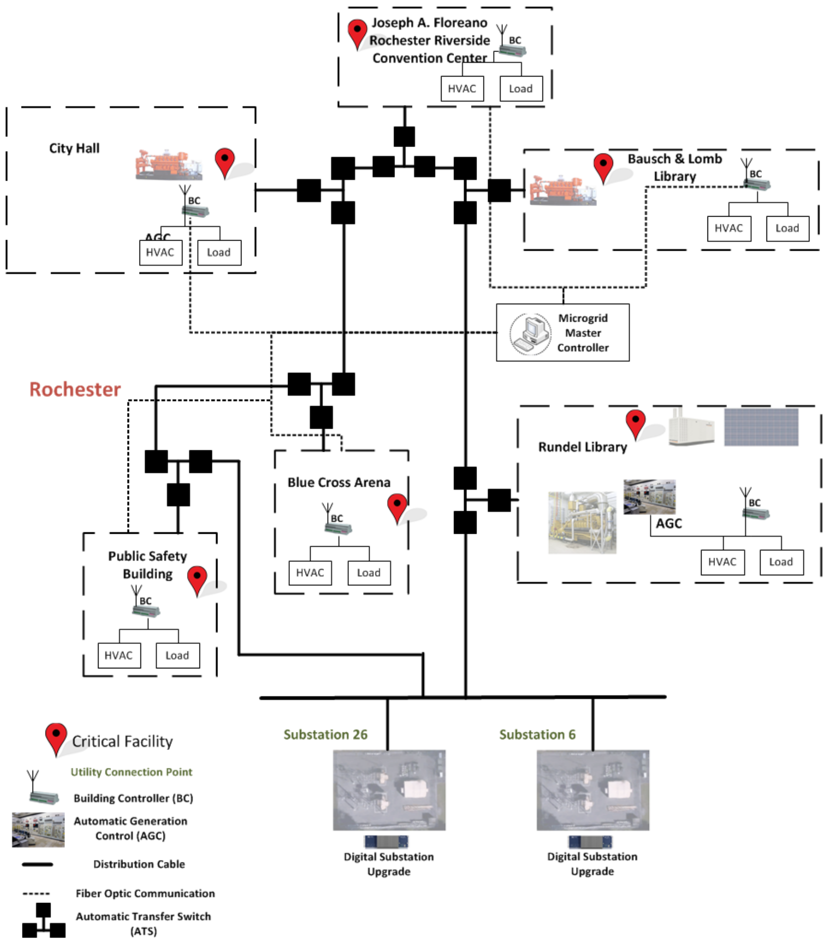


Figure 2.4.1 Conceptual Design of Rochester Community Microgrid

Resilience of the Electrical and thermal Infrastructure

This failure of points of connection would remove electric service to all of Rochester's customers, including critical facilities such as city hall and public safety services. The community of Rochester has long been concerned about the vulnerability to interruption of bulk supply.

Resilience refers to the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions, i.e., the ability to recover from a disturbance[9]. The electrical and thermal infrastructure is vulnerable to many phenomena, such as, hurricanes, earthquakes, drought, wildfire, flooding, and extreme temperatures, etc. Some extreme weather events have become frequent and severe in recent years due to climate change. Snow storms and peak loads in winter season could cause equipment damages or outages on the distribution system in Rochester. Also heat waves in summer could affect distribution line conductor sags and any equipment that needs to be cooled off, such as, transformers, battery storage, etc. A wind gust could cause tower/pole and

[9] Increasing the Resilience, Reliability, Safety, and Asset Security of TS&D Infrastructure. Available online: http://energy.gov/sites/prod/files/2015/04/f22/QER%20ch2%20final_1.pdf

conductor faults due to trees falling. It would be also necessary to upgrade designs and focus more on emergency planning and restoration. For example, hurricane sandy occurred in 2012, which caused a widespread blackout of the power system in the eastern seaboard and left millions of homes in the dark from a couple hours to a few weeks. Natural gas disruptions are less likely than electricity disruptions, however, it is relatively more difficult to recover from the natural gas system failure driven outages than electric systems because of the difficulty to locate and repair the underground leakages. The extreme weather would affect both individual equipment failure and system operations. The damage from such events can impose large costs on distribution system as well as severe impact on the local economies.

In order to optimize the selection and operation of distributed energy resources, DER-CAM is applied here for microgrid simulations. A case in which maintaining the critical facilities' power with a one week disruption of power supply from the utility grid is presented here to show the investment options for addressing the system resilience. Table 2.4.1 and Figures 2.4.4-2.4.5 present the DER-CAM simulation results. DER-CAM suggested 2,600 kW CHP, and 250kW solar PV along with battery to supply power to all Rochester' critical facilities where even there are seven day's outages in utility grid. Shown in Figure 2.4.4, the proposed community would mainly depend its own DERS (proposed and existing) to supply the load demand (left pie chart). The middle pie chart in Figure 2.4.4 shows the DER-CAM suggestions and right pie chart is the existing DERs as the input data for DER-CAM simulations, all these pie charts are produced by DER-CAM. It can be seen from Figure 2.4.5-1 that all the critical facilities can be satisfied by the new added DERs along with the existing generation resources. The local DERs can also provide power to critical facilities during grid-connected mode shown in Figure 2.4.5-2 which would improve the energy resilience of the critical facilities. It can be seen that the critical facilities would mainly be served by the proposed CHPs even in grid-connected mode.

Table 2.4.1 The annual costs savings by the investment for supplying the Facilities in Rochester and Tarrytown with islanding in peak load season (July)

	Base Case (no investment)	Investment Case (investment)	Saving
Total Annual Energy Costs (K$)	5601.9	4676.8	**16.5%**

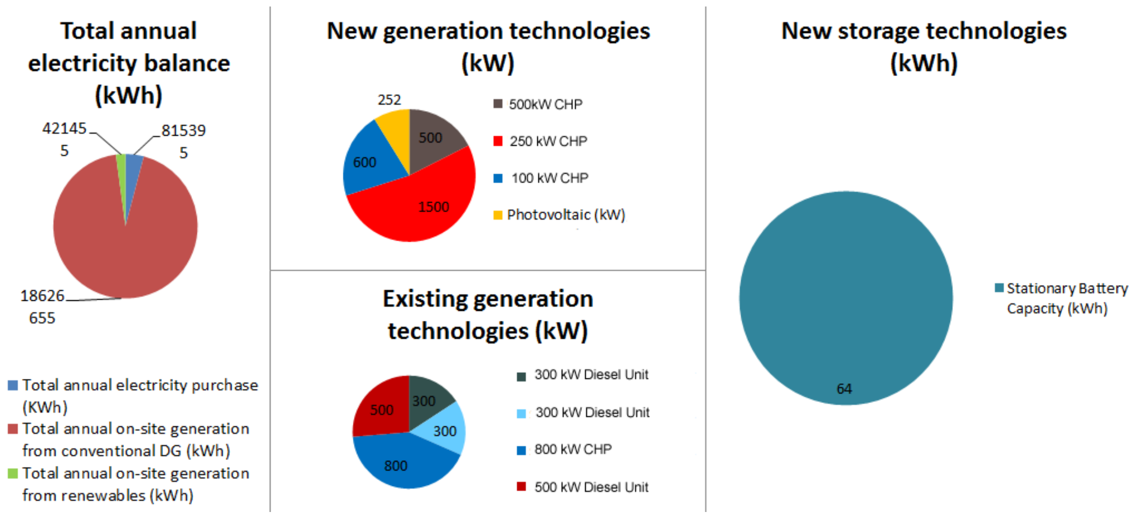


Figure 2.4.4 DER-CAM investment results – Serving Total System Critical Facilities with one week island in January[10]

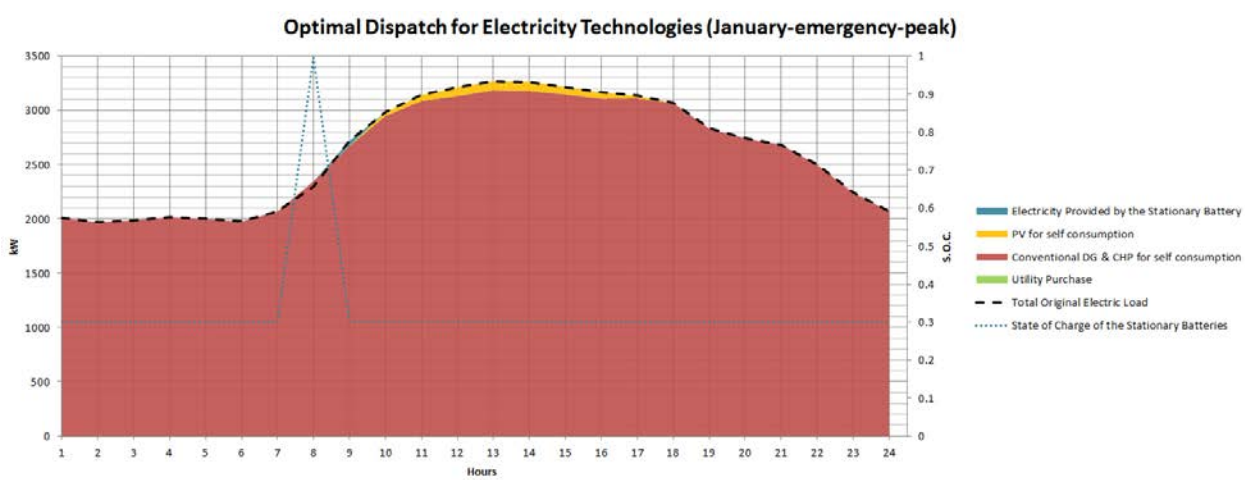


Figure 2.4.5-1 Total System Optimal Dispatch during islanding mode

[10] DER-CAM simulation results.

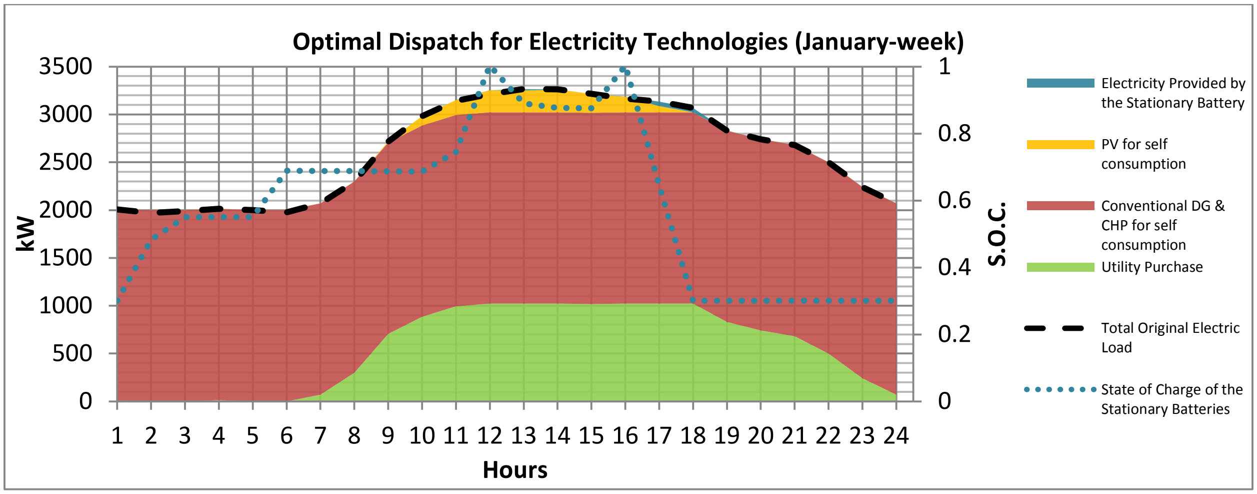


Figure 2.4.5-2 Total System Optimal Dispatch in Grid-Connected Mode

Regarding the critical facilities, DER-CAM is applied for the analysis of serving power to critical facilities with different islanding time periods, from one day to one week, and also different load levels are taken into account (load curtailment levels). The proposed DER capacity and operational costs to serve all the critical facilities (100% level/No curtailment) obtained from DER-CAM simulation are shown in Figure 2.4.6. The proposed new capacity would depend on the peak critical load and doesn't change along with the islanding time period. The operational costs are almost flat with the increase of islanding time period in the 100% load level since most of the loads is served by local DERs and local DER operation cost is only depend on natural gas price. While DER operation is dependent only on natural gas price, overall operation cost, included as the red line the charts below, includes amortized capital cost as well as the cost of running diesel backup generators, which is more expensive per kWh than the natural gas turbines. These differences explain the only minor fluctuations in operation cost as the level of DER proposed changes to serve the microgrid during islanding.

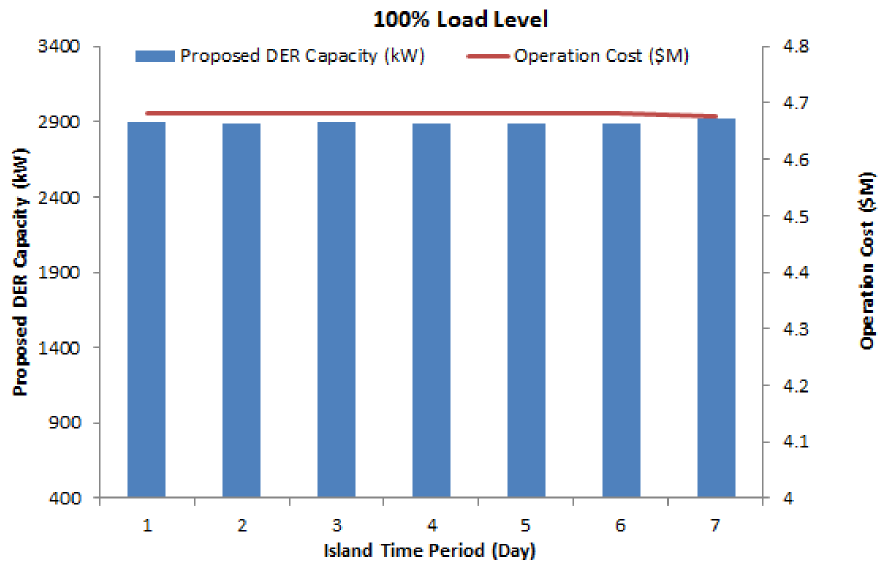


Figure 2.4.6 Proposed DER Capacity and Operation Cost for Serving 100% of Total System Critical Facilities

Figures 2.4.7-2.4.10 show the simulation results with 10%-40% load curtailment of critical facilities (for serving 90%-60% of critical facilities' loads), respectively.

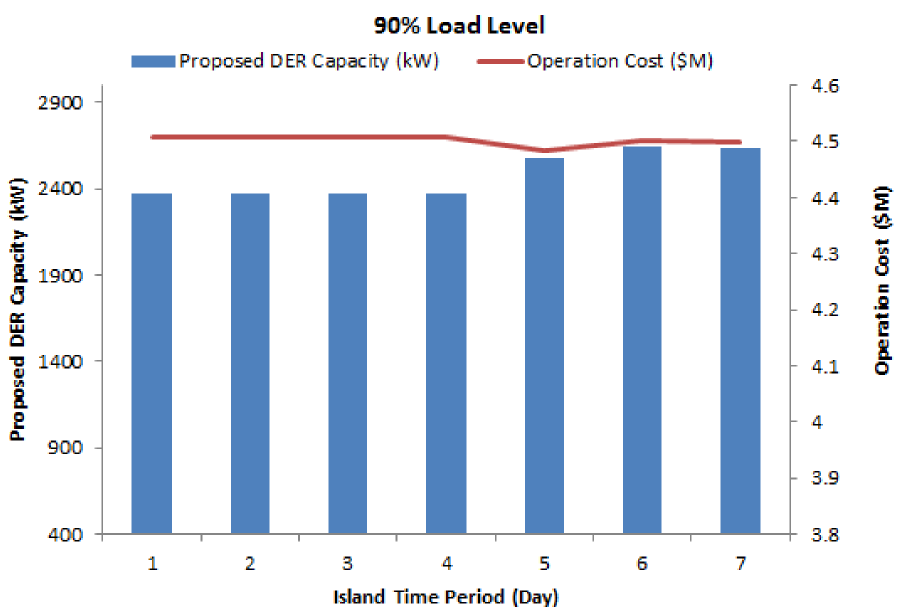


Figure 2.4.7 Proposed DER Capacity and Operation Cost for Serving 90% of Total System Critical Facilities

In Figure 2.4.8, as seen in this case the extra 10% reduction in peak load causes the de-commitment of 300kW unit compared with that in Figure 2.4.7.

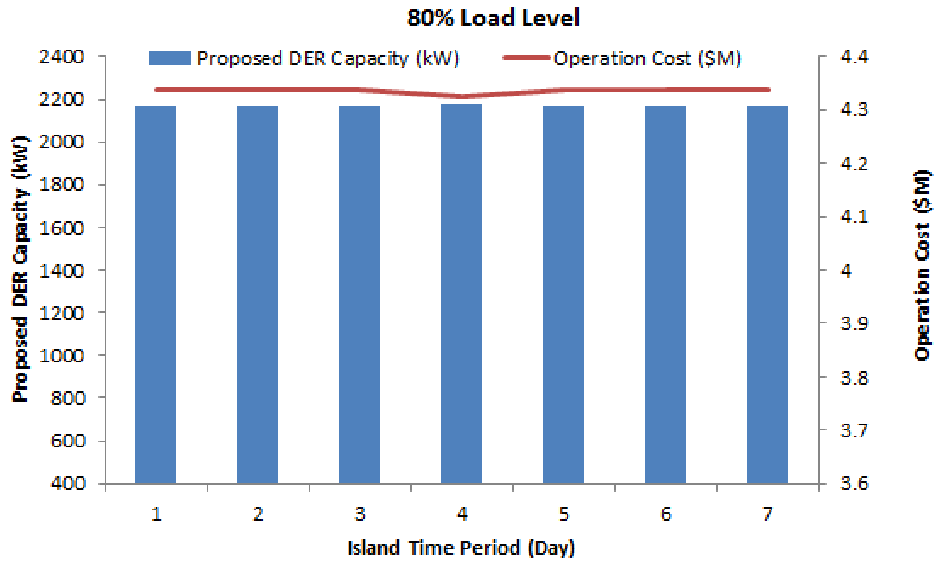


Figure 2.4.8 Proposed DER Capacity and Operation Cost for Serving 80% of Total System Critical Facilities

In Figures 2.4.9 and 2.4.10, another 10% causes the de-commitment of another 60kW and 400kW unit, respectively. It can be seen that lower investments would be needed as more load is curtailed, just as the operational costs are reduced, which indicate that higher resilience of critical facilities can be achieved through either load management or adding new generation resources. The new added CHP would also help in reducing the operation cost.

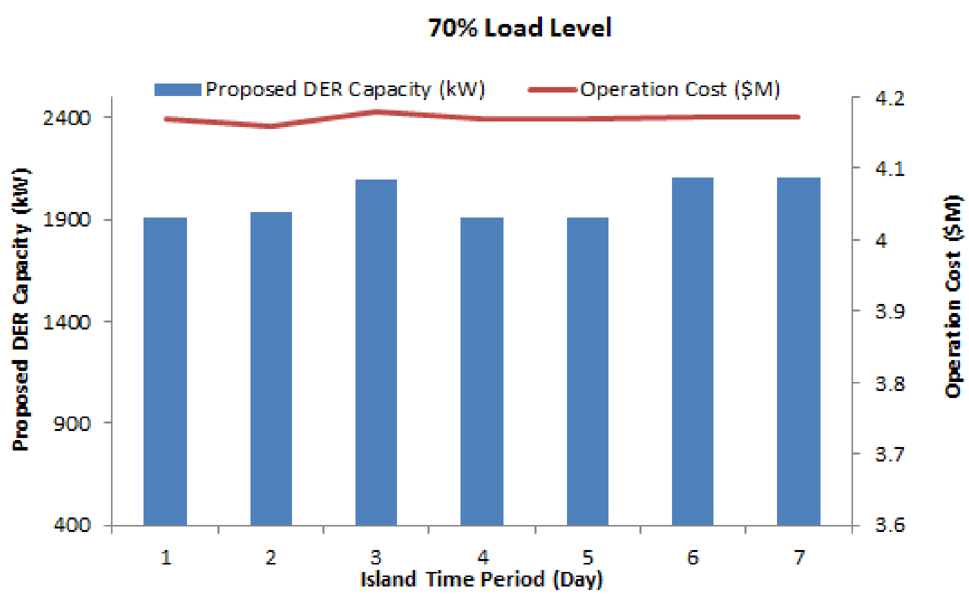


Figure 2.4.9 Proposed DER Capacity and Operation Cost for Serving 70% of Total System Critical Facilities

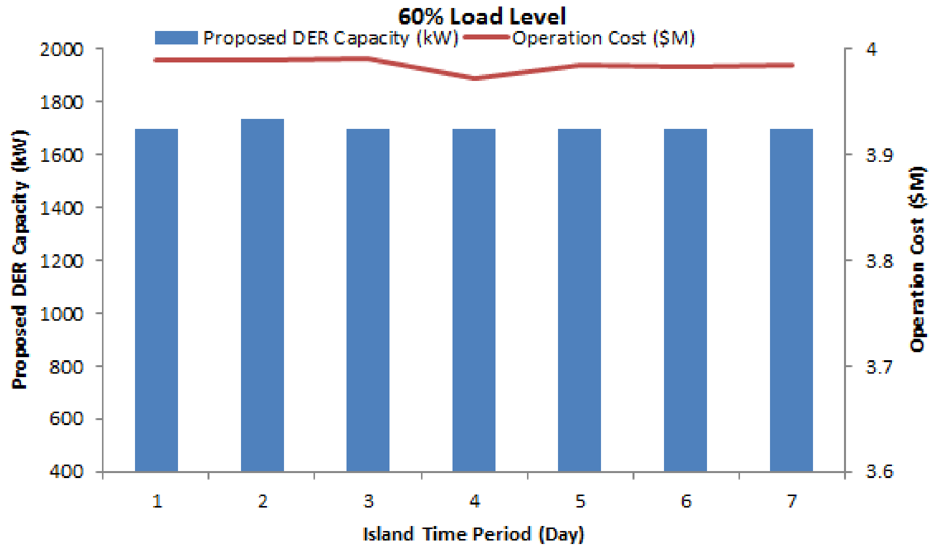


Figure 2.4.10 Proposed DER Capacity and Operation Cost for Serving 60% of Total System Critical Facilities

The DER-CAM simulation results are also shown in Table 2.4.2 and Table 2.4.3 based on the order of resilience in which we define that the capacity serving critical facilities without any disruption for seven days with no critical load curtailment as 100% resiliency and the capacity of serving 60% critical load for one day as 10% resiliency.

Table 2.4.2 The annual costs savings by the investment for supplying power for total system critical facilities with one week islanding in peak load season (July)

Islanding Days	Load Curtailment (%)	Resilience (%)	Proposed DER Capacity(kW)	Operation Cost ($)	Investment Cost ($)
7	0	100%	2,916	4,676,844	8,644,830
	10%	97.35%	2,636	4,498,293	7,731,910
	20%	94.71%	2,167	4,336,646	6,327,800
	30%	92.06%	2,103	4,171,077	6,302,200
	40%	89.41%	1,700	3,984,338	4,971,000
6	0	86.76%	2,889	4,680,478	8,578,019
	10%	84.12%	2,648	4,500,358	7,870,517
	20%	81.47%	2,167	4,336,783	6,327,800
	30%	78.82%	2,103	4,171,165	6,302,200
	40%	76.18%	1,700	3,983,821	4,971,000
5	0	73.53%	2,889	4,680,568	8,578,019
	10%	70.88%	2,575	4,483,514	7,531,000
	20%	68.24%	2,167	4,336,837	6,327,800
	30%	65.59%	1,912	4,170,474	5,661,208
	40%	62.94%	1,700	3,984,654	4,971,000

4	0	60.29%	2,889	4,680,603	8,578,019
	10%	57.65%	2,371	4,507,527	6,921,819
	20%	55.00%	2,177	4,325,069	6,331,800
	30%	52.35%	1,913	4,170,573	5,664,455
	40%	49.71%	1,700	3,972,835	4,971,000
3	0	47.06%	2,889	4,680,486	8,578,019
	10%	44.41%	2,371	4,507,840	6,921,819
	20%	41.76%	2,167	4,336,898	6,327,800
	30%	39.12%	2,100	4,179,165	6,301,000
	40%	36.47%	1,700	3,971,875	4,971,000
2	0	33.82%	2,889	4,680,608	8,578,019
	10%	31.18%	2,371	4,507,879	6,921,819
	20%	28.53%	2,167	4,336,952	6,327,800
	30%	25.88%	1,941	4,158,572	5,587,400
	40%	23.24%	1,734	3,969,598	5,078,549
1	0	20.59%	2,889	4,680,666	8,578,019
	10%	17.94%	2,371	4,507,581	6,921,819
	20%	15.29%	2,167	4,337,005	6,327,800
	30%	12.65%	1,907	4,170,683	5,647,821
	40%	10.00%	1,700	3,968,967	4,971,000

Table 2.4.3 Serving Total System Critical Facilities with Islanding in Peak Load Season (July

Islanding Days	Load Curtailment	Resilience Weight (%)*	Proposed DER Capacity(kW)	Operation Cost (K$)	Investment Cost (K$)
7	0-40%	100% - 89.41%	2,916-1,700	4,686–3,984	8,645 –4,971
6	0-40%	86.76% -76.18%	2,889-1,700	4,680-3,983	8,578 – 4,971
5	0-40%	73.53% - 62.94%	2,889-1,700	4,680-3,984	8,578 – 4,971
4	0-40%	49.71% - 73.53%	2,889-1,700	4,680-3,972	8,578 – 4,971
3	0-40%	47.06% - 36.47%	2,889-1,700	4,680-3,971	8,578 – 4,971
2	0-40%	33.82% - 23.24%	2,889-1,700	4,680-3,969	8,578 – 4,971
1	0-40%	20.59% - 10%	2,889-1,700	4,680-3,968	8,578 – 4,971

*Resiliency weight is introduced based on the maximum number of days that critical facility capacity is being responded in the grid outage duration and maximum level of critical facility which can be served. We define that the capability of serving critical facilities with no curtailment for seven days (as customer's requirement) is 100% resiliency and the capability of serving 60% critical facilities for one day is 10% resiliency.

Willdan recommends a loop-based network which has the capability of supplying power to critical facilities from two feeders in order to improve the energy resilience of critical facilities. In cases of extreme weather events, if one feeder fails, the loads can transferred to another feeder and will still receive power feed. The load transfer procedure is shown in Figure 2.4.11.

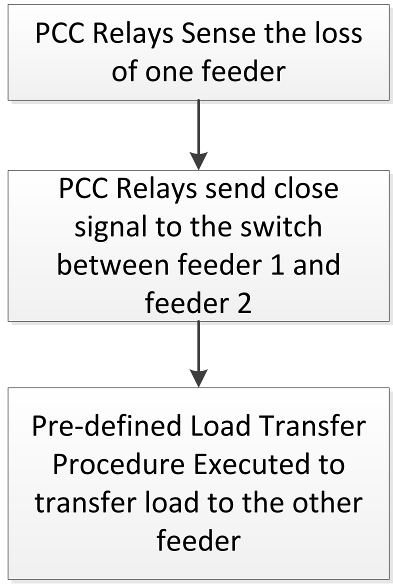


Figure 2.4.11 Load Transfer Procedure

Connecting Rochester Community Microgrid with Grid and Microgrid Protection

The two substations which the feeder are connected in the proposed community would be the point of common coupling (PCC) where the proposed community microgrid could be isolated from the utility grid in order to operate in island mode in case of emergency, and resynchronize with the utility grid in order to operate in grid-connected mode.

Three phases power flow is integrated with the master controller which ensures stability and security of the community microgrid in both grid-connected and islanded mode. A hierarchical protection configuration strategy is proposed to for the Rochester community microgrid protection which mainly contains four-level protection: load way, loop way, loop feeder way and microgrid level. Each level is equipped with protection devices. Also the four levels are coordinated. The protection devices and operational rules in each level are summarized in Table 2.4.4. The load-shedding and other control schemes could also be implemented on the load-way protection level based on under/over-voltage and under/over-frequency functions of these relays. The hierarchical strategy aims at addressing the challenges in isolating various faults in time from loop based microgrids. The performances of microgrid protection are as summarized as follow.

- Detect and isolate of faults both inside and outside of microgrids,
- Detect and isolate the faults inside the microgrid in both grid-connected and islanded mode
- Detect and immediately isolate the faults of the loads and DGs,
- Prime protection and backup protection for protective device malfunction
- Compromise between selectivity and speed.

Table 2.4.4 The Protection Devices and Operation Rules at Each Protection Level[11]

Protection Level	Protection Devices and Operation Rules in Grid-Connected and Island Modes
Load-way protection	Directional Overcurrent (DOC) digital relay with adaptive relay setting (responding to lower fault current in island mode): —Operates only in load-way faults (DOC and auto reclosing).
Loop protection	DOC digital relay with adaptive relay setting: —Operates in loop faults [primary and backup permissive overreach transfer trip (POTT) Schemes —Backup protection for load-way protection.
Loop-feeder protection	Non-direction Overcurrent (OC) relay: —Operates to isolate the faulted loop only when the load-way and loop protections have failed within the loop.
Microgrid-level protection	OC relay and PCC switch: *In grid-connected mode:* —Unintentional islanding operation due to external fault or disturbance based on the signal from the MC —OC relay (backup protection for the entire microgrid) —Intentional islanding operation based on the islanding command from the MC. *In island mode:* —Resynchronization initiated by a command from the MC.

Sub Task 2.5 Microgrid and Building Controls Characterization

Rochester Community Microgrid Control Architecture

Figure 2.5.1 shows the overall Rochester community microgrid elements, functions, and control tasks associated with reliability and economics. In order to optimize the economics, microgrids apply coordination with the utility grid and economic demand response in island mode. The short-term reliability at load points would consider microgrid islanding and resynchronization and apply emergency demand response and self-healing in the case of outages. Functionally, three control levels (primary, secondary, and tertiary) are applied to the microgrid to support the proposed community microgird in grid-connected and islanded operations:

- Primary control, which is based on droop control, for sharing the microgrid load among DER units.
- Secondary control which performs corrective action to mitigate steady-state errors introduced by droop control and procures the optimal dispatch of DER units in the microgrid.
- Tertiary control which manages the power flow between the microgrid and the utility grid for optimizing the grid-coordinated operation scheme.

Primary and secondary controls are performed at the DER level using the local component controls. The centralized tertiary controls are performed by the master controller. The primary control utilizes the droop control in order to share the load among DER units with droop characteristics and avoid

[11] Adaptive Protection System for Microgrids: Protection practices of a functional microgrid system. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6774516

circulating currents among DER units because of different set points on real and reactive power dispatch. The secondary control restores the nominal frequency of power supply in islanded operation. Tertiary control is the upper level of the control system, which ensures the optimal operation of the microgrid by determining the set points of the generation and load to meet demands in grid-connected and islanded modes.

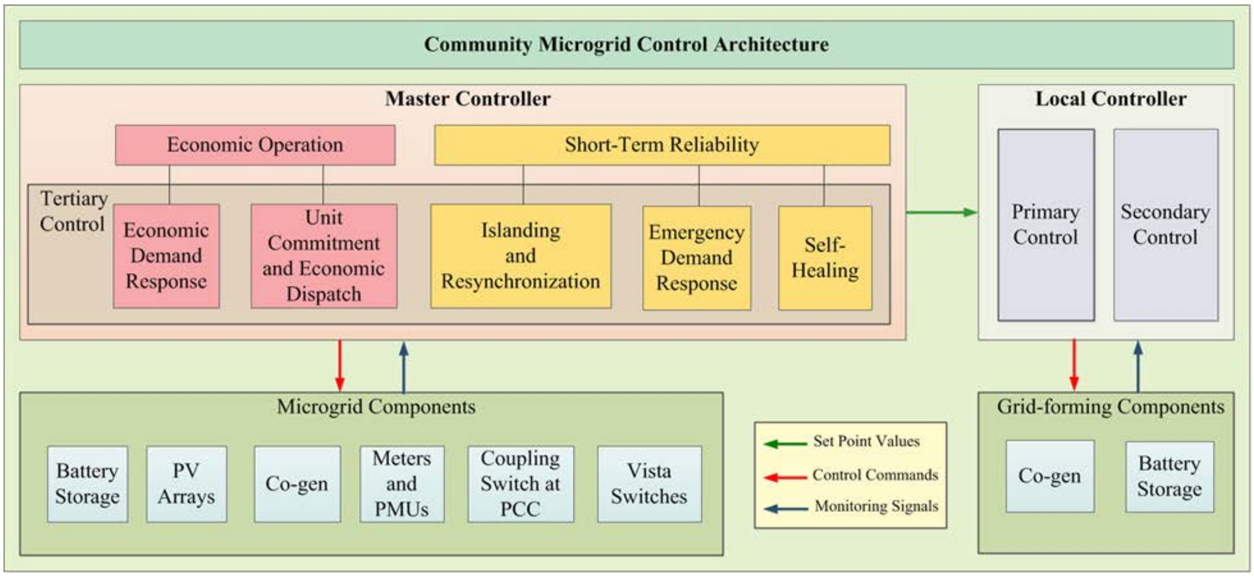
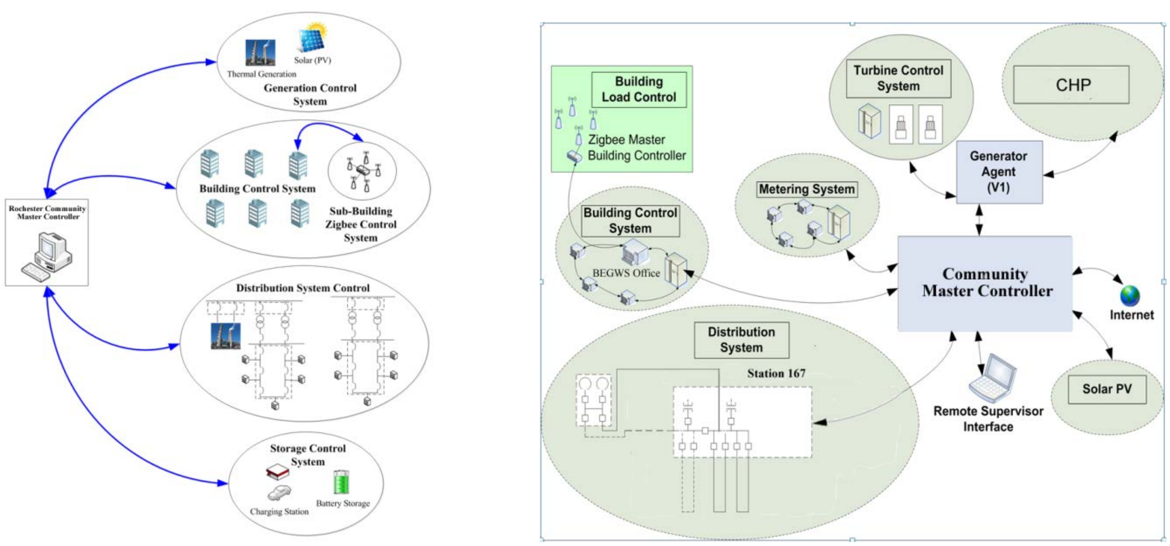


Figure 2.5.1 Objectives and functions for the control and operation of the Rochester community microgrid



(a) (b)

Figure 2.5.2 Architecture of the Rochester Community Microgrid Master Controller

A major element of the Rochester community microgrid is its master controller. The control signals from the master controller (MC) include the setpoints to adjust the proposed CHP or other dispatchable DERs within Rochester (grid-forming elements for maintaining frequency and voltage if any), and the signals to open/close switches. The master controller applies hierarchical control via Supervisory Control and Data Acquisition (SCADA) software to ensure reliable and economic operation of the microgrid. It also coordinates the operation of on-site generation, storage, and individual building controllers. Intelligent switching and advanced coordination of the master controller technologies through the communication systems facilitates rapid fault assessments and isolations. In case of the failure of master controller, the primary control and secondary control would keep maintaining the stability of voltage and frequency within Rochester community microgird. The main functions of the Rochester community microgrid master controller are as follows.

- Communications and errors management – detection and or safe shutdown
- P/Q control for generators
- Energy Storage System Management
- Point of Common Coupling (PCC) management - Power factor correction
- PCC management - Peak shaving/smoothing
- PCC management - Islanding and reconnection to grid
- Following active power command and voltage management
- Loss of communications safety
- Power limits, both kW and kVAR
- Loss of generation/storage asset management during grid-tied conditions
- Loss of generation/storage asset management during islanded conditions
- Unit commitment/availability
- Load shedding/Shifting
- Event logging

Rochester community microgrid master controller (MC) provides the tertiary control functions for economic optimization and event-driven actions. Economic optimization is part of the unit commitment and economic dispatch functions (UC/ED).

- Economic Operations

  UC/ED (day-ahead):

  - Executed daily (islanded or grid-connected mode)
  - Initiated by MC for a 24-hour horizon and hourly time intervals
  - **Objectives:** cost minimization
  - **Input:** day-ahead forecasts for load, ancillary services requirements, solar PV, component status, fuel price, market price of electricity, load curtailment cost, maximum allowable load curtailment, utility grid power limit, and the ramping capability of co-gen and battery
  - **Output:** hourly commitment and dispatch of co-gen, battery, and demand response of adjustable loads (setpoints for controllable elements)

UC/ED (real-time):

- Executed every 1 minute (islanded mode, or for regulation of power exchange between utility grid and microgrid in grid-connected mode), every 10 minutes (grid-connected mode), or based on events (sudden step change of load, reconnection of load)
- Initiated by MC for the next 1 minute or 10 minutes
- Objective: cost minimization
- Input: the current operating point, forecasted load and solar PV in the next 1 minute (islanded mode) or 10 minutes (grid-connected mode) , ancillary services requirements, component status, fuel price, market price of electricity, economic demand response flag, load curtailment cost (for economic demand response), maximum allowable load curtailment (for economic demand response), utility grid power limit, and the ramping capability of co-gen and battery
- Output: set points for co-gen and battery, trip signals for load switches of load groups to be curtailed (for economic demand response)

The Rochester community microgrid master controller will run a day-ahead scheduling optimization algorithm which will optimize the use of microgrid local generation and balance the hourly demand response (load curtailment and shifting of non-essential microgrid loads) for minimizing the cost of supplying the microgrid load. At times, the controller will consider demand response rather than power purchases from the grid. The generation dispatch signals are sent to distributed energy resource (DER) units, and the load signals are sent to building controllers across the Rochester and the neighbor critical buildings. The master controller also receives the day-ahead price of electricity, weather data, cloud coverage and other data for utilizing the renewable sources within the community microgrid.

An interactive grid-forming control would be used either in island or grid-connected mode. In island mode, DERs apply this control scheme to share the load, while in the grid-connected mode DERs apply this control scheme to regulate the power exchange between the microgrid and the utility grid. In the grid-connected mode, the DER unit with grid-following control follows the microgrid voltage and frequency, which is set by the utility grid in grid-connected mode and by other DER units in island mode.

The hierarchical secondary control approach would receive information from loads and power supply entities as well as information on the status of the distribution network and implement the optimal solution via an hourly unit commitment and real-time economic dispatch. Figure 2.5.1 shows the hierarchical framework of the master controller proposed for the microgrid project. In Figure 2.5.2, the monitoring signals provided to the master controller indicate the status of DER and distribution components, while the master controller signals provide set points for DER units and building controllers. Building controllers will communicate with sub-building controllers and monitoring systems to achieve a device-level rapid load management.

With the master controller, the Rochester community microgrid would be able to provide ancillary services to the grid including voltage support, frequency regulation, and distribution system restoration. The master controller would collect the real-time data and send out set-point information through SCADA. Normally the master controller would operate in autonomous mode based on predefined rules while optimizing the reliability and economics of the microgrid. In case of emergency, the master controller would isolate the microgrid from the utility grid and operate in island mode. Within the microgrid, the non-critical load could be curtailed or disconnected through smart meters or ATS, and the local distribution network would be reconfigured so that the local DERs could supply power to the critical loads.

Rochester Community Microgrid Controllable Resources

Master controller incorporates the following controllable resources:

- Grid-forming (controllable) resources: co-gen and battery; load adjustment (for economics/reliability management); load curtailment (for resilience purposes),
- Grid-following resources: solar PV and/or any other intermittent renewable resources which will be treated as negative load.
- Loads, loads are prioritized or grouped for curtailment;

Local Controls

Generation and load management within Rochester community microgrid is performed locally through local generator controls and customer load controllers, or building load management systems. In addition, protection, system re-configuration, and load restoration schemes of the microgrid is managed by distribution automation scheme, coordinated through event-driven commands from the master controller.

CHP Control

CHP facility is equipped with a local generation control unit to manage operation of the natural gas turbines and unit cycling, if required. The local controller receives active and reactive power setpoints from the master controller during the grid connected mode for the CHP power dispatch. The fine tuning of the generation output is implemented through droop control scheme with adjustable setpoints. Once the system is islanded, CHP unit can be switched to Isochronous mode to operate at fixed speed (for the given frequency setpoint) and to regulate voltage within the island (based on the voltage setpoint). CHP unit control and operation is essential in ensuring the stability of the island. Each CHP manufacture utilizes vendor-specific control device for generator control and operation. The CHP control is in charge of engine start-up, synchronization and shut-down steps. The control utilizes “Power Control” for grid-parallel operation with user-adjustable active power setpoint, and speed control for island (isolated) operation. The multiple engine configurations have a master synch control panel, this assists with transitioning back and forth among multiple units and load balancing.

Battery Energy Storage System (BESS) Control

As an example, PureWave Storage Management System[12] (SMS) package from S&C is considered in Rochester community microgrid. The SMS with high energy density can provide power flow control (charge/discharge) and/or frequency control in the islanded mode. The power conversion system (PCS) of the SMS is comprised of four bidirectional inverters in parallel with 250 kW/268 kVA rating per

[12] http://www.sandc.com/products/energy-storage/sms.asp

inverter. The PCS is connected to the Rochester community microgrid through a 1.5 MVA step-up transformer. The BESS control platform combines a robust control and communication protocols that ensure a flexible converter configuration and versatile applications that support stable, effective, and efficient solutions for energy management, power smoothing, grid stability, and power quality. The master controller defines the setpoints of the inverter controller; communicates with the SMS to manage the battery status; and provides dynamic islanding capability and remote SCADA control, using DNP3 TCP/IP protocol.

Distribution Automation Control

Vista smart switches are applied throughout the microgrid. The switches are equipped with distribution automation scheme (DAS) for fault detection, isolation and circuit reconfiguration. Each structure within the scheme can incorporate and control eight switches in the decision approach. Each distribution automation scheme is supervised by a "Coach". The coaches from adjacent schemes have the responsibility to communicate and coordinate the operation of the switches within a scheme based on thermal load rating of each source feeding the schemes, and fault detection/location information. DAS monitors real time current and voltage throughout the Rochester system and uses this information to make smart switching decisions within Rochester community microgrid. DAS uses loss of voltage for automatic disconnection of the switches within a team. DAS equipped controls utilize DNP 3.0 protocol and peer-to-peer communication via radio or fiber-optic transceivers.

Load Control and Building Management Systems

Critical building loads within Rochester and neighbor area are either controlled directly and/or through their building management system. Building controllers facilitate the building consumption management. The reduction in building consumption is accomplished by defining several operating modes representing different consumption levels in each building. Once the operation mode for each building is set by the master controller, the building controller will send signals to sub - building controllers to set the requested load level associated with the selected mode and feeds back the confirmation signal to the master controller to acknowledge the mode change. The building controllers are also able to monitor and control the energy flow within the buildings including hot and chilled water flow, heating and cooling loads, and can monitor the temperature of different spaces within the building.

Services and Benefits of the Rochester Community Microgrid

The proposed microgrid would be able to provide black start services, frequency and voltage support, and active and reactive power control. The functions provided by the master controller within Rochester community microgrid are described as follows. The islanding would follow the procedure shown in Figure 2.5.3, resynchronization follows the procedure shown in Figure 2.5.4 and self-healing follows the procedure in Figure 2.5.5, respectively.

- Rochester community microgrid Islanding
    - ➢ Event driven which is initiated by relays at PCC (based on the loss of grid frequency and voltage)

  - Signals are sent by PCC relays to individual switches for a priority-based load shedding (emergency demand response in islanded mode) if the microgrid frequency cannot be restored at the secondary control level. Hierarchical control will then set the normal frequency and voltage at the islanded mode.
  - Mater Controller will perform load restoration (via tertiary control) by committing offline units and dispatching grid forming elements (objective: maximize load restoration based on the current operating point, estimated loads to be restored, and the ramping capability of co-gen and battery; output: setpoints for co-gen and battery, close signals for load switches)
- Rochester community microgrid resynchronization
  - Event driven which is initiated by microgrid operator
  - Passive synchronization approach will be used.
  - Check frequency difference (<0.1 Hz) and voltage magnitude difference (<3%) for reconnecting the first feeder
  - Check frequency difference (<0.1 Hz), voltage magnitude difference (<3%), and voltage angle difference (<10^{o}) for reconnecting the second feeder; MC sends resynchronization signal to the relay at PCC when conditions are satisfied.
  - Master controller will perform load restoration once the PCC switch is reclosed (objective: maximize load restoration based on the current operating point, estimated loads to be restored, and the ramping capability of co-gen and battery; output: setpoints for co-gen and battery, close signals for load switches)
  - Black start (executed by MC using pre-defined black start procedure)
- Rochester community microgrid Self-Healing
  - Event driven by fault
  - Fault located and isolated by switches for self-healing
  - If fault leads to the permanent opening of the switch, signal will be sent to MC to perform UC/ED (real-time) for load balancing; Master controller will perform another UC/ED (real-time) once the switch is reclosed and fault is cleared.
  - Load transfer: event driven; losing one feeder -> load transferred to the other feeder; lose both feeders -> islanded mode); initiated by Vista switches based on pre-defined load transfer procedure
- Rochester community microgrid Emergency Demand Reponse
  - Event driven by utility grid request (grid-connected mode), or trip of co-gen (grid-connected mode or islanded mode)
  - Master controller performing priority-based load shedding
  - Master controller performing priority-based load reconnection once the emergency demand response is completed
  - Master controller performing real-time UC/ED to balance the generation and load

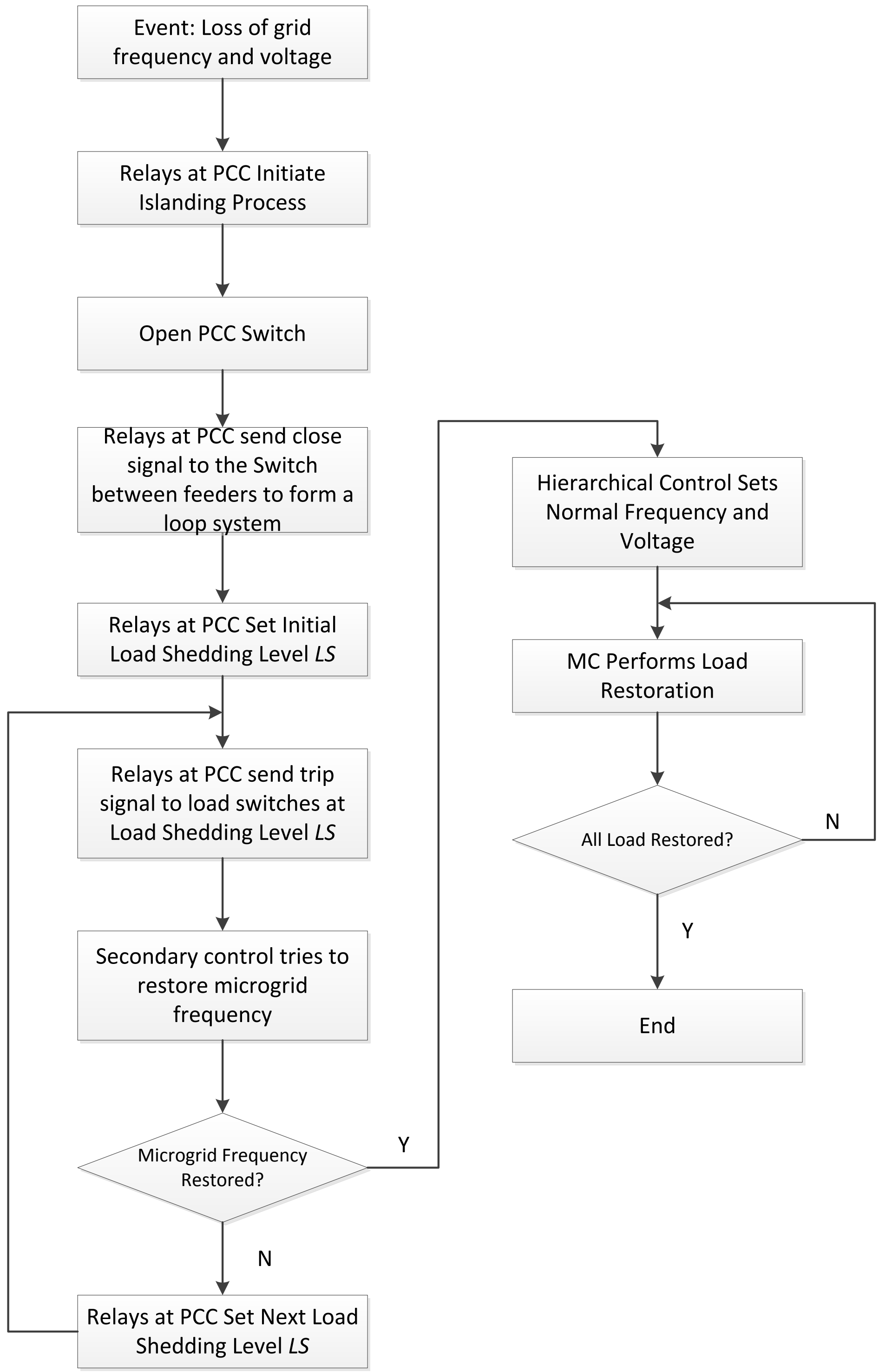


Figure 2.5.3 Rochester Community Microgird Islanding Procedure

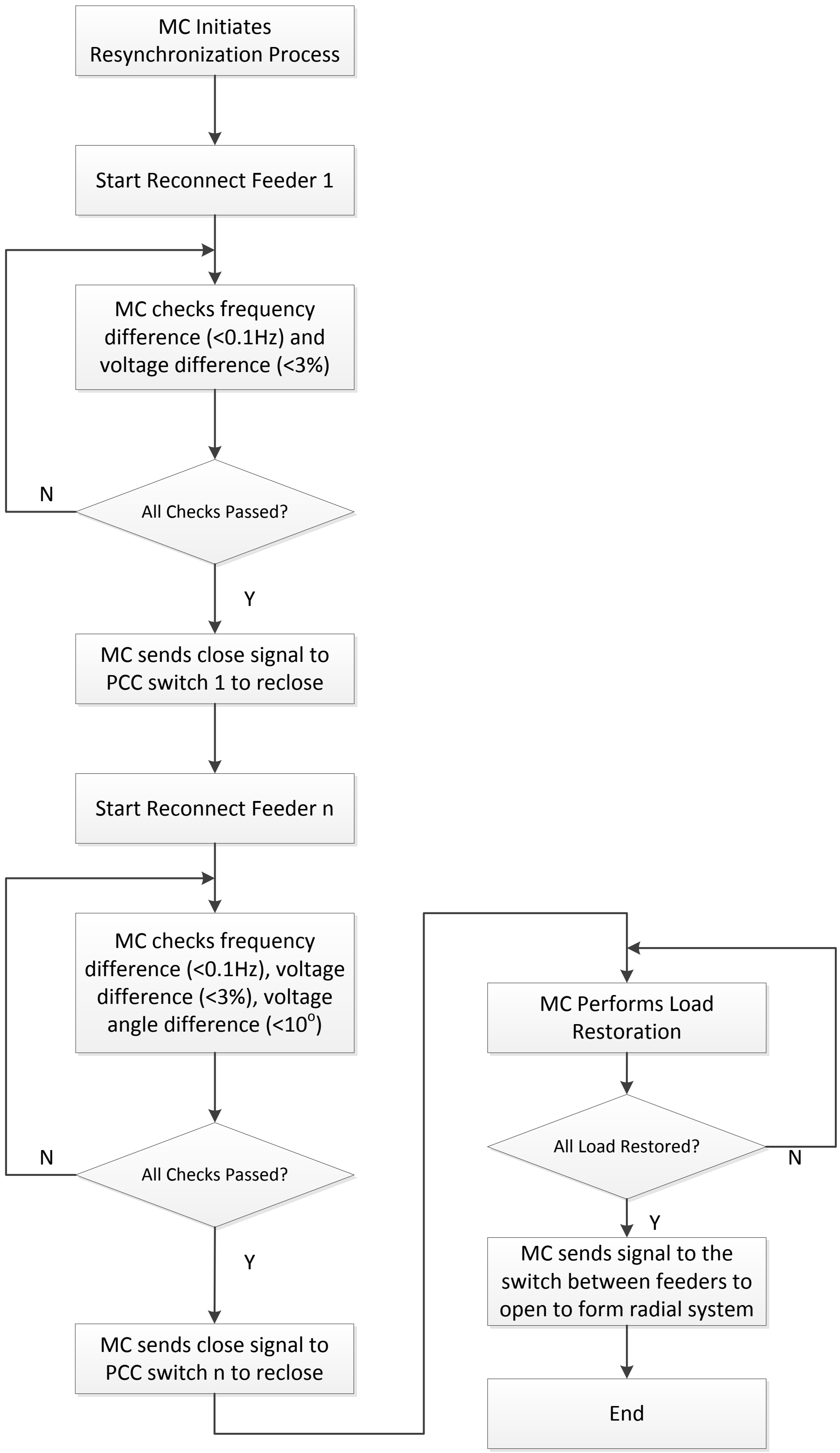


Figure 2.5.4 Rochester Community Microgird Islanding Resynchronization Procedure

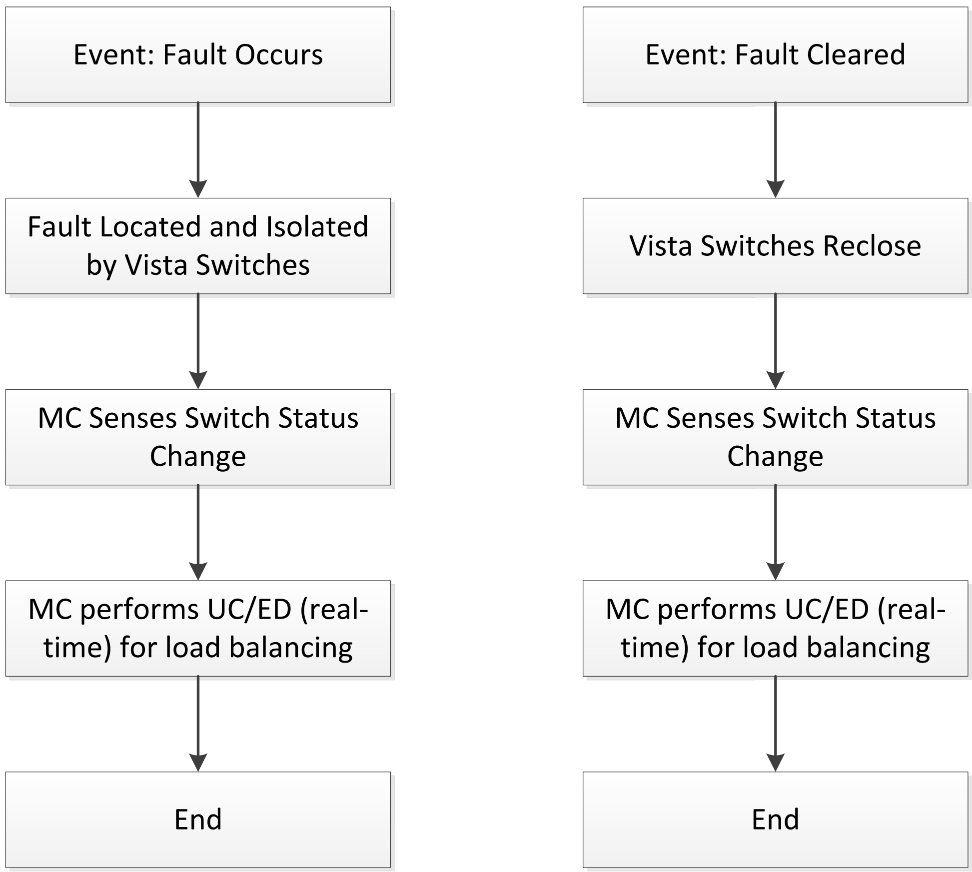


Figure 2.5.5 Rochester Community Microgird Islanding Self-healing Procedure

The Rochester distribution system has a very good power factor due to the prevalence of electric heat. The proximity of power generation to microgrid load could result in improved power quality, lower power losses, better voltage stability, and higher reliability (fewer customer outages) by engaging fewer components and by eliminating additional transmission services. With the added DERs, ATS, and other smart devices, the proposed Rochester community microgrid could significantly improve the reliability indices which include the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI), Expected Energy Not Supplied (EENS), and Loss of Load Expectation (LOLE). The main services and benefits which the microgrid could provide are summarized as follows:

1. *Increase safety and resiliency*

   The reliability would be improved in normal operating conditions through infrastructure reconfiguration, using a high reliability distribution system which senses and clears faults with virtually no impact on building loads. The grid would be made more self-healing and fault-tolerant by reducing the number of single points of failure by adding redundancy to the electrical and communications networks and by adding alternate sources of generation to serve critical and non-critical loads.

During emergency operating conditions, the microgrid would be able to provide uninterrupted power to critical loads, through the use of DERs and load shedding schemes that ensure safe and reliable operation of the buildings that matter most in emergency situations. Long term outages would be mitigated by a natural gas-fed CHP plant, which would maintain a black-start capability in the event that the outage occurs when the CHP facility is not active. This plant would rely on robust natural gas pipelines and produce enough power to serve all of the critical facilities as well as public street lighting and security lighting.

2. *Reduce energy cost uncertainties and exposure to market fluctuations*

   The microgrid would reap economic benefits in the form of added revenue streams from demand response, alternate generation sources, and energy efficiency measures to reduce overall energy costs, as well as participating in ancillary service markets such as fast regulation and operating reserve markets. Based on the price of electricity and the availability of Distributed Energy Resources (DERs), the master controller would optimally dispatch the units to provide the cheapest, cleanest, and most reliable energy possible to the microgrid facilities.

Sub Task 2.6 Information Technology (IT)/Telecommunications Infrastructure Characterization

IT/Communication Infrastructure

Any modern utility or system operator relies heavily on their communication infrastructure to monitor and control their grid assets. For a microgrid master controller and microgrid operators, this architecture enables real time control, rapid digestion of critical grid information, and historical data for analysis and reporting. As part of a feasible microgrid, assessment and upgrade of the equipment and protocols used in the microgrid area will be performed.

Existing Resources

As the facilities are served by RG&E for electricity and RDH for heat, they only have limited building controls for HVAC and lighting.

Consequences

A limited communications architecture can lead to increased frequency and duration of outages if problems must occur and be reported rather than having symptoms trigger notifications to grid operators of location and scope of the issue. Limited information and delay in this information leads to man hours wasted and longer duration of customers without power, putting strain on residential customers and potentially costing commercial customers significant amounts of money. Systems could have telltale signs of issues for weeks, but operators may not discover these until they have caused damage and outages to the electric grid or substations, costing the utility money and potentially endangering employees and customers.

Opportunities

Rochester would benefit from an Advanced Metering Infrastructure (AMI) expansion, which would involve adding wireless communication infrastructure throughout the City of Rochester to allow for automatic and digital meter reads. The key advantage of this expansion would be the network addition, which often utilizes the 900 MHz ISM band and relies on communication between integrated Network Interface Cards (NICs) that form a mesh network, allowing signals to hop between any installed meters to reach their ultimate destination and increases the propagation range of the signal in proportion to the number and dispersion of integrated NIC Smart Meters. The integrated NICs are connected to a local Access Point (AP) that transmits the metering and control signals for the streetlights over a cellular wireless network back to the utility data center, where it can be fed into the SCADA platform for use in billing or monitoring the overall grid.

Proposed/Suggested Improvements

The Rochester Community Microgrid would be connected efficiently and productively, through the use of modern communication architectures and equipment, enabling a master controller to optimize the microgrid control and giving operators the tools they need to perform their daily duties. Exact upgrades or additions to existing communications infrastructure will need to be determined in a Phase 2 design. This network would leverage the AMI network and seek to strengthen it through the use of connected LED streetlights, which require half the power of the existing High Pressure Sodium (HPS) fixtures and shorten the overall payback of a street lighting upgrade through the implementation of smart photocells or integrated NICs that individually meter and control each streetlight, seen in figure 2.6.1.

In addition to meters and streetlights, circuit breakers, relays, reclosers and other switchgear are vital to the control of the Rochester Community Microgrid. While some distributed switchgear can utilize a similar wireless infrastructure, with data being fed through substations instead of through a cloud network, the control equipment is more vital to the safe operation of the microgrid and would ideally use a fiber optic backbone between the installed switches and the substation. The substation relays may have to be upgraded to communicate using the DNP3 protocol over TCP/IP, the de facto standard for modern utility communications, which will be used to monitor and control the proposed DER as well.

Once accessed, the data will be fed into an upgraded or added SCADA system to allow operators to access, visualize, and control, all of the microgrid assets.

Benefits

Utilizing a fully connected microgrid, with every vital piece of equipment monitored and controlled remotely, the master controller will be able to optimize load and generation automatically and in real time, the microgrid operators will be able to view the status, create reports, and plan future developments, and maintenance will be able to quickly assess and address any issues.

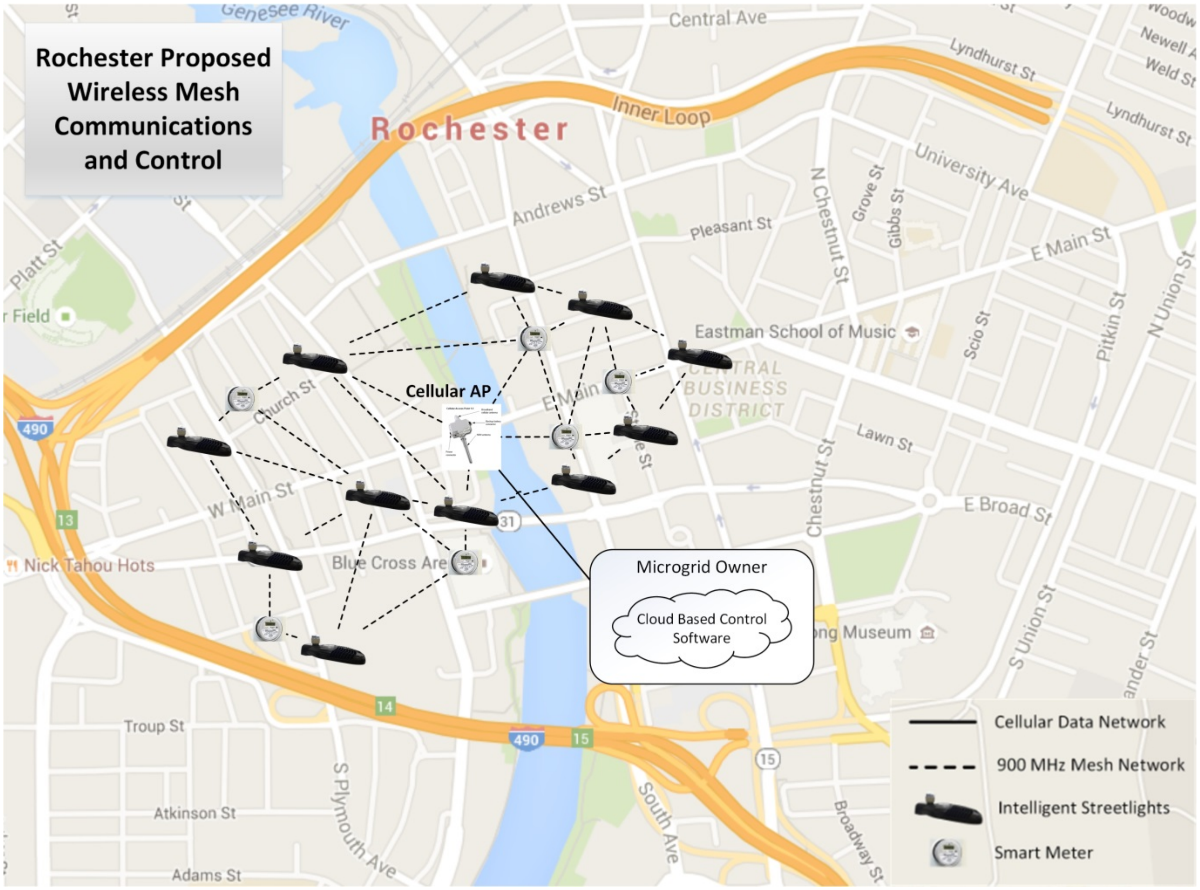


Figure 2.6.1 Rochester Proposed LED Lighting Communications and Control Diagram

Barriers

A more extensive review of existing communications and control equipment needs to be performed to determine the exact quantity and specification of the upgrade. RF testing will need to be performed to determine the layout of the wireless network proposed. Training would have to be done on the SCADA system and the newly implemented relays, and personal may need to be hired to maintain the network and communications equipment. A review of costs of the current system, including streetlight usage and maintenance data, current metering system costs, inaccuracies, and outage information will have to be obtained to determine exact cost savings of upgrading to the new system.

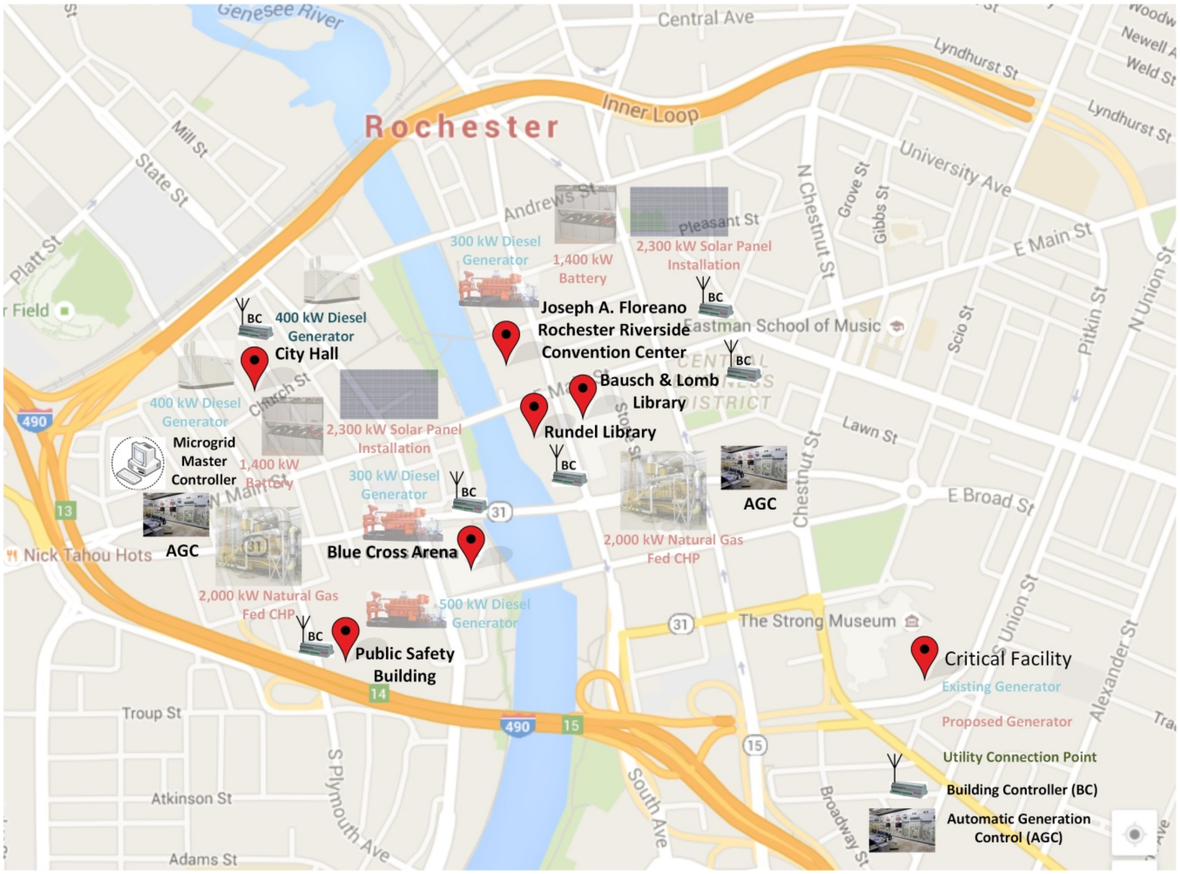


Figure 2.6.2 Network Equipment simplified layout diagram

As the RDH is the proposed owner/operator for the Rochester Community Microgrid, the Master controller could be located in their facilities or wherever is convenient for the chosen microgrid owner. While the master controller would automatically communicate with the Rochester SCADA system as well as with the field devices such as the building controllers (BCs) and automatic generation controllers (AGCs), RDH operators could regulate access and control to the microgrid. This means that any loss in communications that disrupts the microgrid would need to be between building controllers and the master controller/utility data center and that this loss would only prevent communication with one building, while the rest of the microgrid would maintain normal operation.

Willdan's proposed Rochester Community Microgrid would rely heavily on the robust fiber optic backbone and the 900 MHz mesh network for monitoring and control. This system remains extremely resilient in the face of inclement weather due to the fiber optic being underground and the mesh networked being formed by above ground, but heavily redundant, mesh radios. Similar to the building controllers above, if one smart meter or streetlight is unable to communicate, the rest of the lights and meters would remain on the network and leverage each other to maintain a strong network connection.

Conclusion and Recommendations

In addition to the previous sections, which include the technical work completed as part of the Phase 1 NY Prize Feasibility Study, this section serves as the final wrap-up of this project. This section will include an outline of why the project closed early, as well as the closing thoughts of each of the primary team members – RDH, the City of Rochester, and RG&E – and the potential for future projects.

The project began as a collaboration between the City of Rochester and Rochester District Heating. A majority of the City buildings receive low-cost heating from the RDH steam loop running through downtown, and there has been discussion between the team members of expanding RDH's service to include backup heat and power to City facilities through the use of CHP on the RDH system. The primary idea was to design a CHP system and location that could provide RDH with enough heat to cover its summer steam load, while still providing enough electricity for the summer-peaking City buildings. This would benefit RDH by allowing them to shut down their main boilers for maintenance while generating low-cost steam in the summer and selling all of the electricity produced to the City, optimizing the economics of the system. The City would benefit from an additional source of backup power in the event of an outage, as well as low-cost power through a long-term PPA with RDH, mitigating their peak electricity costs.

Initial economic modeling of the system showed that the project was very promising economically, though siting was an issue from the onset. Old RG&E substation #6 seemed to be an optimal location in a very land-constrained downtown area, but RG&E stated that there was no interest in parting with the substation, and no new sites were able to be identified. The project continued due to the economic potential and the fact that no technical barriers had come up, however this changed after the project team's meeting with RG&E in December.

RG&E stated that the Broad Street Corridor of downtown Rochester – the location of the microgrid, City Buildings, and RDH – was in fact a highly reliable portion of the RG&E system. They stated that this area had the highest reliability rating of any section of the RG&E system, and that the double-loop, mesh network downtown may be injured by the development of additional generating systems. Even in the event that the construction was technically feasible, the additional cost of tying into the downtown system would be excessive and likely keep the project for being developed. The City and RDH validated the reliability of the downtown system, and former City Engineers provided feedback supporting RG&E's claims. At this point, both the City and RDH expressed an interest in closing down the project to save time, effort, and state dollars from being spent on a project that would not succeed.

Thoughts and Future Projects

<u>Rochester District Heating</u>

RDH is still interested in developing projects that will save money and allow them to eliminate summer load on their existing boilers. However, the discussion with RG&E made clear that any new development would need to be behind the meter, meaning that the electric production of any individual CHP system would need to be less than, or curtailed to be less than, the load of the facility it was tied into. The original sizing of the CHP required to be useful to RDH was approximately 4MW, and the largest facility in the proposed microgrid had a peak demand of 800 kW. This means that RDH would need to construct multiple CHP plants around its system at numerous critical facilities in order to accomplish the original plan. Unfortunately, this type of project does not experience the same economic benefits as the original, due to the extra cost of constructing 3-5 separate plants as opposed to one central plant. Additional CHP development is possible on RDH's system, though not probable.

City of Rochester

The City of Rochester continues to receive low-cost power and high reliability on the RG&E system. Future projects in City buildings include efficiency upgrades, and possible peak-shaving projects, such as solar+storage in the City's summer peaking critical facilities. The cost-effectiveness of these projects are unknown and must be analyzed as a separate project.

Rochester Gas and Electric

RG&E has developed a high reliability system in the downtown area of Rochester. Any capacity issues in the region are outside of the areas analyzed in this study, and therefore this microgrid project was unlikely to provide any significant benefits to the utility.