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Functional Approach and Recent Experience Designing Resilient Community Microgrids in New York

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SUMMARY

This paper provides a high level overview of several microgrid feasibility studies that GE Energy Consulting and partners have recently performed, and the functional design process employed. It describes the principal tasks involved starting with load and supply analysis, distributed energy resources (DER) selection process, design of the electrical, communication and control infrastructure, and benefit-cost analysis methodology.

KEYWORDS

Microgrid, Resiliency, Distributed Energy Resources, DER, NY REV, NY Prize.

1. INTRODUCTION

Natural disasters in recent years, particularly those in the Northeast USA, have provided the impetus for development of resilient microgrids. Under normal conditions all customers - including those providing mission critical services such as hospitals, police and fire departments, pubic shelters, and water and sewer departments - get affordable, reliable, and efficient power from the traditional interconnected electric grid. However, extreme weather conditions or other natural or man-made disasters, which damage the electric grid and result in system-wise outages, put at risk the delivery of critical services to the population at large. One solution being considered by policy makers is development of resilient microgrids. Microgrids can be isolated and islanded during prolonged grid outages, and provide electrical, and in some cases thermal, energy to critical facilities within the microgrid.

Policy change is also driving the growth of microgrids. New York Reforming the Energy Vison (REV), for example, is an initiative in New York State to give consumers more control over their energy use and engage them as producers. REV is intended to change the way the state's retail electricity market and the way electricity is procured, distributed, and regulated in the state. Under the proposed model, traditional utility business models and cost-of-service regulation may be transformed, while making individual consumers active participants on the grid, with the principal goal of reconfiguring utility regulation to promote energy efficiency, increase the penetration of renewables and grow distributed energy resources (DER). This will allow consumers within various localities to build and operate DER that will create a more sustainable resilient energy system. Similar programs are being developed in California, Hawaii, and Texas. Microgrid feasibility studies are multi-discipline engagements that require a project team with deep domain expertise, a variety of skillsets, and familiarity with a broad portfolio of technologies.

2. MICROGRID DEFINITIONS

There are a number of microgrid definitions in current circulation. A few examples are listed below:

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CIGRÉ C6.22 Working Group: "Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded." [1]

U.S. Department of Energy (DOE) Microgrid Exchange Group, 2010: "A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode." [2]

New York State Energy Research and Development Authority (NYSERDA): "The term "microgrid" shall mean a group of interconnected loads and distributed energy resources that form a single controllable entity capable of operating continuously in both grid-connected and islanded mode to support mission critical loads. Critical loads are deemed essential services that are required for public safety and health. The type of microgrid configurations, incorporating various distributed generation (DG) technologies including but not limited to, combined heat and power, renewable and energy storage that could optimally support mission critical services for extended grid outages greater than one week." [3].

Essentially, a microgrid is a group of interconnected loads and distributed energy resources that function within clearly defined electrical boundaries and can operate as a single controllable entity. It has the ability to optimize energy usage, balance generation, demand, and storage locally when islanded or disconnected from the main grid, and exchange power with the main grid when connected. Figure 1 provides a generic view of a microgrid and its various components.

There are several different types of microgrids that address a number of key objectives, including:

- Energy surety for critical infrastructure
- Electrification of rural & remote areas
- Enabling a diversified energy mix
- Improving grid resiliency and efficiency

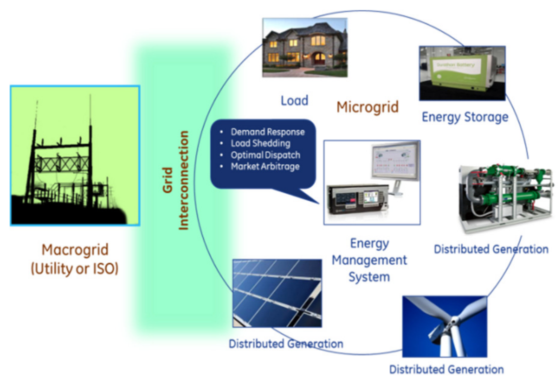

Figure 1: Components of a Microgrid
Source: Reference [3]

A microgrid can also take the form of a small isolated power system serving a remote need or providing power to a far-off secluded village or a small island. A microgrid is a system of highly integrated components and comprises both information systems technology and power systems technology. The sophistication and breadth of technology applied within the microgrid, and the amount of integration required with external systems, will differ based on specific use case. Some microgrids will scale heavy in applying energy management software and utility integration, and other microgrids will be localized electrical distribution systems.

Resiliency, in particular, is the key driver for community microgrids in New York since many communities and critical services (hospitals, WWTP, fire/police, transportation) were devastated by the relatively impacts of Super-storm Sandy and Hurricane Irene.

3. RESILIENT MICROGRIDS

The need for resilient microgrids is increasing. Extreme weather and other natural disasters can threaten lives, disable communities, and disrupt economic activities, and damage electric utilities' generation, transmission and distribution infrastructure. According to US DOE, outages caused by severe weather such as thunderstorms, hurricanes and blizzards account for 58 percent of outages observed since 2002 and 87 percent of outages affecting 50,000 or more customers [4]. Over the last few years, the state of

New York has experienced several unprecedented weather events, including Hurricane Irene, the October 2011 snow storm and Super-storm Sandy in 2012, which caused significant damage across the state, and cost the economy well over a billion dollars. According to most experts, the frequency and intensity of extreme weather events is expected increase even as utilities struggle with physical, fiscal, and resource constraints, increased regulatory scrutiny, and rising expectations for performance.

In June 2011, President Obama released "A Policy Framework for the 21st Century Grid" which set out a four-pillared strategy for modernizing the electric grid [5]. The initiative directed billions of dollars toward investments in 21st century smart grid technologies focused on increasing the grid's efficiency, reliability, and resilience, and making it less vulnerable to weather-related outages and reducing the time it takes to restore power after an outage occurs. In August 2013, the Executive Office of the President issued a report titled "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages". That report estimates the annual cost of power outages caused by severe weather between 2003 and 2012 and describes various strategies for modernizing the grid and increasing grid resilience. One such strategy is to increase system flexibility and robustness by employing microgrids.

Impacted by a number of weather events, the State of Connecticut has already developed policies that position microgrids as a central element in resilient energy supply. Connecticut's microgrid strategy aims at keeping the power on at facilities like hospitals, sewage treatment plants and prisons during severe weather events.

New Jersey also has its own plan for making its grid resilient. For New Jersey, the current focus is on its transit system, the third largest in the nation, carrying 900,000 people a day, and a major evacuation route for Manhattan. The microgrid will have more than 50 megawatts of power, consisting of smart grid technologies and distributed energy resources, such as backup generators, small scale wind and solar plants, and energy storage.

New York State has identified a critical need for improving the state's emergency readiness, preparedness and response capabilities. A key aspect of this effort is hardening the energy infrastructure. The New York State Energy Research and Development Authority (NYSERDA) has taken the leadership position in studying the impact of climate changes on New York State. The findings of a NYSERDA study are published in a report titled "Responding to Climate Change in New York State (ClimAID)" [6]. Another report is the report by the Moreland Commission and the City of New York on utility storm preparation and response.

NYSERDA, New York State Department of Public Service (NY DPS), and New York State Division of Homeland Security and Emergency Services (NYS DHSES) are working collaboratively to assess how microgrids can be used in New York State to support mission critical operations during severe weather events.

4. GE Energy Consulting's MICROGRID FEASIBILITY STUDIES

GE Energy Consulting has performed and is currently performing a number of resilient microgrid feasibility studies. The main objective of the resilient microgrid feasibility studies is to assess the technical and economic feasibility of establishing microgrids to provide continuous, efficient, and reliable electrical (and in some cases thermal) energy to facilities that provide critical public safety, health and security support, upon loss of the electric grid for an extended period (e.g., for at least one week) due to natural or manmade disasters. These microgrids can operate in both grid connected mode (during normal, blue sky days), and in islanded mode (during emergency periods, such as larger grid outages). This section provides a high level description of some of most recent studies in chronological order.

6.1 NYSERDA 5-Site Microgrid Assessment

NYSERDA, NY DPS, and NY DHSES were tasked legislatively by the New York State Government to assess how microgrids can be used in NY State to support mission critical operations and grid resiliency during severe weather events.

GE Energy Consulting was contracted to perform a feasibility study to assess different types of microgrid projects to be implemented in NY State. The project involved functional design and cost estimation of resiliency microgrids in five different locations and cities that represented urban, suburban and rural settings in the NY State, which included critical facilities in Binghamton, Manhattan, Rockland County, Suffolk County, and Nassau County, all in the New York State.

Project tasks included:

- Identifying different types of microgrid configurations and their performance and cost attributes, covering: (a) Load & Supply analysis and modelling to determine the distributed generation and demand side options, (b) functional design of the electrical Infrastructure, (c) functional design of the communications and control infrastructure, and (d) cost estimation of the microgrid components and its development and implementation
- Assessing adequacy of fuel supply and delivery Infrastructure to support operation of various Microgrid configurations.
- Documenting rationale for including technologies and fuels, identify limitations of preferred options, and recommend mitigation strategies to address Contingencies

Final report summarizing findings and recommendations are available at the NYSERDA website [3].

6.2 NYSERDA/National Grid Resilient Underground Microgrid in Potsdam, NY

Project Objective was to:

- Design of a resilient, community microgrid in the village of Potsdam in NY North Country to improve disaster response.
- Construct a National Grid underground system for power and communications
- Interconnect approximately 12 entities: National Grid service facility, Clarkson University, SUNY Potsdam, Canton-Potsdam Hospital, Village of Potsdam buildings, plus commercial providers of fuel, food, and other essential emergency services.

GE Energy Consulting's tasks are being performed in phases:

- Phase 1: Initial Planning: Define normal/emergency loads, identify generation/storage and demand response.
- Phase 2: Microgrid Design: Finalize generation, storage size, quantity, and location. Identify electrical configuration, perform steady state and transient voltage studies, renewable generation impact, system protection strategy, failure mode analysis, optimization analyses. Specify microgrid controller. Identify regulatory issues/approvals needed at state and local levels.
- Phase 3: Specification and Cost Design: Prepare system drawings and specifications for generation, distribution, load management and microcontroller components. Develop cost estimates.

Resulting configuration of the Potsdam Microgrid will then be used in a separate DOE funded project to test and validate a Microgrid Controller being developed by GE Global Research and its partners, including GE Energy Consulting.

National Grid plans to move the Potsdam microgrid design into a second stage which will involve audit-grade engineering design and development of a business model and commercialization plan as a NY REV Demonstration Project.

6.3 NY Prize Stage 1 Projects

NY Prize is a part of a state-wide endeavor to modernize New York State's electric grid, spurring innovation and community partnerships with utilities, local governments, and private sector. A first-in-the nation $40 million competition funded by New York State and administered by NYSERDA is to help communities create microgrids for resiliency. NY Prize covers three stages for the developments of resilient and stand-alone microgrids that can function in both grid-connected and islanded mode and provide uninterrupted power to critical facilities and load within the microgrid.

Stage 1: Feasibility Assessment

Stage 2: Audit-Grade Detailed Engineering Design and Financial/Business Plan

Stage 3: Microgrid Build-out and Operation

Stage 1 is currently ongoing. Out of 150 state-wide applicants, including many towns and villages across the state, 83 were selected for the Stage 1 microgrid feasibility studies. GE Energy Consulting is working with ten communities: six in urban/suburban settings (Brooklyn, Albany, Schenectady, Binghamton, Syracuse, Oswego), and four in suburban/rural communities (Southampton, Port Jefferson, Long Beach, Greenport). GE's portfolio of technologies and expertise with microgrids is key to these engagements.

The principal tasks in Stage 1 are:

- Task 1: Description of Microgrid Capabilities
- Task 2: Develop Preliminary Technical Design Costs and Configuration
- Task 3: Assessment of Microgrid's Commercial and Financial Feasibility
- Task 4: Develop Information for Benefit Cost Analysis

After completion of Stage 1, each of these projects will be submitted for selection in Stage 2 of NY Prize.

6.4 Functional Design of the Microgrids

Microgrids studied by GE Energy Consulting, as part of NY Prize Stage 1 come in different sizes, with peak loads ranging from 2 MW to 25 MW, and including variety of critical facilities, such as hospitals, police departments, fire stations, water and sewage departments, gas stations, grocery stores and other entities whose services and products would be essential for the general population during emergencies. Some of the microgrids included large renewable resources, such as solar power systems, waste-to-energy plants, and run-of-river hydro stations. Some of the designs included battery energy storage systems, and also thermal cool storage. A number of microgrid design include combined heat and power (CHP) or combined cool and heat and power (CCHP), enabling recovery of otherwise wasted thermal energy to replace existing boiler based heating or central chiller based cooling of the facilities. In each microgrid considered, allowances were made for load curtailment during emergency periods, and provision of demand response (DR) during normal blue sky days.

Figure 2 provides an overview of the one of the selected locations where GE Energy Consulting performed a microgrid technical feasibility study. Figure 3 displays the layout of the electrical infrastructure for the microgrid. Blue lines represent existing electrical network but not part of the microgrid. Solid red lines represent existing electrical network that are included in the microgrid. Dashed red lines are proposed new additions to the microgrid electrical network.

Figure 4 depicts the one-line diagram of interconnections for the electrical network of the microgrid. The diagram also includes various electrical equipment switchgear required for operation of the microgrid in both grid-connected and islanded modes.

Figure 5 shows the Control & Communications network overlaid on top of the electrical one-line diagram.

Figure 2: High Level of View of one of the earlier NYSERDA Microgrid Feasibility Study Locations

(Source: Reference [3])

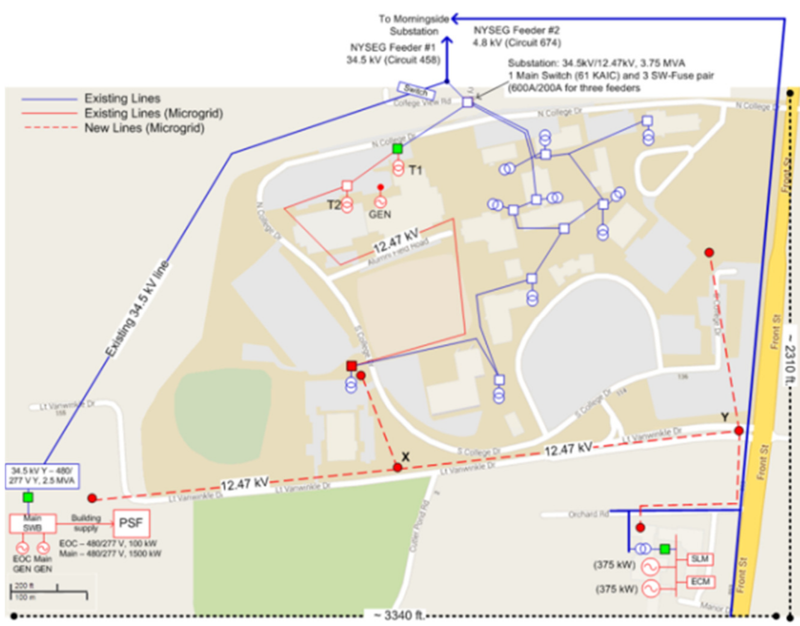

Figure 3: Layout of Electrical Infrastructure

(Source: Reference [3])

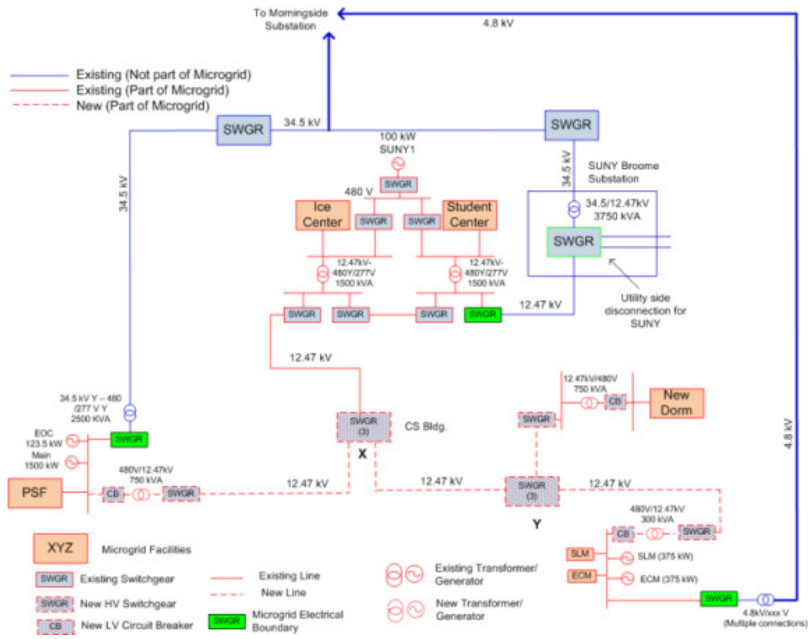

Figure 4: One-Line Diagram of the Electrical Infrastructure

(Source: Reference [3])

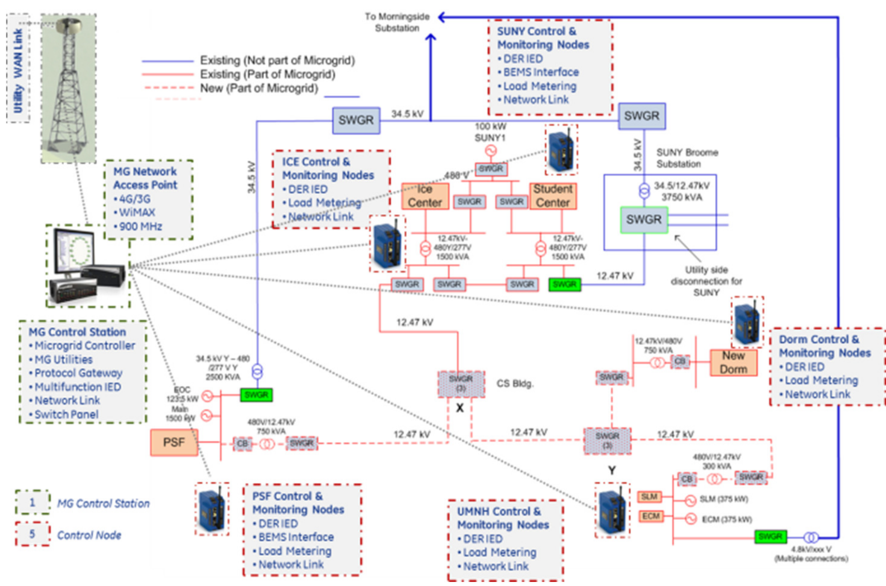

Figure 5: Control & Communications Infrastructure

(Source: Reference [3])

The control and communications network includes the hardware and software elements that are required for communication among various elements of the microgrid and also for communication with the external grid, and for the overall monitoring of the status of critical loads and DER assets, and the microgrid EMS and controller necessary for load and supply balancing and DER scheduling and reliable operation of the microgrid.

Functional design of some of the microgrids was based on dedicated microgrid electrical infrastructure. Others were based on leveraging and maximizing the use of the existing distribution system network and feeders. The latter includes additional non-critical residential and commercial facilities in populated areas, which would enable continuation of normal economic activities and daily life during prolonged outages of the larger grid.

These microgrids would have the ability to operate optimally during gird connected mode based on smart scheduling of internal generation versus utility purchases or even participating in the energy, capacity, and ancillary services markets of the New York Independent System Operator (NYISO).

5. MICROGRID ASSESSMENT AND TASK WORKFLOW

In performing the aforementioned microgrid projects, GE Energy Consulting followed a streamlined set of steps in performing the feasibility studies. As mentioned previously, these tasks are classified into four principal tasks, which include:

- Site Characterization
- Component Selection & Sizing
- Functional Architecture Description
- Business Case Development and Benefit/Cost Analysis

7.1 Site Characterization

Site Characterization is the essential first step. It involves a thorough data collection on all pertinent aspects of the microgrid, including: electrical and thermal load of the facilities within the microgrid; information on any existing DER assets, renewable resources, energy storage, and demand response; and the underlying electrical and information network.

The required steps under site characterization include:

- Mission Characterization: Site-specific objectives, normal versus emergency mission, operational constraints.
- Site Information: Geographic setting, security requirements, facilities and buildings details, public health and safety needs.
- Electrical and IT Infrastructure Characterization: existing networks at the microgrid site, existing networks belong to the utility (distribution system).
- Load Characterization: Critical electrical and thermal loads, Discretionary and curtailable load (i.e., demand response load).
- Generation Characterization: Distributed generation, combined heat and power (CHP), combined cool and heat and power (CCHP), generation operational parameters.
- Fuel Characterization: Fuel delivery network, fuel storage, accessibility during emergency.
- Cost Characterization: Generation costs including capital costs, fixed operations and maintenance (FOM) costs, variable operations and maintenance (VOM) costs, and Fuel costs.
- Electric Rate Characterizations: Applicable utility rates, including fixed charges, monthly and daily demand charges, energy charges, supplier market prices.

- Control Characterizations: Technology, operational modes, utility integration, building energy management systems (BEMS).

7.2 Component Selection and Sizing

Component selection and sizing defines the microgrid system. The selection process includes an electrical and thermal Load & Supply analysis, in order to determine the additional supply side and demand side resources needed in the microgrid and their proper sizing. The four principal tasks include:

- Load & Supply Analysis: Load and supply analysis can be a model based determination of the various DER elements, including distributed generation, Energy Storage, and demand response, in order to meet the microgrid's electrical and thermal requirements (i.e., heating and cooling loads) reliably during emergency (i.e., grid outage) periods and normal blue sky days, and also provide the most economical combination of internal electrical and thermal generation and electrical purchases from the grid during normal (i.e., blue sky) days in grid connected mode.
- Infrastructure Assessment: These include assessment of the following (not an exhaustive list): switching & protection, AC/DC/ bus configuration, Microgrid point of common coupling (PCC), fuel & delivery, communications & sensing, metering, security.
- Control Assessment: Microgrid controller, automation, voltage & frequency management, supply/demand/balancing, power quality management, smart inverter control, ride-thru/islanding.

7.3 Functional Architecture Description

The next step is to develop a functional design of the microgrid. This is functional design of the microgrid that identifies various DER resources included in the microgrid and lays out the electrical network infrastructure and also the control and communications infrastructure. The principal tasks include:

- Electrical Infrastructure Configuration: developing a one-line diagram of the microgrid electrical network, and identifying various electrical devices and components.
- Control & Communications Infrastructure: developing the one-line diagram of the microgrid control & communications network, and identifying various control and communications devices and components (including hardware and software elements).
- Protection Design: This task analyzes the micro-grid to select the protection methodology and scheme and to select the protection equipment necessary to implement that scheme. It will also determine and specify the main voltage and current monitoring equipment and the switching and breaking equipment.
- Microgrid Orchestration: This task specifies the various operational modes of the microgrid during both emergency islanded mode and also during normal, blue sky, grid connected mode.
- Transitional Operations: This task specifies the requirements for islanding, reconnection, shut-down, start-up, and operations under various transitional conditions.

7.4 Business Case and Societal Benefit/Cost Analysis

The final aspect of microgrid feasibility assessment includes developing the business case and performing a societal benefit/cost analysis (BCA). BCA can be performed from various perspectives. For instance, the state's perspective is the overall "societal" benefits and costs, that will take into account the value of resiliency and avoided power interruptions from a broader societal point of view. On the other hand, the microgrid owner or developer perspective is the economic viability, financing prospects, and profitability of the project.

On the cost side, the main items to be quantified include: (a) various costs elements, covering the design, development, and deployment of the microgrid, capital costs of various components, fuel, variable operations and maintenance (VOM), and fixed operations and maintenance (FOM) cost of generation and demand side resources, (b) costs of the electrical network infrastructure, (c) costs of the control and communications infrastructure.

On the benefit side, the main items to be quantified include various potential revenue sources such as utility demand side programs, and those from participating as a virtual plant in the wholesale market (such as ISO markets). Additional benefits include energy efficiency, energy surety, criterial pollutant (i.e., SO_2 and NO_x) and greenhouse gas (i.e., CO_2) emissions reduction, displacement of conventional generation and reduction of fossil fuel usage, deferral of investment in grid scale generation resources and transmission and distribution networks, and avoided costs of power interruptions for different facilities within the microgrid.

The societal benefit cost analysis of New York Prize Stage 1 projects were performed using the Benefit Cost Analysis Model of Industrial Economics, Inc. (IEc). IEc was engaged by NYSERDA to perform the benefit cost analysis of all the New York Prize Stage 1 projects, using the information provided by the project teams. The model is applied first to a scenario where there are no outages during the year (i.e., normal blue sky days). If the Benefit to Cost Ratio is shown to be greater than 1, then the analysis stops there. However, if the Benefit to Cost Ratio is shown to be less than one, then the model is used to determine the number of days of outages in the year, which will result in a Benefit to Cost Ratio equal to 1.

Figure 6 presents the societal benefits and costs for an example microgrid with a Benefit to Cost Ratio of less than 1. Figure 7 presents the societal benefits and costs for the same microgrid with 0.95 days of outage in the year, which results in additional benefits associated with avoided cost of outages for the microgrid's critical facilities.

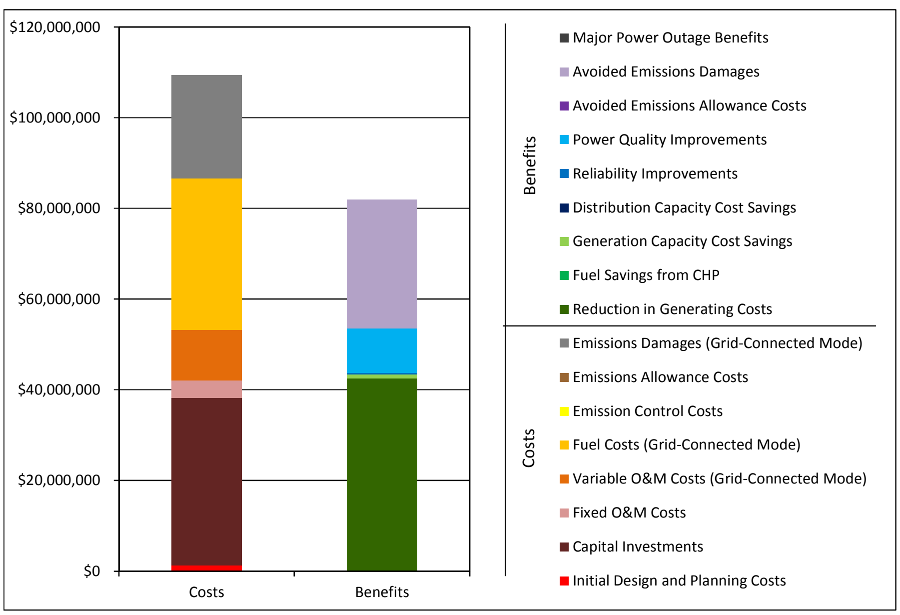

Figure 6: Benefit Cost Analysis Present Value Results with No Major Outages

(Source: Benefit Cost Analysis Model of Industrial Economics, Inc.)

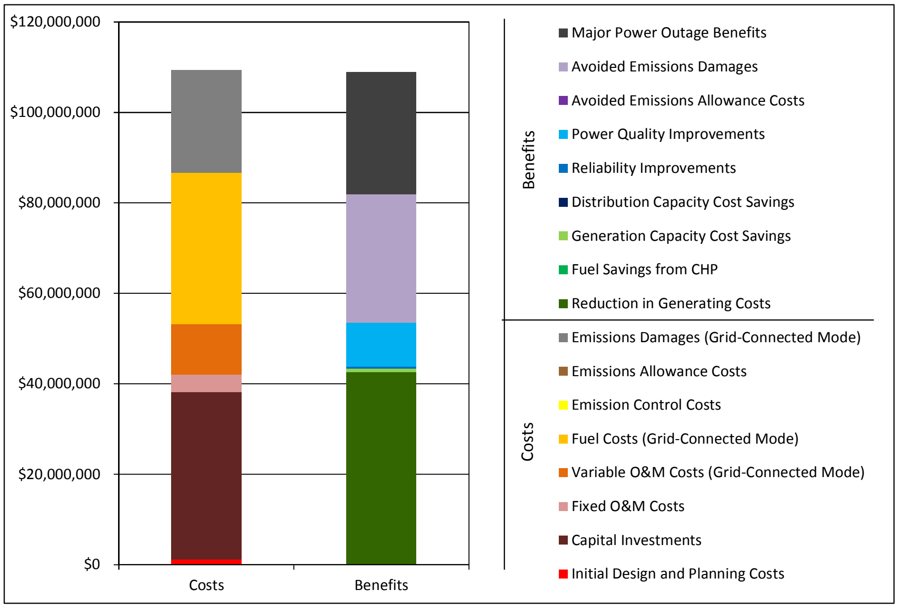

Figure 7: Benefit Cost Analysis Present Value Results with 0.95 Days of Outage per Year

(Source: Benefit Cost Analysis Model of Industrial Economics, Inc.)

6. MICROGRID MODELLING

Using the Distributed Energy Resources Customer Adoption Model (DER-CAM), GE Energy Consulting performed the detailed supply and demand analysis for the selected NY PRIZE projects. DER-CAM has been developed by the Lawrence Berkeley National Laboratory (LBNL) [7 - 10].

The DER-CAM optimization tool, shown in Figure 6, is a mixed-integer linear program (MILP) and its objective is to minimize the total equivalent annual costs or CO_2 emissions for providing energy services to a given site, including utility electricity and natural gas purchases, plus amortized capital and maintenance costs for any DG investments. The approach is fully technology-neutral and can include energy purchases, on-site conversion, both electrical and thermal on-site renewable harvesting, and partly end-use efficiency investments.

Its optimization techniques find both the combination of equipment and its operation over a typical year (average over many historical years) that minimizes the site's total energy bill or CO_2 emissions, typically for electricity plus natural gas purchases, as well as amortized equipment purchases. It outputs the optimal DER and storage adoption combination and an hourly operating schedule, as well as the resulting costs, fuel consumption, and CO_2 emissions. Given its optimization nature and technology-neutral approach, DER-CAM can capture both direct and indirect benefits of having different technologies together, for instance by reflecting the impact of CCHP in cooling loads originally met by electric chillers, thus considering the simultaneity of results.

The model picks optimal microgrid equipment combinations, based on daily (24-hour) electric and thermal (heating, cooling) load profiles of typical weekdays, weekends, peak days of each month in the year, as well as technology costs and performance coefficients, fuel prices, and utility tariffs for all possible electricity, heating, cooling, refrigeration, and domestic hot-water demand loads. The model also provides the 12 Month x 24 Hour dispatch profiles of the DER elements in the year.

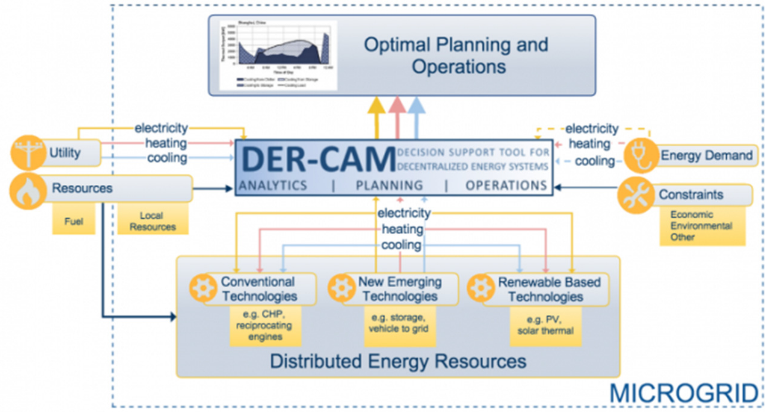

Figure 8: DER-CAM Schematic

(Source: Berkeley Lab)

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