SANDIA REPORT

SAND2014-17842
Unlimited Release
Printed September 2014

City of Hoboken Energy Surety Analysis: Preliminary Design Summary

Jason Stamp, Michael Baca, John Eddy, Ross Guttromson, Jordan Henry, Richard Jensen, Karina Muñoz-Ramos, Ben Schenkman, and Mark Smith
Sandia National Laboratories

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online ordering: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2014-17842
Unlimited Release
Printed September 2014

City of Hoboken Energy Surety Analysis: Preliminary Design Summary

Jason Stamp, Ph.D., Michael Baca, Ph.D., Karina Muñoz-Ramos, and Ben Schenkman
Military & Energy Systems Analysis Department

John Eddy, Ph.D. and Mark Smith, Ph.D.
Systems Readiness & Sustainment Technology Department

Ross Guttromson
Electric Power Systems Research Department

Jordan Henry
Critical Infrastructure Systems Department

Richard Jensen, Ph.D., P.E.
Geomechanics Department

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-1188

Abstract

In 2012, Hurricane Sandy devastated much of the U.S. northeast coastal areas. Among those hardest hit was the small community of Hoboken, New Jersey, located on the banks of the Hudson River across from Manhattan. This report describes a city-wide electrical infrastructure design that uses microgrids and other infrastructure to ensure the city retains functionality should such an event occur in the future. The designs ensure that up to 55 critical buildings will retain power during blackout or flooded conditions and include analysis for microgrid architectures, performance parameters, system control, renewable energy integration, and financial opportunities (while grid connected). The results presented here are not binding and are subject to change based on input from the Hoboken stakeholders, the integrator selected to manage and implement the microgrid, or other subject matter experts during the detailed (final) phase of the design effort.

Acknowledgements

The project team would like to acknowledge the staff of the city of Hoboken for their support, patience, and dedication, including Mayor Dawn Zimmer, Stephen Marks, Brandy Forbes, and the exceptional help provided by Hoboken City Planner Caleb Stratton.

We would also like to thank Rima Oueid from the Department of Energy's Policy Advisor for Energy and Finance (and former member of the President's Hurricane Sandy Task Force). Great appreciation goes to Dan Ton from the Department of Energy's Office of Electricity Delivery and Energy Reliability. Both Rima and Dan were critical champions of this project, and whom the project success relied heavily upon.

We would like to thank Eric Daleo of the New Jersey Governor's Office of Recovery and Rebuilding, and Mike Winka of the New Jersey Board of Public Utilities. Finally, we would like to thank the following Sandia staff for their significant contributions to this project: Abraham Ellis, David Robinson, Robert Hwang, and Michael Hightower.

Contents

Appendices

List of Figures

List of Tables

Executive Summary

In 2012, Superstorm Sandy hit the U.S. Atlantic coast as a Category 2 storm. The hurricane hit land in the New Jersey and New York area during high tides, resulting in storm surges 17 feet above mean sea level, causing flooding across the majority of of Hoboken, New Jersey. Although electric power to major substations in the area remained available, the city's electrical distribution system was de-energized due to major flooding.

The U.S. Department of Energy (DOE) sponsored Sandia National Laboratories to enhance Hoboken's critical infrastructure through the application of their Energy Surety Design Methodology (ESDM). This methodology pursues infrastructure and operational enhancements to electric systems which enhance resilience. This document summarizes design requirements and recommendations for the City of Hoboken's proposed electrical retrofit to support resilient service during extreme conditions.

The operational system design will support designated critical loads within the Hoboken city limits. Critical buildings are those that can cause significant impacts (e.g. economic, human, etc. as defined by stakeholders) if non-operational. The design process applies quantitative analysis methods to develop a preliminary design for the proposed electrical system that achieves a good cost-performance balance. The resulting design requirements and recommendations are presented in this report, intended to support later request-for-proposal (RFP) activities.

The preliminary design for Hoboken developed by the ESDM uses new electrical networks called microgrids that can operate autonomously while disconnected from the grid. Microgrids are combined with distributed energy resources (DERs) including natural gas generators, photovoltaic (PV) systems, and energy storage, to provide power the designated critical mission facilities. The new equipment requires its own supporting infrastructure such as control platforms, networking, electrical switches, transformers etc.

The approach also includes analysis for the application of three key technologies: combined heat and power (CHP), PV, and electrical energy storage. For CHP, nine sites were analyzed and three were immediately attractive. PV costs are fairly high with respect to payback (not counting environmental metrics); therefore, PV is not explicitly required in any design options, and PV costs are not included in any budget estimates. Analysis showed that the best benefit of using energy storage in an ESDM design was in energy shifting for PV systems sized larger than the local load demand, and for managing customer electricity billing by limiting peak demand and energy consumption for time-of-use tariffs.

The Hoboken microgrid's control architecture is essential to its stability and operational efficiency. Whether the control system is centralized or distributed, a dedicated communication network will be required for monitoring and data exchange. Optimal operation requires controllers on energy resources that will likely replace or interface with existing original equipment manufacturer's controls.

Hoboken microgrids will also need cyber security measures to preserve data integrity and availability. Applying both industry standard best practices and microgrid control system segmentation techniques will provide a high level of security for the Hoboken microgrid control system network, reducing the likelihood of disruption due to cyber attack, and minimizing any damage done if an attack should succeed.

Overall, the analysis shows that resilient electrical service can be achieved for Hoboken with a reasonable investment. The suggested design decisions and system configurations are presented as requirements and recommendations. The document also includes an extensive set of appendices that detail the data gathering, modeling, and analysis efforts that led to these recommendations.

Abbreviations and Acronyms

Acronym or Abbreviation	Meaning
A	Amperes
A/C	Air Conditioning
A&E	Architecture & Engineering
AC	Alternating Current
AE	Abnormal Emergency
ANSI	American National Standards Institute
ATS	Automatic Transfer Switch
BPU	Board of Public Utilities
BTU	British Thermal Units
CAES	Compressed Air Energy Storage
CHP	Combined Heat and Power
CIP	Critical Infrastructure Protection
CO2	Carbon Dioxide
CONOPS	Concept of Operations
CSRA	Cyber Security Reference Architecture
deg	Degrees
DBT	Design Basis Threat
DC	Direct Current
DER	Distributed Energy Resources
DoD	Department of Defense
DOE	Department of Energy
DSM	Design Screening Model
ESIP	Energy Savings Improvement Program
ECM	Electronic Commutated Motor
EENS	Expected Energy Not Served
EIA	Energy Index of Availability
EMS	Energy Management System
EN	Environmental
ENM	Electrical Network Model
ES	Energy Storage
ESA	Environmental Services Administration
ESDM	Energy Surety Design Methodology
ESM	Energy Surety Microgrid
ESS	Energy Storage System

Continued on next page

Table 1 – *Continued from previous page*

Acronym or Abbreviation	Meaning
FC	Fuel Cell
FEMA	Federal Emergency Management Agency
FN	Financial
FOI	Frequency of Interruption
gal	Gallons
HILF	High Impact Low Frequency
HQ	Headquarters
Hz	Hertz
ICS	Industrial Control Systems
IEE	Institution of Electrical Engineers
IEEE	Institute of Electrical and Electronics Engineers
IR	Interagency Report
IRR	Internal Rate of Return
k	Kilo
kg	Kilograms
kV	Kilovolts
kVA	Kilovolt·Amperes
kW	Kilowatts
kWh	Kilowatt hours
LBS	Lower Bound Set
LED	Light Emitting Diode
LOLE	Loss of Load Expectation
LV	Low voltage
MC	Monte Carlo
mm	Millimeters
MMBTU	Million British Thermal Units
MSL	Mean Sea Level
MV	Medium voltage
MVA	Megavolt·Amperes
MW	Megawatts
N	Normal
NEMA	National Electric Manufactures Association
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NIST	National Institute of Standards and Technology
NJ	New Jersey
NJBPU	New Jersey Board of Public Utilities
NPV	Net Present Value
NREL	National Renewable Energy Laboratory

Continued on next page

Table 1 – *Continued from previous page*

Acronym or Abbreviation	Meaning
OD	Operational Demonstration
OEM	Original Equipment Manufacturer
P	Real Power
PCC	Point of Common Coupling
PDF	Probability Density Function
pf	Power Factor
PSEG	Public Service Electric and Gas Company
PSI	Pounds per Square Inch
pu	Per-unit
PUC	Public Utility Commission
Q	Reactive Power
QoS	Quality of Service
PRM	Performance-Reliability Model
PV	Photovoltaic
RE	Renewable Energy
RFP	Request for Proposal
RLM	Residential Load Management
ROW	Right of Way
RS	Residential Service
S	Apparent Power
SAA	System Adequacy Assessment
SCADA	Supervisory Control and Data Acquisition
SNL	Sandia National Laboratories
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability & Security
SPSS	Statistical Product and Service Solutions
SREC	Solar Renewable Energy Credit
SUT	Sales and Use Tax
TC	Technical
TD	Technical Demonstration
TE	Typical Emergency
TM	Trade Mark
TMO	Technology Management Optimization
TOU	Time of Use
UBS	Upper Bound Set
UPS	Uninterruptible Power Supply
US	United States
V	Volts
VAR	Volt·Amperes-Reactive
VPN	Virtual Private Network

Chapter 1

Introduction

During the 2012 hurricane season, Superstorm Sandy hit the U.S. Atlantic coast as a Category 2 storm. While not as high in intensity as some previous storms, it was the largest Atlantic hurricane on record and the second costliest in U.S. history.

The hurricane hit land in the New Jersey and New York area during high tides, resulting in storm surges over 17 feet above mean sea level. On October 28th, Hoboken Mayor Dawn Zimmer ordered basement and street level residences to evacuate due to potential flooding, which occurred across a majority of the city. The resulting power outages and stagnant system transportation crippled the city. Although electric power to major substations in the area remained available, the electrical distribution system was de-energized due to major flooding.

The city of Hoboken, in collaboration with the U.S. Department of Energy (DOE), Sandia National Laboratories (SNL), PSEG (Public Service Electric and Gas Company), and the New Jersey Board of Public Utilities (NJBPU) committed to finding ways to mitigate the severe consequences of similar future events. DOE sponsored Sandia to enhance Hoboken's critical infrastructure through the application of their Energy Surety Design Methodology (ESDM). This methodology pursues infrastructure and operational changes to electric systems that enhance resilience. Unlike design methods used by the utility electric power industry, this design mitigates for high-consequence, low probability threats, such as hurricanes and electrical blackouts.

This document summarizes design requirements and recommendations for the City of Hoboken's proposed electrical retrofit to support resilient service during extreme conditions. The design presented here provides guidelines and functional requirements for the implementation of multiple microgrids in the City of Hoboken. This work mirrors previous design efforts for U.S. Department of Defense (DoD) facilities under the SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability & Security) program at Joint Base Pearl Harbor Hickam, Fort Carson, and Camp H. M. Smith. The design is based on the concept of an Energy Surety Microgrid™ (ESM), developed by SNL [1].

1.1 Energy Surety Microgrids

The ESM definition includes a microgrid that can operate either grid-tied or in islanded (standalone) mode. Every ESM comprises the following types of loads and or buildings:

- **Type C** – those loads / buildings that are critical to the mission or function of the facility; these loads usually have dedicated backup generators. Some Type C loads are non-interruptible and will include uninterruptible power supplies (UPS) while other Type C loads can endure short losses of electrical power.

- **Type P** – those loads / buildings that are of high priority ("nice to have"), but that can be switched on or off of microgrids at the discretion of the designated emergency authorities.

- **Type O** – those other loads / buildings that will not be powered during islanded, microgrid operations.

ESM architectures developed using the ESDM demonstrate increased reliability for critical mission loads resulting from the interconnection of electrical generation assets using an electrical distribution network; reduced reliance on fossil-fuel-sourced backup power through the use of renewable energy sources during outages; increased efficiency and better maintenance cycles of backup power generators through careful coordinated operation across the microgrid system; and operational risk reduction through strong focus on cyber security.

1.2 Design Basis Threat

The term design basis threat (DBT) was borrowed from the nuclear industry, where it is a comprehensive document that identifies threats a facility must withstand. The DBT then informs the design of the facility and its systems. Performance objectives are separately listed for each DBT.

For the ESDM, DBT defines the most stringent conditions (threats) that must be met by the system design. These threats may be environmental (such as a hurricane) or man-made (such as a cyber or physical attack).

For the Hoboken project, the DBT is:

- FEMA 100 year flood plain plus 2.5' which translates to 19.5' above mean sea level (MSL)

- Regional electrical blackout

- Cyber security threats faced by automation systems

1.3 Site Specific Requirements

The Hoboken design entails several site specific requirements, including:

- Use of 15 PSI (pounds per square inch) natural gas (NG) systems to support emergency generators
- Where economically viable, installation of photovoltaic (PV) energy systems primarily to support grid-connected conditions
- Where economically viable, installation of combined heat and power (CHP) systems primarily to support grid-connected conditions
- All designated loads are considered interruptible/critical (UPS are assumed to be present where needed)
- Minimal impact (preferably zero impact) on utility operations

To achieve the ESM functionality, many of the following assets and/or changes will be incorporated into the planned backup electrical systems:

- Switches, breakers, and controls to connect distributed energy resources (DER) – specifically backup NG generators – to new low voltage (LV) and medium voltage (MV) networks
- Automatic transfer switches (ATS) that will maintain isolation between new backup electrical systems and the utility grid
- ESM DER controls that can switch distributed sources on/off, change power levels depending on system mode, and that include communication equipment necessary to connect the controls
- New DERs that support revenue generation / cost avoidance while grid-connected
- Protection for DERs and microgrid zones
- Cyber security that conforms to emerging industry standards and the Sandia Cyber Security Reference Architecture (CSRA), which is included as embedded content in Appendix R

1.4 Project Goals

The overriding goal for the operational system is to support designated to support loads within designated critical buildings inside the Hoboken city limits (actual buildings and geography are described in Chapter 3). The performance objectives for the design are to minimize minimize the consequences of DBT events. The primary metrics focus on outages of critical loads during DBT intervals (reducing both frequency and severity).

Another objective for the design process is to apply quantitative analysis methods in order to develop a preliminary design for the proposed electrical system that achieves a good cost / performance balance. Those design requirements and recommendations are in this report, intended to support later request-for-proposal (RFP) activities.

This preliminary design document follows a format that has, for past projects, been readily applicable to an RFP formulation. It is important to note that this design document is not 100% proscriptive – it does not provide a set of blueprints for immediate construction. Rather, the report describes the important concepts and design decisions that will enable an architecture and engineering (A&E) firm to develop a final detailed design that will be well-suited for meeting the project goals.

Chapter 2

System Overview and Integrator Responsibilities

The preliminary design for Hoboken developed by the ESDM utilizes new electrical networks combined with DERs (including NG generators, PV systems, and energy storage) to supply power to the designated critical mission facilities. The new equipment requires controls to make them compatible with the ESM concept of operations (CONOPS) including control platforms, networking, electrical switches, transformers etc, as necessary. The ESM will include multiple points of disconnection where loads can be switched between the Hoboken ESM or the utility feed.

2.1 Concept of Operations for the Hoboken Microgrids

The following figures illustrate the process used to operate the electrical microgrid networks in the preliminary design for Hoboken. The diagrams show how the various DERs and buildings go from being grid tied to an islanded ESM. Figure 2.1 illustrates a new, dedicated MV ESM feeder with three buildings (A, B, and C) which are ordinarily fed by two utility feeders. All three buildings contain critical load (otherwise, they would not be connected to the ESM) and two (A and B) include backup NG generators, while the third has a PV installation. The NG generator in building B includes CHP capability, meaning that it is operating while grid-connected (although with minimal utility impact). Redundant transformers are included for the ESM feeder to ensure no impact to utility operations from the new electrical infrastructure. In the base case, the utility is active and the ESM is de-energized (“on” is designated as red, and “off” is green).

If the power is lost (Figure 2.2), all load is temporarily lost, and the PV and CHP shut down due to anti-islanding protection. Anti-islanding is a protective measure that ensures all electrical sources are shut down so that utility workers can make repairs without worrying that customer-owned equipment is creating hazardous voltages. Critical loads within buildings that require uninterruptible supply may operate on their own using a UPS.

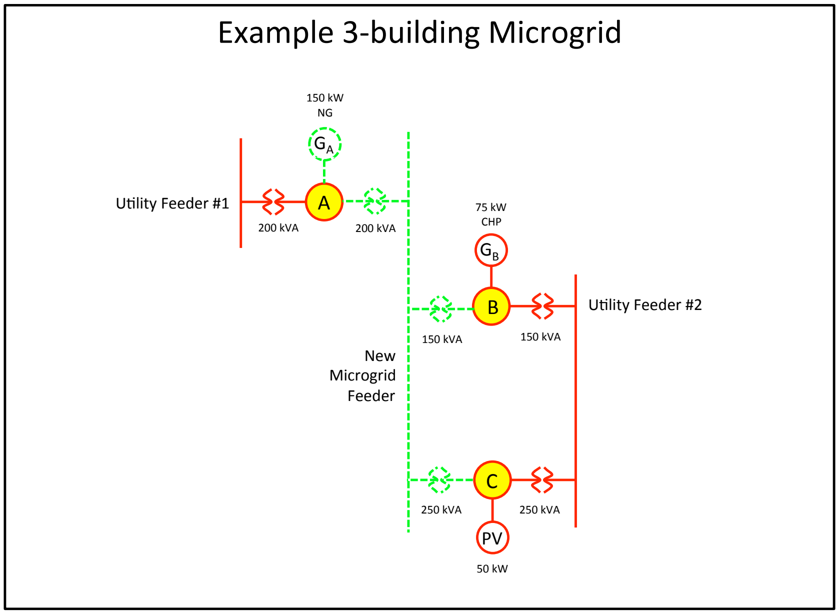


Figure 2.1: All buildings on the microgrid are powered by the local utility

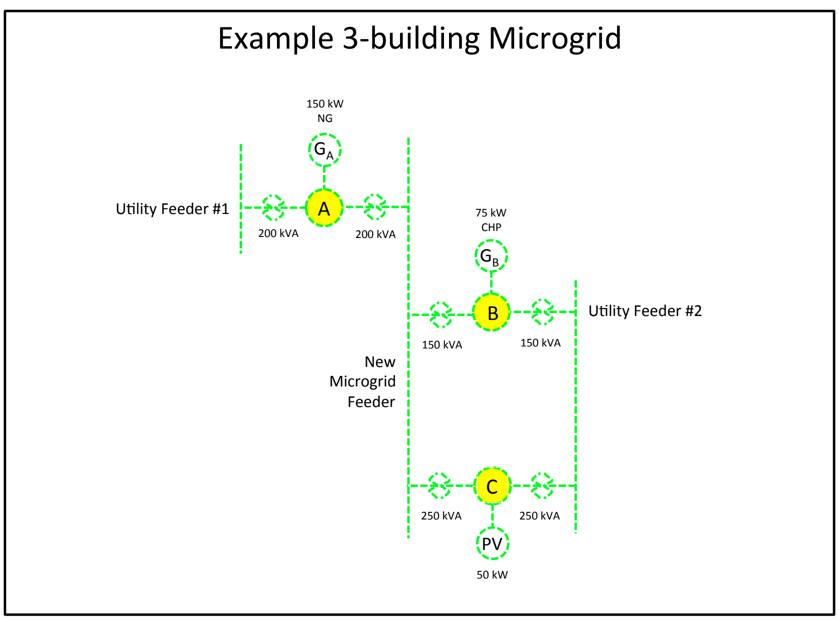


Figure 2.2: All buildings on the microgrid lose power immediately after the utility is lost

Backup NG generators will start and serve local load, and the CHP system also restarts once the building is disconnected from the utility feeder (which will require the ESM control systems to open a breaker or switch). This recovers some load, as shown in Figure 2.3.

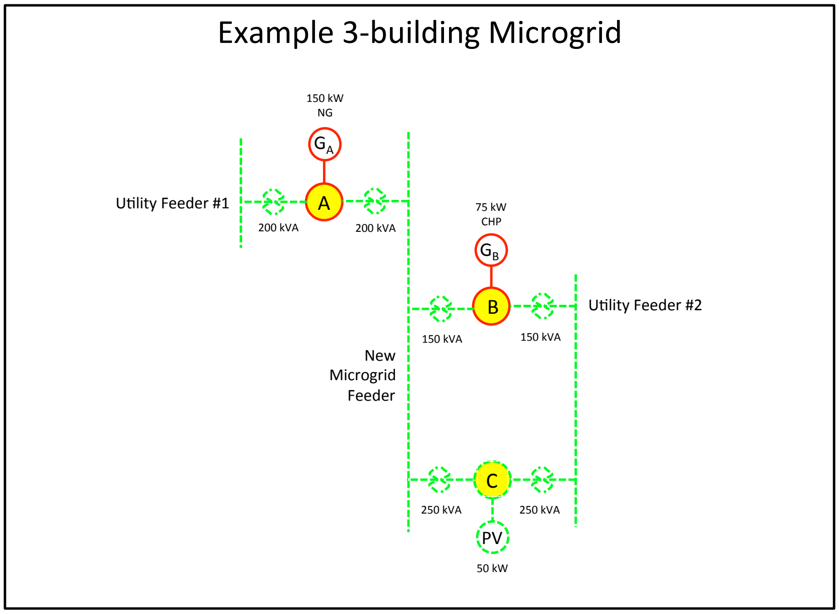


Figure 2.3: Some buildings on the microgrid are supplied by backup NG generators shortly after the utility is lost

If loss of power is greater than some predetermined interval, then on-site personnel can enable microgrid operation. Then the generators are synchronized sequentially to the ESM portion of the feeder until they are all in parallel on the ESM electrical network. This must done carefully, in stages, to ensure that the electrical disturbances caused by these connections do not impact the already-connected critical loads. The ESM network will allow critical buildings to receive electrical energy if they do note have a NG generator on site (Building C in Figure 2.4).

If the ESM is energized for greater than five minutes (the typical anti-islanding lockout interval), then as shown in Figure 2.5 the renewable energy source can come back online to start supplying power. Then the power provided by the NG generatoes is automatically adjusted for more efficient use. When utility power is restored (for some interval deemed sufficient by site personnel), the buildings reconnect to the utility and the ESM is deactivated. The steps are depicted graphically in Figure 2.6.

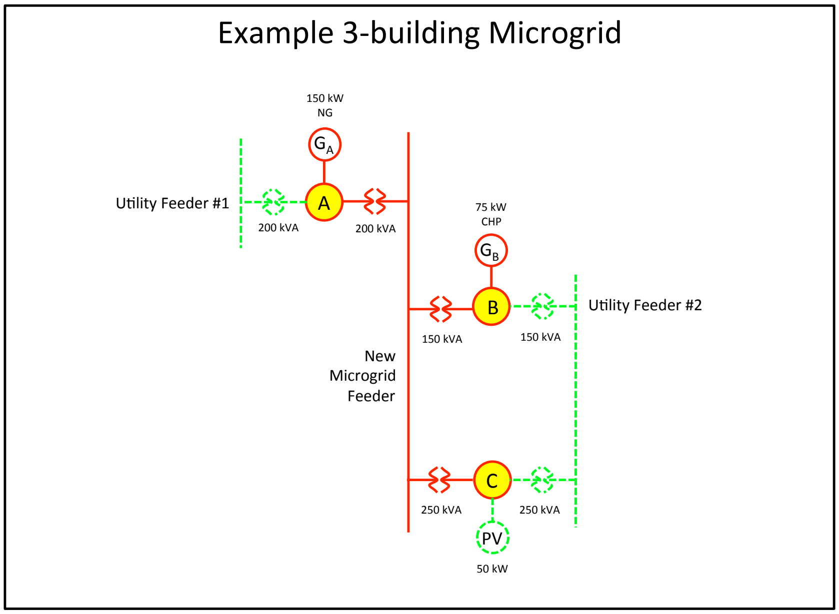


Figure 2.4: Once the ESM network becomes active, all buildings on the microgrid are supplied with power

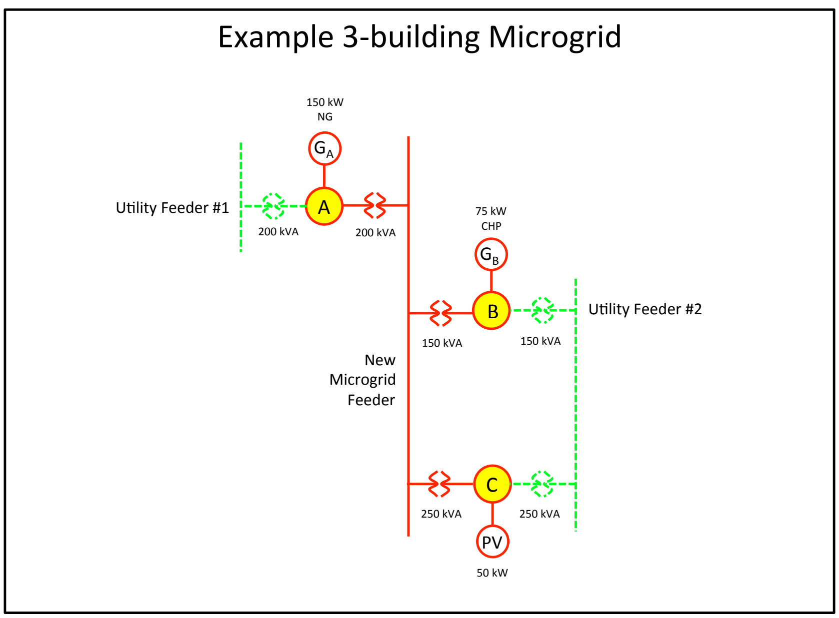


Figure 2.5: After the ESM is active, RE may reconnect and supply power

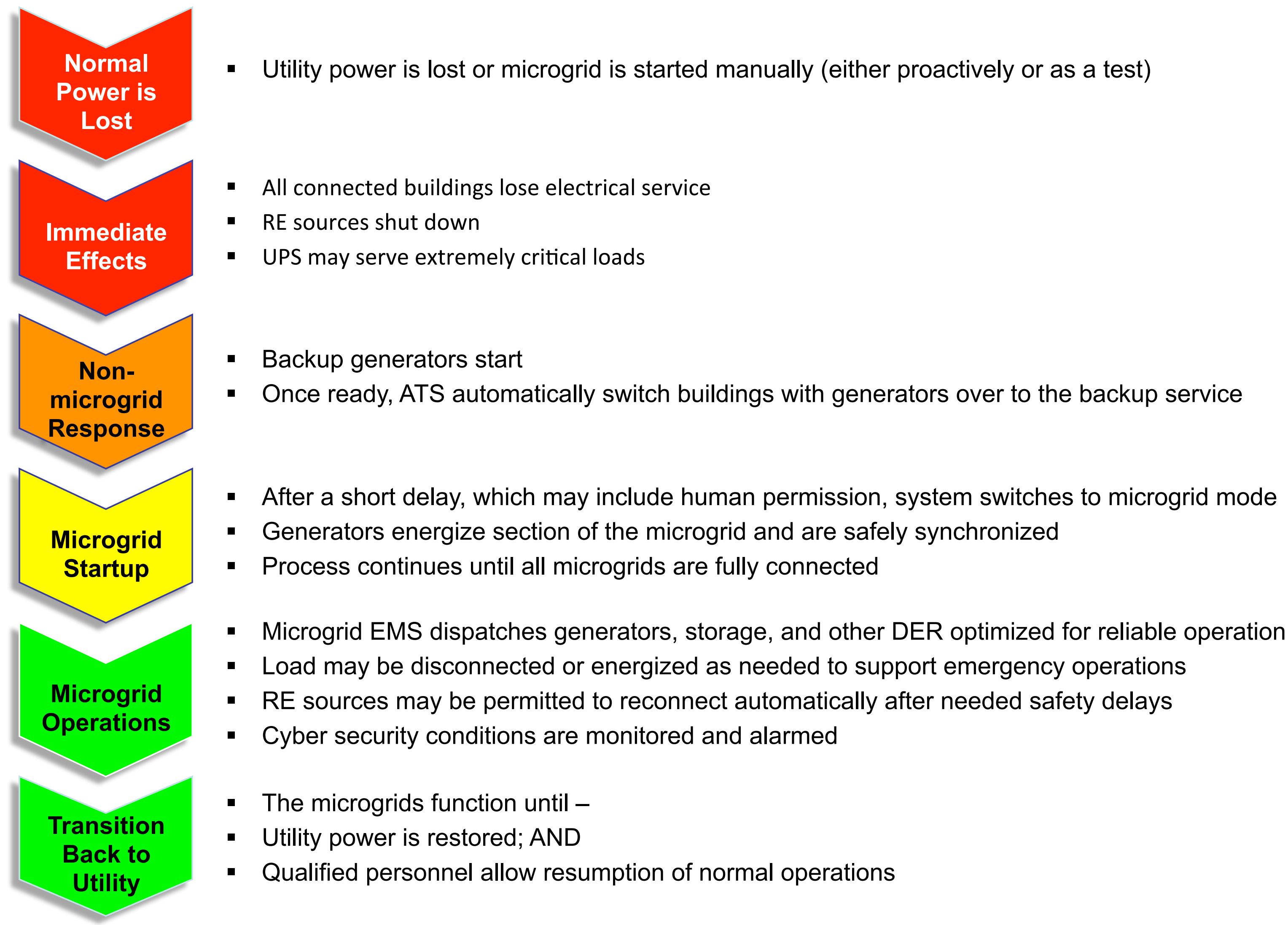


Figure 2.6: Stages of the Hoboken CONOPS

2.2 Integrator Responsibilities

This document is a preliminary design. The selected integrator is responsible for development of the detailed (100%) design. As part of the detailed design process, the integrator will solicit feedback from the Hoboken stakeholder team.

2.2.1 Construction Requirements and "Seamless Transition"

The implementation of the microgrid should have as low of an impact to ongoing operations within Hoboken as is technically and programmatically feasible. A key element of this is to ensure that various systems can transfer to microgrid or backup modes seamlessly. (Here, the word "seamless" refers to the electrical loads not perceiving any service interruption.) Of course, the specified basic CONOPS for the microgrid (discussed previously) explicitly eliminates seamless transition as a requirement for the transfer to microgrid operation, but in this discussion the requirement is that the system can seamlessly transfer *when the failover is planned* and the utility remains operational. The intentional lack of requirement to support seamless transition for situations where there is an *unplanned utility outage* remains applicable. Note that seamless transition out of islanded microgrid mode is still desirable, provided it is achievable per interconnection requirements.

2.2.2 Coordination of Energy Projects in Hoboken

The ESM installations and other electrical work for Hoboken may need to coordinate with other post-Sandy projects. In particular, there is ongoing work where a bond issue is finding some generator installations in the city. As full detail was not available at the time of the analysis contained in this report, these generators were not included in the design. However, they may be adapted for use if suitable and potentially reduce the estimated project cost slightly because NG generation would need to be purchased later.

2.2.3 Participation in the Technical and Operational Demonstrations

The fully implemented Hoboken microgrids will require an operational demonstration prior to final project completion. Subsystems may be demonstrated during the time preceding the operational demonstration as part of technical demonstrations that will be coordinated with the stakeholders. As part of the operational demonstration, the following requirements must be met:

- During the demo, all critical loads will be connected to the microgrid
- The microgrid must island and reconnect within the time required
- Protective relays must operate safely within acceptable parameters
- Power quality must remain at acceptable levels
- Cyber security must meet applicable standards
- Control systems will optimize operation of available generation resources

Chapter 3

Assets and Facility Characterization

The first task was to characterize the critical facilities for the Hoboken ESDM application. This was done with cooperation of both SNL and New Jersey personnel. Critical buildings are those that are essential during BDT conditions, and/or if were non-operational can cause significant losses (e.g. economic, human, etc. as defined by stakeholders). Once the critical buildings were identified, energy requirements for these buildings were determined.

3.1 Building/Load Categorization

Hoboken (Figure 3.1) resides in Hudson County, New Jersey were the population is approximately 50,000 people in an area of 2.01 square miles. The Hudson River is on the east side of Hoboken which overflows during heavy rains and floods the city streets. Superstorm Sandy devastated Hoboken on October 29, 2013 with high winds and flooding. Many buildings were damaged from the water and many were without electric power.

Using the design base threat of a 100 year flood (where the water level is 19.5 feet above sea level) and electric power being down for 7 days, buildings were chosen to meet the criteria that the safety of the citizens and emergency responders can survive and operate. The team that created this list was the Hoboken city authorities, SNL, and various stakeholders which were determined in many working meetings. After initially sorting the 55 buildings into four tiers (as described in Appendix C), the stakeholders elected to have two groups of buildings. The first (called the upper bound set or UBS) included all of them, while a second (the lower bound set or LBS) had only 34 of them. The reason for this is that the stakeholders were interested in the potential cost differences that the ESDM could calculate, since the UBS may be unaffordable and they were desiring a fallback. The final categorization is shown in Table 3.1. The buildings are shown overlaid onto a flood map in Figure 3.2.

Figure 3.1: City of Hoboken

Table 3.1: Critical buildings for the Hoboken ESDM

Building #	LBS/ UBS	Building Name	Type	Location
1	Both	Fire Engine Company 3	Emergency	1313 Washington Street
2	Both	Fire Engine Company 4	Emergency	801 Clinton Street
3	Both	Fire Headquarters	Emergency	201 Jefferson Street
4	Both	Fire Engine Company 1	Emergency	43 Madison Street
5	Both	Police Headquarters	Emergency	106 Hudson Street
6	Both	University Medical Center	Emergency	308 Willow Avenue
7	Both	Sewage Treatment Plant	Flood Control	Adams Street
8	Both	Pump Station 5th Street	Flood Control	500 River Road
9	Both	Pump Station 11th Street	Flood Control	83 11th Street
10	Both	Pump Station H1	Flood Control	99 Observer Highway
11	Both	Volunteer Ambulance Corps	Emergency	707 Clinton Street
12	Both	Hoboken City Hall	Operation	94 Washington Street
13	Both	Hoboken High School	Shelter	800 Clinton Street
14	Both	Wallace School	Shelter	1100 Willow Avenue
15	Both	Hoboken Homeless Shelter	Shelter	300 Bloomfield
16	Both	St. Matthew's Church	Shelter	57 8th Street
17	Both	St. Peter and Paul Church	Shelter	404 Hudson Street
18	UBS	A&P	Groceries	614 Clinton Street
19	Both	Kings 1	Groceries	325 River Street
20	Both	Kings 2	Groceries	1212 Shipyard Lane
21	Both	Sunoco	Gas Station	1301 Willow Avenue
22	Both	Multi-Service Center	Shelter	124 Grand Street
23	UBS	Public Works Garage	Operation	256 Observer Highway
24	Both	Garage B	Parking Garage	28 2nd Street
25	Both	Garage D	Parking Garage	215 Hudson Street
26	Both	Garage G	Parking Garage	315 Hudson Street
27	Both	Midtown Garage	Parking Garage	371 4th Street
28	Both	Columbian Arms	Senior Housing	514 Madison Street
29	Both	Marion Towers	Senior Housing	400 1st Street
30	Both	Columbian Towers	Senior Housing	76 Bloomfield Street
31	UBS	Housing Authority 1	Affordable Housing	655 6th Street
32	UBS	Housing Authority 2	Affordable Housing	501 Marshall Drive
33	UBS	Housing Authority 3	Affordable Housing	400 Marshall Drive
34	UBS	Housing Authority 4	Affordable Housing	320 Marshall Drive
35	UBS	Housing Authority 5	Affordable Housing	300 Marshall Drive
36	UBS	Housing Authority 6	Affordable Housing	321 Harrison Street
37	UBS	Housing Authority 7	Affordable Housing	311 Harrison Street
38	UBS	Housing Authority 8	Affordable Housing	320 Jackson Street

Continued on next page

Table 3.1 – *Continued from previous page*

Building #	LBS/ UBS	Building Name	Type	Location
39	UBS	Housing Authority 9	Affordable Housing	310 Jackson Street
40	UBS	Housing Authority 10	Affordable Housing	311 13th Street
41	UBS	Housing Authority 11	Affordable Housing	804 Willow Avenue
42	Both	Fox Hill Housing	Senior Housing	900 Clinton Street
43	UBS	5 Church Towers	Affordable Housing	Grand Street
44	UBS	10 Church Towers	Affordable Housing	Clinton Street
45	UBS	15 Church Towers	Affordable Housing	Grand Street
46	UBS	Clock Towers	Affordable Housing	300 Adams Street
47	UBS	Marineview 1	Affordable Housing	331 Hudson Street
48	UBS	Marineview 2	Affordable Housing	301 Hudson Street
49	UBS	Applied 1	Affordable Housing	111 Newark
50	UBS	Applied 2	Affordable Housing	1203-1209 Willow Avenue
51	Both	YMCA (SROs)	Affordable Housing	1301 Washington Street
52	Both	Police Dept Radio Repeater	Emergency	N/A
53	Both	Fire Dept Radio Repeater	Emergency	N/A
54	Both	CVS	Pharmacy	59 Washington Street
55	Both	Walgreens	Pharmacy	101 Washington Street

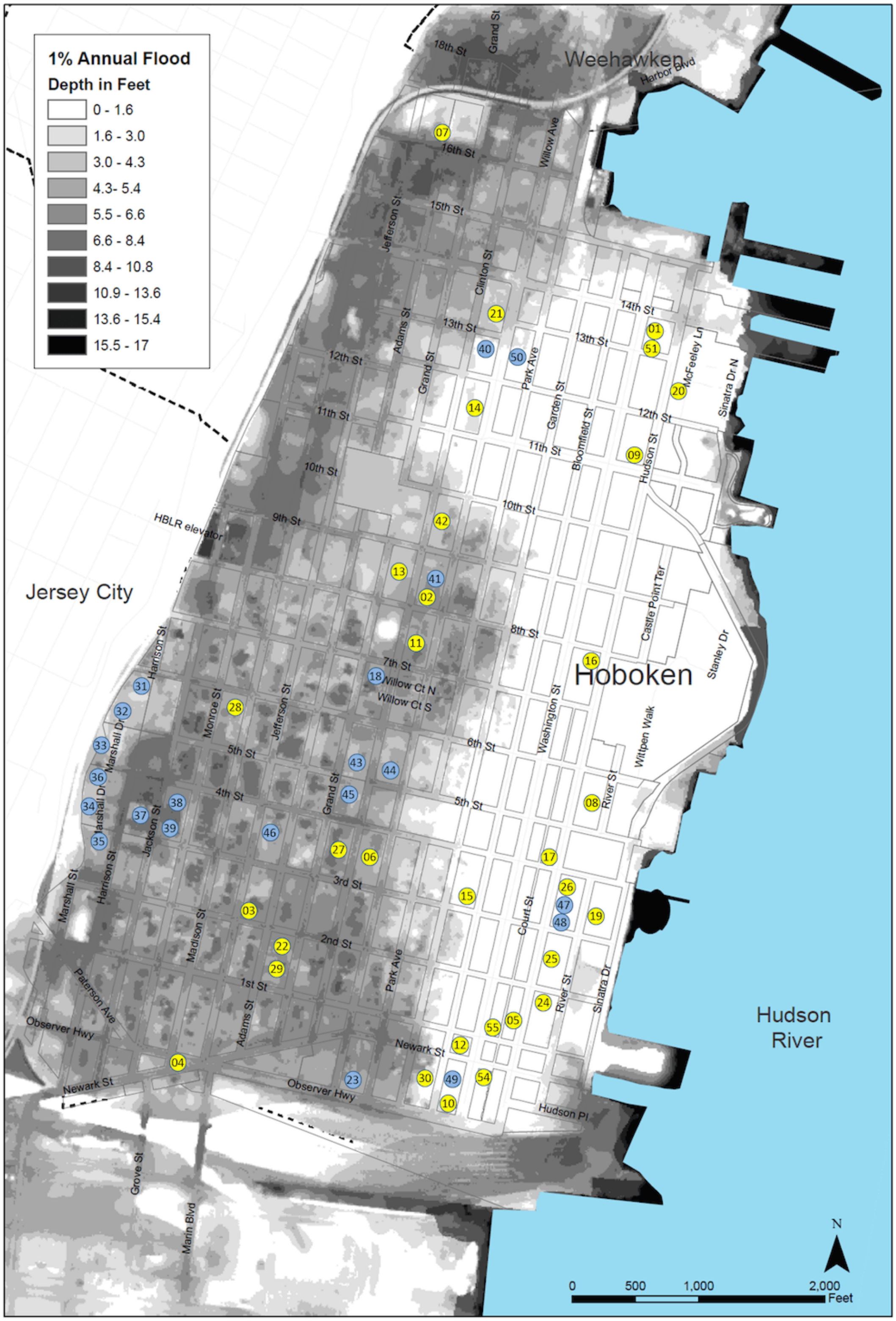


Figure 3.2: Buildings shown on flood map, yellow is UBS/LBS and blue is UBS only

3.2 Data Requirements

In order to characterize the existing energy system from the selected buildings and do a preliminary ESDM design and follow-on work to implement an actual ESDM, electric feeder and building information is necessary for load characterization and for system studies as described in the latter sections of the report. The information needed includes:

- Feeder information for PSEG feeder(s) potentially included in the ESDM area such as feeder conductor configurations and ratings (kV, size, length), transformer ratings (kVA) of building service entrances, and feeder peak and winter loads (kVA, kW) as well as any knowledge of projected growth for the ESDM
- Building information for critical buildings including transformer ratings (kVA), peak summer and winter loads (kVA, kW), distribution of critical and non-critical loads within each building, and existing backup generator ratings
- Backup generator information for sites that already have them (although they won't be included in the Hoboken microgrid, they are still available to provide power for the site under some circumstances)
- List of proposed/potential DER for the ESM including CHP and PV.
- Backup generator information for each backup generator to be included in the ESDM including generator manufacturer, size (kW, kVA), fuel type (natural gas, diesel, etc.), fuel storage capabilities (tank capacity) if applicable, height above flood zone, operational and historical information on backup generators (e.g. maintenance schedule)
- Overall fuel transport and storage capabilities (e.g. diesel storage repository, etc.)
- Ownership of critical building (privately owned, municipality, housing authority, etc.)

3.3 Electrical Network Characterization

PSEG provided a one-line diagram showing existing 13.8kV feeders electrically powering the City of Hoboken and the internal configuration of the substations. After discussions with PSEG concerning safety related issues relating to back feeding the existing electrical feeders and electricians, it was determined that new 13.8kV underground feeders would be installed by the city to avoid back feeding any PSEG equipment when any ESMs are operating. Since the feeders are going to be newly installed, Sandia used Google Earth to lay out potential locations of new electrical feeders (details of the approach are covered in the appendices). Figure 3.3 shows the building locations in the Google Earth model.

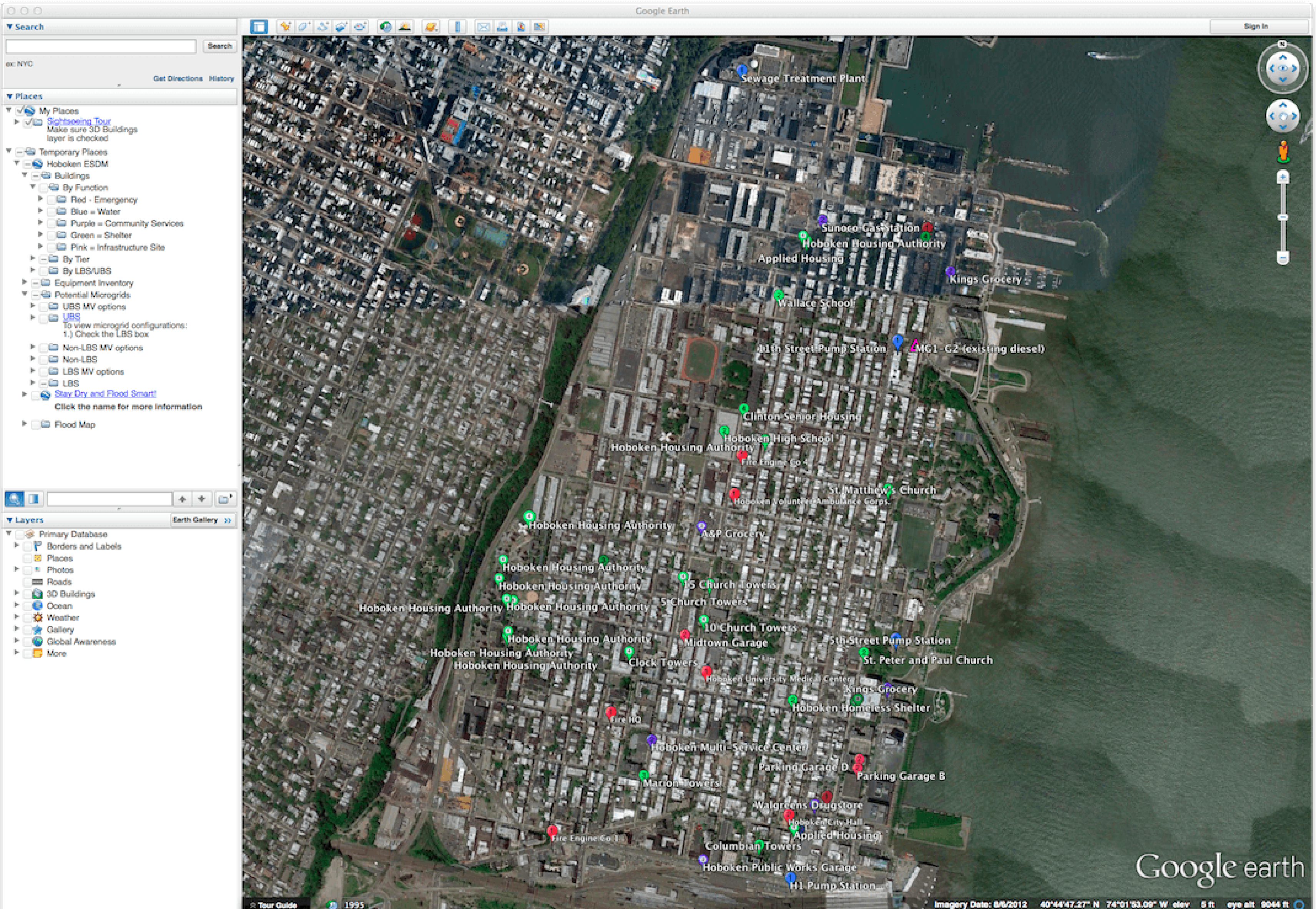


Figure 3.3: Hoboken Google Earth map

3.4 Load Characterization

Metered data was only available for a very few buildings, so a 30% rating of the building's transformer was used to determine the continuous kW load of each building. The 30% comes from SNL's experience using the ESDM with similar building types. Table 3.2 shows the building names and the estimated load in kW.

Table 3.2: Hoboken mission critical building load demand

Building	Estimated Load (kW)
Grocery – Kings	450
YMCA (SROs)	150
Fire Engine Company 3	150
11th Street Pump Station	15
Gas Station – Sunoco	15
Applied	45
Hoboken Housing Authority	450
Wallace School	250
Senior Housing Fox Hill	45
Hoboken High School	150
Hoboken Volunteer Ambulance Corps	15
Fire Engine Company 4	22.5
804 Willow Ave	90
Hoboken University Medical Center	1000
Midtown Garage	150
Clock Towers	150
Church Towers 5	45
Church Towers 10	150
Church Towers 15	90
Grocery – A&P	45
Fire Head Quarters	37.5
Hoboken Multi-Service Center	90
Marion Towers	225
Columbian Arms	90
Hoboken Housing Authority	90
Hoboken Housing Authority	45
Hoboken Housing Authority	67.5
Hoboken Housing Authority	90
Hoboken Housing Authority	45
Hoboken Housing Authority	45
Hoboken Housing Authority	90
Hoboken Housing Authority	90

Continued on next page

Table 3.2 – *Continued from previous page*

Building	Estimated Load (kW)
Hoboken Housing Authority	90
Fire Department Radio Repeater	15
St. Matthew's Church	15
5th Street Pump Station	750
St. Peter and Paul Church	30
Marineview 1	450
Garage G	150
Marineview 2	450
Grocery – Kings	450
Garage D	225
Garage B	90
Police Head Quarters	150
Police Department Radio Repeaters	450
Walgreens	90
Hoboken City Hall	225
Applied	225
CVS Pharmacy	150
Columbian Towers	150
H1 Pump Station	225
Hoboken Public Works Garage	30
Sewage Treatment Plant	900
Fire Engine Company 1	45
Hoboken Homeless Shelter	45
TOTAL	9.883

At present, there is approximately 9.9MW of load demand for the mission critical buildings in the City of Hoboken. These loads will be considered in the ESDM and will have to be powered during the DBT. To be conservative, new underground 13.8kV electrical feeders in the design will be rated for 10MW so that power can be shifted anywhere throughout the systems.

3.5 Generation Characterization

The next assets evaluated were existing sources of generation. Generator location and sizes were given to Sandia by the City of Hoboken and validated by Sandia site visits. Some generators were being installed under a bond issue program during this project but the ratings of these generators were not all disclosed to SNL. Therefore, these generators were not included in the ESDM – if/when installed, they will improve the performance of the system or defray some of the needed additional generation. Table 3.3 shows the diesel generators that are existing assets. In subsequent design efforts, these are assumed to be unavailable to the microgrid, although they can power the local site if both the microgrid and utility are unavailable.

Table 3.3: Existing generators in Hoboken

Building	Existing Generators (kW)
11th Street Pump Station	200
5th Street Pump Station	335
H1 Pump Station	750
Sewage Treatment Plant	1750

Even if the ESDM could re-use the existing generation, the total is only approximately 3MW, and this is not enough to cover the entire load of the mission critical buildings. Additional generation will have to be added to meet the load demand. Early on, the Hoboken stakeholders determined that new generators will preferably be of the natural gas fuel type. There is a high pressure natural gas line that runs throughout the city which did not lose operation during the super storm Sandy. Through many discussions, it was decided that this natural gas pipe line would be available throughout the DBT making the natural gas generator more attractive and resilient than adding diesel generators. New generators that are added will have to be installed above the 19.5' flood zone which means that they will be installed on top of roofs or on some support structures.

3.6 Service Entrances

Most of the building service entrances are below the DBT of 19.5', rendered them useless in a flood. In order to keep these buildings energized, the service entrances would have to be raised. Sandia National Labs contracted EI Associates to conduct a short term study to estimate raising a service entrance in 5 buildings which are representative of all the types of buildings in the ESDM. The five buildings that were chosen are the Hoboken Multi Service Center, Fire Headquarters, Hoboken High School, Kings Grocery Store and the Hoboken Housing Authority at 300 Marshall. The costs for raising the service entrances at buildings in the flood zones are extrapolated from these sites (complete details are included in Appendix G).

Chapter 4

Optimal Design Selection, Functional Requirements, and Recommendations

The site data in the previous section was applied to the ESDM to develop a set of design decisions. Several key assumptions include:

- Peak loads used for buildings are assumed to be 30% of transformer kVA ratings
- PSEG infrastructure will not be used
- There will be minimal (preferably zero) impact on PSEG system operations
- Assumptions have been made that Right-of-way (ROW) crossings will not impact system design
- All cabling between sites will be installed under streets
- Public-private partnerships will be established by the city between all those connected to the microgrid; this will include:
  - Financial responsibilities for capital, maintenance, and operations
  - Agreements on liabilities
  - Agreements on public and private use and also operational priorities
- All installed equipment will include costs to be adequately protected from flooding
- The microgrids will not sell power or services to the grid or any other entity
- A third party will operate and maintain the microgrid system on behalf of the owner(s)
- All generation will be connected to 15 PSI natural gas, avoiding the need to store fuel and avoiding potential flood contamination of the low pressure NG supply
- All load served is assumed to be critical (Type C) and interruptible (meaning that any non-interruptible load must have its own existing UPS)

Cost estimation includes the following:

- Trenching, conduit, and cabling (both MV and fiber optic for control)
- NG generation and installation
- Retrofitting electrical systems for buildings in the DBT flood zones
- Renewable energy and electrical energy storage (where applicable)
- Controls, including local control, system control (with a control center), and protection
- Cyber security technology and documentation
- Final design costs for the selected A&E firm (25% of the subtotal)
- Contingency costs (additional 15% of the subtotal)

The various analysis and modeling results and reasoning led to the following determinations for best cost-benefit solutions for both the UBS and LBS problems. For clarity and conciseness, only the most relevant results and reasoning are included in this chapter. Refer to the appendices of this document for detailed discussions, data, results, and reasoning.

4.1 Optimal Design Selection

4.1.1 Recommended and Attractive CHP Sites

Nine sites were analyzed for CHP applications (Table 4.1). Only three were immediately attractive, and are presented in Table 4.2. Suggested CHP installations are based on an internal rate of return (IRR) after 20 years of 5% or greater and a positive net present value (NPV). The locations were selected, and are suggested, based on available data for city buildings. However, these locations must be approved by PSEG to validate the ability of these systems to stay connected "behind the meter" during times when the microgrid is not operating. Data is in the form of monthly electricity and monthly peak (over a 30 minute horizon) and monthly natural gas consumption. CHP was sized based on average peak electrical demand as detailed heat demand data was not available. The locations are economically justifiable for installing CHP without state incentives. Currently, state incentives would not be available as full operation of these units (heat and electricity) would not go beyond the currently required 8,000 hours of service. There is a proposal under consideration in the New Jersey state legislature to modify this to 5,000 hours for resiliency purposes. However, considering that most of these buildings are rather old, they do not use centralized air conditioning. Based on the data and a rough estimate, it does not appear this 5,000 hour threshold would be met to qualify for incentives. CHP provides for a reduction in electricity and gas costs, overall energy use and greenhouse gas emissions, while also able to provide emergency power for critical loads.

Table 4.1: Hoboken CHP analysis (all buildings)

Location	CHP Size (kW)	Peak Electric Load (kW)	20 year NPV at 5% Cost-of-Capital ($2013)	Internal Rate of Return w/o incentives (%)
City Hall	100	143	$47,307	8%
Public Works Garage	37	56	$175,643	26%
Volunteer Ambulance Corps	13	17	$(12,418)	-1%
Fire Department HQ	27	36	$(50,158)	-12%
Fire Engine Co 4	16	22	$(46,857)	N/A
Fire Engine Co 3	12	21	$33,582	18%
Fire Engine Co 1	15	20	$(67,352)	N/A
Multi Service Center	94	142	$(251,706)	N/A
Police HQ	81	110	$(100,321)	-4%

"N/A" appears for any with a uniformly negative cash flow for over all 20 years

Table 4.2: Recommended CHP installation sites and sizing

Location	CHP Size (kW)	Peak Electric Load (kW)	Net Savings ($2013)	Int. Rate of Return (w/o incentives) (%)	20-yr NPV at 5% Cost of Capital (w/o incentives) ($2013)	Total installed cost ($2013)
City Hall	100	143	$21,700	8%	$47,300	$221,000
Public Works Garage	37	56	$21,300	26%	$175,600	$81,000
Fire Engine Co 3	12	21	$5,000	18%	$ 33,600	$27,000

4.1.2 Attractive PV Sites

Table 4.3 includes suggested sites that could support PV. PV costs are fairly high with respect to payback (not counting environmental metrics). Therefore, PV is not explicitly required in any design options, and PV costs are not included in any budget estimates.

4.1.3 Two Options for the Number of Buildings

As described in Chapter 3, the stakeholders in the City of Hoboken were unsure about the costs associated with the planned energy surety improvements, so two options were analyzed by SNL. The Hoboken stakeholders will determine which of the lower- or upper-bound sets will be funded for construction after the completion of this report. Because of the different buildings included in each, the LBS and UBS has somewhat different characteristics. Good-performing solutions for each of the UBS and LBS building sets are presented afterward. These solutions provide design details for:

- Which buildings are connected together
- Where backup NG generation is located
- Performance

Note that the designs include CHP as shown in Table 4.4 (rounded to the nearest available generator size) instead of Table 4.2. The reason for this is that grid-connected CHP benefits were analyzed separately from the islanded microgrid conditions, although the CHP generation benefits both. Early in the design process the larger set of nine CHP sites was fixed in the islanded performance optimization. If CHP is not selected for any of those sites, then conventional NG generation may be substituted equivalently with no loss of modeled performance.

Table 4.3: Potential good PV installations for Hoboken

Location	Rooftop Available (sq meters)	Usable PV Output	System Cost	Energy Value (PV Only)	SREC Value
Hoboken High School	7780	550.0	$2,635,000	$156,600	$94,900
University Medical Center	5110	360.0	$1,724,000	$102,500	$62,100
Grocery - Kings	4247	300.0	$1,437,000	$ 85,400	$51,700
Garage B	3389	240.0	$1,150,000	$68,400	$41,400
Wallace School (shelter)	3039	210.0	$1,006,000	$59,800	$36,200
Grocery - Kings	2639	180.0	$862,000	$51,300	$31,000
Hoboken Housing Authority	2382	170.0	$814,000	$48,400	$29,300
Grocery - A&P	2166	150.0	$719,000	$42,700	$25,900
Hoboken Multi-Service Center	1459	141.0	$675,000	$40,200	$24,300
Hoboken Public Works Garage	1841	130.0	$623,000	$37,000	$22,400
YMCA (SROs)	1096	78.0	$374,000	$22,200	$13,500
Marion Towers	990	71.0	$340,000	$20,200	$12,200
St. Peter and Paul Church	954	68.0	$326,000	$19,400	$11,700
Columbian Arms	820	58.0	$278,000	$16,500	$10,000
Columbian Towers	623	44.0	$211,000	$12,500	$7,600
Hoboken City Hall	782	29.4	$141,000	$8,400	$5,100
St. Matthew's Church (shelter)	382	27.0	$129,000	$7,700	$4,700
Hoboken Homeless Shelter	279	20.0	$96,000	$5,700	$3,400
Volunteer Ambulance Corps.	172	12.0	$57,000	$3,400	$2,100
Gas Station - Sunoco	165	11.0	$53,000	$3,100	$1,900
Police HQ	491	11.5	$55,000	$3,300	$2,000
Fire HQ	188	10.0	$48,000	$2,800	$1,700
Fire Engine Co 2	222	6.0	$29,000	$1,700	$1,000
Fire Engine Co 3	147	5.0	$24,000	$1,400	$900
Fire Engine Co 6	158	4.0	$19,000	$1,100	$700

Table 4.4: Summary of CHP design selections

Building #	Building Name	Size	UBS or LBS	Notes
1	Fire Engine Co 3	15	both	1
2	Fire Engine Co 3	25	both	1
3	Fire HQ	37.5	both	1
4	Fire Engine Co 1	15	both	1
5	Police HQ	100	both	
11	Volunteer Ambulance Corps	25	both	1
12	City Hall	100	both	
22	Multi-Service Center	100	both	
22	Public Works Garage	37.5	UBS	1

1: CHP units smaller than 100kW do not supply the microgrid

Recommended UBS Solution

The UBS configuration options are shown in Table 4.5, and a geospatial diagram is shown in Figure 4.3. In the figure, blue circles are buildings in the UBS only, while yellow are in both UBS and LBS.

Recommended LBS Solution

The general configuration options are shown in Table 4.5, and a geospatial diagram is shown in Figure **??**. The design includes CHP as shown in Table 4.4 above (less the Public Works Garage, which is not in the LBS).

Table 4.5: Summary of UBS design solution

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings	400, 600	450
	51	YMCA (SROs)	200	150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	50	Applied		45
	40	Hoboken Housing Authority	300, 600	450
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill	60, 150	45
	13	Hoboken High School	250	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	30, 25 CHP	22.5
	41	804 Willow Ave	175	90
	6	Hoboken University Medical Center	30	450
	27	Midtown Garage	200, 275	150
	46	Clock Towers	275	150
	44	Church Towers		45
	45	Church Towers	200, 275	150
	43	Church Towers	275	90
	18	Grocery - A&P		45
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	100 CHP	90
	29	Marion Towers	350	225
	28	Columbian Arms	125, 150	90
	31	Hoboken Housing Authority	125, 250	90
	32	Hoboken Housing Authority	60	45
	33	Hoboken Housing Authority	100	67.5
	34	Hoboken Housing Authority		90
	35	Hoboken Housing Authority		45
	36	Hoboken Housing Authority		45
	37	Hoboken Housing Authority		90
	38	Hoboken Housing Authority	125, 300	90
	39	Hoboken Housing Authority		90
	53	Fire Department Radio Repeater	30	15
	16	St. Matthew's Church (shelter)	75	15
	8	5th Street PS	500, 600	750
	17	St. Peter and Paul Church	30	30
	47	Marineview 1		450
	26	Garage G		150
	48	Marineview 2	600	450
	19	Grocery - Kings	300	450
	25	Garage D	300, 400	225
	24	Garage B	125	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	400	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	49	Applied	300	225
	54	CVS	200	150
	30	Columbian Towers	200	150
	10	H1 PS		225
	23	Hoboken Public Works Garage	37.5 CHP	30
Unconnected	7	Sewage Treatment Plant	1200	900
Unconnected	4	Fire Engine Co 1	125, 150, 15 CHP	45
Unconnected	15	Hoboken Homeless Shelter	60, 60, 150	45

Table 4.6: Summary of LBS design solution

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings		450
	51	YMCA (SROs)		150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill		45
	13	Hoboken High School	200, 300, 500	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	25 CHP	22.5
	6	Hoboken University Medical Center		450
	27	Midtown Garage	200, 200	150
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	100 CHP	90
	29	Marion Towers	250, 300, 350, 350	225
MG2	8	5th Street PS	350	750
	17	St. Peter and Paul Church		30
	26	Garage G		150
	19	Grocery - Kings	350, 350, 600	450
	25	Garage D		225
	24	Garage B	250	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	250, 250, 600	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	54	CVS	250	150
	30	Columbian Towers	250	150
	10	H1 PS		225
MG3	53	Fire Department Radio Repeater	30	15
	16	St. Matthew's Church (shelter)	30, 30	15
Isolated	4	Fire Engine Co 1	50, 50, 15 CHP	45
Isolated	28	Columbian Arms	125, 125	90
Isolated	7	Sewage Treatment Plant		900
Isolated	15	Hoboken Homeless Shelter	60, 60	45

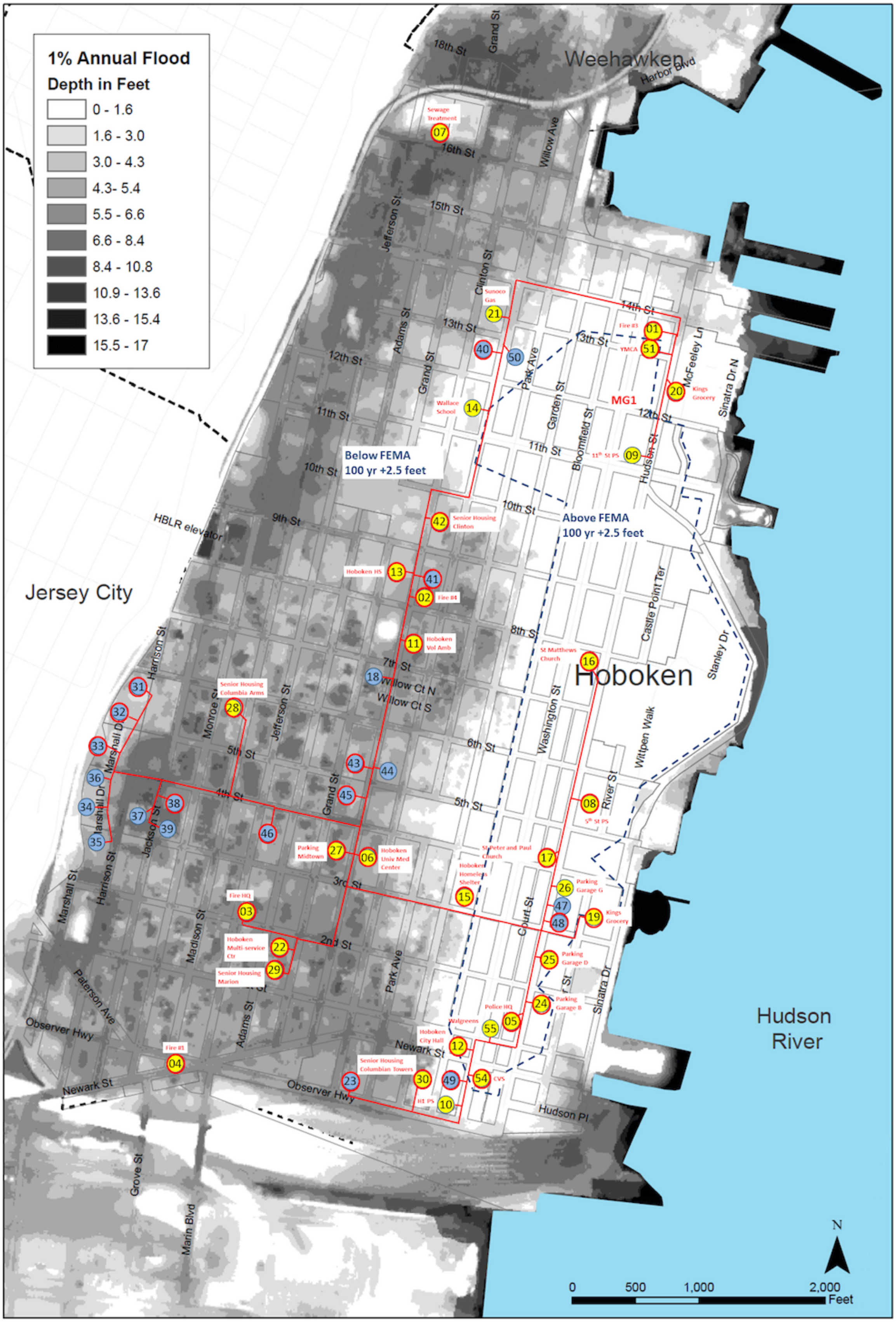


Figure 4.1: Geospatial configuration for the recommended UBS solution

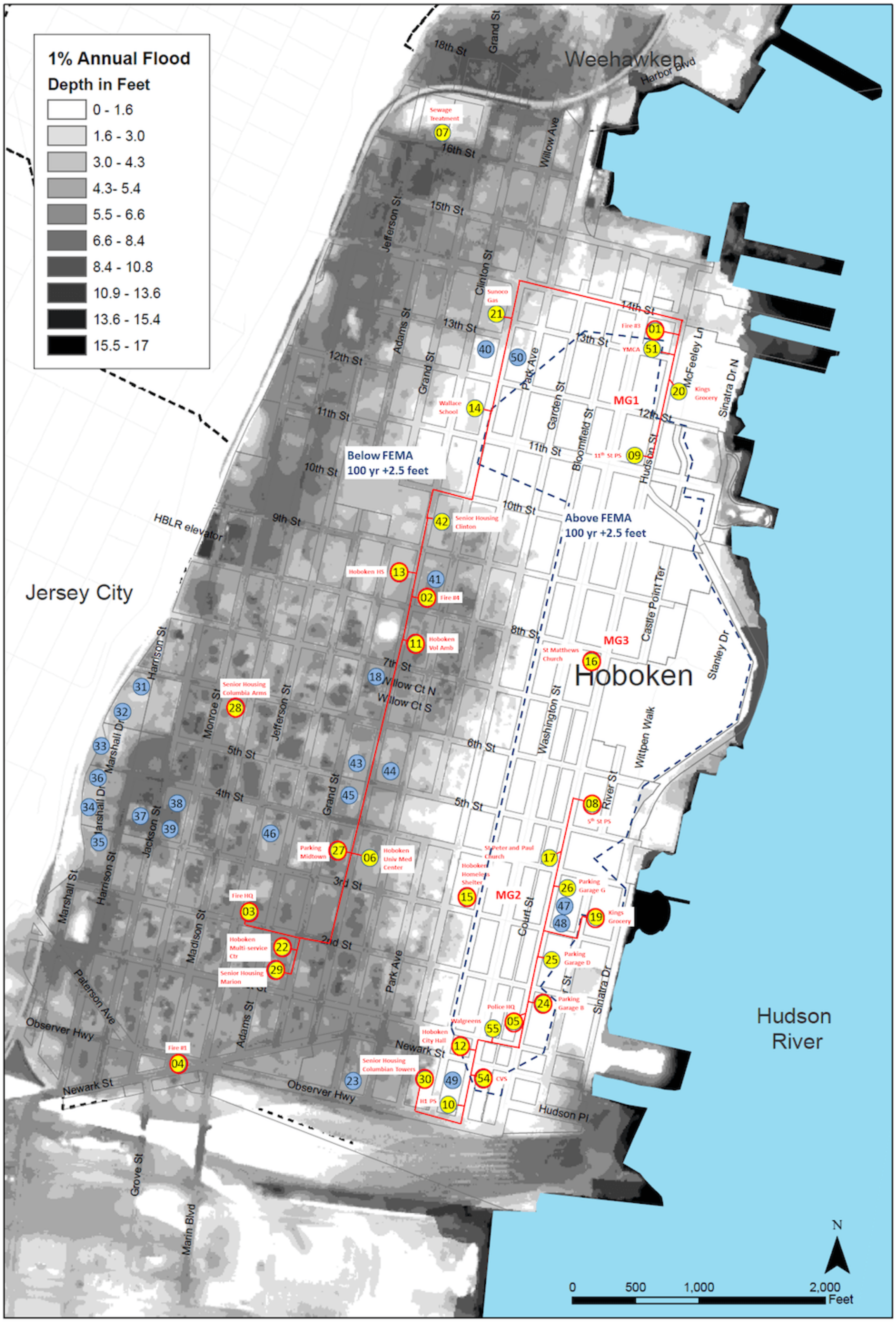


Figure 4.2: Geospatial configuration for the recommended LBS solution

Table 4.7: Summary of design solutions

Design Parameter	UBS	LBS
Buildings	55	34
Critical Load (kW)	9232.5	6360.0
New NG Generators	56	37
New NG Generation (kW)	12340.0	7327.5
Building Retrofit Sites	37	19
Microgrids	1	3
Isolated Buildings	3	4

Table 4.8: Summary of estimated cost breakdowns

Type of Cost	UBS	LBS
Building Retrofits	\$6.5M	\$2.7M
Control and Communications	\$5.6M	\$3.7M
Microgrid Infrastructure	\$21.7M	\$12.1M
Combined Heat and Power	\$0.9M	\$0.8M
Design and Engineering	\$8.6M	\$4.8M
Contingency	\$5.2M	\$2.9M
Totals	\$48.4M	\$26.9M

The best cost-benefit designs for the two are summarized in Table 4.7 and the corresponding estimated cost breakdown is shown in Table 4.8. Note that PV estimates are not included in those tables – these are to be selected later by the stakeholders based on the options provided in Table 4.3.

4.2 Requirements and Recommendations

The functional requirements for this design are presented in the following sections. Functional requirements and recommendations addressed in the optimal design include:

- Basic characteristics and generation assets
- Medium- and low-voltage electrical topology
- Islanding, restoration, and operating modes
- Control systems (including protection)
- Cyber security

4.2.1 Microgrid Basic Characteristics and Generation Assets

Requirements

- The design must supply all designated critical load with better reliability than isolated building-dedicated backup generators alone.
- The microgrid generation and control assets must ensure adequate power quality for loads.
- The microgrid must continue to operate with full load capability even if one of the largest generators is lost.
- The installed equipment will be hardened as needed against the effects of the DBT to ensure reliable operation
- The design will include either CHP or PV (or both) as further specified by the Hoboken stakeholders and installed per PSEG requirements

Recommendations

The recommended configurations are included in Section 4.1. Depending on the final decisions of the Hoboken stakeholders, different recommendations may apply.

4.2.2 Microgrid Medium- and Low-voltage Electrical Topology

Requirements

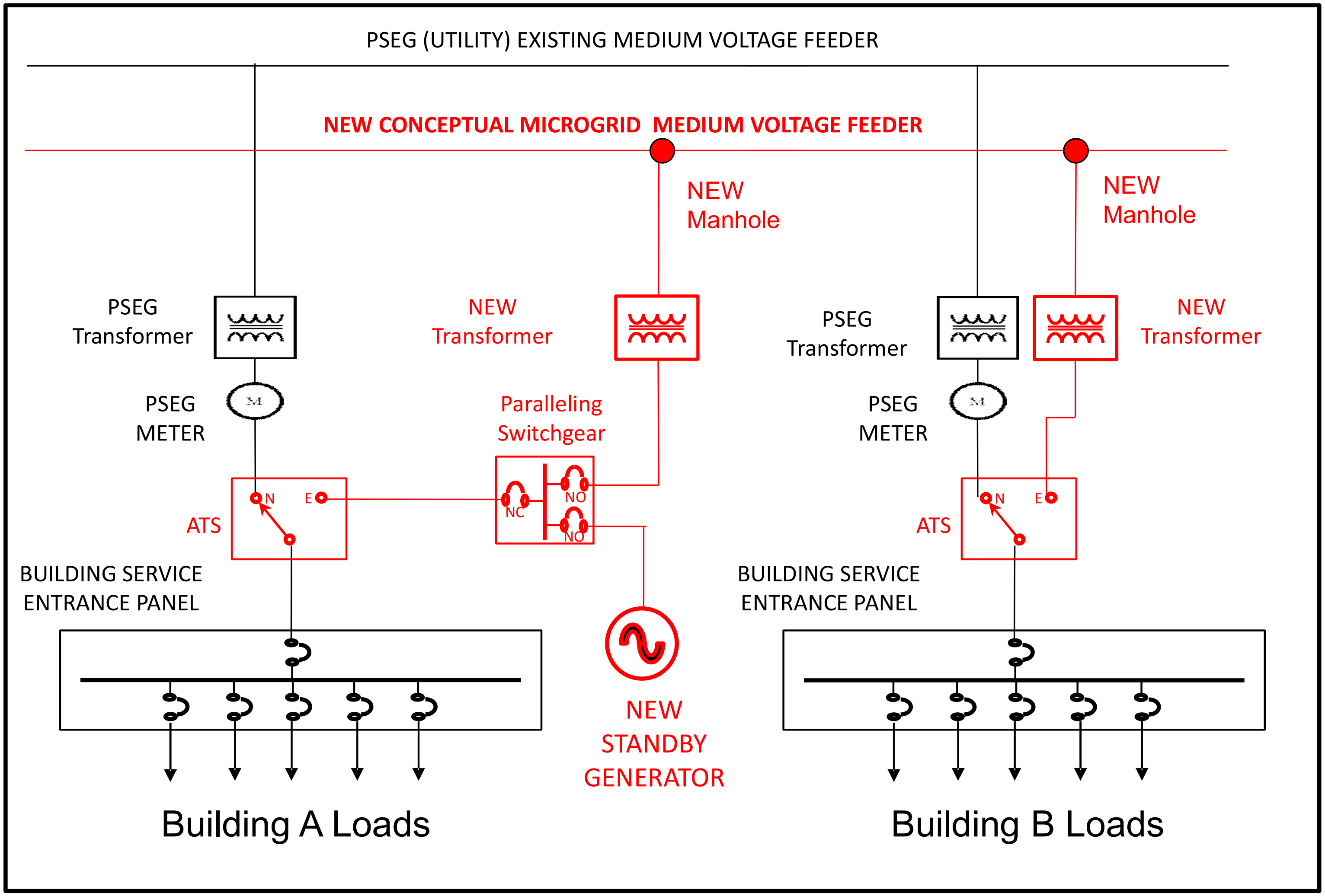
- Microgrid feeders (or sections of feeders) must be isolated from the utility during microgrid operation.
- Sections of microgrid feeders will be connected together to form the microgrid MV zones.
- Switching operations must be remotely controlled.
- All switch states must be verifiable as necessary to support safety and operations.
- Grounding apparatus will be added where necessary to support adequate system protection.

Recommendations

Utility isolation can be achieved using ATS as shown in Figure 4.3. This connection includes the following characteristics:

- The ATS is configured sot that the microgrid and utility cannot be connected together
- The equipment is installed on the customer side of the meter, minimizing impact to the utility
- The ATS can be configured to manually switch to the microgrid side for testing or preventative islanding

Figure 4.3: Diagram for recommended building connections



4.2.3 Microgrid Islanding, Restoration, and Operating Modes

Requirements

- Utility power must be off for a time period of significant length (to be determined in conjunction with Hoboken stakeholders) before permissively enabling microgrid operation, to ensure that the microgrid is not needlessly started (i.e. perhaps not for a 30 second nuisance outage).
- During a utility outage, if the microgrid is operational, it must be physically isolated from the utility grid (to meet interconnection requirements).
- The system can seamlessly (or with very minimal impact) transfer to microgrid operations when the failover is planned and the utility remains operational (to minimize impacts on facilities during construction and planned transfers).

Recommendations

The recommended process for use when unexpectedly islanding is described in Section 2.1. As suggested in Figures 4.3 and 2.5, the microgrid assets may be controlled to carefully (and seamlessly) transition to an islanded state even if the utility is still active, assuming that the microgrid EMS can control the ATS and force them to switch off of the utility. During the restoration process, the mirogrid EMS should allow utility reconnection permissively through the ATS, to avoid any disturbances on the utility grid caused by too rapid of load restoration.

4.2.4 Communications and Controls

The objective of the microgrid control system will be to manage and optimize microgrid operations to ensure the safe, secure, reliable, sustainable, and efficient distribution of power during microgrid operations and transitions. Such a control strategy implies the need for supplementary communications between controlled assets and the addition of sensing, monitoring and processing equipment to provide accurate situational awareness of the microgrid state. Whether or not the architecture of these communication and controlled assets are based on a distributed or centralized control philosophy depends on the feasibility of available commercial solutions; however, either architecture will provide additional control and monitoring functionality to better optimize microgrid operations.

Below are requirements and recommendations for the Hoboken microgrid control system and supporting communications. Although some requirements are better understood after implementation details are known, the following provide design details to support final design and implementation. Implementation details will only be fully realized after the following information is collected and defined:

- A site survey (e.g., inventory of specific loads, infrastructure components, etc.),
- Location, size, and configuration of all capacitor banks, voltage regulation equipment, reactors, protective and sectionalizing equipment, and transformers,
- Load characteristics and requirements for proper operation,
- Acceptable voltage imbalances tolerable at specific points in the system,
- Acceptable dynamic stability limits,
- Generator dynamic characteristics and voltage and frequency ride-through capabilities,
- Microgrid system parameters (e.g., system grounding, fault levels, impedances, voltage regulation, protection schemes, and automation),
- Acceptable voltage, frequency, and harmonic range during normal and transient conditions (selective load shedding will be employed to maintain microgrid operation in extreme cases of imbalance),
- Maximum rates of frequency change for supplied power,
- Ratings and types of existing equipment,
- Existing protection equipment settings,
- Specific monitoring, communication, control technologies used,
- Provisions for future expansion than may be required.

4.2.4.1 Microgrid Communication Network

The Hoboken microgrid communication network is the enabling technology for advanced microgrid control since it facilitates microgrid situational awareness, automated and manual control, control system maintenance, and execution of some protection schemes. Principally, the microgrid communication network is the communication backbone for which microgrid telemetry data, control signals, system maintenance and remote access communications will traverse.

Requirements

At minimum, network connectivity is required for the following:

- all microgrid controlled assets,
- all microgrid monitored assets,
- the primary and secondary control and monitoring centers.

Network communications must satisfy low latency requirements for control and provide a highly reliable information channel that retains the accuracy of data. Management of the control system network must meet industry standard best practices for cyber security to ensure an appropriate level of confidentiality and security (also refer to section 4.2.5). Network infrastructure equipment must be located above the agreed upon DBT flood level and have provisions for backup power when main grid fails.

Also, network architecture and communication protocols must have point-to-point and broadcast capabilities that fit into the ISO OSI data model. All communications must support interoperability between all distributed devices using published object functions, standard commands, and standard protocols and must be adequately extensible for future additions. Interoperability will also require network and communication device time synchronization between all transacting parties within a reasonable degree of accuracy.

Recommendations

Network connectivity should be provided to all:

- generator sets,
- controllable breakers and relays,
- controllable switches,

- network-capable PV inverters,
- smart meters,
- telemetry devices,
- microgrid control and operation centers.

Fiber optic communications, either existing dark fiber or new fiber cables, are recommended for microgrid communications since they generally provide higher reliability, data rates, and security. Wireless data radios, cellular communications, publicly switched telephone network communications, etc. are generally less reliable, more susceptible to interference, easier to subvert, and provide lower data rates.

In addition to simple logical isolation, all microgrid control system network communications should be physically isolated from all other networks; however, provisions for remote access to communication network devices (i.e., routers, switches, etc.) should be provided to allow for troubleshooting, remote maintenance, and software updates if physical access to the devices is not possible due to DBT conditions. The network architecture should include redundant communication paths, such as a ring or mesh architecture, to remove single points of failure and mitigate the effects of accidental cable cuts, equipment failures, or DBT caused failures.

4.2.4.2 Energy Management System and SCADA

The energy management and SCADA systems together provide monitoring, control, and optimization functionality for the Hoboken microgrid. These systems equip operators with increased situational awareness, administer advanced control functions, and yield more efficient operations that increase energy reliability and power stability.

Requirements

An isolated EMS and SCADA system must be installed separate of any current Hoboken information systems and must include a human-machine interface (HMI) for man-in-the-loop control. A full backup energy management capability must also be included (possibly mobile, if the cyber security issues can be adequately addressed) to provide redundancy in control capabilities. The EMS and SCADA will monitor all critical parameters of the microgrid to manage frequency, voltage, load connection/disconnection, load shedding, microgrid activation, generation asset optimization, and return to utility service in accordance with ANSI/NEMA C84.1-2006 [2] and IEEE 1547 [3] standards. The EMS must provide manual and automated start capabilities to initialize the Hoboken microgrid. Automated start capabilities must also exist for simple building level backup in the event control and monitoring centers go offline.

Additionally, provisions for manual testing switch-over must also be included to allow the microgrid to disconnect from utility power on request to test the microgrid systems during normal operation. The control system must maintain real and reactive power capability and response characteristics (e.g., for motor starts that require large amounts of reactive power) and maintain adequate reserve margins that are a function of the load factor, the magnitude of the load, the load shape, and reliability requirements of the load. Remote access to the EMS should be provided to permit remote monitoring, diagnosis, troubleshooting, and control during normal and DBT conditions. Remote access functionality must satisfy cyber security best practice requirements to prevent unauthorized access (Reference cyber security section).

Recommendations

All parameters and measurements should be archived using data historian functionality and should be used heuristically by the EMS system to further optimize ESM operation. Such possibilities include using weather forecasting and predicted generation and load to determine optimal dispatch of resources. Data historian should be complete with data filters based on time and value rate of change, configurable sampling rates (e.g., 1 sec, 10 sec, 1 min, 10 min, 1 hr, etc.), and should either save all historical data in provisions for long term storage or have a round robin database with sufficient storage. Data acquisition equipment should contain set, get, forced, and unforced capabilities and all equipment exposed to outdoor environments should be protected by environmentally hardened enclosures to protect against the elements and tampering. The system may interface with the existing maintenance and engineering systems that will be included in the microgrid(s) to further optimize operation (for maximum reliability, minimum cost, and minimum environmental impact). The energy management system should also maximize the use of renewable energy contributions within stability limits and should operate generators in their most efficient ranges, with sufficient spinning reserves to accommodate load fluctuations.

The HMI for the system should provide man-in-the-loop capabilities for:

- monitoring data points,
- changing parameters,
- sending control commands,
- visualizing historical data,
- viewing real-time and historical trends,
- viewing alarm states and history.

The nature of the Hoboken microgrid does not necessarily suggest 24/7 human interaction and monitoring is necessary; however, the energy management system should provide monitoring and alert capabilities via a paging system (or something similar) to operations personnel if system failures are encountered during normal, non-emergency (grid-connected) operations. As such, remote monitoring and control capabilities should be provided.

Persistent remote access to the EMS and SCADA systems, however, is discouraged (unless the capability can be adequately secured against cyber threats). Rather, planned connections that are brief and temporary should generally be permitted to allow for emergency remote monitoring, vendor application support, and software updates. These connections should be controlled with connection timeouts and strong encryption/authentication methods (including two-factor authentication).

4.2.4.3 Natural Gas Generator Control

Inertial generation in the form of natural gas generator sets are part of the Hoboken microgrid design and will help maintain grid stability by balancing out non-inertial effects and intermittency of inverter-based renewables. Natural gas power generation will provide voltage regulation, frequency regulation, and dynamic support.

Requirements

All generator sets that are involved in complex microgrid operations will require a networked connected controller. Depending on the make, model and age of the generator, any existing OEM controllers may be bypassed, interfaced with new controllers, or utilized as is. Distributed generator controls must regulate voltage and frequency during microgrid operation and each generator should be retrofitted with an ATS to provide building level backup power. Existing control for simple isochronous operation of the generators should be left in place to provide single backup capability and allow the possibility for deactivation or decommissioning of the microgrid. Natural gas generators must provide adequate dynamic response so that transient stability will be maintained for load steps, generation unit outages, and faults.

Recommendations

Generator controllers should allow remote starting and stopping, permit exciter set-point control, include synchronization functionality, and provide detailed operational data for monitoring and situational awareness purposes (e.g., fuel consumption, temperature, alarms, etc.). In the event of CHP implementation, continuous monitoring and control should be implemented by recording vital operational parameters (e.g., heat & power outputs, fuel consumption, water consumption, gas pressure & temperature, etc.) and reporting alarm conditions to a remote monitoring center, preferably for monitoring of real-time data by viewing a dynamic HMI.

4.2.4.4 Photovoltaic Array Control

Photovoltaic energy options can provide clean renewable energy that augments natural gas generator power and reduces natural gas consumption during microgrid conditions; however, given that PV arrays are intermittent sources and inverters alone do not possess the inertia traditional generators do, tighter control is required to ensure microgrid stability. On the other hand, more sophisticated inverter controls can also provide more complex functions that allow PV systems to improve grid stability, including supporting voltage and improving power factor.

Requirements

In the event that PV systems are included in the Hoboken microgrid, network-connected controls that allow, at minimum, connection and disconnection of the PV output, should be provided. Additionally, PV output power measurements (i.e., real and reactive power, power factor, frequency) need to be collected and made available to the EMS to facilitate control. Distributed inverter controls must exist to ensure automatic disconnection of the PV power in the event of utility outages (per IEEE 1547 requirements [3]).

Recommendations

Connection of the PV should be controlled using integrated inverter controls if possible. PV power limitation setpoints should also be included to prevent potential over penetration of PV power and low voltage ride through capabilities should be possible to reduce PV interruptions when in microgrid mode. Voltage and current measurements of the array output during both islanded and grid connected operation should also be collected via the inverter and real-time and historical power generation data should be logged and used to facilitate grid stability and provide metrics for decision making based on the predicted or expected PV power output. If possible, voltage regulation capabilities to activate or modify volt/VAR support functions should also be provided.

4.2.4.5 Loads

Microgrid loads represent the critical buildings and facilities Hoboken personnel have identified as essential for resilient response to emergency conditions. Given the nature of the DBT and the operational plans to shelter in place, establish community shelters, and operate all emergency facilities at capacity, larger than average load levels at existing buildings is probable which requires the need for tighter load monitoring and control.

Requirements

Loads will require control to manage their connections so that emergency load-shedding schemes can be implemented to protect against overloaded conditions. Microgrid load monitoring to record real power, reactive power, and voltage must be implemented at minimum for building level visibility and at high enough fidelity to conduct load-shedding schemes. Inrush current mitigation strategies should be implemented for all problematic loads, including large motor loads and transformers, to prevent frequency and voltage sags that may diminish grid stability. Since single-phase loads can vary significantly during different times of day or due to protective devices dropping large single-phase loads, loads must be controlled to maintain a balanced system so that the microgrid operates with no more current imbalance than specified in ANSI/NEMA MG 1-2006 [4].

Recommendations

Automation should be added to medium and/or low voltage switchgear to regulate load connections, depending on the building location and cost. Real-time and historical load data for building loads during islanded and normal operation should be collected and used to facilitate grid stability and provide metrics for decision making based on the predicted or expected load. Smart metering can be used to facilitate load data collection and augment grid telemetry in general. The presence of any large motor loads should be retrofitted with variable frequency drives to control ramp rates and reduce inrush currents that could degrade microgrid stability. Inrush current mitigation for transformer inrush can be accomplished using numerous methods, including dead-bus closing or series inrush limiting reactors. Such measures will also alleviate cold-load pickup effects and abate the stress inflicted on generation assets. Filtering or demand response actions should be implemented for sensitive loads and large loads that may exacerbate harmonic distortion and poor power quality. Also, grounding schemes need to be maintained during microgrid operations, therefore, it may be necessary to switch in ground sources to maintain an adequate ground source at all times.

4.2.4.6 Protection Systems

Protection schemes and devices are essential elements of the microgrid design, given their role in preventing equipment damage, minimizing the effects of faults, and protecting people from harm. When correctly designed and implemented in a hierarchical fashion, protection systems can increase the overall reliability of the microgrid and reduce outages.

Requirements

At minimum, overcurrent relays, synchronizing relays, breakers, and fuses are necessary to protect generation assets and other equipment during islanded conditions, normal operations, and the brief reconnection intervals.

- All protection must conform to industry requirements, including the addition of grounding apparatus if necessary for MV systems.

- For faults within a microgrid cluster, the cluster must be isolated from the rest of the microgrid before the entire microgrid is disbanded, requiring buildings within the cluster to revert to standard building backup.

- For faults within a building, the building must disconnect from the microgrid before other (unfaulted) buildings assume that the fault is in the MV network.

- Faults within generators and other equipment will result in their disconnection before other protection is activated in either the LV or MV network.

Recommendations

To achieve the coordination necessary to have optimum selectivity, some coordination between relays will be useful. As an example, fault currents flowing out of a generator seen at its breaker that occur at the same instant is inwardly directed fault currents for the building would indicate a fault inside the building. In that case, an optimum trip of both elements can be realized with no intentional delay via interconnects. Then the generator can attempt to serve its building load through the ATS and, if the fault remains, then the generator will finally trip. However, the balance of the microgrid MV network continues to operate.

For an active building, outwardly directed fault currents for the building indicate either an MV fault or a problem within another building, and should include a time delay to allow fault diagnosis and isolation at the remote site. For faults within an active building, the building will be decoupled from the microgrid before other (unfaulted) buildings assume that the fault is in the MV network.

Connections for microgrid-enabled generators will need a synch check function for paralleling the generator with the microgrid. Fault recorders and diagnostic equipment should be deployed as feasible on the microgrid to help determine where fault locations when the MV network is tripped. Additionally, adaptive relaying may be implemented to provide adequate protection for a variety of system operating modes.

4.2.4.7 Controls Summary

The control architecture for the Hoboken microgrid is essential to the stability and efficiency of its operation. Whether the control system is centralized or distributed, a dedicated communication network will be required for monitoring and data exchange. Optimal operation will require controllers on energy resources that will likely replace or interface with OEM controls.

4.2.5 Control System Cyber Security Considerations

A safe, secure, reliable, and sustainable microgrid for the city of Hoboken requires a cyber security architecture commensurate with the criticality of facilities on the microgrid and the level of risk deemed acceptable by Hoboken leadership. Industry standard best practices for typical power grid industrial control systems (ICS), including those found in NERC CIP [5] and NISTIR 7628 [6], should be incorporated where possible; however, the Hoboken microgrid should be more robust than that of traditional ICSs given that:

- The Hoboken microgrid will be used in emergency situations and may be critical to continuity of emergency operations.
- The Hoboken microgrid must function during active attack by a capable adversary.

As such, traditional design and implementation of an ICS is likely not sufficient for implementing a robust and secure Hoboken microgrid.

In addition to referenced best practices, additional rigor should be applied to strengthen defense-in-depth for the Hoboken microgrid control system. Best practices for securing ICSs often leverage network segmentation [6]-[8]; however, in most cases, network segmentation is focused on separation of the control system network from other less-trusted networks, such as an enterprise network and the Internet. The concept of network segmentation within the control system itself should be leveraged to further reinforce defense-in-depth practices. Such a scheme is consistent with Sandia's Cyber Security Reference Architecture [9] developed for Department of Defense (DOD) microgrid implementations and provides a framework for a higher level of security than industry best practices can provide alone.

Some example industry standard cyber security best practices and control system segmentation techniques to support a secure microgrid for the city of Hoboken are detailed in the following sections.

4.2.5.1 Industry Standard Best Practices

Although there are currently no substantive information security standards specifically geared toward microgrid control systems, existing information security standards for typical ICSs, in which many are specific to power systems and the grid, can be leveraged. For example, the following set of relevant standards should be considered, at minimum, when architecting and implementing the Hoboken microgrid control system and incorporated where possible:

- The North American Electric Reliability Corporation's (NERC) Critical Infrastructure Protection (CIP) version 5 [5]
- The National Institute of Standards and Technology (NIST) Interagency Report (IR) 7628 [6]
- NIST 800-82 [8]
- NIST 800-53 [10]

Although many of these standards overlap and not all recommendations in each standard are applicable to microgrid applications (such as many of the transmission level applications in NERC CIP), these standards provide an excellent starting point for developing a secure microgrid control system. More detailed information regarding all industry standard best practices, including some implementation guidelines, can be found in the standard documents themselves.

The cyber security best practices enumerated in Table 4.9 below are a list of typical control system defense-in-depth strategies that are recommended for the Hoboken microgrid. These high-level recommendations are documented in NERC CIP standards [5], NISTIR 7628 [6], and NIST 800-82 [8].

Table 4.9: Typical high-level defense-in-depth measures recommended for the Hoboken microgrid control system

Policy / Procedural:
Developing and maintaining security policies, procedures, training and educational material that applies specifically to the microgrid control system.
Establishment of a cross functional cyber security team is required and should consist of IT staff, control engineer, control system operator, network and system security experts, management staff, and physical security department member at minimum.
Addressing security throughout the lifecycle of the microgrid control system, including architecture design, procurement, installation, maintenance, and decommissioning.
Evaluate control system security policies and procedures based on the Homeland Security Advisory System Threat Level and deploy increasingly heightened security postures as the Threat Level increases.
Reviewing user accounts on regular basis and providing a means of quickly changing accounts when access privileges change (e.g., employment termination).
Authentication / Encryption:
Using separate authentication mechanisms and credentials for users of the control system network and corporate network.
Restricting user privileges to only those that are required to perform each person's job (i.e., establishing role-based access control and configuring each role based on the principle of least privilege).
Applying security techniques such as encryption and/or cryptographic hashes to control system data storage and communications where appropriate.
Using modern technology, such as smart cards, for additional factors for identity verification.
Segmentation:
Implementing a network topology for the control system that has multiple layers, with the most critical communications occurring in the most secure and reliable layer.
Providing physical separation between the corporate and control system networks.
Employing a DMZ network architecture to prevent direct traffic between corporate and control system networks while allowing historian data transfer.
Redundancy / Spares:
Ensuring that critical components are redundant and are on redundant networks.
Designing critical systems for graceful degradation (fault tolerant) to prevent catastrophic cascading events.
Physical Protection:
Restricting physical access to the control system network and devices.
Monitoring / Audit:
Tracking and monitoring audit trails on critical areas of the control system.
Establishing use restrictions, monitors, and effectively managing access to the control system.

Continued on next page

Table 4.9 – *Continued from previous page*

Change Control:
Expeditiously deploying security patches after testing all patches under field conditions on a test system if possible, before installation on the control system.
Security Controls:
Implementing security controls such as intrusion detection software, antivirus software, and file integrity checking software, where technically feasible, to prevent, deter, detect, and mitigate the introduction, exposure, and propagation of malicious software to, within, and from the control system network.
Disabling unused ports and services on control system devices and networking equipment.
Establishing usage restrictions and implementation guidance for allowing remote vendor connections, including authorization of remote access prior to each connection, automatic session termination, and physical disconnection of remote connection when complete.
Implementation of strong, non-default passwords and two-factor authentication where feasible.

These high-level defense-in-depth practices provide layers of security that help minimize the impact of a failure or subversion of any one mechanism. As such, these practices should be implemented at Hoboken and the relevant security standards should be referenced for more details regarding each mechanism. Details regarding control system segmentation, including provisions for remote access; however, is discussed in further detail below given it's importance to the overall security posture and potential to reinforce the defense-in-depth practices listed above.

4.2.5.2 Microgrid Control System Segmentation

To further enforce defense-in-depth and expand on industry standard best practices, segmentation strategies within the Hoboken microgrid control system itself are recommended to reduce the risk of widespread control system damage as a result of malevolent behavior or unexpected failures.

Sandia's approach to control system segmentation, the microgrid Cyber Security Reference Architecture [9], involves cleaving the microgrid control system network into enclaves defined by system functions, physical locations, and/or security concerns. An enclave is defined as a collection of computing environments that is connected by one or more internal networks and is under the control of a single authority and security policy. This concept of enclaves (already leveraged by DOD information systems in operation today [11]-[12]) reduces the complexity of configuring and managing a segmented control system network. Enclaves are then grouped into functional domains that allow actors (i.e., control system devices/systems) to collaborate in operational system functions that crosscut enclaves. Functional domains support reliable and secure data exchange necessary to accomplish a system function by determining the necessary level of access for participating enclaves and arbitrating inter-enclave communication between actors within enclaves based on data exchange requirements. The figures below illustrate an example of how enclaves and functional domains can be applied to a generic microgrid system. Figure 4.4 depicts a typical flat control system network for a notional microgrid that is isolated from any public networks (e.g., corporate networks or the Internet). This notional microgrid – which includes a couple of microgrid building clusters, control centers, and a building (labeled "WWTP") – has a centralized control system network where the energy management system (EMS) interacts with the HMI server, data historian, system controllers (which interface with breakers, generators, switches, and other devices depending on the control system selected), and intelligent devices such as smart meters, compatible generators, etc.

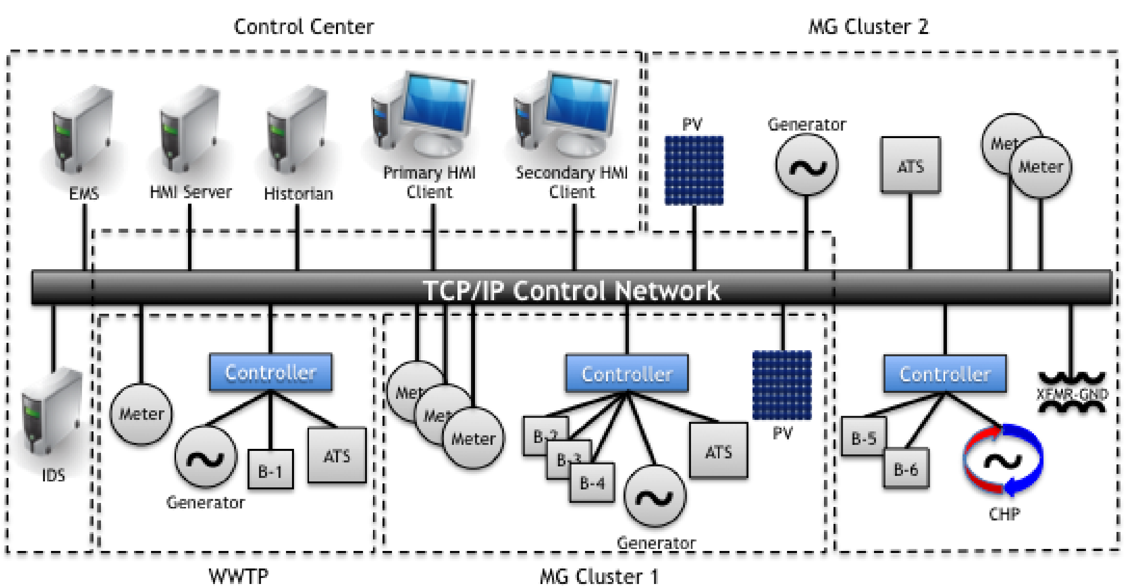


Figure 4.4: Typical flat ICS network configuration

To enhance security and reduce the risk of widespread control system damage, further segmentation can be accomplished by grouping actors through various methods – including by building, by a group of buildings and loads that form a microgrid cluster, by function (such as renewable energy or operations), or by security concerns (such as concern over the criticality of the central EMS and supporting servers) – to create enclaves and functional domains. Such a scheme might logically take the form depicted in Figure 4.5.

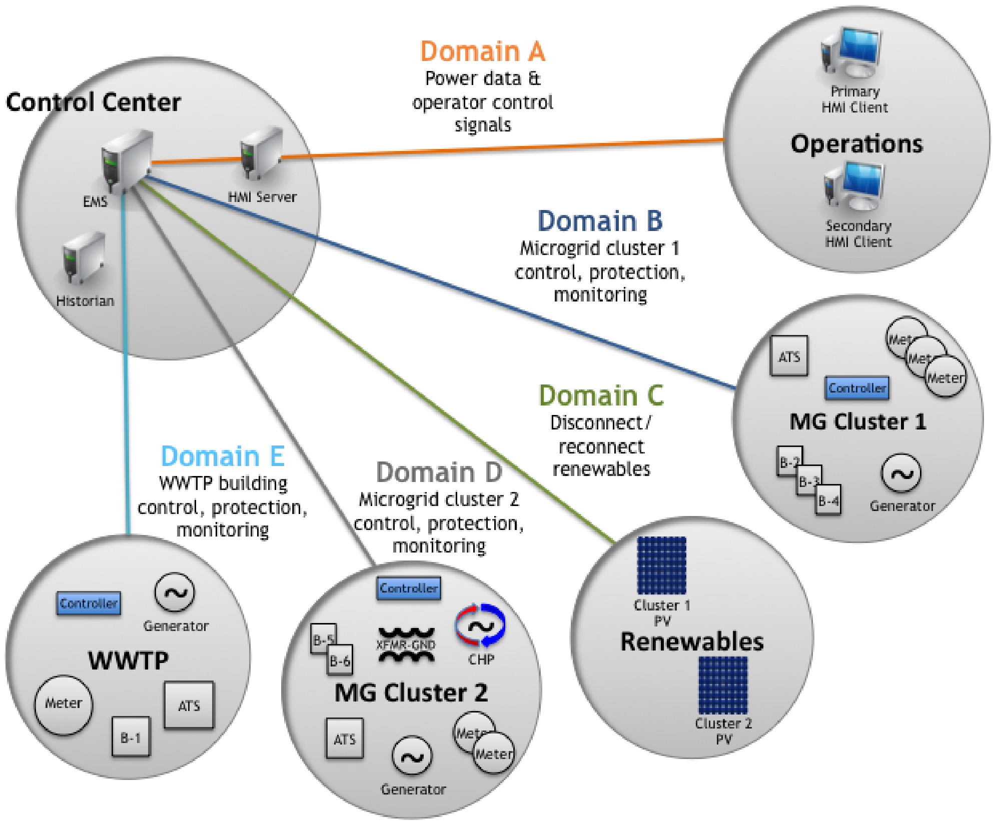


Figure 4.5: Example logical network segmentation strategy

As seen in Figure 4.6, six enclaves and five functional domains were created using various grouping techniques. The operations, renewables, WWTP, and cluster enclaves all participate in a unique functional domain with the control center enclave to facilitate monitoring and control of each asset. As such, direct communication between the operations, renewables, WWTP, and cluster enclaves should not be permitted. This provides a higher level of security for each enclave in the event the operator HMI is compromised, for example. A network representation of such a scheme might take the form depicted in Figure 4.6, where network permissions and firewall rules would be established to enforce communication restrictions and provisions for remote access is included for remote maintenance and control during an emergency.

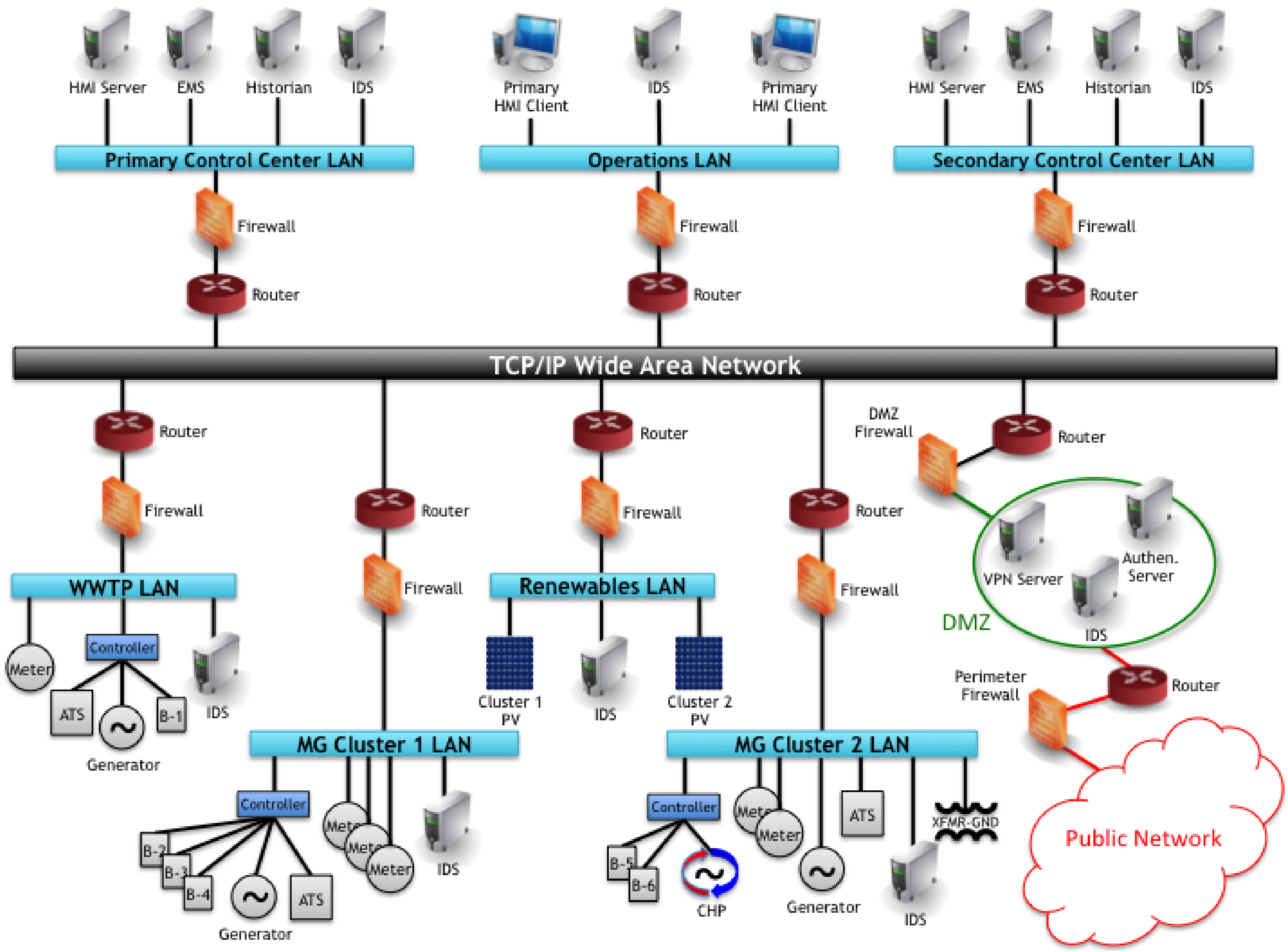


Figure 4.6: Network representation of enclave segmentation

By leveraging network segmentation within the control system network itself in a fashion similar to above, the flowing performance and vulnerability mitigations are expected:

- Each enclave operates under a single authority and security policy and provides a trusted environment for actors that need to communicate. Actors who wish to join a particular enclave must meet or exceed the level of security for the enclave in order to become part of that enclave. This ensures that all actors of the enclave are secured at the same rigor and level as actors with which they are communicating.
- Enclave inter-communication is restricted and managed by functional domains. The functional domains govern the policies that enable actors in on enclave to communicate with actors in another enclave based on necessary data exchange attributes.
- Enclave boundaries provide good locations to monitor for intrusion detection, unauthorized access attempts, and other logged events.
- Cleaving the logical network based on functional necessities, physical locations, and/or security concerns ensures a higher level of trust on each network segment.
- Isolation of enclaves minimizes both malicious opportunities and accidental damage done by a trusted, valid party. Providing communication barriers between enclaves and implementing enclave-specific security policies limits access by malicious actors within enclaves. This isolation also has the side effect of compartmentalizing valid actor access to only the enclave- or functional domain-level needed.
- Network performance may be improved based on necessary latency, bandwidth, and QoS (quality of service).
- Traffic monitoring can be implemented within enclaves to perform deep packet inspection and detect any anomalous message codes. Since each data exchange has very specific attributes, the message code on the microgrid control system messages should be known for each actor interaction. The reduced traffic per enclave (due to fewer actors on the network segment) enables more accurate parsing and inspection of the traffic being monitored.

Provisions for remote access to the microgrid control system network also represent a serious threat to the overall security of the network and significantly increase the attack surface for adversaries. While it's ideal to eliminate all provisions for remote access from a security standpoint, an important design requirement for the Hoboken microgrid is to permit remote activation and swift troubleshooting of the microgrid system in the event of system failures or physical access restrictions during DBT conditions. As such, the high-level cyber security recommendations enumerated blow should be combined with industry implementation guidance (such as [13]) to highly restrict remote connections and protect against unauthorized access.

- Enforce the principle of least privilege to promote strong, granular access controls.
- Implement full tunnel VPN appliances with strong, industry standard encryption standards for remote access.
- Require two-factor authentication.
- Rather than providing on-demand remote access that operation personnel might have, further restrict vendor access by requiring formal authorization to establish connection (e.g., physical connection of remote port).
- Segment authentication, VPN services, etc. into a demilitarized zone to prevent direct connections to control network.
- Require strong authentication credentials.
- Log, monitor, and alert any remote connections.
- Avoid the use of modem connections.
- Use dedicated hardware and software for remote connections.
- Use separate authentication services for separate roles (e.g., vendors/integrators vs. operators).
- Implement session termination based on set times, predefined triggers, inactivity, QoS, etc.

4.2.5.3 Cyber Security Summary

The goals of the cyber security measures to be implemented for the Hoboken microgrid control system can be attributed to many things; however, the goals of preserving data integrity and availability are the key reasons for protecting control network systems and devices. Although confidentiality still requires adequate attention, integrity and availability remain the highest priorities and application of both industry standard best practices and microgrid control system segmentation techniques will provide a higher level of security for the Hoboken microgrid control system network which will not only reduce the likelihood of disruption as the result of a cyber attack, but also minimize any damage done if one should succeed.

Chapter 5

Conclusion

This report details the recommendations and requirements for the proposed microgrids in the City of Hoboken, New Jersey, based on the ESDM analysis developed by SNL and DOE. The document also includes an extensive set of appendices that detail the data gathering, modeling, and analysis efforts that led to the decisions.

As this report is a preliminary design, the selected integrator is responsible for developing a final design suitable for construction. The design should effectively address the relevant sections of this report. All final decisions should be made in coordination with on-site engineering staff, government personnel, and other stakeholders.

References

[1] "Energy Surety Microgrid," http://energy.sandia.gov/?page_id=819

[2] American National Standards Institute/National Electric Manufactures Association C84.1-2006, "American Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz)," 2006.

[3] Institute for Electrical and Electronics Engineers, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," 2003.

[4] American National Standards Institute/National Electric Manufactures Association MG 1-2006, "Motors and Generators," 2006.

[5] North American Electric Reliability Corporation (NERC), "CIP Standards," Retrieved 26 November 2013, from http://www.nerc.com/pa/Stand/Pages/CIPStandards.aspx.

[6] Smart Grid Interoperability Panel (SGIP) – Cyber Security Working Group (CSWG), "Guidelines for Smart Grid Cyber Security," NIST Interagency Report (NISTIR) 7628, Vol. 1-3, National Institute of Standards and Technology (NIST), August 2010.

[7] Control System Security Program (CSSP), "Recommended Practice: Improving Industrial Control Systems Cybersecurity with Defense-in-depth Strategies," tech. rep., National Cyber Security Division (NCSD), Department of Homeland Security (DHS), October 2009.

[8] K. Stouffer, J. Falco, and K. Scarfone, "Guide to industrial Control Systems (ICS) Security," NIST Special Publication (SP) 800-82, NIST, Gaithersburg, MD, June 2011.

[9] C.K. Veitch, J.M. Henry, B.T. Richardson, and D.H. Hart, "SPIDERS Microgrid Cyber Security Reference Architecture," Sandia Report SAND2013-17689, SNL, Albuquerque, NM, March 2013.

[10] Joint Task Force Transformation Initiative Interagency Working Group, "Recommended Security Controls for Federal Information Systems and Organizations," NIST SP 800-53, Revision 3, NIST, Gaithersburg, MD, August 2009.

[11] DoD, "Information Assurance (IA) Implementation," DoD Instruction (DoDI) 8500.2, DOD, February 2003.

[12] DoD, "Information Assurance (IA)," DOD Directive (DoDD) 8500.01E, DoD, October 2002. Certified current as of April 23, 2007.

[13] Centre for the Protection of National Infrastructure, "Configuring and Managing Remote Access for Industrial Control Systems," November 2010.

Appendix A

ESDM Approach

An energy surety design has the following five key attributes:

- Safety
- Reliability
- Security
- Sustainability
- Cost Effectiveness

The first attribute, *safety*, ensures that energy is provided to the end user in a safe manner. A microgrid must function well in the event of an unplanned power outage but also must be designed with safety as a top concern. Specifically, an ESM design must ensure that the interconnection of distributed generation and/or the addition of renewable energy to the system will not compromise safety and that at all stages human safety issues, such as electric shock hazards, are mitigated.

The second feature, *reliability*, reflects a power system's ability to meet its mission-critical electric demands. Although it may be impossible to ever achieve 100 percent reliability, installing a microgrid system can significantly improve onsite reliability. On-site generation not only reduces the number of failures associated with long-distance power transmission but also reduces single points of failure at a given site. Moreover, a microgrid configuration also reduces the likelihood that the failure of any one generator will affect critical load; if a microgrid is well designed, other generators in the network will have sufficient energy to power all critical mission buildings.

Security makes a power system more resilient to various cyber and physical threats, including terrorist attacks. Threats against power systems have escalated in recent years, enforcing the realization that terrorist threats are real. As a result, cyber security standards such as encryption, firewalls, strong password requirements, etc. must be baked into an ESM's command and control systems. Another simple but effective way to improve security is to locate distributed backup generators inside a military facility, as opposed to outside the perimeter, where it is harder to physically access them and cause damage to the system.

Sustainability is the ability to operate a power system not only for a long period of time but in a manner that will not compromise the future. Sustainability can be improved at a microgrid site, for example, by including renewable sources of distributed generation such as solar or wind power, thus reducing – or even eliminating – a facility's dependency on fossil fuel resources. The ESM design process should therefore include a sustainability analysis that has the ability to predict or manage the cost of electricity generated by various fuel sources. Such an analysis should reflect resource availability and promote strategies, such as switching to a different fuel, to minimize or eliminate dependency on depleting resources and also reduce carbon emissions.

Finally, *cost effectiveness*, although not always considered an element of an ESM, reflects the value of providing power at the lowest possible cost. The addition of renewable energy, for example, reduces a site's dependence on the utility grid and also on diesel fuel when utility power is unavailable, thus leading to cost savings.

The report that results from the application of the Energy Surety Design Methodology will help customers to thoroughly analyze the cost and performance of optimal design sets. The ESDM report quantifies resiliency, reliability, and the exposure of specific loads. The report also presents the trade-space among several feasible solutions that, while meeting design criteria, all offer different levels of resiliency at different infrastructures costs. These feasible solutions are then narrowed down to a specific solution that best fits the needs of the customer.

The ESDM is intended to support resiliency for energy. A grid defined only by reliability is no longer adequate. What is needed instead is a grid that can adapt to both large-scale environmental and manufactured events, and remain operational in the face of adversity, thus minimizing the catastrophic consequences that affect quality of life, economic activity, national security and critical-infrastructure operations. Specifically, the concept of reliability needs to be supplemented with a resiliency approach, one that looks at the grid not strictly as a flow of electrons but as a grid that services, interfaces with, and impacts people and societies. *Put another way, it is the consequences, not the outages per se that matter.*

Enacted properly, a resiliency framework improves upon the traditional reliability approach to grid operations in three key ways: 1) the term resiliency is formally defined to include threats against the grid and the consequences of grid disruption; 2) the concept of resiliency includes a set of metrics for measuring resilience; and 3) a resilient grid would, in contrast to a merely reliable grid, be more responsive and adaptive, able to react predictively to threats and adjust to disasters before they happen.

ESDM Steps

1. Define the boundaries of the system to be considered

2. Identify critical loads

3. Define existing critical infrastructure (components such as switches and transformers)

4. Obtain stakeholder input for defining performance goals

5. Work with stakeholders to identify the Design Basis Threat that should be applied to the ESDM and identify boundaries on the maximum allowable (tolerable) consequences.

6. Determine what modifications to the system to consider as high level options

7. Using high level options found in (6), engineer low cost potential solutions and show feasibility

8. Evaluate engineered solutions and determine the Pareto frontier, and with input from the stakeholders, select optimal designs

9. Compare reliabilities of baseline and engineered solution cases

Value Propositions for Energy Resilience Improvements

A key concept for ESDM is that energy surety investments are intended to improve performance for the DBT. However, investments in energy surety can also provide improvement during normal periods, or more conventional emergencies (not to the level of the DBT). The three operating period are defined as:

- *Normal:* No emergency conditions.
- *Typical Emergency:* Abnormal conditions that fall under the purview of good planning or engineering (like utility outages in line with historical reliability figures, etc.).
- *Abnormal Emergency:* High impact, low frequency (HILF) events, which may be included in the DBT.

Different value propositions apply to each mode. The value propositions can be classified as:

- *Technical:* Applies to benefits that are not immediately quantifiable using dollars or environmental measures; these measures are quantifiable using engineering or other metrics, like expected outage duration, fuel consumed, etc.
- *Financial:* Benefits that are calculated in dollars (possibly as a net present value).
- *Environmental:* Values for the environment, like deferred emissions or pullutants.

While the technical benefits during abnormal emergency events are expected to dominate an ESDM design, the other benefits help with the cost and investment justification and should be calculated when feasible and useful. Overall, the value propositions may be sorted as shown in Table A.1.

Table A.1: Taxonomy for benefits from grid resiliency investments

			Operating Mode		
			Normal	Typical Emergency	Abnormal Emergency
		Abbreviation	*N*	*TE*	*AE*
Benefit	Technical	*TC*	N-TC	TE-TC	AE-TC
	Financial	*FN*	N-FN	TE-FN	AE-FN
	Environmental	*EN*	N-EN	TE-EN	AE-EN

Examples of values for each of these include:

- Abnormal emergency, technical (AE-TC):
  - Improved energy availability for critical loads during extreme events, including differentiated reliability
  - Reduced loss of energy availability for DBT events
  - More rapid recovery for energy during DBT events
  - Flexibility to easily power non-critical loads during extended outages
  - Better fuel endurance
  - Better maintenance opportunities
- Abnormal emergency, financial (AE-FN):
  - Grid resiliency efforts reduce outage times of key systems supporting site operations or local/regional economic activity
  - lower operations and maintenance costs during extended outages through energy generation efficiency and easier maintenence
- Abnormal emergency, environmental (AE-EN):
  - Deferred emissions from better generation efficiency and easier integration of renewable energy assets
- Normal, technical (N-TC):
  - Improved power quality if equipment from resiliency measures support it

  - Simpler backup testing through improved control and energy flexibility
  - For permanently islanded systems (rural, military, etc.), a benefit may be more efficient generation

- Normal, financial (N-FN):
  - Reducing energy billing costs through energy consumption management
  - Revenue from market/demand response participation
  - Revenue from energy contracts with utilities
  - Possible savings form reduced fuel usage for islanded systems
  - Lower O&M costs from easier maintenance

- Normal, environmental (N-EN):
  - Deferred emissions from reduced consumption or improvements to utility operations

- Typical emergency, technical (TE-TC):
  - Improved reliability for critical loads: systems designed for resiliency could be used to support critical load during normal outages if there are failures in normal backup procedures or equipment

- Typical emergency, financial (TE-FN):
  - With improved critical load reliability, there may be reduced impacts to operations which might be expressed in financial terms

- Typical emergency, environmental (TE-EN):
  - Given typical emergency outage durations amounting to fractions of a percent per unit time, little environmental benefits are foreseen from resiliency measures

One other benefit to the rollout of an advanced energy infrastructure is the improvement in energy awareness, resulting from the communications and sensing infrastructure that is a necessary component for modern control. The data accrued from these systems will enable data-driven decisions on energy management.

Analyzing the Value Propositions

The ESDM includes quantitative analysis for the proposed ESDM improvements against some set of the selected value propositions for the DBTs. One well-accepted method for valuing the performance of an engineered system is Monte Carlo (MC) sampling. The process has been used extensively for power system planning, with formulations for both generation adequacy and system adequacy assessment (the latter includes the electrical network, while the former is more about simple generator capacity). The desired analysis will leverage existing system adequacy assessment (SAA) formulations[1].

Existing software called the PRM (for performance-reliability model) is used for the SAA and to calculate performance metrics. It includes a few specific characteristics:

- The DBT is expressed as a probability density function (PDF) of expected utility outages (in hours)
- Instead of a bulk power system, the analysis was for microgrids, which share similarities with bulk power
- A sequential Monte Carlo was used, modeling the entire outage interval; this allowed modeling for operational characteristics (like generator conditional restart attempts)
- The system includes the ability for multiple energy islands and backup connections between them
- Currently modeled are diesel generators (and fuel consumption), two tiers of load (critical and nice-to-have), energy storage, lines and transformers, UPS, renewable energy (PV)
- New generation, lines, transformers, storage, or energy storage operation methods can be analyzed
- Outage rates, recovery rates, variable RE output, variable loads, and start probabilities are included
- The system uses an event-driven simulation approach, which allows for variable time steps (seconds, hours, others) and maximum execution efficiency (calculating new states only when things change)

Loads are categorized as:

- *Tier C:* Critical loads, further subgrouped as Tier CU (uninterruptible) and Tier CI (interruptible, can withstand momentary losses of power without loss of critical function, like while waiting for a backup generator to start)
- *Tier P:* Priority, nice-to-have loads; not strictly critical
- *Tier O:* Other

[1]Roy Billinton and Wenyuan Li, *Reliability Assessment of Electric Power Systems Using Monte Carlo Methods*, Plenum Press, New York (1994)
Ron Allan and Roy Billinton, et al., "Reliability Assessment of Composite Generation and Transmission Systems," IEEE Power Engineering Society Tutorial, 90EH0311-1-PWR (1989)
J.R. Ubeda and Ron Allan, "Sequential Simulation Applied to Composite System Reliability Evaluation," *IEE Proceedings C*, Vol. 139, No. 2, pp. 81-86 (March 1992)

Optimizing within the ESDM using TMO

TMO (Technology Management Optimization) is Sandia-developed software that uses a meta-heuristic optimization to solve technology insertion problems. TMO uses a genetic algorithm to solve optimization problems that are:

- Dynamic (decisions over time and constraints that are a function of time)
- Nonlinear
- Multi-objective
- Algebraically inexpressible (like sequential MC, or problems with decision variables that are operational or behavioral – like how to operate something)

TMO is used to optimize the performance of the microgrid system, using the PRM as an external non-algebraic evaluator. TMO calculated an initial generation of potential solutions from a large possible set of feasible solutions and evolved them toward better financial and technical performance (environmental was subsumed into technical). The best feasible cost/benefit set from the end of the calculation formed the Pareto frontier for the optimization problem, which provided great insight into potential design decisions.

In order to include multiple objectives (called response functions), TMO requires the specification of the minimum acceptable performance standard and the desired performance for each measure. Using a piecewise quadratic approach, TMO forces the evolving population to strongly choose against design selections that do not meet the minimum standards, and to only weakly prefer design solutions that achieve better than the desired performance. (This also serves to normalize the response functions so that they can be added for the resulting Pareto frontier, although they can be further weighted if desired.)

Resiliency Performance Metrics

Performance of an ESDM design can be calculated using different TC, FN, and EN metrics for AE, TE, and N modes.

Proposed primary AE-TC metrics include:

1. Frequency of interruption (FOI), number of times per occurrence of abnormal emergency conditions (for subtype I, includes events outside the allowable interruption duration for the load, or the maximum time-windowed number of interruptions)
2. Conditional expected energy not served (EENS), kWh or MWh per hour of abnormal emergency (for subtype I, only for events that accumulate under FOI)

Other potentially interesting AE-TC metrics can be calculated, like the energy index of availability (EIA), a unitless ratio over all simulated hours of abnormal emergency (defined as the desired load energy over the delivered load energy). Of course, just because a metric is calculable or interesting does not mean that it will drive ESDM investment planning. Similarly, improvements may also be found for TE-TC performance like FOI, LOLE, and EENS. Again, improvements in metrics for N and TE help justify investment in energy resiliency measures for AE resiliency. The project includes one other financial metric: project capital cost ($COST_C$, as NPV).

Analysis Process

Figure A.1 shows the analysis process graphically. Four data gathering activities (in purple) feed three modeling activities (in green). The design screening model (DSM) enables the development of a range of options for good solutions (step 6 in the ESDM; also the leftmost orange analysis activity). The electrical network model (ENM) is used by the PRM to evaluate performance of different combinations of solution options (supervised by TMO, as shown in the next orange activity (second from the left). After developing a good recommended design, controls and cyber security requirements are developed. Finally, the work is examined, and if further information is needed or desired, then the analysis may repeat.

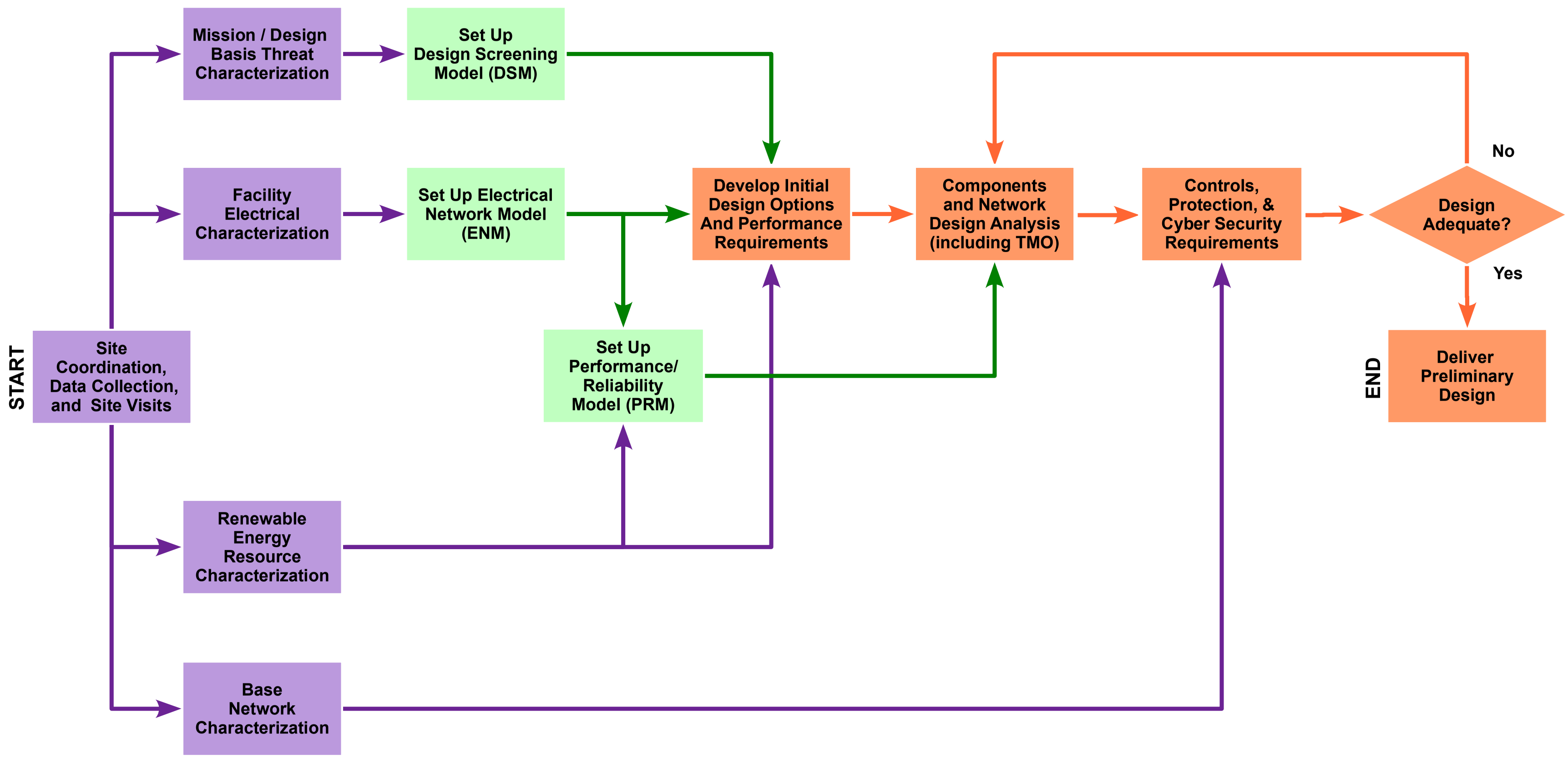


Figure A.1: ESDM analysis flowchart

Appendix B

Design Basis Threat and Metrics

In conjunction with the Hoboken stakeholders, the following DBT statement was developed for the project. *The DBT for the Hoboken ESDM is a flood at the FEMA 100 year flood plain level plus 2.5' which translates to 19.5' above mean sea level (MSL). This also results in a seven-day regional electrical blackout. Finally, ongoing cyber security threats are active during this period.*

Performance Objectives

- Design options provide electrical power to support critical functions (e.g. police, fire, hospital, shelters, etc.)
- Electric power for normal operations will be provided for up to 7 days after the DBT event occurs including facilities identified as designated shelters for residents displaced during the DBT. Electric power will not be provided for floors below the flood zone (19.5' above mean sea level) and are assumed to be damaged during the DBT.
- Shelter in place (50k residents must stay in residences or seek designated shelters during storm)
- Industry standards for safety, performance, and reliability (including critical infrastructure protection) will be met

Performance Metrics and Targets

The performance metrics for the designs are three (described in Appendix A):

- Frequency of interruption per DBT
- Conditional expected energy not served during DBT
- Capital cost (including NPV of recurring costs or benefits)

Table B.1: Metric thresholds and targets

Metric	Threshold	Preferred
FOI	10%	0%
Cond EENS	10kWh	0kWh

The engineering (AE-TC) metrics include minimum and preferred performance standards, as shown in Table B.1.

Appendix C

Buildings Included in the Design

Using the design base threat of a 100 year flood (water level 19.5 feet above sea level) and electric power being down for 7 days, buildings were chosen to meet the criteria that the safety of the citizens and emergency responders can survive and operate. The team that created this list was the Hoboken city authorities, SNL, and various stakeholders which were determined in many working meetings. Table C.1 presents the four functions in which the buildings selected can be categorized.

Table C.1: Function of building tier groups

Tier	Description
Tier 1	Emergency response and flood control
Tier 2	Shelters, parking garages, pharmacies, grocery stores, gas stations, others
Tier 3	Senior housing
Tier 4	Affordable housing

Critical Mission Selection

55 buildings were selected from the working meetings to be part of the ESDM which are described in the following tables. Table C.2 lists the 13 buildings determined to be Tier 1. A Tier 1 building indicates that they have the highest priority to be electrically powered and needed to have the city operate and maintain safety for its people.

Table C.3 lists the 18 buildings determined to be Tier 2. A Tier 2 building indicates that they have the second highest priority to be electrically powered (or, in the case of garages, could also function as host sites for electrical equipment). Most of these buildings are to create a safe infrastructure and housing for the operations that Tier 1 provides.

Table C.4 lists the 4 buildings determined to be Tier 3. A Tier 3 building indicates that they have the third highest priority to be electrically powered. These buildings are the shelter in place residents residing in a senior housing community and do not have the means to flee from the 100 year flood.

Table C.2: Tier 1 buildings

Tier	Building Name	Type	Location
1	Fire Department Radio Repeater	Emergency	N/A
1	Pump Station 5th Street	Flood Control	500 River Road
1	Police Head Quarters	Emergency	106 Hudson Street
1	Pump Station 11th Street	Flood Control	83 11th Street
1	Police Department Radio Repeater	Emergency	N/A
1	Fire Engine Company 3	Emergency	1313 Washington Street
1	Pump Station H1	Flood Control	99 Observer Highway
1	Fire Engine Company 4	Emergency	801 Clinton Street
1	Fire Head Quarters	Emergency	201 Jefferson Street
1	Fire Engine Company 1	Emergency	43 Madison Street
1	Hoboken University Medical Center	Emergency	308 Willow Avenue
1	Sewage Treatment Plant	Flood Control	Adams Street
1	Hoboken Volunteer Ambulance	Emergency	707 Clinton Street

Table C.3: Tier 2 buildings

Tier	Building Name	Type	Location
2	St. Matthew's Church	Shelter	57 8th Street
2	St. Peter and Paul Church	Shelter	404 Hudson Street
2	Garage G	Parking Garage	315 Hudson Street
2	CVS	Pharmacy	59 Washington Street
2	Hoboken City Hall	Operation	94 Washington Street
2	Kings	Groceries	325 River Street
2	Garage B	Parking Garage	28 2nd Street
2	Garage D	Parking Garage	215 Hudson Street
2	Walgreens	Pharmacy	101 Washington Street
2	Wallace School	Shelter	1100 Willow Avenue
2	Hoboken Homeless Shelter	Shelter	300 Bloomfield
2	Kings	Groceries	1212 Shipyard Lane
2	Sunoco	Gas Station	1301 Willow Avenue
2	Hoboken Public Works Garage	Operation	256 Observer Highway
2	Hoboken High School	Shelter	800 Clinton Street
2	A&P	Groceries	614 Clinton Street
2	Hoboken Multi-Service Center	Shelter	124 Grand Street
2	Midtown Garage	Parking Garage	371 4th Street

Table C.4: Tier 3 buildings

TIER	Building Name	Type	Location
3	Columbian Towers	Senior Housing	76 Bloomfield Street
3	Columbian Arms	Senior Housing	514 Madison Street
3	Marion Towers	Senior Housing	400 1st Street
3	Fox Hill	Senior Housing	900 Clinton Street

Table C.5 lists the 20 buildings determined to be Tier 4. A Tier 4 building indicates that they have the fourth or last priority to be electrically powered part of the critical building list. These buildings are the shelter in place residents residing in an affordable housing and do not have the means to flee from the 100 year flood.

Table C.5: Tier 4 buildings

TIER	Building Name	Type	Location
4	Marineview 1	Affordable Housing	331 Hudson Street
4	Marineview 2	Affordable Housing	301 Hudson Street
4	Applied	Affordable Housing	111 Newark
4	Applied	Affordable Housing	1203-1209 Willow Avenue
4	YMCA (SROs)	Affordable Housing	1301 Washington Street
4	Hoboken Housing Authority	Affordable Housing	655 6th Street
4	Hoboken Housing Authority	Affordable Housing	501 Marshall Drive
4	Hoboken Housing Authority	Affordable Housing	400 Marshall Drive
4	Hoboken Housing Authority	Affordable Housing	320 Marshall Drive
4	Hoboken Housing Authority	Affordable Housing	300 Marshall Drive
4	Hoboken Housing Authority	Affordable Housing	321 Harrison Street
4	Hoboken Housing Authority	Affordable Housing	311 Harrison Street
4	Hoboken Housing Authority	Affordable Housing	320 Jackson Street
4	Hoboken Housing Authority	Affordable Housing	310 Jackson Street
4	Hoboken Housing Authority	Affordable Housing	311 13th Street
4	Hoboken Housing Authority	Affordable Housing	804 Willow Avenue
4	Hoboken Housing Authority	Affordable Housing	5 Church Towers
4	Hoboken Housing Authority	Affordable Housing	10 Church Towers
4	Hoboken Housing Authority	Affordable Housing	15 Church Towers
4	Hoboken Housing Authority	Affordable Housing	300 Adams Street

After further discussions, the original four tiers of buildings were compressed into two, called the lower- and upper-bound sets (with the former having slightly more criticality than the latter). Those are shown in Table C.6. This was done to enable a project cost estimate for each, so that the stakeholders can consider which option provides the best cost-benefit.

Table C.6: Building classifications for the Hoboken design

Building #	LBS/ UBS	Building Name	Type	Location
1	Both	Fire Engine Company 3	Emergency	1313 Washington Street
2	Both	Fire Engine Company 4	Emergency	801 Clinton Street
3	Both	Fire Headquarters	Emergency	201 Jefferson Street
4	Both	Fire Engine Company 1	Emergency	43 Madison Street
5	Both	Police Headquarters	Emergency	106 Hudson Street
6	Both	University Medical Center	Emergency	308 Willow Avenue
7	Both	Sewage Treatment Plant	Flood Control	Adams Street
8	Both	Pump Station 5th Street	Flood Control	500 River Road
9	Both	Pump Station 11th Street	Flood Control	83 11th Street
10	Both	Pump Station H1	Flood Control	99 Observer Highway
11	Both	Volunteer Ambulance Corps	Emergency	707 Clinton Street
12	Both	Hoboken City Hall	Operation	94 Washington Street
13	Both	Hoboken High School	Shelter	800 Clinton Street
14	Both	Wallace School	Shelter	1100 Willow Avenue
15	Both	Hoboken Homeless Shelter	Shelter	300 Bloomfield
16	Both	St. Matthew's Church	Shelter	57 8th Street
17	Both	St. Peter and Paul Church	Shelter	404 Hudson Street
18	UBS	A&P	Groceries	614 Clinton Street
19	Both	Kings 1	Groceries	325 River Street
20	Both	Kings 2	Groceries	1212 Shipyard Lane
21	Both	Sunoco	Gas Station	1301 Willow Avenue
22	Both	Multi-Service Center	Shelter	124 Grand Street
23	UBS	Public Works Garage	Operation	256 Observer Highway
24	Both	Garage B	Parking Garage	28 2nd Street
25	Both	Garage D	Parking Garage	215 Hudson Street
26	Both	Garage G	Parking Garage	315 Hudson Street
27	Both	Midtown Garage	Parking Garage	371 4th Street
28	Both	Columbian Arms	Senior Housing	514 Madison Street
29	Both	Marion Towers	Senior Housing	400 1st Street
30	Both	Columbian Towers	Senior Housing	76 Bloomfield Street
31	UBS	Housing Authority 1	Affordable Housing	655 6th Street
32	UBS	Housing Authority 2	Affordable Housing	501 Marshall Drive
33	UBS	Housing Authority 3	Affordable Housing	400 Marshall Drive

Continued on next page

Table C.6 – *Continued from previous page*

Building #	LBS/ UBS	Building Name	Type	Location
34	UBS	Housing Authority 4	Affordable Housing	320 Marshall Drive
35	UBS	Housing Authority 5	Affordable Housing	300 Marshall Drive
36	UBS	Housing Authority 6	Affordable Housing	321 Harrison Street
37	UBS	Housing Authority 7	Affordable Housing	311 Harrison Street
38	UBS	Housing Authority 8	Affordable Housing	320 Jackson Street
39	UBS	Housing Authority 9	Affordable Housing	310 Jackson Street
40	UBS	Housing Authority 10	Affordable Housing	311 13th Street
41	UBS	Housing Authority 11	Affordable Housing	804 Willow Avenue
42	Both	Fox Hill Housing	Senior Housing	900 Clinton Street
43	UBS	5 Church Towers	Affordable Housing	Grand Street
44	UBS	10 Church Towers	Affordable Housing	Clinton Street
45	UBS	15 Church Towers	Affordable Housing	Grand Street
46	UBS	Clock Towers	Affordable Housing	300 Adams Street
47	UBS	Marineview 1	Affordable Housing	331 Hudson Street
48	UBS	Marineview 2	Affordable Housing	301 Hudson Street
49	UBS	Applied 1	Affordable Housing	111 Newark
50	UBS	Applied 2	Affordable Housing	1203-1209 Willow Avenue
51	Both	YMCA (SROs)	Affordable Housing	1301 Washington Street
52	Both	Police Dept Radio Repeater	Emergency	N/A
53	Both	Fire Dept Radio Repeater	Emergency	N/A
54	Both	CVS	Pharmacy	59 Washington Street
55	Both	Walgreens	Pharmacy	101 Washington Street

Appendix D

Electrical Load Profile and Modeling

Sandia was unable to obtain building level peak monthly demand data (kW or kVA) for the buildings considered in the upper bound (UBS) and lower bound (LBS) sets of buildings. The monthly energy use (kWh) is measured for billing purposes by the utility which serves the City of Hoboken, PSEG. The majority of these buildings are privately owned, so PSEG upon request was unable to provide this load data to Sandia in order to be able to make use of to make estimates of the peak loads for modeling purposes without the consent of individual building owners. Given the effort which would be required to obtain this data in short time frame, Sandia was forced to make load assumptions for the 55 UBS and 34 LBS building loads in order to develop proposed solutions using TMO analysis.

PSEG was able provide the ratings for the 13.8 kV transformers in kVA for the majority of the buildings associated with UBS and LBS buildings. These were the transformers which connect the PSEG 13.8 kV distribution grid and step voltages down to each incoming main services (typically three phase 480/277V or 208/120V, but can be single or two phase as well). A few buildings in which transformer ratings were unavailable were estimated based upon similarly sized buildings.

The City of Hoboken was able to obtain and provide peak demand data for a small subset of city owned buildings as listed in Table D.1. These peak demands were compared to the transformer sizes of the incoming transformers providing power to each of these buildings. As shown in Table D.1, the peak demands represented loading ranging from 4% to 34% of the transformer ratings, with an average loading of 17.5% loading for these buildings.

Table D.1: Loading for sample buildings

Building Name	Address	Peak Demand (kW)	Transformer Size (kVA)	Loading (%)
City Hall	94 Washington St	143	750	19.1
Fire Headquarters A	201 Jefferson St	36	125	28.8
Firehouse #3	1313 Washington St	21	500	4.2
Firehouse #4	801 Clinton	22	75	29.3
Firehouse #1	Madison & Observer	26.1	150	17.4
Police HQ	106 Hudson	110	500	22.0
Voluntary Ambulance Corps	707 Clinton Street	17.2	50	34.4
	Totals	375.3	2150	17.5

Additionally, meter readings were obtained by a contractor (EI Associates) for a few select buildings during the week of 12/31/2013 – 01/06/2014 (see Appendix E for details). During this week the peak loads found for two of these buildings was found to be:

- Hoboken Fire Department Headquarters: 6 kVA peak /125 kVA transformer rating or ˜4.8% loading
- Hoboken High School: 204 kVA peak/500 kVA transformer rating or ˜40.9% loading

The Hoboken High School load was driven by a periodic inductive load spike which made the peak much higher than average load measurements (again, Appendix E). This would probably not be typical for most buildings.

Given these facts, it was assumed that building peak demands were 30% of kVA ratings of transformers supplying each building. Some of the buildings in Table D.1 were close to 30% loaded but most were less. Without monthly energy use data obtained for individual UBS and LBS buildings as well as direct metered data of individual facilities to track whether building peak loads have daily spikes as found in the Hoboken High School, it is impossible to make more accurate load estimates for use in TMO and PRM analysis. Tentatively we suggest that a 30% load estimate represents a moderate to conservative estimate of the actual peak loads in the system based on the limited data set we have.

The recommendations in the body of the report as determined by the TMO and PRM analysis suggest one to several large clusters of buildings to be clustered together as well as a few buildings be kept isolated and protected by backup generation as being the most optimal solution sets available. The TMO and PRM optimize generation to supply these clusters of loads. If the 30% assumption is accurate, but the building loads vary considerably across buildings, this would likely lead to the same configurations of clustering of buildings being selected with the same overall amount of generation required. For the same overall load, for the 30% assumption used, what likely would change is where the size and placement of individual generators within the clusters of buildings according to the actual distribution of loads. If it turned out that the actual overall loading was 40% of rated transformers, this would entail larger amounts of overall generation required for the microgrid clusters, and subsequently proportionally higher overall costs. It is not clear what clusters of buildings would be recommended by TMO analysis with higher loads, but it likely would be close to the same overall configurations of clustered buildings recommended by TMO with more generation spread across a different configuration of buildings. Therefore the current results for TMO are somewhat robust to alterations in these load assumptions.

Tables D.2 and D.3 below shows the load estimates for the LBS and UBS sets of buildings. The estimated peak load of the 34 LBS buildings using the 30% transformer rating assumption is 6360 kW, and for the 55 UBS buildings is 9232.5 kW. These assumptions are used by TMO and PRM to perform analysis to optimize recommended clusters of buildings and associated distribution links and generation for the LBS and UBS sets of buildings as outlined in the body of the report.

Table D.2: Load estimates for LBS/UBS buildings

Building #	Building Type	Service	Transformer Size (kVA)	Estimated Load (kW) (30% loading)
53	Communications	Fire Dept Radio Repeater	50	15
8	Pump Station	5th Street PS	2500	750
16	Community Services	St. Matthew's Church	50	15
17	Community Services	St. Peter and Paul Church	100	30
26	Parking	Garage G	500	150
5	Emergency	Police HQ	500	150
9	Pump Station	11th Street PS	50	15
52	Communications	Police Dept Radio Repeater	1500	450
54	Community Services	CVS	500	150
12	Community Services	Hoboken City Hall	750	225
19	Community Services	Grocery – Kings	1500	450
24	Parking	Garage B	300	90
25	Parking	Garage D	750	225
55	Community Services	Walgreens	300	90
1	Emergency	Fire Engine Co 3	500	150
10	Pump Station	H1 PS	750	225
14	Community Services	Wallace School (shelter)	500	150
15	Community Services	Hoboken Homeless Shelter	150	45
20	Community Services	Grocery – Kings	1500	450
21	Community Services	Gas Station – Sunoco	50	15
30	Senior Housing	Columbian Towers	500	150
51	Affordable Housing	YMCA (SROs)	500	150
2	Emergency	Fire Engine Co 4	75	22.5
3	Emergency	Fire HQ	125	37.5
4	Emergency	Fire Engine Co 1	150	45
6	Emergency	University Medical Center	1500	450
7	Sewerage Treatment Plant	Adams Street	3000	900
11	Emergency	Volunteer Ambulance Corps	50	15
13	Community Services	Hoboken High School	500	150
22	Community Services	Multi-Service Center	300	90
27	Parking	Midtown Garage	500	150
28	Senior Housing	Columbian Arms	300	90
29	Senior Housing	Marion Towers	750	225
42	Senior Housing	Senior Housing Fox Hill	150	45

Table D.3: Load estimates for UBS-only buildings

Building #	Building Type	Service	Transformer Size (kVA)	Estimated Load (kW) (30% loading)
47	Affordable Housing	Marineview 1	1500	450
48	Affordable Housing	Marineview 2	1500	450
49	Affordable Housing	Applied	750	225
23	Community Services	Public Works Garage	100	30
50	Affordable Housing	Applied	150	45
18	Community Services	Grocery - A&P	150	45
31	Affordable Housing	Hoboken Housing Authority	300	90
32	Affordable Housing	Hoboken Housing Authority	150	45
33	Affordable Housing	Hoboken Housing Authority	225	67.5
34	Affordable Housing	Hoboken Housing Authority	300	90
35	Affordable Housing	Hoboken Housing Authority	150	45
36	Affordable Housing	Hoboken Housing Authority	150	45
37	Affordable Housing	Hoboken Housing Authority	300	90
38	Affordable Housing	Hoboken Housing Authority	300	90
39	Affordable Housing	Hoboken Housing Authority	300	90
40	Affordable Housing	Hoboken Housing Authority	1500	450
41	Affordable Housing	804 Willow Ave	300	90
43	Affordable Housing	Church Towers	300	90
44	Affordable Housing	Church Towers	150	45
45	Affordable Housing	Church Towers	500	150
46	Affordable Housing	Clock Towers	500	150

Appendix E

Metered Load Data

Sandia purchased 2 Power Standard Labs PQube meters which were installed at the Hoboken High School and Fire Department Headquarters service entrances behind the PSEG meter. The PQube meters are designed to monitor the voltage and current incoming to the building at 256 samples per cycle reporting for 24 hours 7 days a week. Data is recorded is 1 minute intervals, logging the minimum, maximum, and average for each 1 cycle and 12 cycle interval during the minute. The data gathered is sent through a file transfer protocol from the Hoboken personnel to Sandia to be analyzed. There was only time to gather 1 week of data which was from 12/31/2013 – 01/06/2014.

Sandia created a program in MATLAB to analyze the data both for each day and also comparing the days. The following figures are from the recorded data from the Fire Department Headquarters for 01/04/2014 which gives an example of the type of data being analyzed.

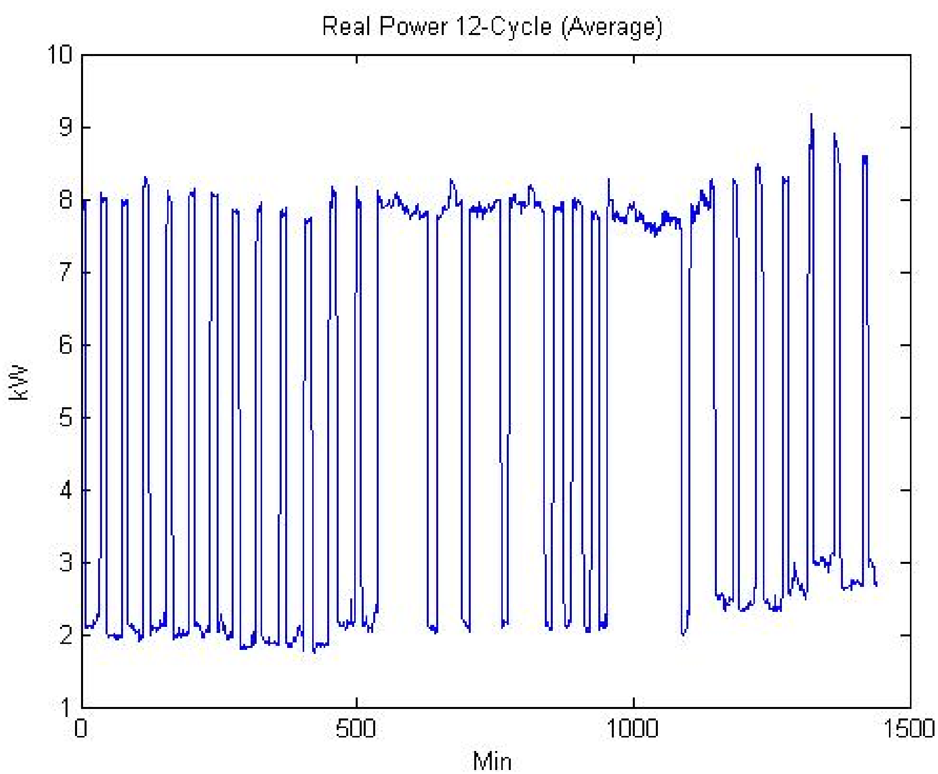


Figure E.1: Real power 12-cycle (average) for Hoboken Fire Department Headquarters

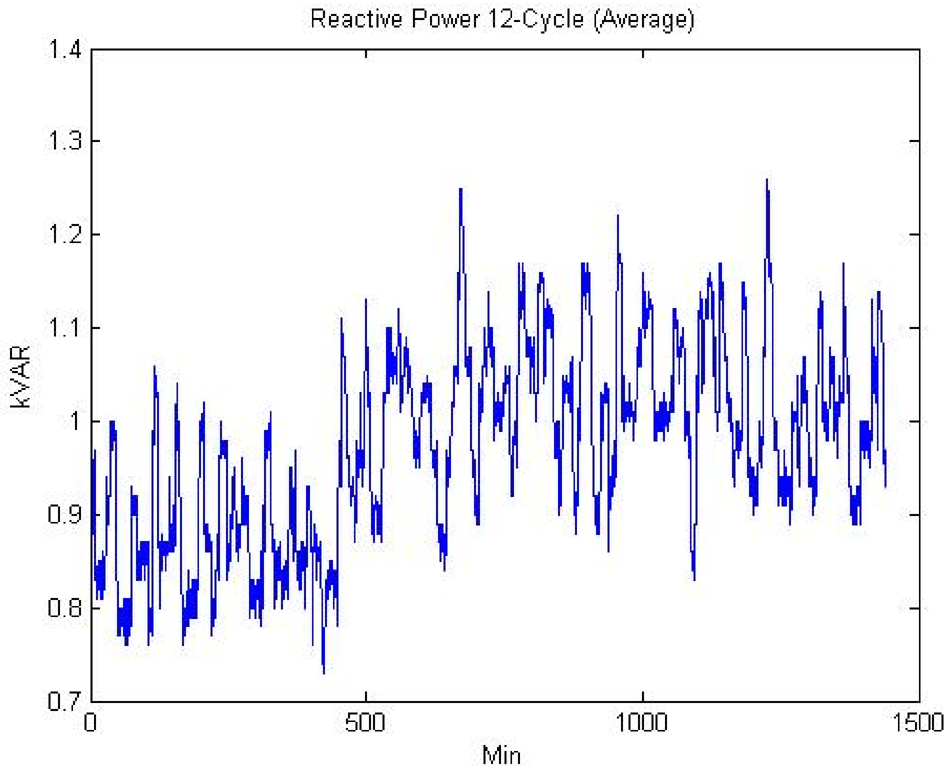


Figure E.2: Reactive power 12-cycle (average) for Hoboken Fire Department Headquarters

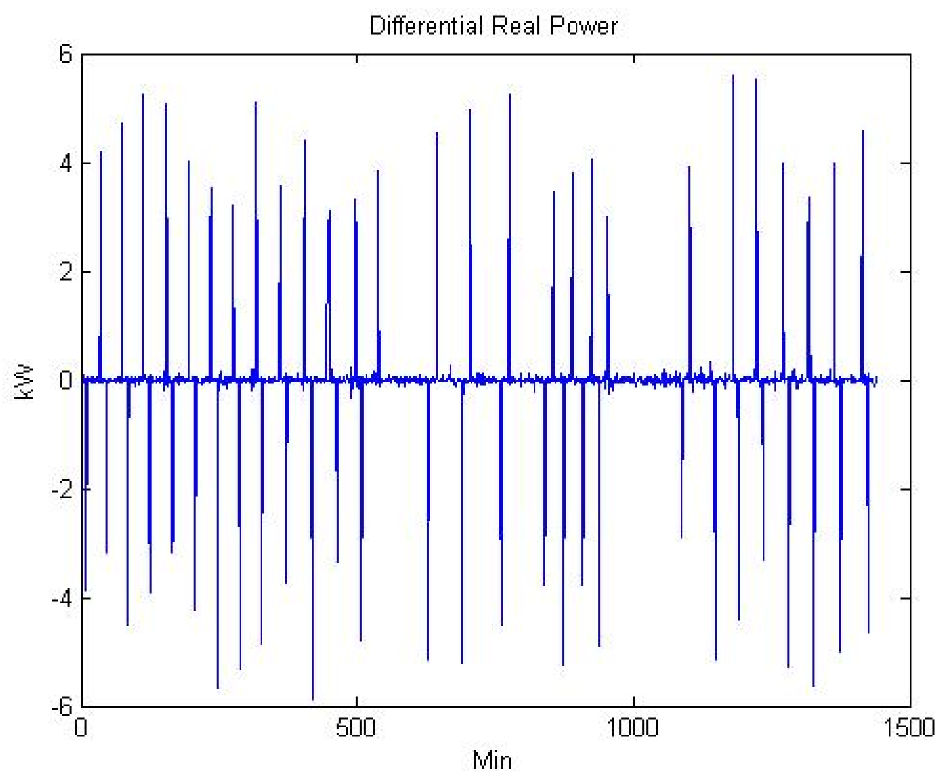


Figure E.3: Differential real power 12-cycle (average) for Hoboken Fire Department Headquarters

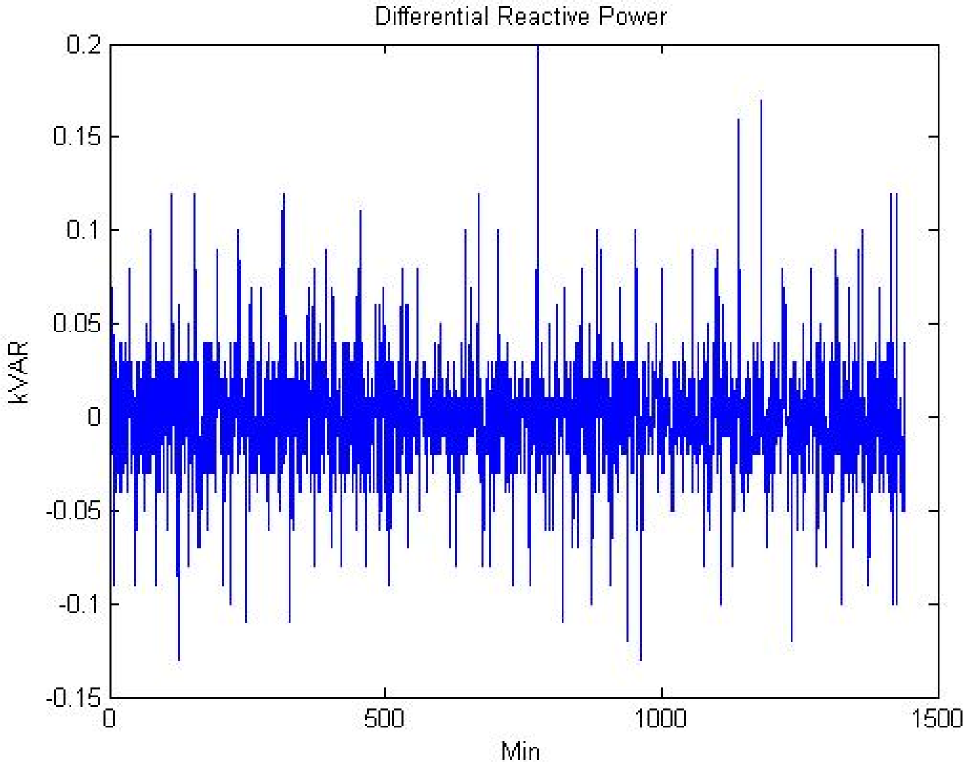


Figure E.4: Differential reactive power 12-cycle (average) for Hoboken Fire Department Headquarters

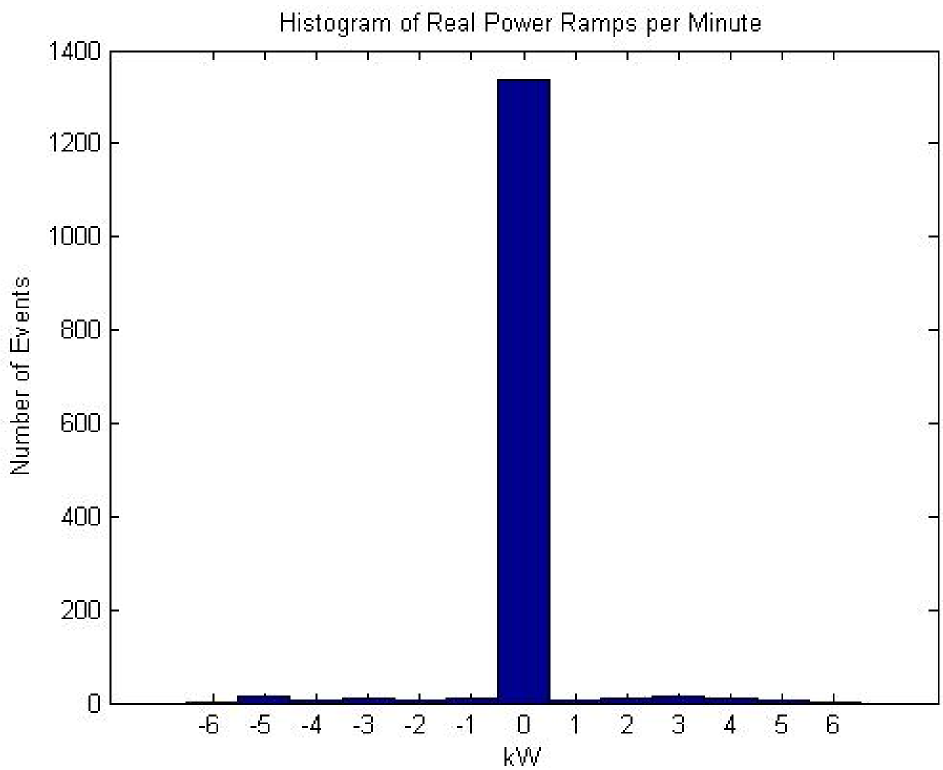


Figure E.5: Histogram of real power ramps – 12-cycle (average)

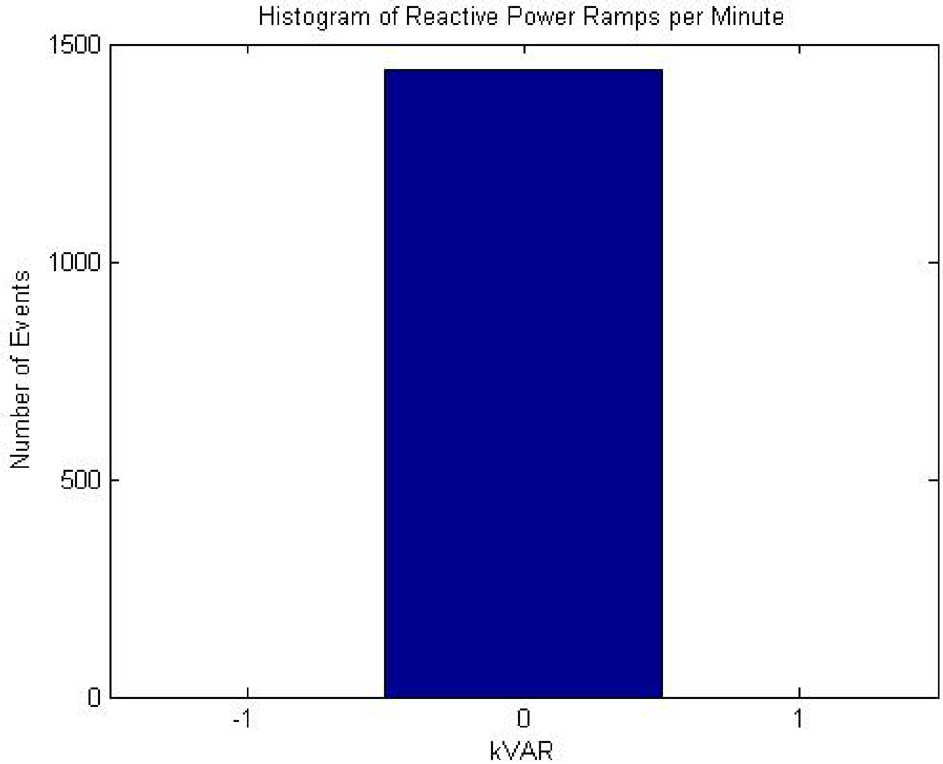


Figure E.6: Histogram of reactive power ramps – 12-cycle (average)

In the following tables, each day is compared to the other days for the Hoboken High School and Fire Department Headquarters. The tables report each days minimum, maximum and average for the real and reactive power per minute based on the 300 12-cycles intervals within the minute. The ramps for increasing and decreasing real and reactive power at the service entrance are also presented.

The load at the Hoboken fire station is mostly resistive with the load real power increasing and decreasing with a maximum of approximately 6kW from Table E.1. There is not much reactive load which is shown in the power factor that is approximately 0.98 lagging. As can be seen in Figure E.1, there is a resistive load that turns on about every 20-30 minutes which the load increases from 2kW to 8kW. A generator sized for this building will have to be able to perform a 6kW/min ramp to be able to maintain electrical stability. The maximum power seen for the Hoboken fire station headquarters is 12.35kW. In the analysis, Sandia used a 30% rating of the PSEG service entrance transformer as the loading profile which for the fire station headquarters came out to be 50kW. This proves to be a very conservative number not having metered load data.

Table E.1: One week of data for Hoboken Fire Department headquarters

Date	Real Power			Reactive Power			Real Power Ramp		Reactive Power Ramp	
	Power Min	Power Avg	Power Max	Power Min	Power Avg	Power Max	Ramp Max	Ramp Min	Ramp Max	Ramp Min
12/31/2013	1.76	6.19	12.35	0.65	1.00	1.79	5.49	-5.57	0.49	-0.40
1/2/2014	1.52	5.00	11.97	0.60	0.95	1.38	5.84	-5.90	0.24	-0.20
1/3/2014	2.01	6.09	10.74	0.69	0.95	1.30	5.85	-5.96	0.20	-0.18
1/4/2014	1.75	5.02	9.16	0.73	0.98	1.26	5.58	-5.88	0.20	-0.13
1/5/2014	2.27	5.40	8.90	0.72	0.99	1.26	5.93	-5.77	0.20	-0.17
1/6/2014	1.86	3.52	10.11	0.59	0.97	1.39	5.32	-5.89	0.29	-0.22

Table E.2: One week of data for Hoboken High School

Date	Real Power			Reactive Power			Real Power Ramp		Reactive Power Ramp	
	Power Min	Power Avg	Power Max	Power Min	Power Avg	Power Max	Ramp Max	Ramp Min	Ramp Max	Ramp Min
12/31/2013	38.80	43.79	53.60	68.10	75.45	90.60	8.50	-6.20	14.80	-12.10
1/2/2014	39.70	83.71	147.20	69.10	138.60	240.50	12.60	-9.90	21.50	-16.60
1/3/2014	39.40	47.40	58.50	68.10	80.47	100.90	6.70	-7.40	11.00	-13.20
1/4/2014	38.50	51.30	73.40	66.90	86.67	119.80	7.40	-6.80	11.80	-11.90
1/5/2014	38.80	48.90	78.80	66.10	82.33	132.30	10.10	-9.30	15.30	-15.80
1/6/2014	39.50	85.92	145.00	67.60	141.94	234.30	11.40	-8.70	20.40	-16.80

In Table E.2, the Hoboken High School is more of a reactive load rather than resistive load which can be seen through the power factor being approximately 0.5 to 0.6 lagging. This could be because the high school has a large HVAC load. The maximum real power load in the week recorded is 147.2kW and the maximum reactive power is 141.94 kVAR. Real power per minute can change up to approximately 12kW and reactive power can change up to 20.4 kVAR. Large change in the reactive power suggests that there is a large inductive motor being turned on. Generator sized for this load will have to sustain more reactive power than a typical generator. Typical generators operate at a power factor of 0.8 lagging; here, an asynchronous generator may be needed with a four quadrant inverter, or a custom generator will have to be ordered or manufactured.

Appendix F

Cost Estimation Approach

Assumptions

This appendix outlines the overall approach used to estimate equipment and project costs associated with the TMO recommended solutions in the main report. Sandia was unable to obtain building level peak monthly demand data (kW) for the buildings considered in the upper bound (UBS) and lower bound (LBS) sets of buildings. Therefore, it was assumed that building peak demands were 30% of kVA ratings of transformers supplying each building. Some peak demand data for a few buildings was available to support the 30% demand assumption. Additionally, meter readings obtained from select buildings also confirmed this assumption (See Appendix E for further details).

A second assumption was that all proposed designs would be "behind the meter" meaning that they would not involve connections with the existing PSEG distribution grid. As discussed further below, this entails that additional equipment proposed in conceptual design options such as new standby generation or a network of standby generators on a new microgrid will be connected to the existing system downstream of the existing PSEG grid, namely past the incoming main service to each building considered. This implies that new connections between buildings to form microgrids at a medium voltage level necessarily involve additional transformers, switchgear, and cabling, as well as new generation to connect these buildings together downstream or "behind the meter" of the PSEG system.

Overall Approach

Capital costs associated with each conceptual design option as well as overall preliminary option recommendations based on TMO and PRM analysis are based upon costs associated with the following cost components:

- Installation Costs
- Design and Engineering Costs

- Contingency Costs
- Overall Construction Costs

Installation costs include estimates of all project costs involved in procurement and labor involved with the installation of all equipment associated with the conceptual design considered. The assumptions made for the equipment needed as well as for their associated costs is presented below. Design costs involve estimates of the costs associated with preparing a set of detailed designs as well as associated analysis necessary to install the equipment for the project. Engineering costs involve all costs involved in additional engineering analysis as well as the engineering oversight of the installation, testing and energization of the final installed system. Based upon previous experience, design and engineering costs are estimated to be 25% of the total installation costs. Contingency costs are factored in to estimate unanticipated costs associated with the project. These can include costs associated with permitting, inspections, use of temporary power for buildings during installation, or other things not captured by the cost estimates. Contingency costs are estimated to be 15% of the total installation costs. Overall project costs are the sum of all costs. For example if installation costs for a project are estimated to be $1000k, then engineering and design costs will be estimated to be $250k, contingency costs at $150k, so the overall project costs will be estimated to be $1400k. The following section describes each of the costs considered as well as the cost assumptions used for each. An example follows to elaborate on how these costs are calculated.

Installation Costs

Installation costs include estimates of all project costs involved in procurement and labor involved with the installation of all equipment associated with the conceptual design considered. Equipment costs were derived with a use of the combination of CostWorks 2013 RS Means cost estimating tool (a well recognized industry tool for cost estimates of electric component costs), information from Hoboken and other experts, and previous project experience. Relevant cost tables used to calculate costs are summarized in tables in a later section. The installation costs are further subdivided into the following categories:

- Distribution infrastructure costs
- Generation
- Cyber security and controls
- Retrofitting
- CHP, PV, and energy storage

Each of these subcategories of installation costs is described in the following sections.

Distribution Infrastructure Costs

This includes:

- Transformers
- Cables – primarily medium voltage (13.8 kV)
- Trenching and conduits
- Manholes

The distribution infrastructure costs include all of the costs associated with connecting building loads together into clusters to form microgrids utilizing equipment downstream of the PSEG metering without impacting the operation of the existing PSEG utility grid. This infrastructure is implemented in nearly all cases as determined by TMO analysis most optimally by medium voltage cabling connecting grid segments between buildings together. Due to lack of availability of many areas within the City of Hoboken to utilize existing overhead feeder right of ways either due to lack of space availability or because no overhead exists, all new distribution infrastructure proposed is to be implemented with underground cables. Each building is proposed to be installed with a new transformer which matches the existing PSEG transformer size to connect the building to new microgrid clusters as determined by TMO analysis.

Cables were sized to be able to provide power to a 10 MVA system, which is greater than the total estimated load for all of the upper bound set of buildings (9 MVA). Specifically, two parallel runs of 4/0 cables per phase along with a #2 ground cable was assumed as the cable needed for medium voltage connections in the microgrid clusters. This cost is estimated to be $140/foot based upon CostWorks RS Means data. Cable cost estimates for various sized cabling are shown in Table F.1 and F.2 below.

Connections between buildings involve installation of conduits, with associated trenching, backfilling and road repair. For a minimum of 5 – 5" PVC conduits, 4 dedicated for each phase plus ground, plus an additional conduit for communication cables, then estimated costs are $160/foot based upon information provided by area contractors. These costs can also be estimated from RS Means, but known local costs were used since they provide a best resource for historical information. So the total cost for installing cabling, trenching and conduits is estimated to be $300/foot.

Since the conceptual designs do not utilize the existing PSEG infrastructure, buildings included in any conceptual microgrid must be provided transformers to serve their respective building peak loads. The assumption used was to size any new transformer to match the rating of the existing PSEG transformer. Cost tables for transformers based upon CostWorks RS Means data is shown in Table F.3 below.

Table F.1: Low voltage cable costing, 600V copper type THWN-THHN stranded

Size	Cost	Unit	Amperage
#14	$79.00	100 feet	20
#12	$97.50	100 feet	25
#10	$116.00	100 feet	35
#8	$153.00	100 feet	50
#6	$209.00	100 feet	65
#4	$284.00	100 feet	85
#3	$325.00	100 feet	100
#2	$380.00	100 feet	115
#1	$460.00	100 feet	130
1/0	$560.00	100 feet	150
2/0	$670.00	100 feet	175
3/0	$820.00	100 feet	200
4/0	$980.00	100 feet	230
250 kcmil	$1,150.00	100 feet	255
300 kcmil	$1,300.00	100 feet	285
350 kcmil	$1,475.00	100 feet	310
400 kcmil	$1,625.00	100 feet	335
500 kcmil	$1,900.00	100 feet	380
600 kcmil	$2,325.00	100 feet	420
750 kcmil	$3,550.00	100 feet	475
1000 kcmil	$4,975.00	100 feet	545

Table F.2: Medium voltage cable costing (splicing and terminations not included)

Size	Cost	Unit	Amperage
1/0	$ 945.00	100 feet	150
2/0	$1,050.00	100 feet	175
4/0	$1,300.00	100 feet	230
250 kcmil	$1,400.00	100 feet	255
350 kcmil	$1,725.00	100 feet	310
500 kcmil	$2,000.00	100 feet	380

Table F.3: Transformer cost estimates

kVA Rating	Cost
150	$15,300
225	$17,300
300	$19,600
500	$29,200
750	$32,300
1000	$40,000
1500	$47,000
2000	$58,000
2500	$68,500
3000	$81,500
3750	$101,500

Each conceptual microgrid cluster proposed consists of a main feeder background with tapped connections to individual buildings. Each tap is implemented via spliced connections in underground manholes along the corridor of the underground microgrid cable in conduit as described. Based on information provided by area contractors, the cost of an individual manhole to facilitate building connections in the microgrid is estimated to be $11K/manhole. How these costs are calculated is presented in an example below.

Generation Costs

This includes:

- Generators
- Associated switchgear (ATS or paralleling switchgear)

The City of Hoboken has an extensive gas infrastructure existing throughout the city supplied by PSEG. Due to this factor plus the desire to lessen the impacts of CO2 emissions, a decision was made that all new generators considered for the project would be natural gas supplied generators. These include generators considered for CHP applications. Generator costs for new buildings include associated switchgear involved in making these connections to buildings, including ATS devices and/or parallel switchgear to connect generators to buildings. NG generator costs are estimated to vary from about $1200/kW to $800/kW depending on the size of the generator as summarized in Table F.4 below. Buildings included in a new conceptual microgrid which do not have a new generator will require additional ATS devices in order to make them available for use in microgrid configurations. ATS cost estimates are shown in Table F.5. How these costs are calculated is presented in the example below.

Table F.4: Diesel and natural gas generator cost estimates

Gen Size (kW)	Diesel Cost	Natural Gas Cost
30	$27,000	$81,000
50	$32,600	$97,800
60	$35,700	$107,100
75	$41,800	$125,400
100	$46,600	$139,800
125	$49,200	$147,600
150	$56,000	$168,000
175	$61,000	$183,000
200	$62,500	$187,500
250	$72,500	$217,500
275	$75,500	$226,500
300	$78,000	$234,000
350	$88,000	$264,000
400	$106,000	$318,000
500	$132,000	$396,000
600	$169,000	$507,000
650	$202,500	$607,500
750	$207,500	$622,500
800	$216,000	$648,000
900	$249,000	$747,000
1000	$258,000	$774,000
1200	$332,316	$996,948

Table F.5: ATS cost estimates

Ampere Rating	Cost
30	$3,425
60	$3,500
100	$3,725
150	$4,500
225	$5,700
260	$6,425
400	$8,350
600	$11,800
800	$13,900
1000	$17,800
1200	$23,800
1600	$27,100
2000	$30,600

Cyber Security and Controls Costs

This includes:

- Control Infrastructure
- Generator Controls
- System Protection
- Cyber security implementation
- Control Centers

Cyber security and control costs consists of all of the control infrastructure necessary to implement the design such as individual microgrid generator controls, fiber links between generators, overall system protection, the cyber security apparatus necessary to ensure that these controls are performed securely as well as the control center locations in which microgrids can be monitored and controlled remotely. Further detailed information on what these items consist of is found in the main report. Based upon interactions with manufacturers for generator controls and infrastructure necessary to implement cyber security and controls, as well as previous project experience, these costs can be determined as a function of the number of generators included in the microgrid designs, as a cost per generator. $100K/generator was used as a basis for estimating these costs.

Retrofitting

This includes:

- Relocation of service equipment
- New service equipment
- Demo/retrofitting of service equipment

A performance requirement to meet the DBT is for electric power to be available to the UBS or LBS buildings for the DBT (100 year flood +2.5 feet). Based upon FEMA data, a flood map of the City of Hoboken was developed and the locations of which buildings in the UBS and LBS with respect to the DBT were determined. Buildings located in areas below the DBT will have flooding during a DBT occurrence so must be designed to be able to supply electric power during a DBT event. An assumption is made that the first floor of these buildings will be flooded during the DBT and unavailable, so the performance requirement calls for these buildings to be supplied with power above the first floor of these buildings. Further details on how these retrofit costs were estimated is discussed in Appendix G.

CHP, PV and Energy Storage

This includes:

- Heat load and CHP
- PV
- Energy storage

The potential to utilize CHP, PV and energy storage was extensively analyzed within buildings in the City of Hoboken to determine the best locational opportunities to deploy these resources. These sites were chosen solely based on grid-connected economic analysis. Analysis associated with heat loads and CHP is discussed further in Appendix I, and PV is discussed further in Appendix J. Analysis for energy storage is included in Appendix K, and policy considerations for all of these options are discussed further in Appendix H.

Example Cost Analysis

A simple example with three buildings presented below illustrates how costs are estimated. The same processes to calculate these costs have been extrapolated to determine cost estimates for optimized solutions for the UBS and LBS buildings as determined by TMO presented in the main report.

In this example, Building A is serviced by a medium voltage Feeder #1 with a 200 kVA transformer and has an existing 60 kW standby generator as shown in Figure F.1. Building B and C are serviced by a second Feeder #2 with individual transformers but no existing standby generators. Building C is also located in a region below the DBT so requires retrofitting to enable it to be able to meet performance requirements.

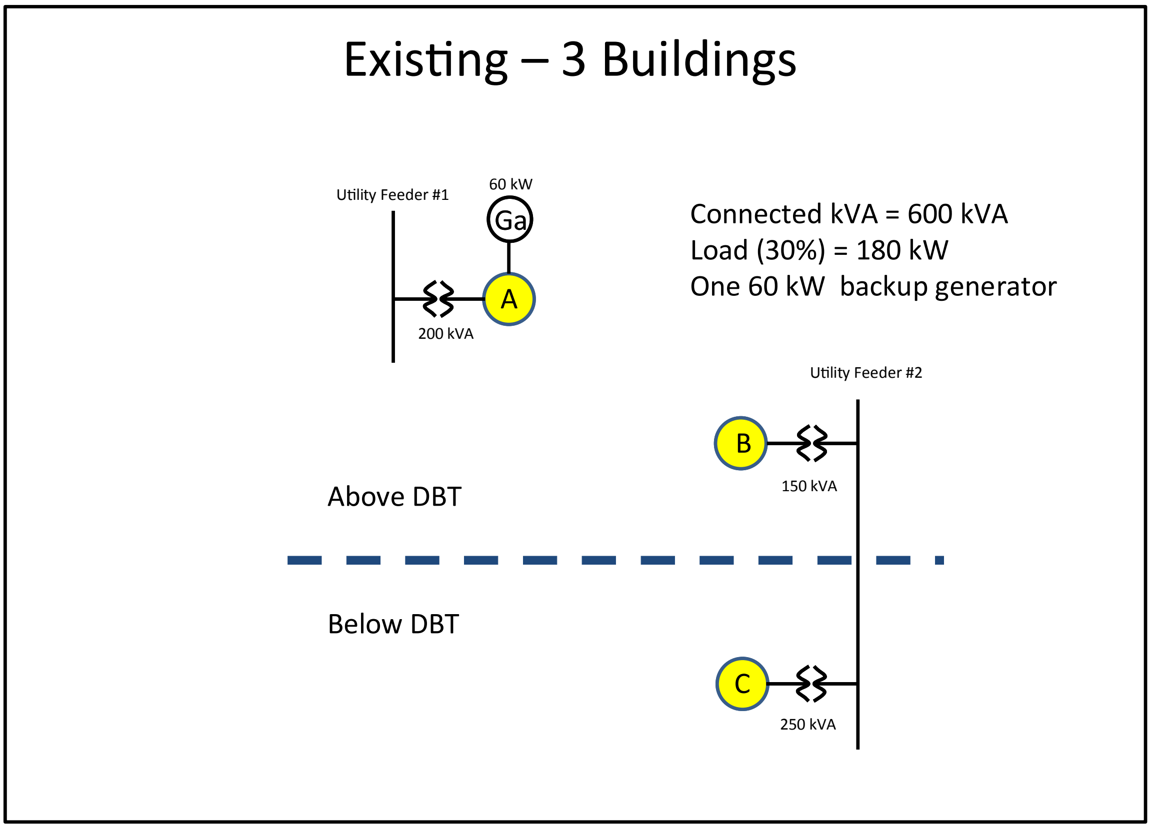


Figure F.1: Example system with 3 buildings

Table F.6 shows that peak load requirements of the system are derived by calculating 30% of the transformer ratings that feed each building. This total load value determines the minimum amount of generation to feed loads to all three buildings of 180 kW. Figure F.1 illustrates that a new system independent of the utility in which all three buildings are connected together in a microgrid configuration independent of the existing utility. In this case it is determined that this entails a total of 1200 feet of underground medium voltage cabling with associated trenching, backfilling and conduit runs with a per unit cost of $300/ft to implement. The microgrid is implemented with two new 125 kW generators with associated switchgear to supply the 180 kW load in addition to the existing 60 KW generators. Using an N-1 design, implies that if any single generator fails, other generators in the microgrid are available to serve the peak load requirements. In this case if any one of the two 125 kW or 60 kW generators in the system fails, a minimum of 185 kW of generation would still be available to serve the 180 kW peak load, so the system is N-1 compliant. As shown in Figure F.2 and Table F.7, three manholes are required at $11k/manhole to connect the microgrid underground feeder to each building. The microgrid requires a separate set of transformers to implement independent of the utility system and the control infrastructure costs to implement the microgrid are calculated as well as shown in Figure F.2. Building B has 50 kW of PV potential at $4.8/kW. Building C is located below the DBT so requires retrofitting of its electrical infrastructure as well as the location of its new 125 kW standby generator to be above the levels of the DBT.

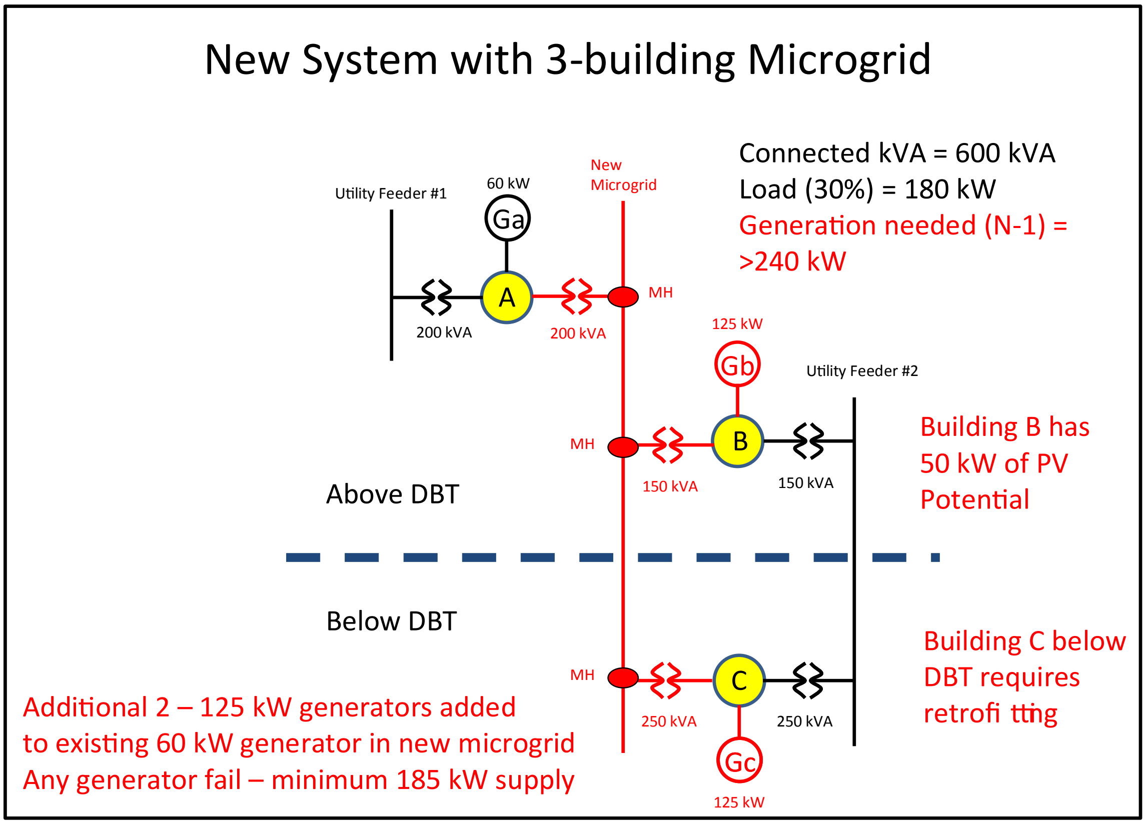


Figure F.2: Example system with 3 buildings and new dedicated microgrid

As shown in Table F.7, the total infrastructure costs associated with this conceptual microgrid design is $1.5M. The infrastructure costs account for both procurement and implementation of this equipment. A 25% cost associated with a detailed design and engineering necessary to implement the project, and a 15% contingency is added resulting in a final estimated cost for this example at $2.1M. This same cost estimate approach is used to make estimates as described below for baseline and TMO determined UBS and LBS solution costs.

Table F.6: Example system load data

Building	Existing Transformer Rating (kVA)	Peak Load Estimate (30%) (kW)	Existing Backup Generator (kW)	Below DBT?
A	200	60	60	N
B	150	45		N
C	250	75		Y
Total	600	180	60	

Table F.7: Cost estimates for example system

Equipment	Per unit cost ($K)	Units	Cost ($K)
Cables	0.3	1200	360.0
Generators	147.6	2	295.2
Controls	100.0	3	300.0
Transformers	17.5	3	52.5
Manholes	11.0	3	33.0
PV	4.8	50	240.0
Retrofit	220.0	1	220.0
		Infrastructure Total	1500.7
		Design/Engineering	375.2
		Contingency	225.1
		Total with contingency	2101.0

Figure F.3 below shows a one-line diagram of two buildings which are connected to a utility grid which now connects as part of a conceptual microgrid. It illustrates how connections are made downstream of existing utility equipment so they can operate independently of the existing system. Building B is an example of a building connected to a new microgrid in which a new transformer and ATS are connected to building loads between the utility meter and incoming main breaker to the building. The ATS allows loss of utility power to be detected and transferred to the new conceptual microgrid seamlessly and keeps the power fed to the building during emergency conditions isolated from utility power on the conceptual microgrid. Building A illustrates one possible implementation of a generator in to a building in a conceptual microgrid. Like Building B, an ATS allows loss of utility power to be detected and transferred over to the conceptual microgrid. A set of paralleling switchgear breakers allow the new generator to supply backup power to Building A as well as feed power to the conceptual microgrid through a new transformer. The control system interfaces with ATS, paralleling switchgear, and generators to monitor and control synchronization of generators to the system and power flow outputs of the generators to optimize power outputs during emergency conditions when the microgrid is functional. Building A and B transformers connect buildings together through underground cabling systems connected together in manholes. These same cost approaches are used to calculate TMO solutions for the UBS and LBS buildings presented in the main report.

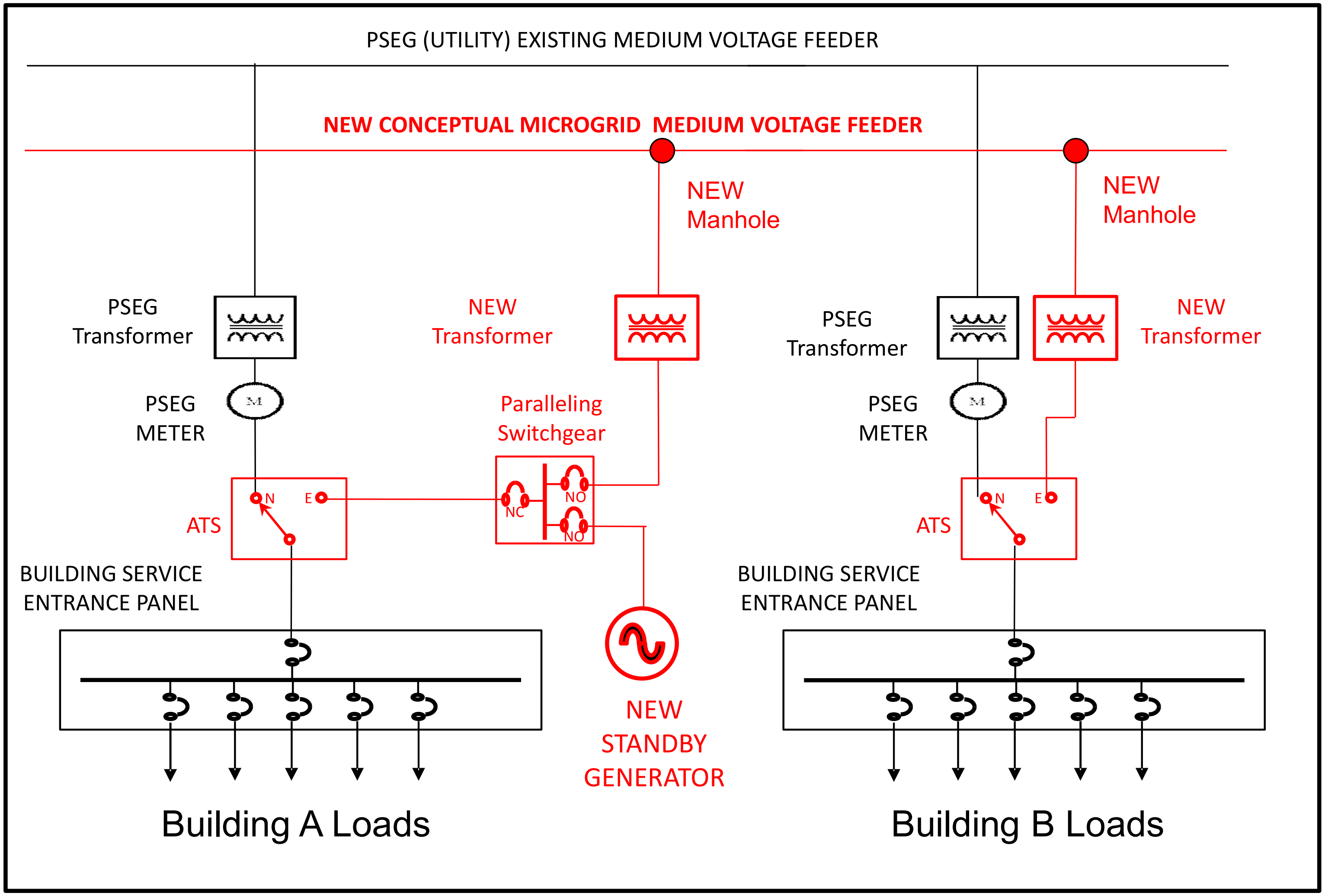


Figure F.3: Details showing how connections are made to create microgrids

Appendix G

Retrofitting for DBT Conditions

A performance requirement to meet the design basis threat (DBT) analyzed in this report is for electric power to be available to the UBS or LBS buildings for the DBT (100 year flood +2.5 feet). Based upon FEMA data, a flood map of the City of Hoboken was developed and the locations of which buildings in the UBS and LBS with respect to the DBT were determined. Buildings located in areas below the DBT will have flooding during a DBT occurrence so must be designed to be able to supply electric power during a DBT event. An assumption is made that the first floor of these buildings will be flooded during the DBT and unavailable, so the performance requirement calls for these buildings to be supplied with power above the first floor of these buildings.

Figure N.1 shows the locations of the 55 buildings (both UBS and LBS) mapped onto a FEMA 100 year flood plain. Incorporating the 100 year flood plain plus 2.5 as designated by the DBT extends the location of the flood plain slightly. The enclosed area within the dotted line in Figure D1 shows the regions within Hoboken above the DBT which we do not anticipate to be affected by the DBT, since they are above the levels of the DBT. These buildings also align with the storm effects of Sandy, in which some of these buildings may have had temporary flood excursions from the storm surge but they were intermittent due to the higher levels of these areas. Some of these buildings had power outages but not due to flooding, instead due to upstream power substations and equipment being effected by the flood waters. We assume therefore, that all buildings above the DBT levels (outside the blue dotted line in Figure N.1) will require retrofitting to meet the DBT, and buildings below the DBT will not. For calculations purposes, two buildings on the edge, the YMCA (Building #51) and Kings Grocery (Building #19) were considered below the DBT and in need of retrofitting. Also, the design did not consider retrofits for the Sewage Treatment Plant (Building #07) since, from discussions with plant personnel, it requires extensive facility renovation above and beyond that needed to make emergency backup systems available during flood conditions, and there is a separate plan being proposed by the plant owners to address these requirements to meet the future DBT. Additionally we did not include retrofits for the Hoboken Hospital based upon information that the existing emergency generators are located above DBT levels and functioned during Sandy. The Hoboken Hospital was evacuated during Sandy, due to infusion of contaminated water unrelated to emergency power delivery.

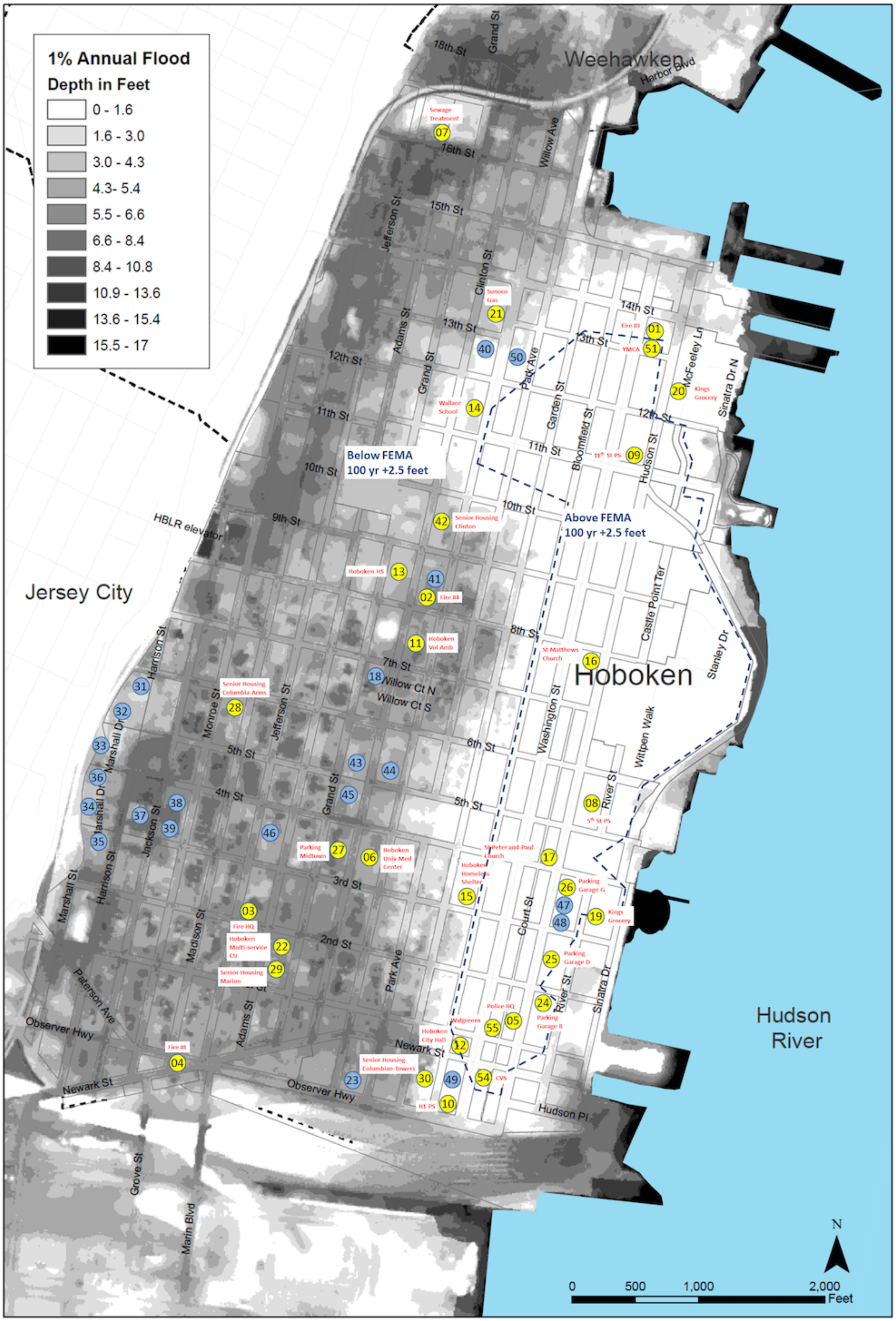


Figure G.1: Hoboken Flood Map showing locations of LBS (yellow) and UBS (yellow plus blue) buildings above and below DBT

EI Associates was contracted by Sandia to perform preliminary estimates to determine the requirements to relocate existing service equipment, install new service equipment and do any necessary demolition and retrofitting of service equipment to make emergency power viable during a DBT event (refer to separate EI Associates report: Design Study for City of Hoboken, to Establish Microgrids, December 2013) for a few select buildings. The equipment necessary for retrofitting include the incoming main breaker to the facility, and all transformers, panels and wiring involved in distributing power throughout each building as well as existing emergency standby generators and wiring. All of this equipment must be retrofitted to permit power to be delivered to buildings below the DBT.

EI Associates did a site survey performed further analysis and made estimates of the costs necessary to retrofit select buildings in the City of Hoboken as listed below. The survey included the requirements to relocate equipment either by moving it to another floor, or installing new support structures above the DBT in order for the equipment to be serviceable during a DBT.

- Hoboken Multiservice Center - $217.5 K
- Fire Headquarters - $77.6 K
- Hoboken High School - $173.9 K
- Kings Grocery Store - $121.1 K
- Hoboken Housing Authority - $222.1 K

Sandia took these estimates and extrapolated these costs to other buildings of similar size and function to estimate retrofit costs for UBS and LBS buildings above the DBT. It is noteworthy that these costs do not take into account additional costs involved to relocate people if power is out for a portion of the time necessary for the building retrofits, or other workarounds needed if this isn't possible as well as any regulatory or permitting costs associated with these retrofits. Tables G.1 and G.2 lists out the retrofit cost estimates for the UBS and LBS buildings. Totaled, the costs for all UBS buildings are $6465k and LBS-only buildings are $2650k.

Table G.1: Retrofit cost estimates for UBS/LBS buildings

Bldg #	Name	Retrofit Costs ($K)
53	Fire Department Radio Repeater	N/A
8	5th Street PS	N/A
16	St. Matthew's Church (shelter)	N/A
17	St. Peter and Paul Church	N/A
26	Garage G	N/A
5	Police HQ	N/A
9	11th Street PS	N/A
52	Police Department Radio Repeater	80
54	CVS	N/A
12	Hoboken City Hall	N/A
19	Grocery - Kings	120
24	Garage B	N/A
25	Garage D	N/A
55	Walgreens	N/A
1	Fire Engine Co 3	80
10	H1 PS	80
14	Wallace School (shelter)	120
15	Hoboken Homeless Shelter	120
20	Grocery - Kings	120
21	Gas Station - Sunoco	120
30	Columbian Towers	220
51	YMCA (SROs)	N/A
2	Fire Engine Co 4	80
3	Fire HQ	80
4	Fire Engine Co 1	80
6	Hoboken University Medical Center	N/A
7	Adams Street	N/A
11	Hoboken Volunteer Ambulance Corps.	120
13	Hoboken High School	175
22	Hoboken Multi-Service Center	220
27	Midtown Garage	175
28	Columbian Arms	220
29	Marion Towers	220
42	900 Clinton Senior Housing Fox Hill	220

Table G.2: Retrofit cost estimates for UBS-only buildings

Bldg #	Name	Retrofit Costs ($K)
47	Marineview 1	N/A
48	Marineview 2	N/A
49	Applied	N/A
23	Hoboken Public Works Garage	175
50	Applied	220
18	Grocery - A&P	120
31	Hoboken Housing Authority	220
32	Hoboken Housing Authority	220
33	Hoboken Housing Authority	220
34	Hoboken Housing Authority	220
35	Hoboken Housing Authority	220
36	Hoboken Housing Authority	220
37	Hoboken Housing Authority	220
38	Hoboken Housing Authority	220
39	Hoboken Housing Authority	220
40	Hoboken Housing Authority	220
41	804 Willow Ave	220
43	Church Towers	220
44	Church Towers	220
45	Church Towers	220
46	Clock Towers	220

Appendix H

Policy Considerations

The intent of this section is to inform project stakeholders of the policy considerations that are likely to apply moving forward with the microgrid design options presented in this report, and how they may impact the project in terms of technical performance risk, process issues (timelines, permitting, etc.) and cost.

Issues Relating to Right of Ways

Infrastructure Installation

The report assumes that all solutions presented do not require the use of utility right of ways (ROWs) or infrastructure from PSEG. Liability issues are likely to prevent the use of PSEG infrastructure from being a timely solution. Any considerations will require the installation of new, independent infrastructure to provide electric service.

Outside of using PSEG infrastructure, when connecting city buildings, much of the ROW use will be city ROW and will not present a problem from an installation perspective. This will involve the installation of generation and electrical connection of this generation to city loads under city streets and sidewalks. Where it physically crosses a utility ROW, as long as the new infrastructure passes above or below, and does not interfere with the existing infrastructure in the utility ROW, the installation will be considered as passing a city ROW in a public street or sidewalk.[1] In the situation that there is interference with non-city owned right of ways, whether this is during the installation process or the installed infrastructure itself, approval would be required by the ROW owner.

Retail Wheeling

However, when considering operations, the right of way issue may present a problem. Per NJ State law, the installation of microgrids with distributed generation as proposed in this effort is subject

[1] From staff at the New Jersey Board of Public Utilities (BPU)

to the generations' qualification as an "on-site generation facility."[2] Alternatively, the city would have to become a public utility to own and operate the proposed microgrid, something the city may be unlikely or unwilling to do considering the resources required to undertake this process. That said, other municipalities in New Jersey have become public utilities and it is an option under this situation.

An on-site generating facility means "a generation facility... located on the property or on property contiguous to the property on which the end users are located. An on-site generation facility shall not be considered a public utility." When the proposed solutions in this report are expected to be located on the property or property contiguous to city property that they will serve, generation would likely fall under this definition. The definition further clarifies that "the property of the end use customers and the property on which the on-site generation facility is located shall be considered contiguous... if they are geographically located next to each other, but may be otherwise separated by an easement, public thoroughfare, transportation or utility-owned right-of-way." This, however, restricts the distribution of electricity only to contiguous property that is owned, by one owner. In the situation that there are multiple loads owned by multiple owners, as presented in the microgrid solutions here, that are not contiguous under this definition, that is, they cross more than one more than one easement, public thoroughfare, or transportation or utility-owned right-of-way, there is uncertainty whether this would be allowed by state law irrelevant of whether it is an emergency situation. Said in a different way, the city would be unable to provide electricity to a third-party, even in an emergency situation, under current rules.

This obviously presents a problem as many of the microgrid solutions presented here may no longer be valid per this rule. Generation, whether PV, CHP or backup natural gas, would be limited to provide service to contiguous property that is owned by a single entity. Outside of a rule change, the city may need to petition the New Jersey Board of Public Utilities (BPU) for an exemption because of the strong public interest associated with the project. This approach has been historically successful in limited circumstances.

Alternatively, the BPU is considering proposing an amendment to the law that would: 1) Allow more than one end use customer of an on-site generation facility; 2) Allows more than one right-of-way to be crossed if the on-site generator and the end use customer is a governmental entity; and 3) would allow more than one right-of-way to be crossed if the on-site generator is used for emergency backup purposes only. If this amendment is approved by state legislature, any problems around this issue are no longer valid and all microgrid solutions presented in this report would be allowed per state law.

[2] Section 3 of P.L.1999, c.23 (C.48:3-51)

Renewable Energy and Combined Heat & Power

For several important policies, including natural gas sales and use tax and a pending portfolio standard change, New Jersey legislators have defined "contiguous property" in a manner that includes a CHP system and an end-user separated by an easement, a right-of-way, or another building. It also allows an end-user who may not physically be located next door to be deemed "contiguous" if the end-user takes thermal power from the CHP system.

This definition is significant, because it recognizes that the thermal host for a CHP system may sometimes not be in the same building as the end-user, and that the CHP system might have excess electricity that it would like to sell. Importantly, the legislation also requires that the sale of electricity to a contiguous property can employ existing utility distribution infrastructure to "wheel" the power, and that the utility must treat it as a typical wheeling customer. This definition also could apply to district energy systems that might wish to incorporate CHP systems.

For solar installations, a municipal entity can aggregate all of its loads and can net metered with the local utility. Nonetheless, the on-site generation restrictions discussed above still apply.

Owning and Operating Infrastructure

As discussed above, the City of Hoboken can own and operate electric infrastructure, subject to New Jersey State Law. As the law currently stands, this is limited to behind the meter, or on-site generation, that can serve contiguous property crossing one right of way. There are have hundreds of these installations already. In the situation that an exception is made or the law is amended, the city can then own and operate infrastructure beyond this limitation, providing emergency service to third parties and crossing multiple ROWs.

There are a couple of additional questions that the city needs to answer as it considers implementing the solutions proposed in this report. These include:

1. How will this infrastructure be paid for? Are tax dollars appropriate for this use especially when emergency services will be targeted to critical loads? A further discussion following in the next section.
2. Can the city own resiliency infrastructure on private property?
3. In the situation of multiple owners of resiliency infrastructure equipment (private or public), how will the state ensure that operational responsibility, legal liability and insurance needs are addressed?
4. Economic considerations: How will the state define the value of reliability and resiliency? This is a critical question in the consideration of capital investment. What level of investment is acceptable to meet reliability and resiliency goals?

Financing Considerations

A few financing considerations the city may explore include:

- *The New Jersey Energy Savings Improvement Program (ESIP):*
  This program, from Public Law 2009, Chapter 4, authorizes government entities to make energy related improvements to their facilities, paying for the costs of these improvements through the resulting energy savings. It is assumed that the city will take this approach, and is built in to the financial analyses presented in this report.

- *Municipal Bonds:*
  Municipal bonds allow a city or other local government to generate revenue. The bonds could be general obligations of the city or be tied to specific projects. Interest earned by a holder of these bonds would be exempt from most federal, state and local tax.

- *Funds from the New Jersey Energy Resiliency Bank:*
  The state has contracted McKinsey and Company to design and develop an energy resiliency bank to help municipalities invest in energy technologies that provide resiliency.[3] The bank is currently under development. See link for further information.

- *Power Purchase Agreement:*
  The city could contract with a third party under a power purchase agreement. In this situation, the third party would procure, install and maintain the CHP or PV system, with the city paying a contracted rate for energy. This would remove the burden of large capital investment and provide the third party with the following benefits, that in turn would benefit the city, being able to negotiate lower energy rates:

- *Investment tax credits:*
  The Federal Government provides investment tax credits (ITC) at a rate of 30% of investment for PV and 10% for CHP, and accelerated depreciation benefits (MACRS: Modified Accelerated Cost Recovery System) classifying PV and CHP as five year property to commercial entities installing these systems. The ITC and MACRS allow interested investors to reduce their tax liability directly though the ITC and through tax deductions for the recovery of solar PV and CHP property under MACRS. Both provide significant market certainty and can allow an entity, such as a city that contracts to a commercial broker who finds interested tax investors, to reduce its overall investment in these technologies.[4]

- *SRECs:*
  Solar renewable energy credits (SRECs) for the generation of renewable solar energy by resources specified in this report. Current market values for SRECs range from $100-$200/MWh, but are likely to be reduced as more solar is installed. In the near term, there is significant revenue opportunity.

[3] See: http://www.state.nj.us/treasury/purchase/noa/contracts/g1009_14-r-23231.shtml.

[4] See: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US06F, http://www.seia.org/policy/finance-tax/depreciation-solar-energy-property-macrs

State Incentives

An excellent reference for the state energy incentives is located at http://www.njcleanenergy.com/commercial-industrial/home/home.

Combined Heat and Power

Incentives are available for CHP and fuel cell (FC) systems with recovery and productive use of waste heat that are located on-site. The eligibility page at the NJ state cite mentioned above has additional details, as well as information for projects using renewable fuel (on the biopower web page). Table H.1 includes a summary of available options.

Incentives will be processed and paid as follows: thirty percent of the incentive upon proof of equipment purchase; sixty percent upon project completion and verification of installation; and the remaining ten percent upon acceptance and confirmation the project is achieving the required performance thresholds based on twelve months of operating data.

Local Government Energy Audits

Hoboken has already accomplished most or all of these. The local government energy audit program targets buildings owned by local governments, New Jersey state colleges and universities, and 501(c)(3) non-profit agencies. Such facilities may include, but are not limited to: offices, courtrooms, town halls, police and fire stations, sanitation buildings, transportation structures, schools and community centers. All local governments, New Jersey state colleges or universities, and non-profit agencies exempt from federal tax under section 501(c)(3) of the Internal Revenue Code that are located within the service territory of at least one of the state's regulated utilities are eligible.

The program requires that participating local government agencies pass a resolution enabling submittal of the program application. Sample resolutions that may be used by a governing body are included in the complete package of guidelines and application forms provided in the NJ state link at the beginning of this section. The Division of Local Government Services (DLGS) within the Department of Community Affairs (DCA) has issued a local finance notice to allow participants in the LGEA program to pass a resolution later in the process, when the participant is selecting an auditing firm. That notice and the sample resolution for that option can be found at http://www.state.nj.us/dca/divisions/dlgs/lfns/09/2009-12.doc.

Participants will select from a list of pre-qualified auditing firms who will follow the strict parameters of New Jersey's Clean Energy Program and deliver an energy audit. The program will subsidize 100% of the cost of the audit. More information about the New Jersey Division of Purchase and Property State Contract (T-2545) and the selected firms is available on the NJ state web site. The completed audit will have a list of recommended, cost-effective energy efficiency measures and facility upgrades that will reduce operating expenses and, in many cases, improve the

Table H.1: Incentives and applications

Eligible Technology	Size (Installed Rated Capacity)	Incentive ($/Watt)[5]	P4P Bonus[6] ($/Watt) (cap $250,000)	% of Total Cost Cap per project	$ Cap per project
Combined Heat & Power[1]	≤500 kW	$2.00	$0.25	30-40%[7]	$2 million
	>500 kW – 1 MW	$1.00			
	>1 MW – 3 MW[4]	$0.55		30%	$3 million
	>3 MW[4]	$0.35			
Fuel Cells[2]	≤1 MW w/ waste heat	$4.00		60%	$2 million
	≤1 MW	$3.00			
	>1 MW w/ waste heat	$2.00		45%	$3 million
	>1 MW	$1.50			
Heat Recovery[3]	≤1 MW	$1.00		30%	$2 million
	>1 MW	$0.50		30%	$3 million

Footnotes:

[1] Non-renewable fuel, e.g. internal combustion engine, combustion turbine, microturbine

[2] Powered by non-renewable fuel source; incentives available for systems both with and without waste heat recovery

[3] Powered by non-renewable fuel source, heat recovery or other mechanical recovery from existing equipment utilizing new electric generation equipment (e.g. steam turbine); projects installing CHP-FC and Heat Recovery generation will be eligible for incentives shown above, not to exceed the lesser of percent per project cap or dollars per project cap of the CHP-FC

[4] Incentives for CHP systems greater than 1 MW are tiered; for example, a 4 MW CHP system would receive $0.55/watt for the first 3 MW and $0.35/watt for the last 1 MW (no other incentives are tiered)

[5] In the past, utilities offered incentives towards CHP and FC ranging from $0 to $1,000,000; although no utility incentives are currently available, should they become available at a later time NJCEP incentives will subsidize utility incentives to bring the combined incentive up to the $/Watt amount shown in the table above, to the maximum caps listed, so a consistent incentive is paid

[6] Any facility successfully participating in Pay for Performance prior to applying for CHP or Fuel Cell incentives will be eligible for an additional $0.25 per Watt from the NJCEP, not to exceed $250,000; this amount is in addition to the “$ cap per project” listed above (the “% of project cost” caps listed above will be maintained)

[7] The maximum incentive will be limited to 30% of total project; this cap will be increased to 40% where a cooling application is used or included with the CHP system (e.g. absorption chiller)

health and productivity of the buildings' occupants. Of course, most of those measures will be eligible for additional incentives available through the NJ SmartStart Buildings program. Applicants may receive support from *New Jersey's Clean Energy Program* representatives to help them take advantage of incentives on equipment upgrades performed after the audit. To ensure the opportunity for participation by many public school districts throughout the state, this program is subject to an incentive cap of $100,000 per fiscal year, per agency.

List of Equipment Incentives from the NJ SmartStart Buildings Program

Electric Chillers

- Water-cooled chillers ($12 - $170 per ton)
- Air-cooled chillers ($8 - $52 per ton)

Gas Cooling

- Gas absorption chillers ($185-$450 per ton)
- Gas Engine-Driven Chillers (Calculated through custom measure path)

Desiccant Systems

- $1.00 per cfm – gas or electric

Electric Unitary HVAC

- Unitary AC and split systems ($73 - $92 per ton)
- Air-to-air heat pumps ($73 - $92 per ton)
- Water-source heat pumps ($81 per ton)
- Packaged terminal AC & HP ($65 per ton)
- Central DX AC Systems ($40 - $72 per ton)
- Dual Enthalpy Economizer Controls ($250)
- Occupancy Controlled Thermostats ($75 each)
- A/C Economizing Controls ($85 - $170 each)

Ground Source Heat Pumps

- Closed Loop ($450-750 per ton)

Gas Heating

- Gas-fired boilers < 300 MBH ($300 per unit)
- Gas-fired boilers $\geq$ 300 MBH - 1500 MBH ($1.75 per MBH)
- Gas-fired boilers $\geq$ 1500 MBH - $\leq$ 4000 MBH ($1.00 per MBH)
- Gas-fired boilers > 4000 MBH (Calculated through Custom Measure Path)
- Gas furnaces ($300-$400 per unit)
- Gas infrared heaters - indoor only ($300 - $500 per unit)
- Boiler economizing controls ($1,200 - $2,700 per unit)

Variable Frequency Drives

- Variable air volume ($65 - $155 per hp)
- Chilled-water pumps ($60 per hp)
- Compressors ($5,250 to $12,500 per drive)

Natural Gas Water Heating

- Gas water heaters $\leq$ 50 gallons ($50 per unit)
- Gas-fired water heaters > 50 gallons ($1.00 - $2.00 per MBH)
- Tankless water heaters replacing a free standing water heater > 82% energy factor ($300 per heater)
- Gas-fired booster water heaters ($17 - $35 per MBH)

Premium Motors

- Three-phase motors ($45 - $700 per motor) – the incentive was discontinued effective March 1, 2013 except for buildings impacted by Hurricane Sandy; approved applications will have the standard timeframe of one year from the program commitment date to complete the installation

Refrigerator/Freezer Case Premium Efficiency Motors

- Fractional (< 1 HP) electronic commutated motors ($40 each for replacement of existing shaded-pole motor in refrigerated/freezer cases)

Prescriptive Lighting

- New Linear Fluorescent
  - T-12, high intensity discharge and Incandescent to T-5 and T-8 ($25 - $200 per fixture) – note: T12 replacements are only available for buildings impacted by Hurricane Sandy
- New Induction ($70 per replaced HID fixture)
- New LED
  - Screw-in/Plug-in ($10 - $20 per lamp)
  - Refrigerator/Freezer Case ($30 - $65 per fixture)
  - Outdoor pole/arm/wall-mounted luminaires ($100 - $175 per fixture)
  - Display case ($30 per case)
  - Shelf-mounted display and task ($15 per linear foot)
  - Wall-wash, desk, recessed ($20 - $35 per fixture)
  - Parking garage luminaires ($100 per fixture)
  - Track or Mono-Point directional ($50 per fixture)
  - Stairwell and Passageway luminaires ($40 per fixture)
  - High-Bay, Low-Bay ($150 per fixture)
  - Bollard ($50 per fixture)
  - luminaires for Ambient Lighting of Interior Commercial Spaces - Linear panels ($50 per fixture)
  - Fuel pump canopy ($100 per fixture)
  - LED retrofit kits (custom measures)
- New Pulse-Start Metal Hallide ($25 per fixture)
- Linear Fluorescent Retrofit ($10 - $20 per fixture)
- Induction Retrofit ($50 per retrofitted high intensity discharge fixture)
- New construction / complete renovation (performance-based)

Note that incentives for T-12 to T-5 and T-8 lamps with electronic ballast in existing facilities ($10 per fixture, 1-4 lamps) and T-5/T-8 high bay fixtures ($16 - $200 per fixture) were discontinued effective March 1, 2013 for T-12 retrofits and replacements except for buildings impacted by Hurricane Sandy. Approved applications will have the standard timeframe of one year from the program commitment date to complete the installation.

Lighting Controls

- Occupancy Sensors
  - Wall mounted ($20 per control)
  - Remote mounted ($35 per control)
  - Daylight dimmers ($25 per fixture controlled, $50 per fixture for office applications only)
  - Occupancy controlled hi-low fluorescent controls ($25 per fixture controlled)
- High intensity discharge or Fluorescent Hi-Bay Controls
  - Occupancy hi-low ($35 per fixture controlled)
  - Daylight dimming ($45 per fixture controlled)

Refrigeration

- Covers and Doors
  - Energy-Efficient doors for open refrigerated doors/covers ($100 per door)
  - Aluminum Night Curtains for open refrigerated cases ($3.50 per linear foot)
- Controls
  - Door Heater Control ($50 per control)
  - Electric Defrost Control ($50 per control)
  - Evaporator Fan Control ($75 per control)
  - Novelty Cooler Shutoff ($50 per control)

Energy Savings Improvement Program

A new state law allows government agencies to make energy related improvements to their facilities and pay for the costs using the value of energy savings that result from the improvements (Hoboken is already doing these). Under Chapter 4 of the law, the "Energy Savings Improvement Program" (ESIP), provides all government agencies in New Jersey with a flexible tool to improve and reduce energy usage with minimal expenditure of new financial resources. This Local Finance Notice outlines how local governments can develop and implement an ESIP for their facilities. All RFPs must be submitted to the Board for approval at ESIP@bpu.state.nj.us. The Board also adopted protocols to measure energy savings:

The ESIP approach may not be appropriate for all energy conservation and energy efficiency improvements. Local units should carefully consider all alternatives to develop an approach that best meets their needs. Local units considering an ESIP should carefully review the Local Finance Notice, the law, and consult with qualified professionals to determine how they should approach the task. The NJ Board of Public Utilities sponsored Sustainable Jersey in the creation of an ESIP Guidebook that explains how to implement the program. The guidebook also includes case studies of successful projects and a list of helpful resources.

Appendix I

Heat Load and CHP Analysis

CHP Analysis Approach

Hoboken City Hall (Figure I.1) is one of the 55 buildings identified as a critical load in the city and is classified under the highest priority, Tier-C load. This analysis provides an example for the other CHP system analyses presented later. Table I.1 identifies the electric and heat load for Hoboken City Hall.

Figure I.1: Hoboken City Hall

Table I.1: City Hall electric and heat load

Month	Load (MWh)	Demand (kW)	Heat Demand (mmBTU)
June	47	134	430
July	37	143	150
August	37	136	90
September	38	130	30
October	36	103	20
November	25	98	100
December	44	82	100
January	25	82	860
February	26	81	840
March	24	92	120
April	21	77	440
May	19	63	120
TOTAL	379		3300

In this analysis, a combined heat and power system is sized to meet the average of the peak electric load, 102 kW. A natural gas reciprocating engine CHP system will be used to provide the distributed generation in this situation. One 100 kW unit will be used to provide power and heating for City Hall during normal and emergency operational hours. While 100kW is not sufficient to cover the entirety of the building's peak load, it will offset load as an on-site generation resource during normal operations with any excess covered by the local utility. It will be sufficient, assuming the use of demand response to shed non-critical load, to provide power and heat output during an emergency situation. The unit is not sized based on peak load to avoid unnecessary over-sizing and capital costs. Additionally, it is sized on electric load, and not heat load, due to the lack of instantaneous demand data for natural gas.

Per the system's specifications, the reciprocating engine unit requires the following for operation:

- System Heat Rate: 9,866 BTU/kWh[1]
- Yearly gas consumption per unit: 7,800 MMBTU/year at 90% availability

[1] See: US Environmental Protection Agency Combined Heat and Power Partnership, Dec 2008; C&I CHP Technology Cost and Performance Data Analysis for Energy Information Administration, June 2010; and CHP Policy Analysis and 2011-2030 Market Assessment Report, Feb 2012 (for California Energy Commission)

Table I.2: CHP capital cost for Hoboken City Hall

System size	100kW
System cost	$2,200/kW
Incentive[1]	$2.25/W
Cost without incentive	$221,000
Incentive value	$88,000
Total system cost	$132,600

[1]Capped at 40% of total cost or $2 million

The following CHP system can provide electricity output sufficient to cover the majority of Hoboken City Hall's yearly electricity demands and heat output sufficient to cover all of the natural gas demand. Any remaining demand can be covered through utility purchases.

- Electricity output per unit: 100 kW
- Heat output per unit: 0.61 MMBtu/hr (high grade 250^{o}F heat)
- Total heat output over 1 year: 4,800 MMBtu/hr (90% availability).

With respect to system economics, a reciprocating engine CHP system is an expensive technology relative to a standby generation system, but can provide significant value when used as a heat resource coupled with available state incentives. Table I.2 identify capital costs with incentives, yearly operating costs for heat and electricity, savings in natural gas and electricity purchases and overall economics.

The total system's capital costs are roughly $220,000 without incentives and $133,000 with incentives. As City Hall does not have a summertime cooling load, there is no central A/C; it is unlikely that the CHP system would meet the state's minimum operational requirement for CHP use and thus not receive the full incentive benefit.

Table I.3: Heat for Hoboken City Hall

Natural gas price (avg. paid)	$9.5/MMBtu
Status quo natural gas use	3,200 MMBtu/yr
Status quo natural gas cost	$33,000/yr
CHP heat output (max)	4,800 MMBtu/yr
CHP natural gas savings	$33,000/yr

Table I.4: CHP electricity output for Hoboken City Hall

CHP unit output	100 kW
Electricity cost (avg. paid)	$0.175/kWh
CHP electricity savings	$70,500/yr

As is show Tables I.3 to I.5 (especially Table I.5), whether or not incentives are considered, there is a strong economic justification for the investment in a CHP system for Hoboken City Hall with at least an 8% internal rate of return (IRR) over 10 years, and a stronger IRR over further years. If approached through a third-party broker who couples investment tax credits and accelerated depreciation benefits from the federal government, the justification for CHP at City Hall would be that much stronger.

This system would provide heat and electricity to meet most requirements during normal operations and sufficient electricity and heat to operate the building in emergency events. In addition, it could be connected to the microgrid solutions proposed elsewhere in the report to provide electricity to other buildings during emergency operations.

Table I.5: CHP overall economics for Hoboken City Hall

Heat natural gas savings	$33,000/yr
Electricity savings	$70,500/yr
CHP natural gas use	7,800 MMBtu/yr
CHP natural gas cost	$74,000/yr
Yearly net savings	$21,719/yr
20 yr. IRR with incentive	15%
20 yr. NPV with incentive	$132,000
20 yr. IRR no incentive	8%
20 yr. NPV no incentive	$47,000

Table I.6: Additional value provided by an energy storage system for Hoboken City Hall

Energy storage type	4 hr Li-ion
Energy storage cost	$2,400
Energy storage capacity	42.7 kW
Total cost	$102,480
Resulting yr. savings	$5,000
Yearly net savings	$27,000
20 yr. IRR with incentive	10%
20 yr. NPV	$92,900
20 yr. IRR without incentive	5%
20 yr. NPV	$8,693

The addition of an energy storage system to the CHP system would provide for benefits beyond what the CHP system provides. An energy storage resource could bridge critical loads between normal and emergency operations by providing energy if there is a delay in the energy served from the grid or the CHP system. It would also provide balancing services to avoid cycling the CHP system in normal and emergency operations. This would lead to reduced fuel costs, O&M costs and emissions. Unfortunately, these benefits are difficult to quantify without detailed electricity and heat demand data and even then are speculative. Directly quantifiable benefits include reduced energy and demand costs by use the storage system to bridge the gap between the peak demand for city hall and the CHP unit's capabilities. The numbers in Table I.6 represent these roughly-quantified benefits and the value and costs of a 4-hr lithium-ion system. Due to the uncertain assumptions required for this analysis, there will be no recommended CHP systems with energy storage.

CHP Analysis for All Buildings

Table I.7: Hoboken CHP analysis (all buildings)

Location	CHP Size (kW)	Peak Electric Load (kW)	20 year NPV at 5% Cost-of-Capital ($2013)	Internal Rate of Return w/o incentives (%)
City Hall	100	143	$47,307	8%
Public Works Garage	37	56	$175,643	26%
Volunteer Ambulance Corps	13	17	$(12,418)	-1%
Fire Department HQ	27	36	$(50,158)	-12%
Fire Engine Co 4	16	22	$(46,857)	N/A
Fire Engine Co 3	12	21	$33,582	18%
Fire Engine Co 1	15	20	$(67,352)	N/A
Multi Service Center	94	142	$(251,706)	N/A
Police HQ	81	110	$(100,321)	-4%

"N/A" appears for any analysis with a uniformly negative cash flow for over all 20 years

Table I.8: CHP on all buildings

Location	CHP Size (kW)	Peak Electric Load (kW)	Total Installed Cost ($2013)	Electric Consumption (kWh/yr)	Heat Consumption (boiler) (mmBTU/yr)	CHP Heat Output (mmBTU/yr)	NPV of Savings ($2013)
City Hall	100	143	$221,000	379,186	3,291	4,809	$270,672
Public Works Garage	37	56	$81,024	282,430	20,079	1,763	$265,450
Volunteer Ambulance Corps	13	17	$29,642	74,529	2,739	645	$16,603
Fire Department HQ	27	36	$59,992	123,739	6,651	1,306	$7,327
Fire Engine Co 4	16	22	$34,448	85,685	5,529	750	$(14,751)
Fire Engine Co 3	12	21	$26,962	71,640	5,538	587	$62,223
Fire Engine Co 1	15	20	$33,316	46,054	8,448	725	$(37,404)
Multi Service Center	94	142	$208,624	444,120	6,656	4,540	$(55,668)
Police HQ	81	110	$178,237	384,315	10,608	3,879	$72,900

CHP Recommendations

The suggested CHP installations are presented in Table I.9. Suggested CHP installations are based on an IRR after 20 years of 5% or greater and a positive NPV. The locations were selected, and are suggested, based on available data for city buildings. Data is in the form of monthly electricity and monthly peak (over a 30 minute horizon) and monthly natural gas consumption. CHP was sized based on average peak electrical demand as detailed heat demand data was not available. The locations are economically justifiable for installing CHP without state incentives. Currently, state incentives would not be available as full operation of these units (heat and electricity) would not go beyond the currently required 8,000 hours of service. There is a proposal under consideration in the state legislature to modify this to 5,000 hours for resiliency purposes. However, considering that most of these buildings are rather old, they do not use centralized air conditioning. Based on the data and a rough estimate, it does not appear this 5,000 hour threshold would be met to qualify for incentives. CHP provides for a reduction in electricity and gas costs, overall energy use and greenhouse gas emissions, while also able to provide emergency power for critical loads.

Table I.9: Recommended CHP installation sites and sizing

Location	CHP Size (kW)	Peak Electric Load (kW)	Net Savings ($2013)	Int. Rate of Return (w/o incentives) (%)	20-yr NPV at 5% Cost of Capital (w/o incentives) ($2013)	Total installed cost ($2013)
City Hall	100	143	$21,700	8%	$47,300	$221,000
Public Works Garage	37	56	$21,300	26%	$175,600	$81,000
Fire Engine Co 3	12	21	$5,000	18%	$ 33,600	$27,000

Appendix J

PV Analysis

- The selected PV solutions are presented in Table J.1. Solutions with added energy storage (which provide enhanced flexibility for additional cost) are in Table J.2.
- The available roof space for PV installations was calculated using overhead measurement through Google Earth. The corresponding PV capacity was calculated from this measurement and similar installations in the region as presented in the NYC Solar Map initiative.[1] Although these are estimates, they do provide a basis for further analysis of PV at these locations.
- Those locations marked with an asterisk are from detailed audits contracted by the City of Hoboken.[2]
- Reduction in electricity costs, overall energy use and greenhouse gas emissions in normal operations with emergency power to provide critical loads when the electric grid is not available.

[1] See http://nycsolarmap.com/

[2] Concord Engineering Group, 2007, for The City of Hoboken

Table J.1: Recommended PV-only installations for Hoboken

Service	Rooftop Available (sq meters)	Usable PV Output	System Cost	Energy Value (PV Only)	SREC Value
Hoboken High School	7780	550.0	$2,635,000	$156,600	$94,900
University Medical Center	5110	360.0	$1,724,000	$102,500	$62,100
Grocery - Kings	4247	300.0	$1,437,000	$ 85,400	$51,700
Garage B	3389	240.0	$1,150,000	$68,400	$41,400
Wallace School (shelter)	3039	210.0	$1,006,000	$59,800	$36,200
Grocery - Kings	2639	180.0	$862,000	$51,300	$31,000
Hoboken Housing Authority	2382	170.0	$814,000	$48,400	$29,300
Grocery - A&P	2166	150.0	$719,000	$42,700	$25,900
Hoboken Multi-Service Center	1459	141.0	$675,000	$40,200	$24,300
Hoboken Public Works Garage	1841	130.0	$623,000	$37,000	$22,400
YMCA (SROs)	1096	78.0	$374,000	$22,200	$13,500
Marion Towers	990	71.0	$340,000	$20,200	$12,200
St. Peter and Paul Church	954	68.0	$326,000	$19,400	$11,700
Columbian Arms	820	58.0	$278,000	$16,500	$10,000
Columbian Towers	623	44.0	$211,000	$12,500	$7,600
Hoboken City Hall	782	29.4	$141,000	$8,400	$5,100
St. Matthew's Church (shelter)	382	27.0	$129,000	$7,700	$4,700
Hoboken Homeless Shelter	279	20.0	$96,000	$5,700	$3,400
Volunteer Ambulance Corps.	172	12.0	$57,000	$3,400	$2,100
Gas Station - Sunoco	165	11.0	$53,000	$3,100	$1,900
Police HQ	491	11.5	$55,000	$3,300	$2,000
Fire HQ	188	10.0	$48,000	$2,800	$1,700
Fire Engine Co 2	222	6.0	$29,000	$1,700	$1,000
Fire Engine Co 3	147	5.0	$24,000	$1,400	$900
Fire Engine Co 6	158	4.0	$19,000	$1,100	$700

Table J.2: All PV analysis sites for Hoboken, including storage

Building	Rooftop Available (sq meters)	Audit-Based PV Output (kW)	Calculated PV Output (kW)	Usable PV Output (kW)	System Cost ($2013)	Storage System System (kWh)	Storage Value Cost ($2013)	Energy Value (PV Only) ($2013)	SREC Value ($2013)	Total Yearly Value (PV Only)	Simple Payback (yearly savings/ sale only)	IRR
Hoboken High School	7780		559.7	559.7	2,680,766	279.8	671,591	159,391	96,520	255,911	16.8	2.66%
University Medical Center	5110		367.6	367.6	1,760,760	183.8	441,109	104,690	63,396	168,085	16.8	2.66%
Grocery - Kings	4247		305.5	305.5	1,463,395	152.8	366,612	87,009	52,689	139,698	16.8	2.66%
Garage B	3389		243.8	243.8	1,167,753	121.9	292,548	69,431	42,045	111,476	16.8	2.66%
Wallace School (shelter)	3039		218.6	218.6	1,047,153	109.3	262,335	62,261	37,702	99,963	16.8	2.66%
Grocery - Kings	2639		189.8	189.8	909,324	94.9	227,806	54,066	32,740	86,806	16.8	2.66%
Hoboken Housing Authority	2382		171.4	171.4	820,769	85.7	205,621	48,801	29,552	78,352	16.8	2.66%
Grocery - A&P	2166		155.8	155.8	746,342	77.9	186,975	44,375	26,872	71,247	16.8	2.66%
Hoboken Multi-Service Center	1459	141	105.0	141.0	675,390	70.5	169,200	40,157	24,317	64,474	16.8	2.66%
Hoboken Public Works Garage	1841		132.4	132.4	634,356	66.2	158,920	37,717	22,840	60,557	16.8	2.66%
YMCA (SROs)	1096		78.8	78.8	377,650	39.4	94,610	22,454	13,597	36,051	16.8	2.66%
Marion Towers	990		71.2	71.2	341,126	35.6	85,459	20,282	12,282	32,564	16.8	2.66%
St. Peter and Paul Church	954		68.6	68.6	328,721	34.3	82,352	19,545	11,836	31,380	16.8	2.66%
Columbian Arms	820		59.0	59.0	282,549	29.5	70,785	16,800	10,173	26,973	16.8	2.66%
Columbian Towers	623		44.8	44.8	214,668	22.4	53,779	12,764	7,729	20,493	16.8	2.66%
Hoboken City Hall	782	29.44	56.3	29.4	141,018	14.7	35,328	8,384	5,077	13,462	16.8	2.66%
St. Matthew's Church (shelter)	382		27.5	27.5	131,626	13.7	32,975	7,826	4,739	12,565	16.8	2.66%
Hoboken Homeless Shelter	279		20.1	20.1	96,135	10.0	24,084	5,716	3,461	9,177	16.8	2.66%
Volunteer Ambulance Corps	172		12.4	12.4	59,266	6.2	14,848	3,524	2,134	5,658	16.8	2.66%
Gas Station - Sunoco	165		11.9	11.9	56,854	5.9	14,243	3,380	2,047	5,427	16.8	2.66%
Police HQ	491	11.5	35.3	11.5	55,085	5.8	13,800	3,275	1,983	5,259	16.8	2.66%
Fire HQ	188	10	13.5	10.0	47,900	5.0	12,000	2,848	1,725	4,573	16.8	2.66%
Fire Engine Co 2	222	6	16.0	6.0	28,740	3.0	7,200	1,709	1,035	2,744	16.8	2.66%
Fire Engine Co 3	147	5	10.6	5.0	23,950	2.5	6,000	1,424	862	2,286	16.8	2.66%
Fire Engine Co 6	158	4	11.4	4.0	19,160	2.0	4,800	1,139	690	1,829	16.8	2.66%

Appendix K

Energy Storage

To accomplish resiliency, an electrical grid has to be capable of surviving failures of any of the generation sources and without affecting the load or affecting the reliability of the microgrid. Energy storage (ES) can be used to accomplish this, as a ride through to allow time between the failure of a generation source and the starting of another. This would alleviate problems associated with power glitches to sensitive loads. Other applications of ES include firming renewables, time shifting of energy to when it is needed, and increasing the efficiency of any fossil fueled generation serving the microgrid. For this study, each application of the energy storage system investigated was from the standpoint of increasing reliability such as an insurance policy might do where pay-back is not of importance. However, electrical savings were calculated for the times that energy storage system is operating in normal operation providing other services.

Uses for Energy Storage

Energy storage comes in many forms such as electrochemical batteries, flywheels, compressed air (CAES), pumped hydro, etc. Each technology has it pros and cons and performs better for different applications. For the Hoboken ESDM, energy storage was investigated for the following applications using either the lithium ion or lead acid ES technologies:

- Uninterruptible power supply (UPS)
- Photovoltaic energy shifting
- Peak demand response
- Time of use

Lithium ion and lead acid technologies were chosen based on their track records of reliability, cost effectiveness and system physical dimensions. Hoboken is very dense and available real estate to install energy storage systems is small, so energy storage systems such as CAES, pumped hydro and flywheels were not considered.

UPS

An uninterruptible power supply is a device that is used to power electronic equipment during a power disruption for a set amount of time which is typically 15 minutes or until an alternate energy source is provided. A UPS is shown in Figure K.1.

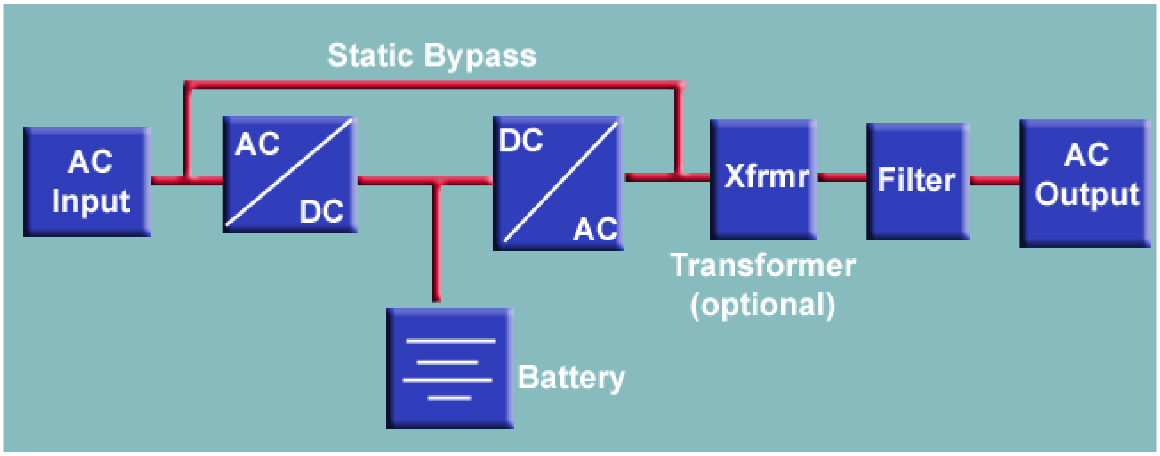


Figure K.1: Uninterruptible power supply block diagram

The incoming AC voltage is converted to a DC voltage on a bus and then inverted back to an AC voltage supplying the load. A DC source is attached to the DC bus. When the AC voltage is disrupted, the DC source supplies a DC voltage to the bus which is inverted to AC. In this operation, the load never experiences a power disruption. The DC source is a finite source which it is sized based on the kW load and the expected duration of the outages resulting in a rating of energy storage kW/kWh.

Hoboken critical loads that need 24/7 power are assumed to have these UPS devices attached to them. Additional UPS systems were not considered since it was determined by the stakeholders that other critical loads could experience a short power outage and maintain functionality.

Photovoltaic Energy Shifting

Photovoltiac (PV) energy systems are a variable source and therefore not a reliable resource to be part of a microgrid generation fleet. The greatest benefit that the PV provides a microgrid is that it is a renewable power producer, saving fuel which equates to monetary savings and prolonged operation. The prolonged operation of a microgrid by using a renewable source will not be seen in the Hoboken microgrid since the fuel supply for the generation sources are deemed to be infinite using natural gas. Policies for the price of natural gas during a state of emergency has not been developed so monetary savings cannot be accurately calculated.

Typically if a PV system is installed in a microgrid, the system is sized to be 30% or below the microgrid average load. This is due to the fact that if the PV system has a cloud cover and the power is dramatically reduced, the other generation sources providing power at that moment have enough capacity and inertia to supply the supplemental power without losing electrical stability. PV systems that were sized for the Hoboken ESDM were based on available roof space and not the electrical load of the building to maximize the return on investment. To avoid going above the 30% penetration level when the Hoboken ESDM is functioning, the inverters will need to limit the current on the PV system. One way to mitigate the problems with PV variability and maximize the use of the PV output is to use energy storage in conjunction with the PV.

To calculate the payback that can be realized with adding energy storage to the PV systems, the energy storage system will have to be functioning during the normal operation of the Hoboken electrical system. When the PV is producing power above the critical building load demand, the excess energy can be stored in an electrochemical energy storage system to be used during the times that the PV is not producing power. Figure K.2 shows how the energy storage can be used to shift energy during normal operation. When the PV is greater than the building load, the excess energy produced is used to charge an energy storage system. As the day continues and the PV system is no longer producing enough power to match the load, the energy storage system is used to provide the power. Enough power is put into the energy storage system from the PV system that at the beginning of the day, the left over energy from the energy storage system satisfies the load for a few hours.

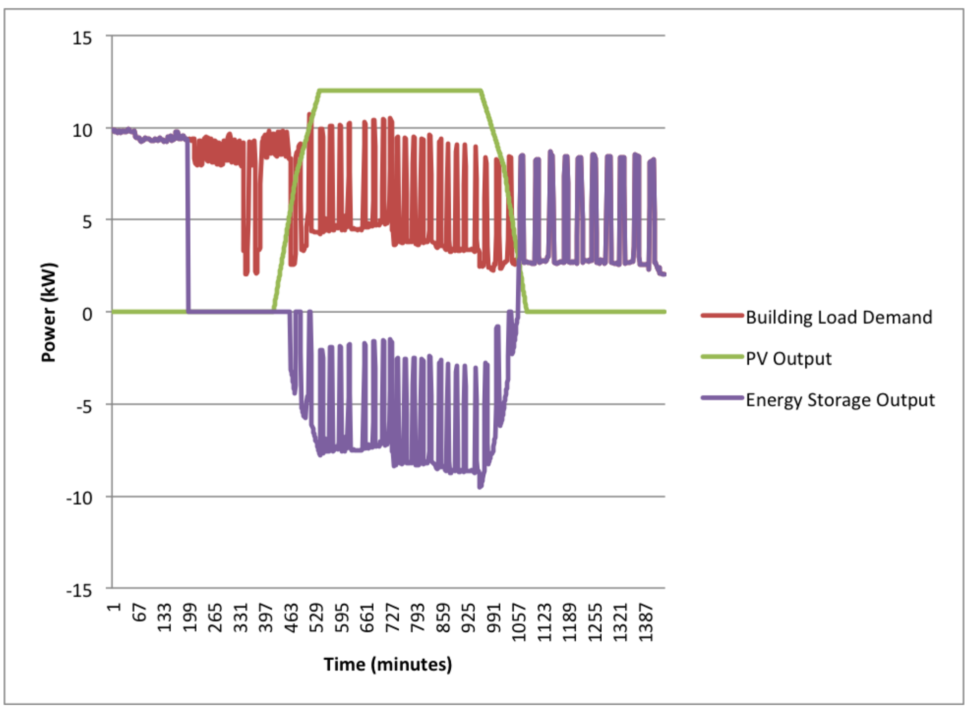


Figure K.2: Photovoltaic energy shifting example

Along with the energy shifting, energy storage can also charge during the off peak hours and discharge when the peak of the system occurs reducing the peak demand charge for the building load. The cost for adding the energy storage system to 9 of the PV systems planned to be installed is shown in Table K.1. Meter billing data for only 9 buildings were given to Sandia so only these buildings were evaluated for adding energy storage to PV. The PV size is based on available roof space for that building and the cost used for installed PV is $4.79/W-dc. Installed cost for PV comes from a recently installed system at 801 2nd Avenue in New York. From the NREL website, PV produces for an average of about 4.5 hours a day at 5 kWh/m2/day which is used for determining the PV value[1]. PV value is the offset of the building electrical demand by the PV system using the average electric rate for Hoboken of $17.34/kWh. Solar Renewable Energy Credit (SREC) is the rate at which the MWh produced by the PV system can be sold back to the utility which is $105/MWh. This number comes from a 10 year trend of the SREC market[2]. Energy storage system is sized to reduce the peak demand load by 50% using a 4 hour lithium ion at a cost of $2,400/kW installed and a round trip efficiency of 80% (ESA, 2014). It is assumed that the peak demand load will last between the hours of 0700 – 0800 and 2100 – 2200 which the energy storage will be able to discharge and charge during the other hours during non-peak load hours. It is assumed that during the non-peak hours, the load will be small enough that when the energy storage is charging, the peak load demand never goes above half the original peak load demand. ESS value is the peak demand load savings for each building and the ESS Cost is the cost to charge the energy storage system after it has been used to reduce the peak demand load. The last four columns are the payback years for combining systems and revenue streams.

By adding the energy storage system to the PV (sized based on available roof space at an entity), the return on investment is decreased. In most cases where the PV size is smaller than the average peak load of the building, the return on investment for adding the energy storage system increases a little more than 2 fold. When the PV system sizes are larger than the peak demand load, as it is for the Hoboken public works garage and the Multi Service Center, the payback years increase by 10% - 30%. The benefit of adding the energy storage system for these two building would allow them to penetrate the ESDM microgrid for greater than 30% for a few hours which will reduce fuel cost which typically is in the 2% - 4% range for that building. The other benefit of adding the energy storage is that it can firm up the PV system output allowing it to be more of a dispatchable generation source creating a better optimization for the energy management system while in microgrid operation.

[1]Distributed Generation Energy Technology Operations and Maintenance Costs; retrieved December 12, 2013, from http://www.nrel.gov/analysis/tech_cost_om_dg.html

[2]SREC Trade 2014, New Jersey; retrieved December 12, 2013, from SREC Trade: http://www.srectrade.com /srec_markets/new_jersey

Table K.1: PV and energy storage payback

Building	PV Size (kW)	PV Cost	PV Value $/year	SREC Value $/year	Avg. Peak kW	ESS Sys Cost	Peak Cost	ESS Value $/year	ESS Cost $/year	PV Only	PV + SREC	PV + ESS	PV + ESS + SREC
City Hall	25	$120	$8	$5	100	$120	$11	$6	$8	15	10	44	23
Public Works Garage	130	$623	$38	$23	37.5	$45	$5	$3	$3	16	11	18	12
Volunteer Ambulance Corps	10	$48	$3	$2	15	$18	$2	$1	$2	16	10	33	17
Fire Department HQ	10	$48	$3	$2	30	$36	$4	$2	$3	16	10	42	21
Fire Department 801 Clinton	5	$24	$2	$1	15	$18	$2	$1	$2	12	8	42	21
Fire Department 1313 Washington	5	$24	$2	$1	15	$18	$2	$1	$2	12	8	42	21
Fire Department 501 Observer	5	$24	$2	$1	15	$19	$2	$1	$2	12	8	43	22
Multi Service Center	140	$671	$40	$25	100	$120	$9	$5	$8	17	11	22	13
Police HQ	10	$48	$3	$2	100	$120	$10	$5	$8	16	10	0	84

All dollar values are in $k, last 4 columns are in years

Peak Demand Response

As the energy storage was used for the peak demand reduction in the PV system above, the peak demand response evaluated in this section is for the energy storage system only and for any peak demand loads throughout the days. PQube quality meters were installed at the Hoboken High School and the Fire Department Headquarters and 1 week of data was recorded and sent to Sandia for analysis. Since there is only 1 week of data, the following conclusions are very general and will need to be further investigated to accurately determine using energy storage systems for peak demand load response.

The peak demand load response was analyzed for the Fire Department Headquarters and not the Hoboken High School since most of the load for the Hoboken High School was inductive (kVAR) and the peak demand cost is based on real power (kW). Energy storage can be used for the Hoboken high school as a power quality device or voltage regulation. Peak demand load for the 1 week at the Hoboken fire department was 12.35 kW which the energy storage was sized to reduce the peak load to 20% which is 9.88 kW. The 20% reduction was based on a sensitivity analysis performed by reducing the peak demand in steps of 5% and increasing kW rating of the energy storage system from 1kW to 13kW. Analysis for the peak demand reduction is shown in Figure K.3. This graph shows the measured demand load of the fire department headquarters in blue with the energy storage system (ESS) output in red and the new demand load curve in green. Positive values for the energy storage system means that the system is discharging power and negative values are means the system is charging.

The energy storage device was sized to be able to pick up the peak load demand of 2.47kW resulting in a rating of 3kW. Analysis showed that the energy storage would have to have at least 4 kWh worth of energy per day to reduce the peak load demand by 20%. Using the lithium ion $/kW which is rated for 4 hours, the system cost for a 3kW / 4kWh energy storage system was $7,200.00. The winter electricity rate for PSEG was $0.182348/kWh for customers not on the Time of Use (TOU) schedule. Using the 1 week data and scaling it up to 4 weeks and multiplying it by the winter electricity rate along with the $2.46 electrical connection fee and peak demand cost for January of $4.80/kW, the electrical bill total was $715.07. When the energy storage was added to reduce the peak demand, the total electrical bill cost was reduced to $704.67 creating a savings of $10.40 per 4 weeks. If this was the savings realized every four weeks, then a savings of $135.21 per year would be seen.

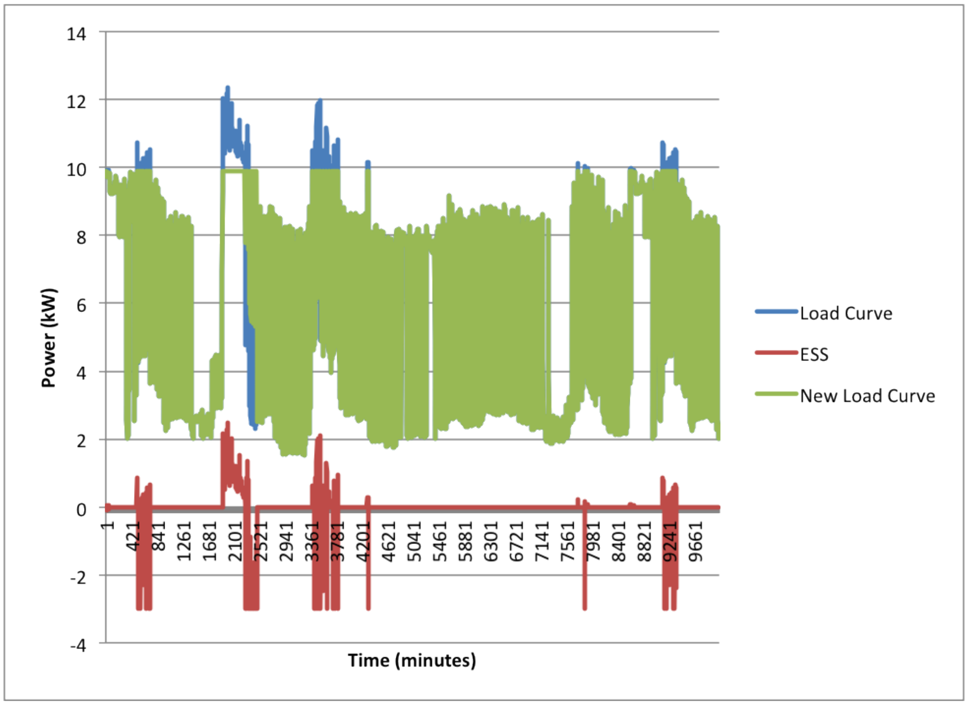


Figure K.3: Energy storage used as peak demand response at Hoboken Fire Department headquarters

Time of Use

Time of Use (TOU) pricing is where the utility varies the price of the electricity rate depending on the time-of-day based on supply and demand. During peak times throughout the days, the cost of electricity is higher which the user can reduce their electrical bills by avoiding using large electrical consumptions at this time. Table K.2 shows the TOU rates PSEG put into place June 2011[3].

Table K.2: PSEG time of use rates effective June 1, 2011

		RLM (Time of Use)		RS (Not Time of Use)	
		Winter	Summer	Winter	Summer
Monthly Service Charge (including SUT)		14.19	14.19	2.46	2.46
Charges per kWh (including SUT)	Off-Peak	0.115864	0.118379		
	On-Peak	0.215341	0.244306		
	0-600 kWh			0.182348	0.173816
	over 600 kWh			0.182348	0.187554

[3]PSEG'S Residential Electric Rates; retrieved December 12, 2013, from PSEG: http://www.pseg.com/info /environment/ev/rlm-rs_rates.jsp

The on-peak times for the RLM rate are during 0700 – 0800 and 2100 – 2200. The winter electricity rate from Table K.2 was used for customers on the Time of Use (TOU) schedule. Using the 1 week data and scaling it up to 4 weeks and multiplying it by the TOU rate along with the $14.19 electrical connection fee, the electrical bill total was $546.97. Just by the Fire Department Headquarters using a TOU rate schedule, a savings of $168.09 was realized. If this was the trend for all the months, a yearly electrical savings of $2,185.21 could be seen.

Energy storage was used to reduce the load demand during this peak times to 0kW which meant that a 12kW /24kWh energy storage system was needed. Using the lithium ion $2400 / kW for 4 hours cost, the system cost was $172,800.00. Figure K.4 shows the output of the energy storage system when used during only the peak hours.

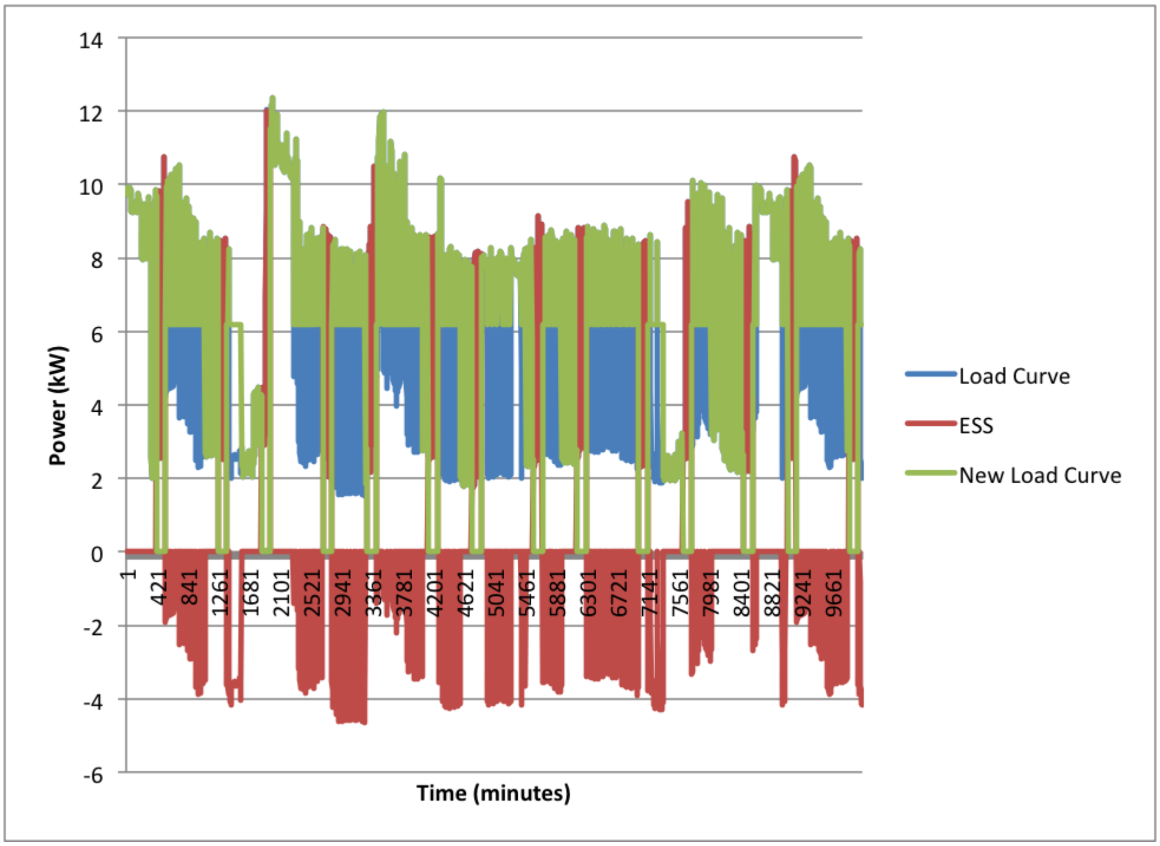


Figure K.4: Energy storage used for TOU at Hoboken Fire Department headquarters

When the energy storage was added to reduce the load during peak times, the total electrical bill cost was reduced to $501.79 creating a savings of $45.19. If this was the savings that would be realized every 4 weeks, a savings of $587.45 per year would be seen.

Peak Demand Response and Time of Use

The last analysis performed was allowing the energy storage device to operate for peak demand response and TOU. Figure K.5 shows the output of the energy storage system when operated this way.

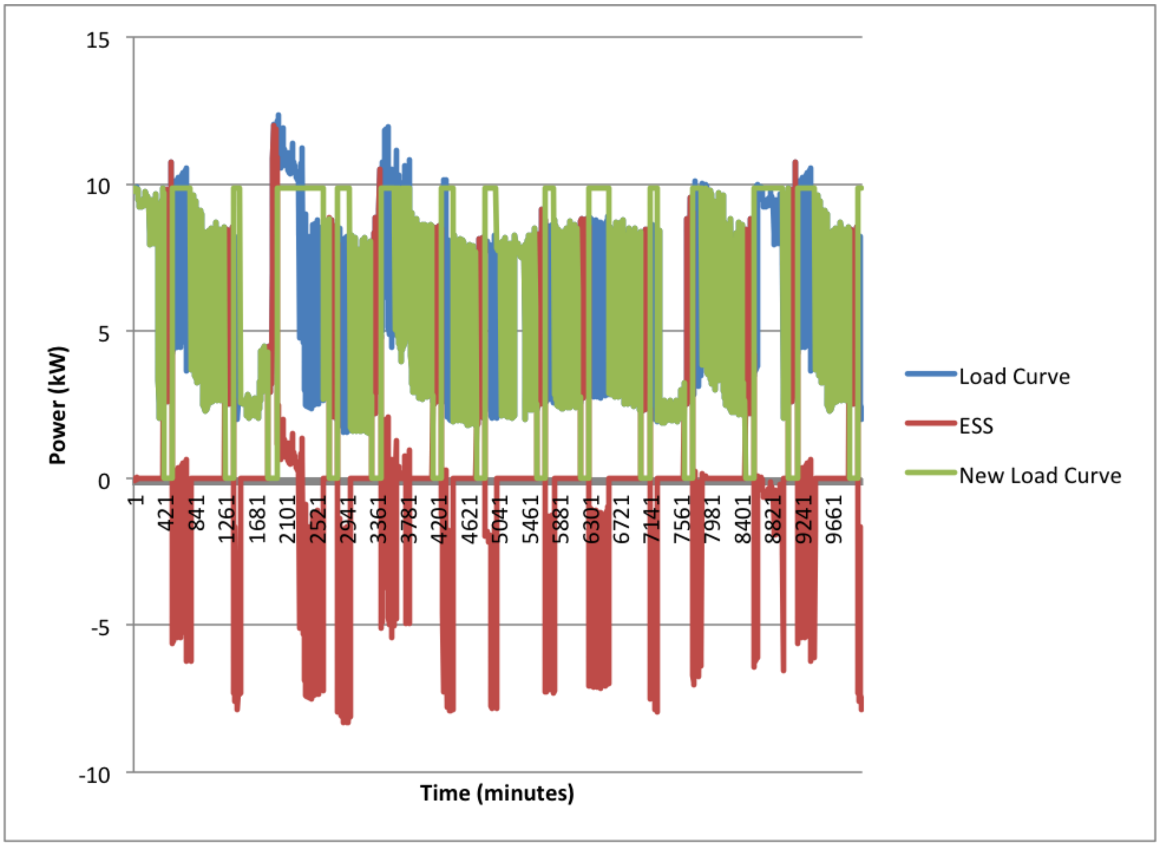


Figure K.5: Energy storage used for TOU and peak demand response at Hoboken Fire Department headquarters

The energy storage system was sized for the TOU application in the previous section which was a 12kW / 24kWh for an installed cost of $172,800.00. The original electrical bill using the TOU rates was $546.97 for the month of January.

When the energy storage was added to reduce the load during peak times and the peak demand, the total electrical bill cost was reduced to $492.20 creating a savings of $54.78. If this was the savings that would be realized every 4 weeks, a savings of $712.08 per year would be seen. By combining the peak demand response and TOU application, the greatest savings were seen.

Energy Storage Summary

Installing an energy storage system is equated as purchasing a standby generator. As the standby generator is not purchased for a revenue stream but as a device that provides insurance which increases the reliability and resiliency, so is the energy storage system. These systems are primarily operated during a utility power outage and can be used during normal operation to reduce electrical bills by providing power during a Time of Use rate schedule and peak demand charge. Energy storage has more capabilities than the standby generator because it can respond faster to a load change, full range of VAR control through four quadrant inverter, store excess renewable energy for load shifting and a lower carbon footprint. As the analysis showed, the best benefit for using the energy storage in an ESDM design was energy shifting for PV systems sized larger than the local load demand and by combining the peak demand response and Time of Use applications.

Appendix L

Base Case (Per-Building Solution) Analysis

Figure L.1 shows a simple diagram of a typical backup generator system deployed at a building. A tap off of a medium voltage feeder supplies building loads through a step-down transformer at rated voltages (120/208V to 277/480V). These loads are facilitated through a network of fused panels, cable, possibly additional transformers to feed all of the electrical facilities in the building. As shown some of these loads are deemed critical so are backed up with temporary UPS battery power as well as a backup generator system. In some cases an entire building can be connected to UPS battery backup power as well as a backup generator rated to supply the entire building load. But more typically, a portion of the loads are deemed critical and are segregated from other building loads through separate panels dedicated to these critical loads. These critical loads are backed up during emergencies with a backup generator system. Some or all of these loads may also be connected to UPS units as well. More typically a more restricted set of critical loads such as computer and communication systems is backed up with UPS units rated for these loads. The UPS is designed to keep these loads from temporarily losing power during an interruption. During an interruption emergency loads will be restored with a backup generator but there will be a slight delay (10-30 seconds) associated with switching and generator startup and synchronization to pick up critical loads. The automatic transfer switch (ATS) upon detection of loss of utility power opens up the incoming power feed from the utility and closes a feed to the backup generator as well as sends a signal for the backup generator to start. The backup generator starts and runs picking up all the critical load it serves until the utility power is restored upon which load is transferred back to the utility and the generator is unloaded and stopped until the next power outage. For diesel engines, backup generators are supplied with a fuel tank which is typically sized to supply power for 1-2 days at full load, but can be sized to supply fuel for longer periods of time. Gas engine backup generators typically do not utilize backup storage, but fuel such as propane can be used as a backup and gasified for use in gas engines if natural gas is unavailable.

Backup generators can be very reliable if maintained properly (around 99%), including periodic startup of the units under load to prevent wet-stacking or lack of complete combustion of diesel fuel. A disadvantage of individual backup generators for buildings is that there is no redundancy against failures without an additional backup generator. Also backup generators are often oversized, so they are not operated efficiently, which increases fuel consumption use and induces wear on engines which lowers their lifespan. One advantage of a microgrid, or any set of connections in which a group of buildings share generation, is that redundancy can be supplied by the shared generation, and the generators can be run more efficiently.

The TMO analysis as presented in the report considers how the collection of UBS and LBS buildings can be supplied by clustering buildings together in an optimum manner so generation is shared across buildings providing redundancy to the system as well as improving efficiency of the generators within the system. For the sake of comparison, the costs associated with a baseline case to meet the DBT in which backup generation is provided to each building in isolation to other buildings is proposed to compare to the TMO option solutions.

Generators are sized for the peak load assumption of 30% of the rated transformer loads for each of the buildings as was done with the TMO analysis for UBS and LBS buildings. Costs for generation, ATS and cabling necessary to meet the estimated loads represented in the UBS and LBS sets of buildings are shown in Table L.1. As shown the peak load estimate for the 34 LBS buildings is 6322.5 kW and for the 55 UBS buildings is 9195 kW. The same load estimates are used to calculate solutions using TMO optimization described below. The total cost to install generators is $11.9M for the LBS buildings and $18.0M for the UBS buildings. With retrofit costs determined in Appendix G, design and engineering costs, and contingency factors (but not recommended CHP) included the LBS costs are calculated as approximately $20.4M, and the UBS costs are calculated as approximately $34.3M. Adding CHP only increases the costs further. The baseline solution is less expensive than the TMO option solutions, but does not provide N-1 redundancy to these buildings so is less reliable than TMO option solutions. The calculated performance metrics are shown in Table L.2.

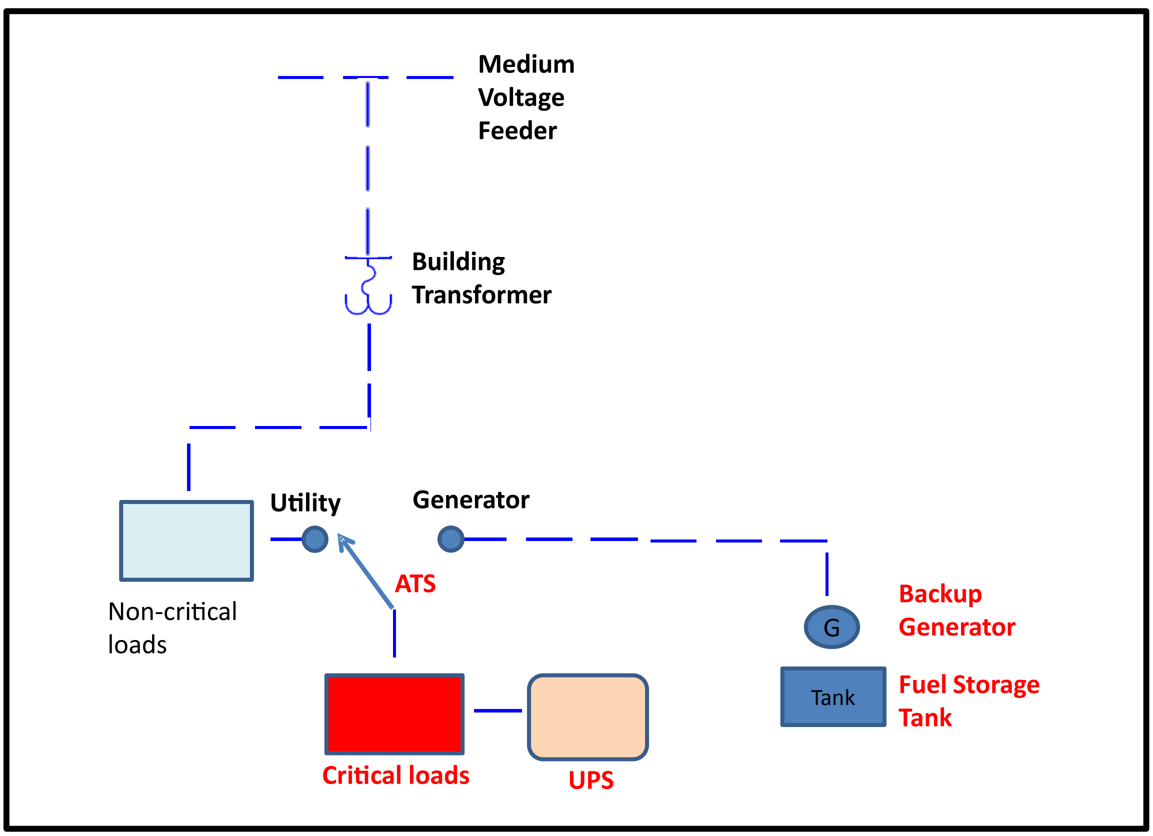


Figure L.1: Baseline cost estimates for standby generators on buildings

Table L.1: Baseline cost estimates for standby generators for all UBS buildings

Building #	UBS or LBS?	Building Name	Transformer Size (kVA)	Estimated Peak Load (kW) (30% loading)	Estimated Total Cost ($K)
53	LBS+UBS	Fire Dept Radio Repeater	50	15	132.5
8	LBS+UBS	5th Street PS	2500	750	1100
16	LBS+UBS	St. Matthew's Church (shelter)	50	15	132.5
17	LBS+UBS	St. Peter and Paul Church	100	30	151.7
26	LBS+UBS	Garage G	500	150	307.8
5	LBS+UBS	Police HQ	500	150	307.8
9	LBS+UBS	11th Street Pump Station	50	15	132.5
52	LBS+UBS	Police Dept Radio Repeater	1500	450	700.4
54	LBS+UBS	CVS	500	150	301.8
12	LBS+UBS	Hoboken City Hall	750	225	407.1
19	LBS+UBS	Grocery - Kings	1500	450	700.4
24	LBS+UBS	Garage B	300	90	229.8
25	LBS+UBS	Garage D	750	225	407.1
55	LBS+UBS	Walgreens	300	90	229.8
1	LBS+UBS	Fire Engine Co 3	500	150	307.8
10	LBS+UBS	H1 Pump Station	750	225	407.1
14	LBS+UBS	Wallace School (shelter)	500	150	293.7
15	LBS+UBS	Hoboken Homeless Shelter	150	45	172.4
20	LBS+UBS	Grocery - Kings	1500	450	700.4
21	LBS+UBS	Gas Station - Sunoco	50	15	132.5
30	LBS+UBS	Columbian Towers	500	150	307.8
51	LBS+UBS	YMCA (SROs)	500	150	307.8
2	LBS+UBS	Fire Engine Co 4	75	22.5	141.5
4	LBS+UBS	Fire Engine Co 1	150	45	172.4
6	LBS+UBS	University Medical Center	1500	450	654.5
7	LBS+UBS	Sewerage Treatment Plant	3000	900	1299.8
11	LBS+UBS	Volunteer Ambulance Corps	50	15	132.5
13	LBS+UBS	Hoboken High School	500	150	307.8
22	LBS+UBS	Hoboken Multi-Service Center	300	90	229.8
27	LBS+UBS	Midtown Garage	500	150	307.8
28	LBS+UBS	Columbian Arms	300	90	229.8
29	LBS+UBS	Marion Towers	750	225	407.1
42	LBS+UBS	Senior Housing Fox Hill	150	45	162
47	UBS	Marineview 1	1500	450	700.4
48	UBS	Marineview 2	1500	450	700.4
49	UBS	Applied Housing	750	225	407.1
23	UBS	Public Works Garage	100	30	149.5

Continued on next page

Table L.1 – *Continued from previous page*

Building #	UBS or LBS?	Building Name	Transformer Size (kVA)	Estimated Peak Load (kW) (30% loading)	Estimated Total Cost ($K)
50	UBS	Applied Housing	150	45	172.4
18	UBS	Grocery - A&P	150	45	172.4
31	UBS	Hoboken Housing Authority	300	90	229.8
32	UBS	Hoboken Housing Authority	150	45	172.4
33	UBS	Hoboken Housing Authority	225	67.5	202.8
34	UBS	Hoboken Housing Authority	300	90	229.8
35	UBS	Hoboken Housing Authority	150	45	172.4
36	UBS	Hoboken Housing Authority	150	45	172.4
37	UBS	Hoboken Housing Authority	300	90	226.4
38	UBS	Hoboken Housing Authority	300	90	229.8
39	UBS	Hoboken Housing Authority	300	90	229.8
40	UBS	Hoboken Housing Authority	1500	450	700.4
41	UBS	Housing Willow Ave	300	90	229.8
43	UBS	Church Towers	300	90	229.8
44	UBS	Church Towers	150	45	172.4
45	UBS	Church Towers	500	150	307.8
46	UBS	Clock Towers	500	150	307.8
		LBS Costs	21075	6322.5	11915.7
		UBS Costs	30650	9195	18031.5

Table L.2: Performance analysis for backup generator baseline analysis

UBS/LBS	FOI (%)	Cond EENS (kWh)	EIR
UBS	42.37	37.72	0.99093
LBS	27.31	25.12	0.99127

Appendix M

Initial Design Options Selection – Generation

The energy surety analysis needs an initial decision space for natural gas generator sizes to choose from to run an optimization. Generator size selections were chosen on a per-cluster basis using a system N-1 contingency metric along with three techniques. The three technique options used were:

- Option 1: Size generators based on the rating of transformers at each building
- Option 2: Size generators based on cost
- Option 3: Size generators based on the predicted building load

The N-1 contingency metric is met if the microgrid load can still be supplied by enough power after any loss of 1 generator in the system without shedding load. The N-1 system analysis is applied to each of the microgrids which includes the buildings in the lower and upper bound lists for that microgrid. To begin performing this analysis, the total real power load has to be calculated for each of the microgrids.

The load is calculated by summing the kVA rating of all the transformers in the microgrid and multiplying it by 30%. This percentage was chosen based off past experience metering building loads and calculations at various microgrid sites with similar loads. Once the load has been calculated it is then divided by 80% which allows a 20% head room for the generators. Head room is needed to allow loads to ramp up and ramp down without exceeding the rating of the generators online. Existing generators in each microgrid is then subtracted from this total which the final number is now the total generation needed for the microgrid.

Having the needed generation per microgrid calculated above, generator sizes are limited by applying one of the three techniques options. The maximum kW rating of a single generator is determined by not allowing the rating of the generator multiplied by 30% to be greater than the calculated load. Wet stacking of a generator starts to occur when the generator is supplying a load at less than 30% of it's rating for a period of time causing damage to the generator and decreasing its reliability and life cycle. Multiple generators can be installed in one location or building which then a maximum kW rating of all the generators has to be met. This is determined by summing up the kW rating of all the generators in that location and subtracting the load at that location and ensuring that it is not greater than the rating of the service entrance transformer. By doing this, oversizing a group of generators does not occur at a single location.

Option 1: Generator Size Based on Transformer Rating

In Tables M.1 and M.2, engineering decisions were used to decide on the quantity and the size of the generators by not oversizing generators to the required load and meeting the criteria in the maximum sizes previously mentioned. The largest transformer in each microgrid is started with and then if there is remaining load needing to be served, the next largest transformer that is closest to the remaining load is sized with a generator. This is performed for each microgrid cluster.

Option 2: Size Generators Based on Cost

In Tables M.1 and M.2, a Matlab model was used to determine the generator sizes for this option. The model takes the criteria of the limitations on the kW ratings of the generators, N-1 system contingency, largest transformer in the microgrid, existing generators and the cost of new natural gas generator sets. There are 24 generator rating sizes the program can choose from with the smallest being a 30kW and the largest being a 2MW. The program will perform all the possible combination of generators that meet the criteria and choose the lowest cost.

Option 3: Size Generators Based on the Predicted Building Load

In Tables M.1 and M.2, generators were sized to the load demands with the 20% generation overhead. Once the load demand and the 20% overhead is covered by the generation available, no other generators are added to avoid over engineering. This option allows for a larger generator fleet that increases the amount of buildings that can supply their local load when isolated from the microgrid.

Note that some buildings are at a distance from the initial microgrid clusters such that they are initially not electrically connected to any other building. To meet the N-1 system contingency criteria, these buildings are assigned two generators rated to meet the load demand and 20% generation overhead. These buildings can also be tied into a nearby microgrid if chosen by later design optimization. In this case, two more generator sizes are included in the decision space. The first generator is rated to be greater than or equal to 30% of the load demand divided by the generator rating. Second generator is the next generator rating smaller than the first generator selected. For both generators selected, the ratings can be no larger than the service entrance transformer.

Also, some buildings in the microgrids are single or split phase which their single phase generator cannot be used to supply power to the microgrids. Isolated buildings from the microgrids are given the generator option space for redundant single phase generators rated for the load demand plus 20% generation overhead. This allows for the building to meet the N-1 system contingency. When the single phase building is tied to a microgrid, the generator option space may contain a single generator rated to the load demand plus 20% generator overhead. In most cases where a single phase building resides, a CHP generator is added which can be utilized during normal operation but will not be connected to the microgrid unless the building is isolated from the microgrid.

The three options are analyzed both for the upper- and lower-bound sets. For the design optimization, set of potential generation options were concatenated into one large set of options for the analysis. Finally, in the "Other Gen" column there are several notations, with the following meanings:

- (S) indicates a single phase CHP unit, which can feed the building load (if islanded) but not the microgrid
- (C) indicates a three phase CHP unit, which can feed the building load (if islanded) and also the microgrid
- (E) indicates a three phase existing backup unit, which can feed the building load (if islanded) but not the microgrid

Table M.1: Generator decision table for the UBS

Cluster	Bldg #	Name	Est Peak Load	Other Gen	Option 1	Option 2	Option 3
1	20	King Grocers	562.5		800, 800	400	400, 600
	51	YMCA	187.5			400	200
	1	Fire Co 3	187.5	(S) 15		400	175
	9	Pump	18.8	(E) 200			
	Totals		956.3		1600	1200	1375
2	42	Senior Housing	56.3		150		60
	13	High School	187.5		500	250, 25	200, 200
	11	Ambulance	18.8	(S) 25			
	2	Fire Co 4	28.1	(S) 15			30t
	41	HOA	112.5		275	175	150
	Totals		403.1		925	450	640
3	3	Fire HQ	46.9	(S) 37.5			30t
	22	Multiservice	112.5	(C) 100		250	100
	29	Marion Towers	281.3		350, 350	250, 100	300, 300
	Totals		440.6		700	600	730
4	8	Pump	937.5	(E) 335		350, 350	600, 500
	17	Peter and Paul	37.5		30		50
	47	Marineview 1	562.5		1500	350, 275	600
	26	Garage G	187.5			350	200
	48	Marineview 2	562.5		1000	300, 300	600
	19	King Grocers	562.5		1500	300, 300	600
	Totals		2850.0		4030	2875	3150
5	53	Fire Radio	18.8				30t
	16	Matthew Church	18.8		30, 30	50	75
	Totals		37.5		60	50	105
6	4	Fire Co 1	56.3	(S) 15	50, 50	150	125
	Totals		56.3		100	150	125
7	25	Garage D	281.3			400	300
	24	Garage B	112.5				125, 125
	5	Police HQ	187.5	(C) 100			100, 100
	52	Police Repeater	562.5		1500, 1500	400	600
	55	Walgreens	112.5				125
	12	City Hall	281.3	(C) 100			200
	49	Applied Housing	281.3			750	300
	54	CVS	187.5			400	200
	30	Columbian Towers	187.5			400	200
	10	Pump	281.3	(E) 750			
	23	Public Garage	37.5	(C) 37.5	75		40
	Totals		2512.5		3075	2350	2415

Continued on next page

Table M.1 – *Continued from previous page*

Cluster	Bldg #	Name	Est Peak Load	Other Gen	Option 1	Option 2	Option 3
8	21	Sunoco	18.8				30t
	50	Applied Housing	56.3				60
	40	Housing Authority	562.5		650, 650	300, 350, 400	600, 600
	14	Wallace School	9.4				30
	Totals		646.9		1300	1050	1320
9	6	Univ Med Center	28.1		30		30
	27	Midtown Garage	187.5		500	275	200, 200
	46	Clock Towers	187.5		500	275	200
	44	10 Church Towers	56.3				60
	45	15 Church Towers	187.5			275	200
	43	5 Church Towers	112.5		300	275	125
	18	A&P Grocers	56.3				60
	Totals		815.6		1330	900	1075
10	28	Columbian Arms	112.5		125, 125	125, 175	150, 150
	Totals		112.5		250	300	300
11	7	Sewage Plant	1125.0	(E) 1750	1200	1500	2000
	Totals		1125.0		1200	1500	2000
12	15	Homeless Shelter	56.3		60, 60	150	125
	Totals		56.3		120	150	125
1UB	31	HOA	112.5		250	275	125
	32	HOA	56.3				60
	33	HOA	84.4				100
	34	HOA	112.5			275	125
	35	HOA	56.3				60
	36	HOA	56.3				100
	37	HOA	112.5		300	275	125
	39	HOA	112.5		300		125
	38	HOA	112.5		300	275	125
	Totals		815.6		1150	900	1045

Table M.2: Generator decision table for the LBS

Cluster	Bldg #	Name	Est Peak Load	Other Gen	Option 1	Option 2	Option 3
1	20	King Grocers	562.5		800, 800	400	400, 600
	51	YMCA	187.5			400	200
	1	Fire Co 3	187.5	(S) 15		400	175
	9	Pump	18.8	(E) 200			
		Totals	956.3		1600	1200	1375
2	42	Senior Housing	56.3				100
	13	High School	187.5		500, 500	300, 300	200, 200
	11	Ambulance	18.8	(S) 25			
	2	Fire Co 4	28.1	(S) 15			30t
		Totals	290.6		1000	600	530
3	3	Fire HQ	46.9	(S) 37.5			30t
	22	Multiservice	112.5	(C) 100		250	100
	29	Marion Towers	281.3		350, 350	250, 100	300, 300
		Totals	440.6		700	600	730
4	8	Pump	937.5	(E) 335		350, 400	1000
	17	Peter and Paul	37.5				50
	26	Garage G	187.5			350	200
	19	King Grocers	562.5		1500, 1500	350, 350, 350	600, 600
		Totals	1725.0		3000	2150	2450
5	53	Fire Radio	18.8				30t
	16	Matthew Church	18.8		30, 30	50	75
		Totals	37.5		60	50	105
6	4	Fire Co 1	56.3	(S) 15	50, 50	150	125
		Totals	56.3		100	150	125
7	25	Garage D	281.3			250	300
	24	Garage B	112.5			250	125
	5	Police HQ	187.5	(C) 100			100
	52	Police Repeater	562.5		1500, 1500	250, 250, 250	600
	55	Walgreens	112.5			250	125
	12	City Hall	281.3	(C) 100			200
	54	CVS	187.5			250	200
	30	Columbian Towers	187.5			250	200
	10	Pump	281.3	(E) 750			300
		Totals	2193.8		3000	2000	2150
8	21	Sunoco	18.8		15, 15		50, 50
	14	Wallace School	9.4		25, 25	30, 30	15, 15
		Totals	28.1		80	60	130

Continued on next page

Table M.2 – *Continued from previous page*

Cluster	Bldg #	Name	Est Peak Load	Other Gen	Option 1	Option 2	Option 3
9	6	Univ Med Center	28.1				30
	27	Midtown Garage	187.5		500, 300	225, 225	200, 200
		Totals	215.6		800	450	430
10	28	Columbian Arms	112.5		125, 125	125, 175	150, 150
		Totals	112.5		250	300	300
11	7	Sewage Plant	1125.0	(E) 1750	1200	1500	2000
		Totals	1125.0		1200	1500	2000
12	15	Homeless Shelter	56.3		60, 60	150	125
		Totals	56.3		120	150	125

Appendix N

Initial Design Options Selection – Microgrids

Selection of Initial Clustering

TMO and PRM analysis collectively determines the performance versus the reliability of a set of options as well as costs for the sets of upper bound and lower bound buildings for the City of Hoboken. A prerequisite for this analysis is the determination of a starting point upon which this further analysis can be done. The best set of conceptual design options is determined by both TMO and PRM analysis. The TMO and PRM compares the performance and reliability of these conceptual design options to a baseline performance and reliability of the existing system without any improvements to meet the DBT in order to make these comparisons.

At a high level the options to be considered consist of the following for both the upper bound and lower bound sets of buildings:

1. Add backup generation (possibly with redundancy) to all facilities, each in isolation from other facilities
2. Tie either all the upper bound or lower bound buildings together into one interconnected microgrid
3. Tie buildings together into clusters of microgrids where appropriate, and utilize individual backup generation at other facilities where appropriate

Option (1) meets the DBT by supplying individual backup generation to each building in isolation. Redundancy (N-1) can be added by supplying two generators to each building to increase system reliability. Option (2) connects all upper or lower bound buildings together while minimizing the cost of the connection and suppling redundant (N-1) reliability. Option (3) lies in between either adding backup generators to all facilities or tying all buildings together into a single microgrid, and is most attractive as it can combine the strengths of the first two while potentially achieving lower cost.

Evaluating option (3) involves first determining which sets of clusters of buildings within the upper and lower bound sets to start from in order to utilize TMO and PRM analysis efficiently to determine what combinations of microgrids and standalone redundant generation produces the highest performance and reliability at the lowest cost. Ultimately the performance and reliability of option (1), (2) and (3) are compared to evaluate the most effective set of conceptual designs and make preliminary recommendations for improvements to the City of Hoboken for the upper and lower bound sets of buildings to meet the DBT according to the performance requirements with the highest performance, reliability and lowest costs based on the analysis.

Providing input options involves selecting an initial set of clusters of buildings for both TMO and PRM to evaluate. This is necessary because the upper bound set consists of 55 buildings and the lower bound set consists of 34 buildings, so there are an extremely large number of arbitrarily sized sets of building clusters of various sizes which could be evaluated as starting points for PRM and TMO for the upper and lower bound sets of buildings respectively. Given that there are a prohibitively large number of building clusters which could be developed, it would be inefficient to evaluate all the possible sets, so a mechanism is needed to reduce the input set of clusters for TMO and PRM to evaluate. When these clusters are selected, TMO and PRM as described below then evaluate how to deploy generation to meet loads within clusters and whether to tie clusters together to determine which combination of microgrid clusters has the highest performance and reliability at lowest costs.

As described further below, a mathematical method known as K-means clustering was used to determine the subset of possible clusters to be provided to TMO and PRM as inputs for further analysis. The results of K-means clustering was combined with further engineering judgment to provide these inputs.

K-means Clustering

K-means clustering is an algorithm to classify or group a set of objects based upon its attributes or features in to K number of groups, where K is a positive integer. The grouping is done by minimizing the sum of squares of distance between the data and the corresponding centroid of the clusters being determined. Thus K-means clustering works to classify a data set into a number of distinct spatial clusters.

To illustrate how K-means clustering works, as an example: data is obtained on a number of objects (20) with two continuous attributes. A plot of the objects in a vector space with axis representing the two attributes, Attribute A and Attribute B, is shown in Figure N.1 below. From a visual examination of the data, initially choose $K = 3$ as the number of clusters to determine for the data set. The K-means clustering algorithm begins by initializing the centroids of the 3 clusters it will be determining (Figure N.1; shown as $1'$, $2'$, and $3'$). Next, the K-means algorithm – in an iterative manner – finds the centroid of each cluster which minimizes the mean square distance of each object to each cluster. Two steps (Figure N.1, shown as “a” and “b”) are required in this example to find the final 3 clusters which group clusters by minimizing the distance between members and their cluster (Figure N.1; final centroids of three clusters are shown as $1''$, $2''$, and $3''$). Each cluster also identifies the objects associated with each cluster (Figure N.1 shows 8 objects in Cluster 1 and 6 objects each for Cluster 2 and 3).

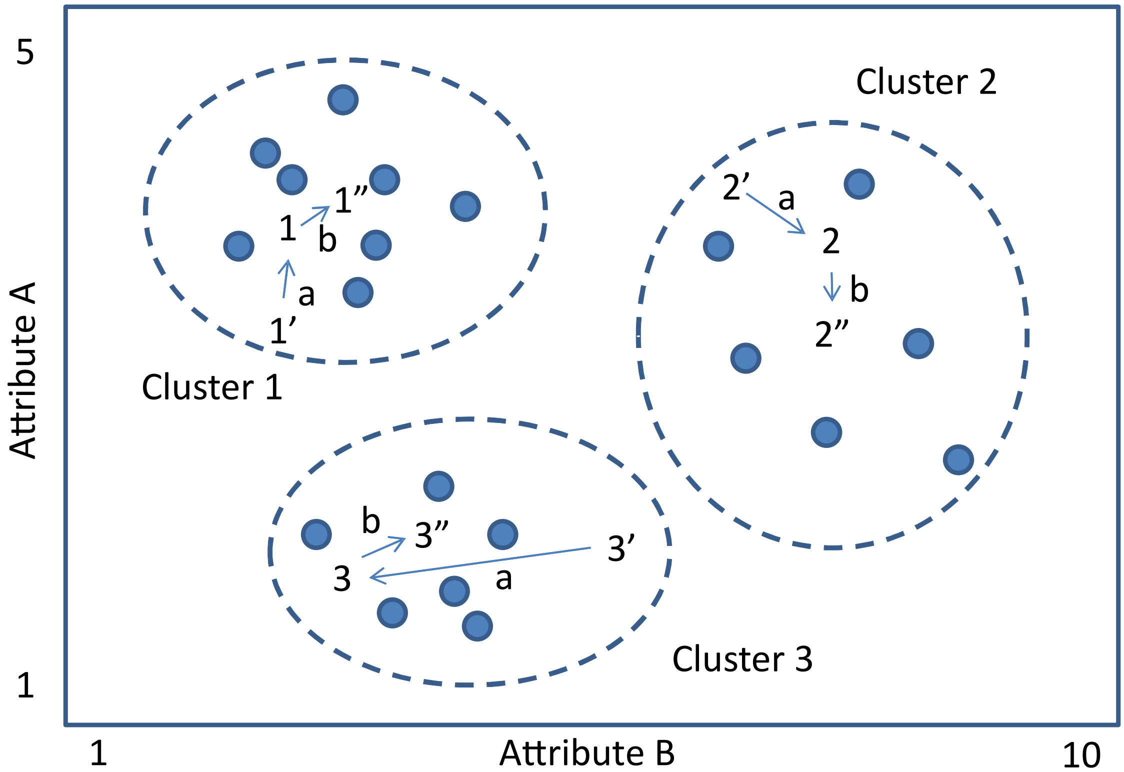


Figure N.1: K-means clustering example with 3 clusters

The K-means clustering algorithm can be performed on an arbitrary large set of objects (or experiments, or samples) of a data set as well as for greater than two attributes (higher dimensions). The major drawback in the K-means clustering algorithm is the necessity in specifying the number of clusters one wants to find in the data set. In this simple example, visualization of the prior to analysis seems to concur with the choice of three clusters. For larger data sets it is not as clear what the optimal amount of clusters should be, or which members should be included in each cluster. Unfortunately there is not a criterion by which one can assign the number of clusters to a data set $K = N$ and specify that this number of clusters N is the optimal number of clusters for a data set. There are ways to narrow down the choices of the number of clusters to select with scientific and engineering judgment, but no way to conclusively specify an optimal set of clusters for a specified data set. Given that the K-means clustering algorithm is being used as a tool to find initial clusters of buildings by which TMO and PRM analysis can be applied, the lack of the ability to specify optimal clusters is not a major issue. The K-means cluster analysis is used to determine initial sets of clusters of building which combined with engineering judgment determines the clusters of buildings further analyzed by TMO and PRM analysis.

As discussed, the upper bound set of buildings consists of 55 buildings and a subset of these buildings termed the lower bound set of buildings consists of 34 buildings. Using Google Earth, the location of each of these 55 buildings was determined within the City of Hoboken based upon their addresses. Next an arbitrary location in the southeast corner of the City of Hoboken was used as a reference, and each building location was referenced to this point. One attribute is the Y coordinate referenced from south to north and the location of the building from the reference location in feet. A second attribute is the X coordinate referenced from east to west and the location of the building from the reference location in feet. The K-means algorithm in the statistical program IBM SPSS (Statistical Product and Service Solutions) version 16 (SPSS 16), a very widely used programing package for statistical analysis, was used to perform the clustering analysis.

Figure N.2 illustrates the locations of upper bound and lower bound sets of buildings (upper bound yellow and blue numbered circles; lower bound yellow circles only) superimposed upon a map of the City of Hoboken with a gradient of the FEMA 1% annual flood depths (100 year flood levels) shown as well. A blue dotted line demarcates the areas within the City of Hoboken above the designated DBT (100 year flood + 2.5 feet) and below to show locations of buildings above and below these DBT levels. Table N.1 shows the building number designations, name, and street locations of the 55 buildings in the upper bound set and lower bound sets well as the X and Y coordinates determined for each building used in the K-means cluster analysis. Building number designations are used to reference the location of each building, but otherwise do not have any other significance.

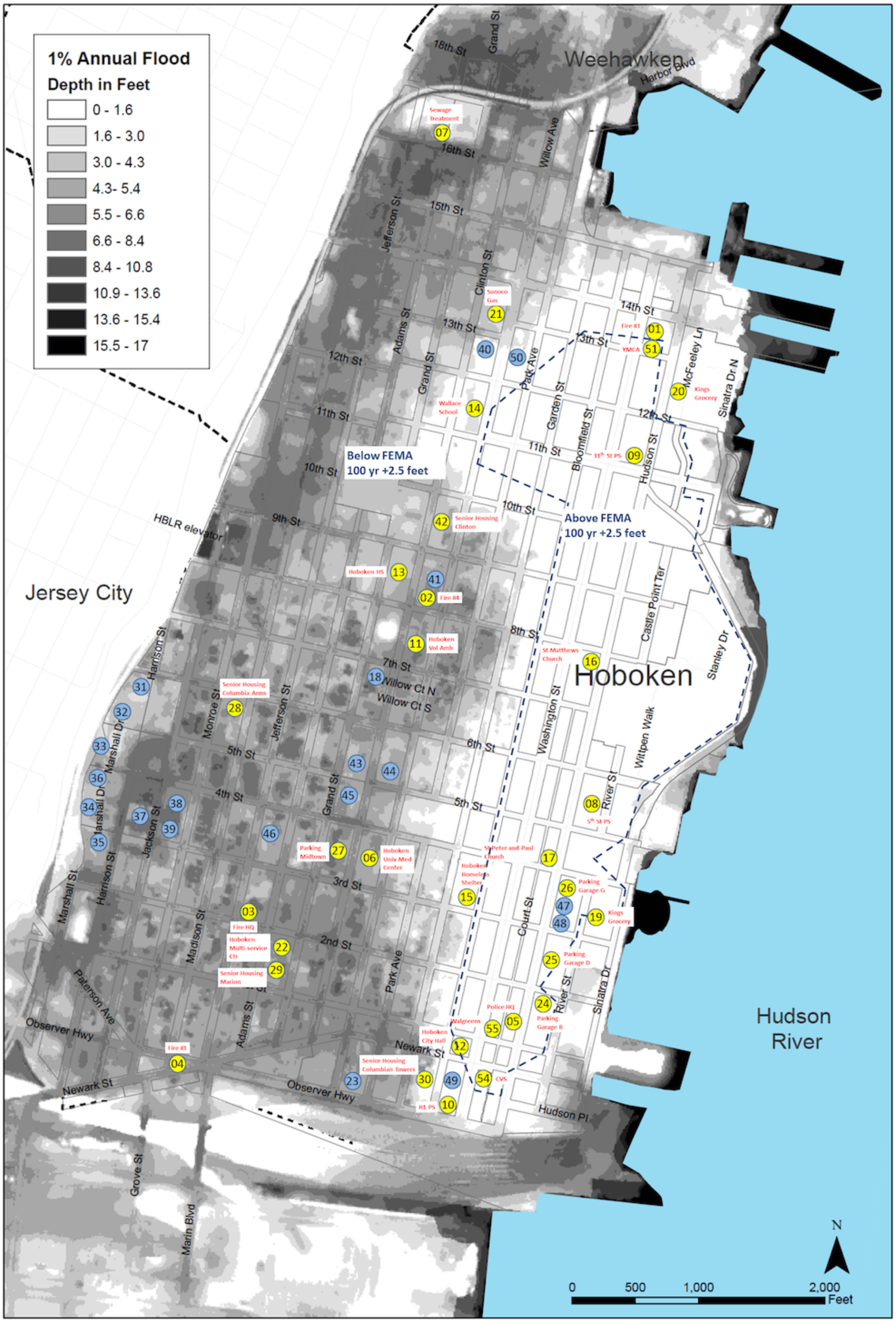


Figure N.2: Location of upper bound (yellow and blue) and lower bound (yellow only) sets of buildings in the City of Hoboken

Table N.1: Coordinates for buildings in Hoboken

Bldg #	UBS/LBS	X coordinate	Y coordinate	Name
53	both	N/A	N/A	Fire Department Radio Repeater
8	both	3999	2408	5th Street PS
16	both	3454	3832	St. Matthew's Church (shelter)
17	both	3327	2192	St. Peter and Paul Church
26	both	3640	1853	Garage G
5	both	3420	817	Police HQ
9	both	3280	5194	11th Street PS
52	both	N/A	N/A	Police Department Radio Repeater
54	both	3261	379	CVS
12	both	3067	605	Hoboken City Hall
19	both	3877	1883	Grocery - Kings
24	both	3636	1049	Garage B
25	both	3636	1378	Garage D
55	both	3284	730	Walgreens
1	both	3437	6408	Fire Engine Co 3
10	both	3240	-50	H1 PS
14	both	1914	5378	Wallace School (shelter)
15	both	2878	1712	Hoboken Homeless Shelter
20	both	3616	6049	Grocery – Kings
21	both	2247	6407	Gas Station – Sunoco
30	both	2942	273	Columbian Towers
51	both	3321	6368	YMCA (SROs)
2	both	1906	3995	Fire Engine Co 4
3	both	1142	1215	Fire HQ
4	both	883	-44	Fire Engine Co 1
6	both	1937	1875	Hoboken University Medical Center
7	both	1337	7551	Adams Street
11	both	1942	3568	Hoboken Volunteer Ambulance Corps.
13	both	1677	4188	Hoboken High School
22	both	1471	997	Hoboken Multi-Service Center
27	both	1968	1942	Midtown Garage
28	both	765	2696	Columbian Arms
29	both	1493	837	Marion Towers
42	both	1848	4560	900 Clinton Senior Housing Fox Hill
47	UBS	3645	2056	Marineview 1
48	UBS	3648	1715	Marineview 2
49	UBS	2996	415	Applied
23	UBS	1926	150	Hoboken Public Works Garage
50	UBS	2248	5995	Applied

Continued on next page

Table N.1 – *Continued from previous page*

Bldg #	UBS/LBS	X coordinate	Y coordinate	Name
18	UBS	1672	3306	Grocery – A&P
31	UBS	0	2877	Hoboken Housing Authority
32	UBS	-202	2556	Hoboken Housing Authority
33	UBS	-206	2296	Hoboken Housing Authority
34	UBS	-121	1978	Hoboken Housing Authority
35	UBS	-121	1978	Hoboken Housing Authority
36	UBS	-90	1718	Hoboken Housing Authority
37	UBS	-90	1718	Hoboken Housing Authority
38	UBS	215	1786	Hoboken Housing Authority
39	UBS	162	1602	Hoboken Housing Authority
40	UBS	1951	5973	Hoboken Housing Authority
41	UBS	2022	4003	804 Willow Ave
43	UBS	1973	2600	Church Towers
44	UBS	1794	2246	Church Towers
45	UBS	1672	2600	Church Towers
46	UBS	1193	1775	Clock Towers

Cluster analysis was performed on both the upper bound and lower bound sets of buildings using K-means clustering with SPSS 16 as described. Given that there is no designated $K = N$ number of optimal clusters which can be determined using K-means clustering, SNL performed K-means cluster analysis with $K = 4, 6, 7, 8, 9, 10, 12$ clusters on both the upper and lower bound set of buildings. In this case, the K-means cluster analysis determines the centroid of each cluster for the number of clusters chosen to be analyzed. Additionally the K-means cluster analysis specifies which buildings are included in each cluster. The centroid of each cluster minimizes the distance between each building within its cluster. The K-means analysis specifies both the location of each centroid as well as the distance of each building in feet from each centroid. From this data, the average distance of all of the buildings to each of their cluster centroids can be determined. Additionally the distance between each of the cluster centroids for the designated number of clusters can also be determined, and the average distance between clusters from this data can be determined. Figure N.3 below illustrates using the 3 cluster analysis example, how distances of each object from each cluster centroid (green – within cluster distance) as well as distances between cluster centroids (red – between cluster distance) can be determined and an average of each can be further quantified.

The average distance within each cluster and between clusters was quantified for different sized clusters using K-means cluster analysis as shown in Figure N.4 for the upper bound set of buildings and Figure N.5 for the lower bound set of buildings.

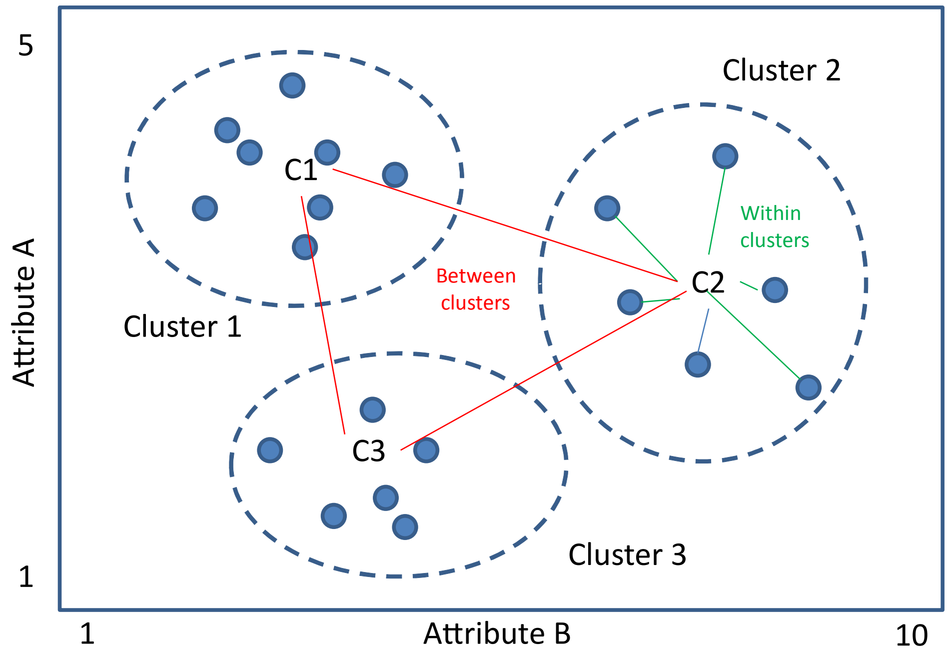


Figure N.3: Determination of distances of objects to cluster centroids within each cluster and between cluster centroids

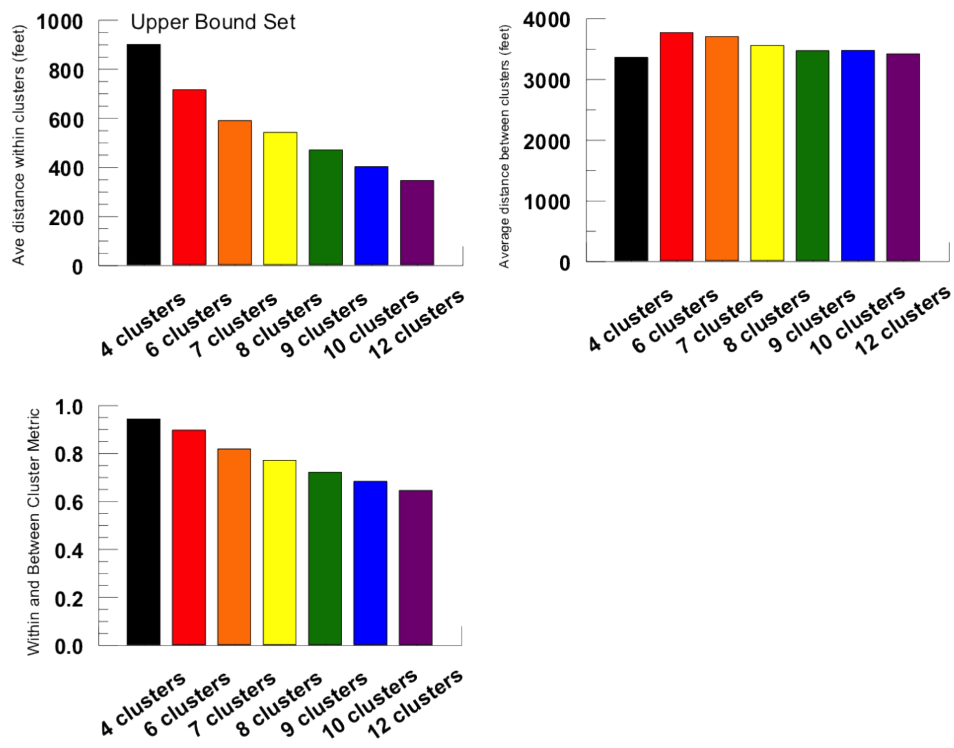


Figure N.4: Results of K-means cluster analysis for the upper bound set of buildings

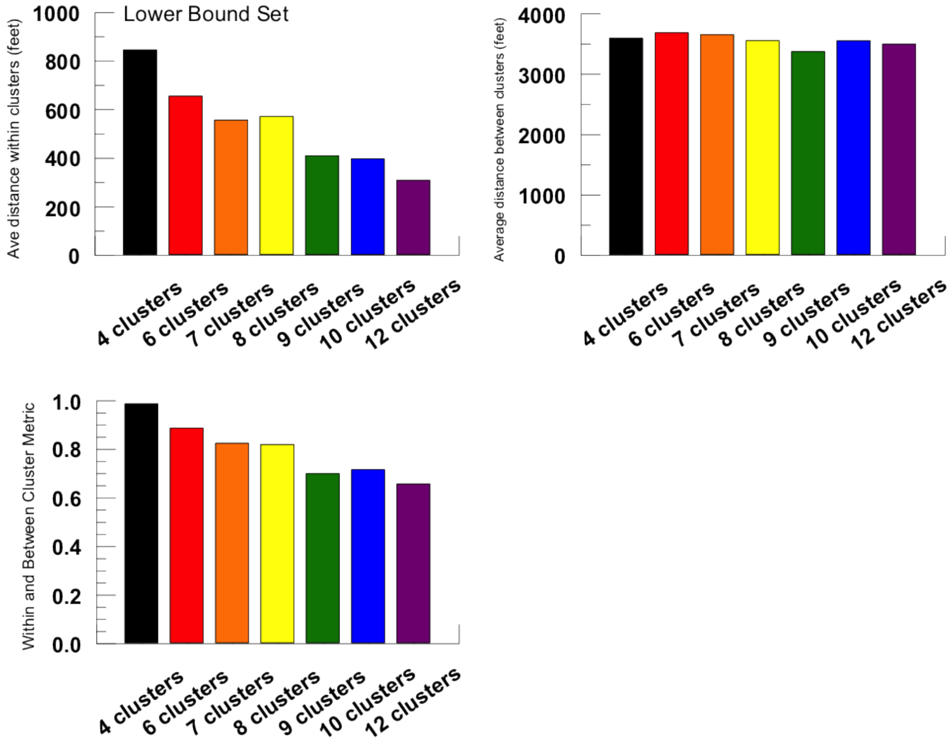


Figure N.5: Results of K-means cluster analysis for the lower bound set of buildings

As shown in Figure N.4 and N.5, the average distance within clusters decreased with increasing number of clusters for both the upper bound set and lower bound set of buildings. This is explained by the fact that as the number of clusters increases, more tightly fitted clusters of buildings with smaller numbers of buildings in each cluster is produced. Also in Figure N.4 and N.5, there was not much change in the average distance between clusters as the number of clusters increased. This implies that the spacing between cluster centroids does not significantly change as the number of clusters increases.

A metric was created to evaluate the combination of the average within and between cluster distances for different number of clusters. The equation is shown below:

Within and between cluster metric = ½ (within cluster distance/highest within cluster distance) + ½ (between cluster distance/highest between cluster distance)

Basically the metric evaluates the contribution of the average distance within each cluster and between each cluster normalized to the highest values found in the evaluation of the sets of clusters examined ($K = 4, 6, 7, 8, 9, 10, 12$ clusters). The lower this metric the better since it indicates tight clusters which are not too far from other clusters. As shown in Figure N.4 and N.5, $K = 9, 10, 12$ clusters showed the smallest metric of the combination of average within and between cluster values.

Next the clusters for $K = 9, 10, 12$ clusters were mapped onto the location map of the upper and lower bound sets of buildings as a starting point for further consideration as to which clusters of buildings to utilize for TMO and PRM analysis. Visually, $K = 9, 10, 12$ were extremely similar, so $K = 10$ was chosen as the initial cluster set to perform additional analysis.

Figure N.6 and N.7 show the 10 clusters determined for the upper and lower bound sets (purple boundaries). Since the lower bound set consists of a subset of the upper bound set, the clusters produced by analyzing each set independently produced slightly different clustering. Since the upper bound set consists of all of the buildings to be examined, the initial cluster set to be used as a basis for TMO and PRM analysis was refined from the results of the $K = 10$ clusters found for the upper bound set.

Engineering judgment was used to further refine the results of the cluster analysis in order to create sets of microgrid clusters to further analyze with TMO and PRM. Figure N.6 and N.7 show these microgrid clusters (13 total: MG1 – MG12, MG1UB) and how they compare to the clusters determined for the upper bound and lower bound sets respectively. For example, one upper bound cluster contains the buildings for MG3 (3, 22, and 29) and MG6 (4) as well as one included in MG7 (23). Building 4 was better suited to be included as a separate cluster, and building 23 as part of MG7, even if cluster analysis revealed them to belong to the same cluster. Similar building 18 was better suited for MG9 than MG2 since it is part of the upper bound set, which can be analyzed with other upper bound set buildings in MG9 (43-45). Similar engineering judgments were made to develop the initial microgrid clusters to be further analyzed by TMO and PRM. The red lines in Figure N.6 and N.7 for each microgrid illustrate how each of the buildings is connected together in each microgrid to be evaluated by TMO and PRM. Table N.2 shows the building numbers and names for each microgrid cluster as well as whether or not each is part of the upper bound or lower bound set of buildings. The costs for the clusters (including trenching, cabling, ducts, manholes, transformers, etc.) are shown in Table N.3.

The initial microgrid clusters are used by TMO and PRM to evaluate the optimal setup for performance and reliability of each of the initial microgrid clusters for both upper bound and lower bound microgrid clusters as well as whether each cluster can be further optimized by connecting neighboring clusters to each other to form larger microgrids, or if each cluster is better suited to be kept as an isolated cluster. As shown in Table Table N.2, some of the clusters consist of individual buildings (MG6, MG10-12), while others include multiple buildings, some of which contain mixtures of upper and lower bound buildings as well (MG2, MG4, MG7-9).

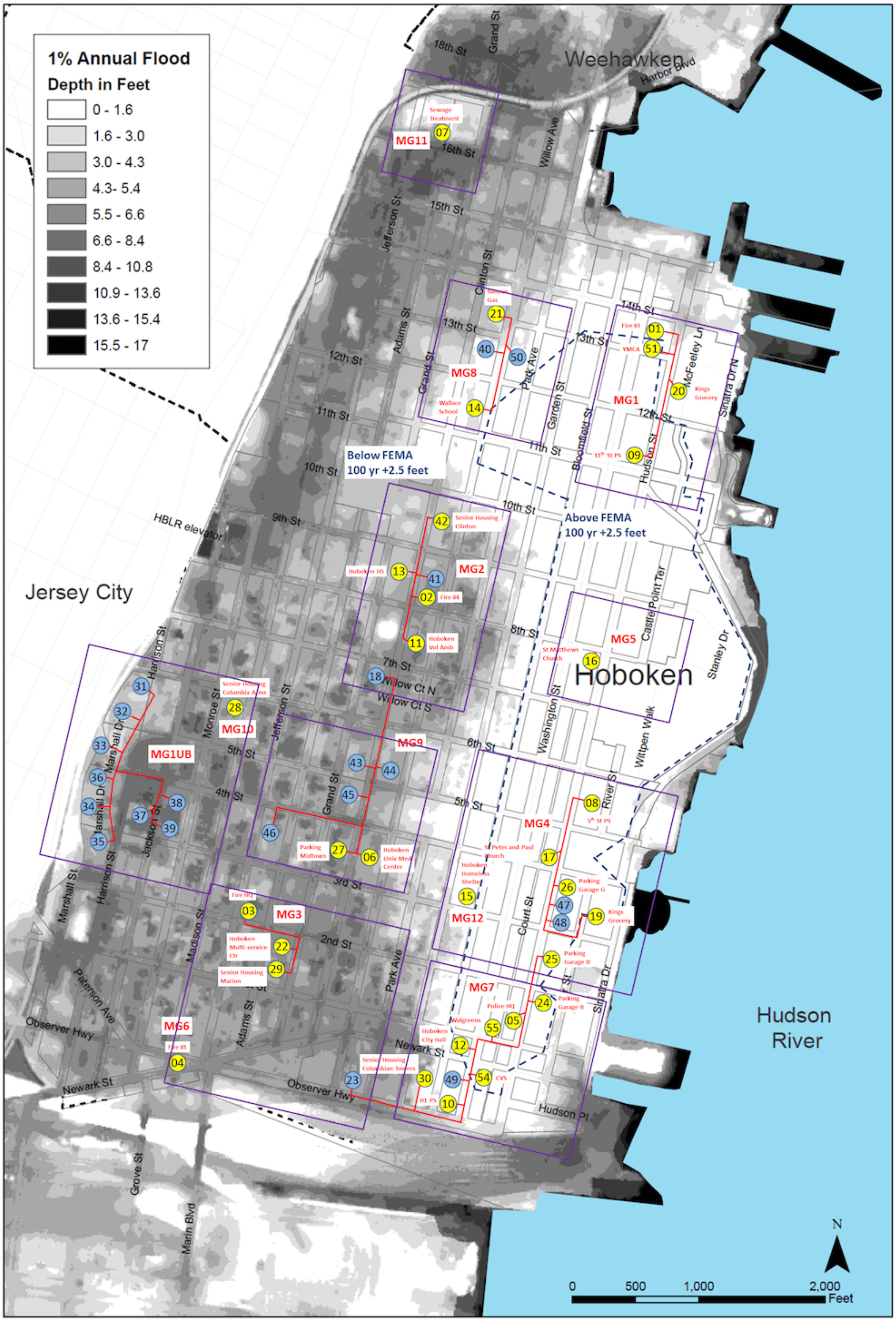


Figure N.6: K-means cluster analysis for 10 clusters for the upper bound set of buildings as well as initial microgrid clusters selected for TMO/PRM analysis

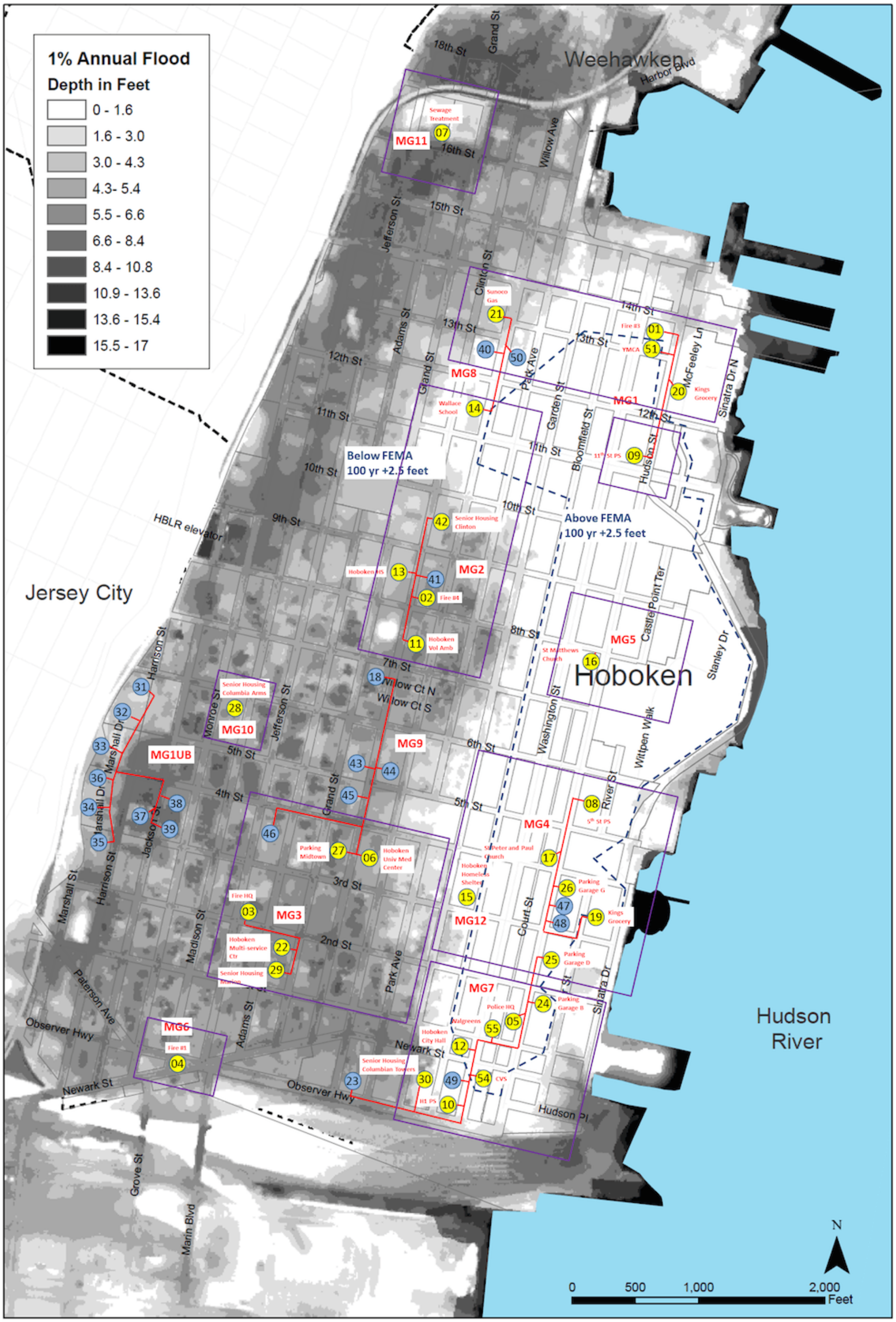


Figure N.7: K-means cluster analysis for 10 clusters for the lower bound set of buildings as well as initial microgrid clusters selected for TMO/PRM analysis

Table N.2: List of microgrid clusters

Cluster	Building #	Name
1	20	Grocery - Kings
	51	YMCA (SROs)
	1	Fire Engine Co 3
	9	11th Street PS
2	42	900 Clinton Senior Housing Fox Hill
	13	Hoboken High School
	11	Hoboken Volunteer Ambulance Corps.
	4	Fire Engine Co 1
	41	804 Willow Ave
3	3	Fire HQ
	22	Hoboken Multi-Service Center
	29	Marion Towers
4	8	5th Street PS
	17	St. Peter and Paul Church
	47	Marineview 1
	26	Garage G
	48	Marineview 2
	19	Grocery - Kings
5	53	Fire Department Radio Repeater
	16	St. Matthew's Church (shelter)
6	4	Fire Engine Co 1
7	25	Garage D
	24	Garage B
	5	Police HQ
	52	Police Department Radio Repeater
	55	Walgreens
	12	Hoboken City Hall
	49	Applied
	54	CVS
	30	Columbian Towers
	10	H1 PS
	23	Hoboken Public Works Garage
8	21	Gas Station - Sunoco
	50	Applied
	40	Hoboken Housing Authority
	14	Wallace School (shelter)

Continued on next page

Table N.2 – *Continued from previous page*

Cluster	Building #	Name
9	6	Hoboken University Medical Center
	27	Midtown Garage
	46	Clock Towers
	44	Church Towers
	45	Church Towers
	43	Church Towers
	18	Grocery - A&P
10	28	Columbian Arms
11	7	Sewage Treatment Plant
12	15	Hoboken Homeless Shelter
1UB	31	Hoboken Housing Authority
	32	Hoboken Housing Authority
	33	Hoboken Housing Authority
	34	Hoboken Housing Authority
	35	Hoboken Housing Authority
	36	Hoboken Housing Authority
	37	Hoboken Housing Authority
	38	Hoboken Housing Authority
	39	Hoboken Housing Authority

Table N.3: MV cluster costs

Cluster	Infrastructure Costs ($K)	
	LBS	UBS
MG1	618.5	618.5
MG2	579.5	749.1
MG3	424.1	424.1
MG4	748.2	906.2
MG5	284.8	284.8
MG6	N/A	N/A
MG7	1436.8	1708.4
MG8	329.6	429.3
MG9	130.6	1177.9
MG10	N/A	N/A
MG11	N/A	N/A
MG12	N/A	N/A
MG1UB	N/A	1109.3
Totals	4552.1	7407.5

Appendix O

Performance/Reliability Modeling Using Technology Management Optimization

Decision Variables for the Hoboken Microgrids

A number of design decisions for new microgrid assets were fixed based on user preferences, engineering judgment, and other analyses; still others were left as options for TMO to search through. The fixed decisions were as follows:

1. Size of natural gas CHP generators to be installed for each building (based on results from Appendix I),
2. Clusters of buildings connected by MV lines which comprise the cores of the microgrids (shown in N).

TMO/PRM has two major categories of decisions that will affect the overall performance of the electrical network for Hoboken. New NG generation will obviously be needed, and the optimization engine will be able to select from the decision variables given in Appendix M. The size, location, and cumulative amount will affect the performance and cost.

The other category of decision variables include the opportunity to invest in additional MV infrastructure (beyond that given in Appendix N). This will have the effect of connecting one or more clusters together, which in turn will improve the reliability of the system (as pools of generation and load are linked), but at the penalty of additional costs.

Making these decisions will determine the final topology of the Hoboken microgrid. The MV linking options and costs (based on length, ducting, installation, cabling, etc. and additional manholes) are shown in Tables O.1 and O.2. Note that some cluster linkages will involve additional transformers, as there are differing voltages between the two (one is MV and the other is LV). Only one additional transformer is required at any time, so if a link is selected that requires one, then subsequent links may be added at a discount.

Table O.1: MV cluster connection options

Cluster 1	Cluster 2	Cost ($)	If selected, Xfmr reqt	Building From	Building To
1	2	782320		9	42
1	5	465250		9	16
1	8	322960		1	21
2	5	413200		2	16
2	8	402160		42	14
2	9	132100	B	11	18
3	6	438680	A	3	4
3	7	592240		22	24
3	9	207700	B	22	6
3	1UB	435400		3	39
4	5	449680		8	16
4	7	97900		48	25
4	9	502300	B	48	6
4	12	201500	E	48	15
6	7	429800	A	4	23
7	9	619700	B	25	6
7	12	356600	E	24	15
8	11	671600	D	21	7
9	10	394400	B, C	27	28
9	12	352800	B, E	6	15
9	1UB	438700	B	46	39
10	1UB	360500	C	28	31

Table O.2: Additional transformers for MV cluster connections

ID	Cluster	Cost
A	6	15.3
B	9	32.3
C	10	19.6
D	11	94.0
E	12	15.3

Measures of Performance for the Hoboken Microgrid

The PRM gathers abundant statistics and is capable of calculating many different measures of performance (reliability, fuel used, efficiency, percentage of failures of a certain type, etc.). However, in the case of Hoboken, the only measure of performance besides cost that was used as a design consideration was reliability under DBT conditions. Two reliability measures were formulated in such a way as to encourage a microgrid design that is capable of sustaining the city's power needs with minimal interruption and minimal likelihood of loss of load. This was achieved by minimizing the magnitude of load that goes unserved on average over the DBT period while simultaneously minimizing the frequency of occurrence of load not served events (as discussed in Appendices A and B). These measures were calculated using the PRM.

Analysis Results

The performance measures are traded off against cost to form a trade-off frontier of efficient solutions. The Pareto chart (with five solutions identified) for the UBS is in Figure O.1, and the corresponding LBS chart is shown in Figure O.2. The performance of the design solutions are shown in Tables O.3 and O.4 for UBS and LBS respectively. Specific solution decisions for solutions A and B for the UBS are summarized in Tables O.5 and O.7. Specific solution decisions for solutions A and B for the LBS are summarized in Tables O.9 and O.11. Geospatial configurations for each are depicted in Figures **??**, **??**, **??**, and **??**. Finally, cost summaries for all four selected solutions are given in Tables O.6, O.8, O.10, and O.12. The results indicate excellent performance for both UBS and LBS, and a difference of about 60% in cost from least performing to best – but *the costs in this analysis are only the costs which can be optimized over* (see discussion in Appendix F). The modest costs calculated by TMO/PRM – as compared to the overall cost, including controls, CHP, microgrid closer cores, etc. – for the more expensive solutions on the Pareto frontier is very reasonable; thus, solution A is the preferred optimal design in both cases.

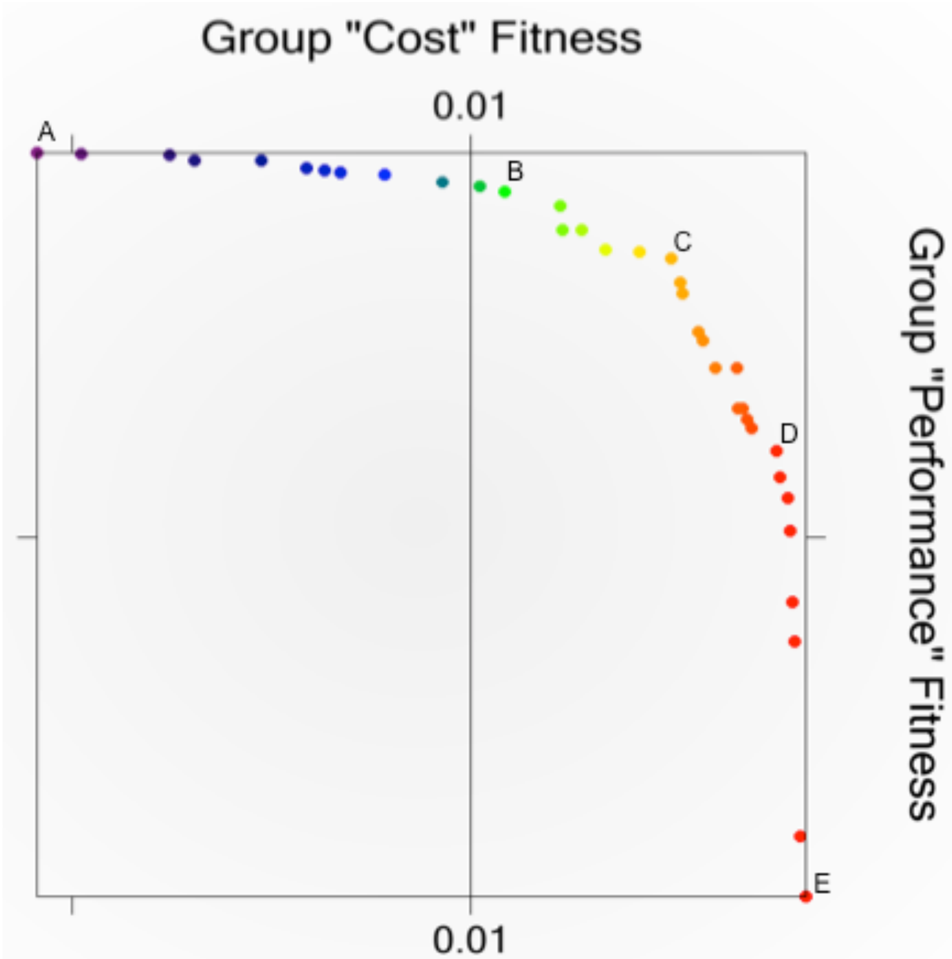


Figure O.1: Pareto chart for UBS solutions

Table O.3: Selected UBS optimization solutions

Solution	Cost ($M)	FOI (% DBT)	Cond. EENS (kWh/h)	EIR
A	14.25	0.001	0.016	0.99999
B	11.80	0.247	0.035	0.99994
C	10.52	0.658	0.069	0.99985
D	9.59	4.295	0.114	0.99899
E	9.33	9.355	0.181	0.99781

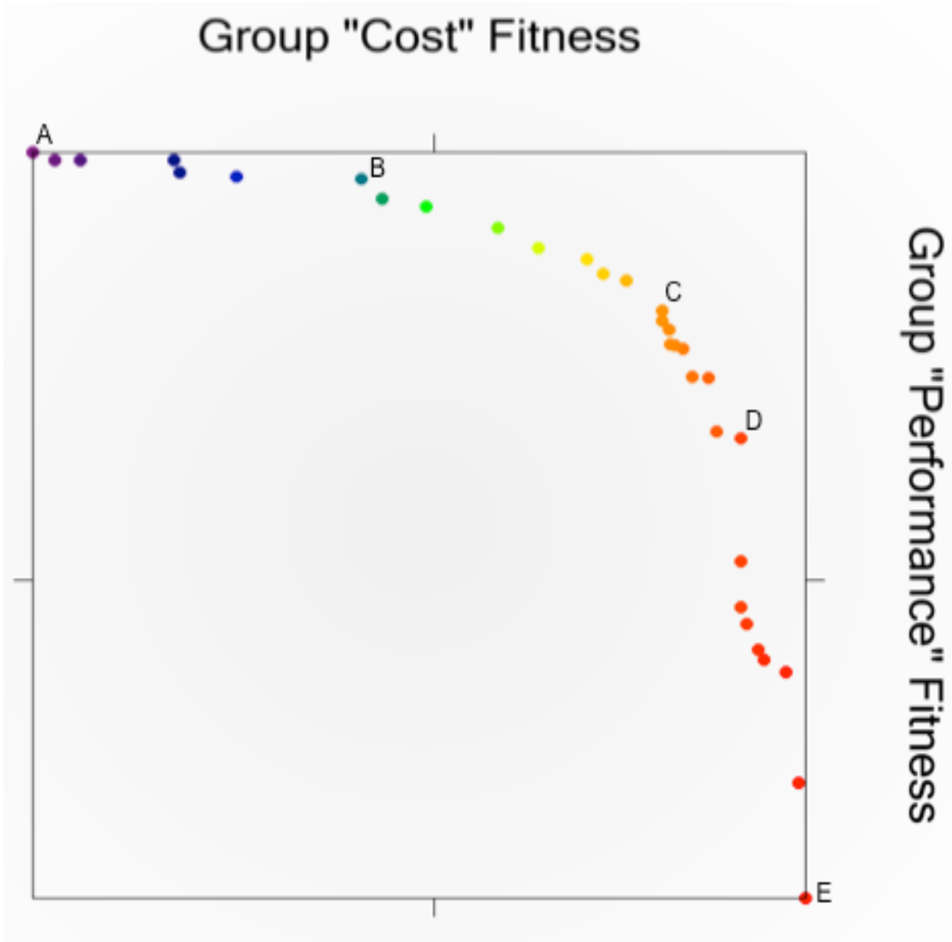


Figure O.2: Pareto chart for LBS solutions

Table O.4: Selected LBS optimization solutions

Solution	Cost ($M)	FOI (% DBT)	Cond. EENS (kWh/h)	EIR
A	7.50	0.000	0.000	0.99999
B	6.76	0.123	0.014	0.99996
C	6.06	1.343	0.071	0.99953
D	5.87	2.006	0.123	0.99930
E	5.71	7.410	0.193	0.99741

Table O.5: Solution A for UBS

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings	400, 600	450
	51	YMCA (SROs)	200	150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	50	Applied		45
	40	Hoboken Housing Authority	300, 600	450
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill	60, 150	45
	13	Hoboken High School	250	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	30, 25 CHP	22.5
	41	804 Willow Ave	175	90
	6	Hoboken University Medical Center	30	450
	27	Midtown Garage	200, 275	150
	46	Clock Towers	275	150
	44	Church Towers		45
	45	Church Towers	200, 275	150
	43	Church Towers	275	90
	18	Grocery - A&P		45
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	100 CHP	90
	29	Marion Towers	350	225
	28	Columbian Arms	125, 150	90
	31	Hoboken Housing Authority	125, 250	90
	32	Hoboken Housing Authority	60	45
	33	Hoboken Housing Authority	100	67.5
	34	Hoboken Housing Authority		90
	35	Hoboken Housing Authority		45
	36	Hoboken Housing Authority		45
	37	Hoboken Housing Authority		90
	38	Hoboken Housing Authority	125, 300	90
	39	Hoboken Housing Authority		90
	53	Fire Department Radio Repeater	30	15
	16	St. Matthew's Church (shelter)	75	15
	8	5th Street PS	500, 600	750
	17	St. Peter and Paul Church	30	30
	47	Marineview 1		450
	26	Garage G		150
	48	Marineview 2	600	450
	19	Grocery - Kings	300	450
	25	Garage D	300, 400	225
	24	Garage B	125	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	400	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	49	Applied	300	225
	54	CVS	200	150
	30	Columbian Towers	200	150
	10	H1 PS		225
	23	Hoboken Public Works Garage	37.5 CHP	30
Unconnected	7	Sewage Treatment Plant	1200	900
Unconnected	4	Fire Engine Co 1	125, 150, 15 CHP	45
Unconnected	15	Hoboken Homeless Shelter	60, 60, 150	45

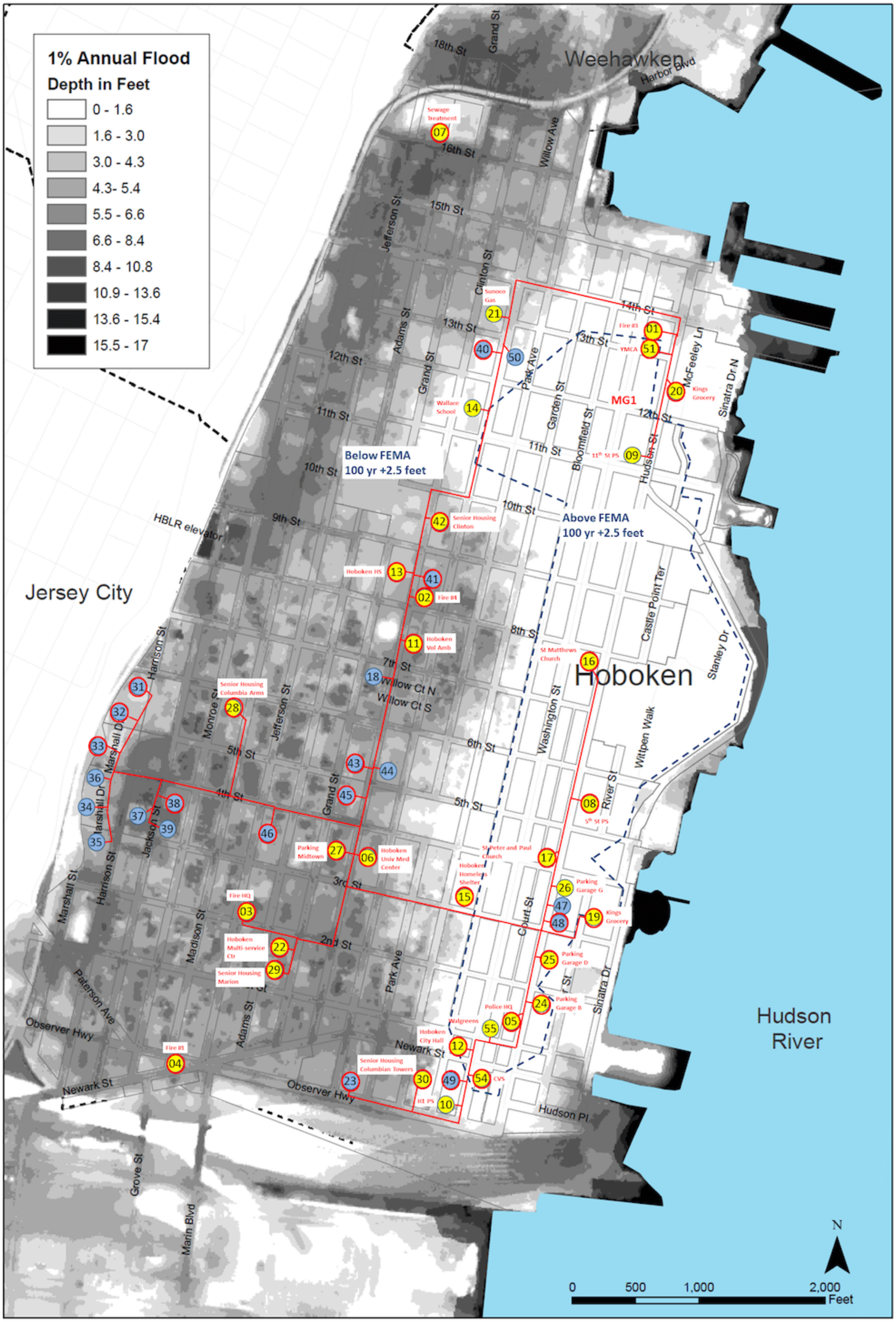


Figure O.3: Geospatial configuration for UBS solution A

Table O.6: Cost breakdown for UBS solution A

Type of Cost	Explanation	Amount
Building Retrofits	Needed at 37 buildings	$6.5M
Control and Communications	Includes 56 gens	$5.6M
Microgrid Infrastructure	The core MV clusters	$7.4M
Microgrid Infrastructure	Additional MV connections & NG gens	$14.3M
Combined Heat and Power	Sized for grid-connected operation	$0.9M
Design and Engineering	25% of subtotal	$8.6M
Contingency	Additional 25% of subtotal	$5.2M
	Total	$48.4M

Table O.7: Solution B for UBS

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings	400, 600	450
	51	YMCA (SROs)		150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	50	Applied		45
	40	Hoboken Housing Authority	600	450
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill		45
	13	Hoboken High School	250, 250	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	25 CHP	22.5
	41	804 Willow Ave		90
	6	Hoboken University Medical Center	30	450
	27	Midtown Garage	500	150
	46	Clock Towers		150
	44	Church Towers		45
	45	Church Towers		150
	43	Church Towers		90
	18	Grocery - A&P		45
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	100 CHP	90
	29	Marion Towers	300, 350, 350	225
	28	Columbian Arms	125, 175	90
	31	Hoboken Housing Authority	125, 175	90
	32	Hoboken Housing Authority	60	45
	33	Hoboken Housing Authority		67.5
	34	Hoboken Housing Authority		90
	35	Hoboken Housing Authority	60	45
	36	Hoboken Housing Authority		45
	37	Hoboken Housing Authority		90
	38	Hoboken Housing Authority	125	90
	39	Hoboken Housing Authority		90
	53	Fire Department Radio Repeater		15
	16	St. Matthew’s Church (shelter)	75	15
	8	5th Street PS	350, 500	750
	17	St. Peter and Paul Church		30
	47	Marineview 1	350	450
	26	Garage G		150
	48	Marineview 2	600	450
	19	Grocery - Kings	300	450
	25	Garage D	300, 400	225
	24	Garage B	125	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	600	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	49	Applied		225
	54	CVS	400	150
	30	Columbian Towers	200, 400	150
	10	H1 PS		225
	23	Hoboken Public Works Garage	37.5 CHP	30
Unconnected	7	Sewage Treatment Plant		900
Unconnected	4	Fire Engine Co 1	125, 15 CHP	45
Unconnected	15	Hoboken Homeless Shelter	60, 60	45

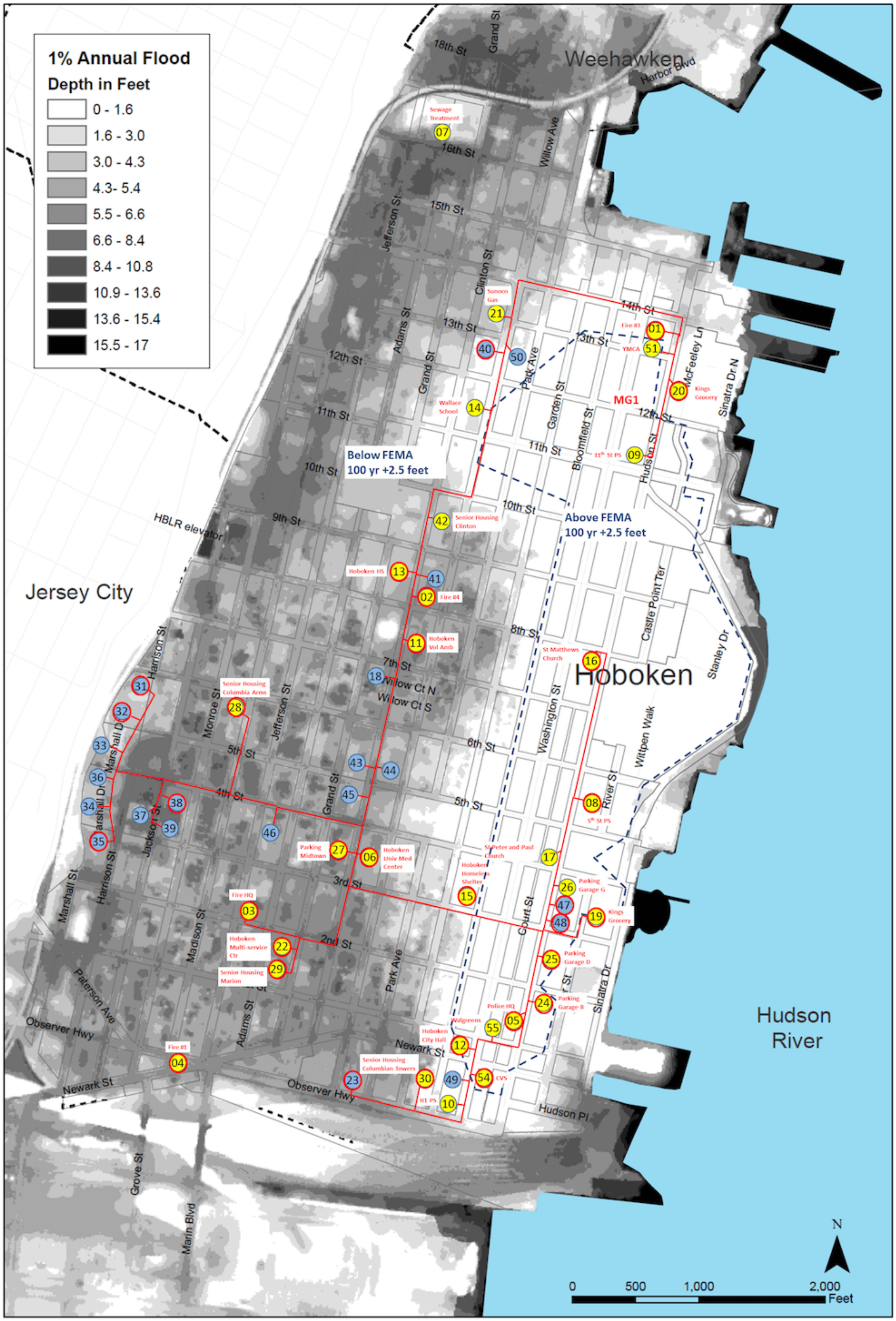


Figure O.4: Geospatial configuration for UBS solution B

Table O.8: Cost breakdown for UBS solution B

Type of Cost	Explanation	Amount
Building Retrofits	Needed at 37 buildings	$6.5M
Control and Communications	Includes 43 gens	$4.3M
Microgrid Infrastructure	The core MV clusters	$7.4M
Microgrid Infrastructure	Additional MV connections & NG gens	$11.8M
Combined Heat and Power	Sized for grid-connected operation	$0.9M
Design and Engineering	25% of subtotal	$7.7M
Contingency	Additional 25% of subtotal	$4.6M
	Total	$43.2M

Table O.9: Solution A for LBS

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings		450
	51	YMCA (SROs)		150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill		45
	13	Hoboken High School	200, 300, 500	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	25 CHP	22.5
	6	Hoboken University Medical Center		450
	27	Midtown Garage	200, 200	150
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	100 CHP	90
	29	Marion Towers	250, 300, 350, 350	225
MG2	8	5th Street PS	350	750
	17	St. Peter and Paul Church		30
	26	Garage G		150
	19	Grocery - Kings	350, 350, 600	450
	25	Garage D		225
	24	Garage B	250	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	250, 250, 600	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	54	CVS	250	150
	30	Columbian Towers	250	150
	10	H1 PS		225
MG3	53	Fire Department Radio Repeater	30	15
	16	St. Matthew's Church (shelter)	30, 30	15
Isolated	4	Fire Engine Co 1	50, 50, 15 CHP	45
Isolated	28	Columbian Arms	125, 125	90
Isolated	7	Sewage Treatment Plant		900
Isolated	15	Hoboken Homeless Shelter	60, 60	45

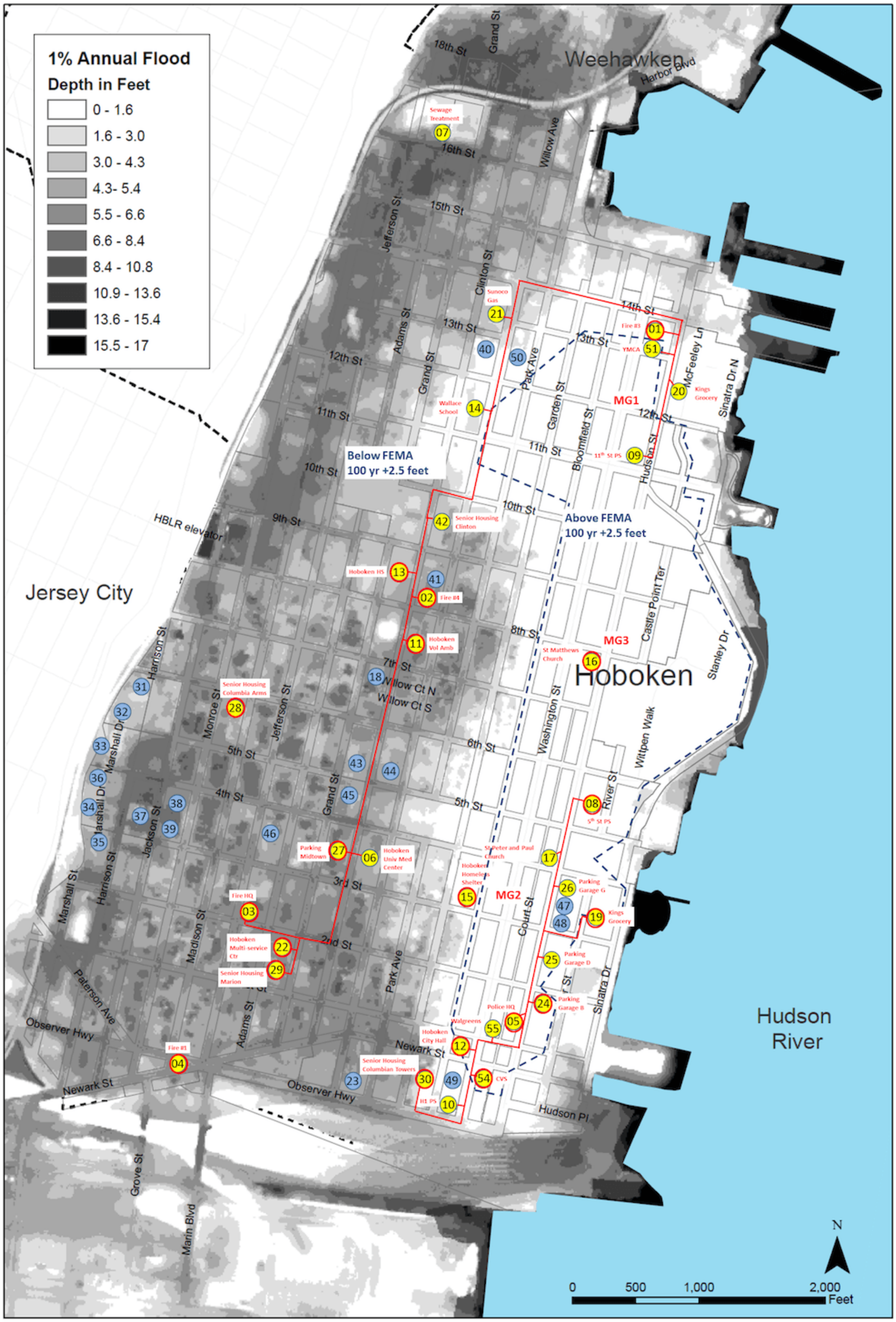


Figure O.5: Geospatial configuration for LBS solution A

Table O.10: Cost breakdown for LBS solution A

Type of Cost	Explanation	Amount
Building Retrofits	Needed at 19 buildings	$2.7M
Control and Communications	Includes 37 gens	$3.7M
Microgrid Infrastructure	The core MV clusters	$4.6M
Microgrid Infrastructure	Additional MV connections & NG gens	$7.5M
Combined Heat and Power	Sized for grid-connected operation	$0.8M
Design and Engineering	25% of subtotal	$4.8M
Contingency	Additional 25% of subtotal	$2.9M
	Total	$26.9M

Table O.11: Solution B for LBS

Microgrid	Building #	Name	Generator Sizes (kW)	Load
MG1	20	Grocery - Kings		450
	51	YMCA (SROs)		150
	1	Fire Engine Co 3	15 CHP	150
	9	11th Street PS		15
	21	Gas Station - Sunoco		15
	14	Wallace School (shelter)		150
	42	900 Clinton Senior Housing Fox Hill		45
	13	Hoboken High School	300, 500	150
	11	Hoboken Volunteer Ambulance Corps.	25 CHP	15
	2	Fire Engine Co 4	25 CHP	22.5
	6	Hoboken University Medical Center		450
	27	Midtown Garage	200, 200	150
	3	Fire HQ	37.5 CHP	37.5
	22	Hoboken Multi-Service Center	200, 100 CHP	90
	29	Marion Towers	300, 350, 350	225
MG2	8	5th Street PS	350	750
	17	St. Peter and Paul Church		30
	26	Garage G		150
	19	Grocery - Kings	350, 600	450
	25	Garage D		225
	24	Garage B	250	90
	5	Police HQ	100 CHP	150
	52	Police Department Radio Repeater	250, 250, 600	450
	55	Walgreens		90
	12	Hoboken City Hall	200, 100 CHP	225
	54	CVS	250	150
	30	Columbian Towers	250	150
	10	H1 PS		225
MG3	53	Fire Department Radio Repeater	30	15
	16	St. Matthew’s Church (shelter)	30	15
Isolated	4	Fire Engine Co 1	50, 15 CHP	45
Isolated	28	Columbian Arms	125, 125	90
Isolated	7	Sewage Treatment Plant		900
Isolated	15	Hoboken Homeless Shelter	60	45

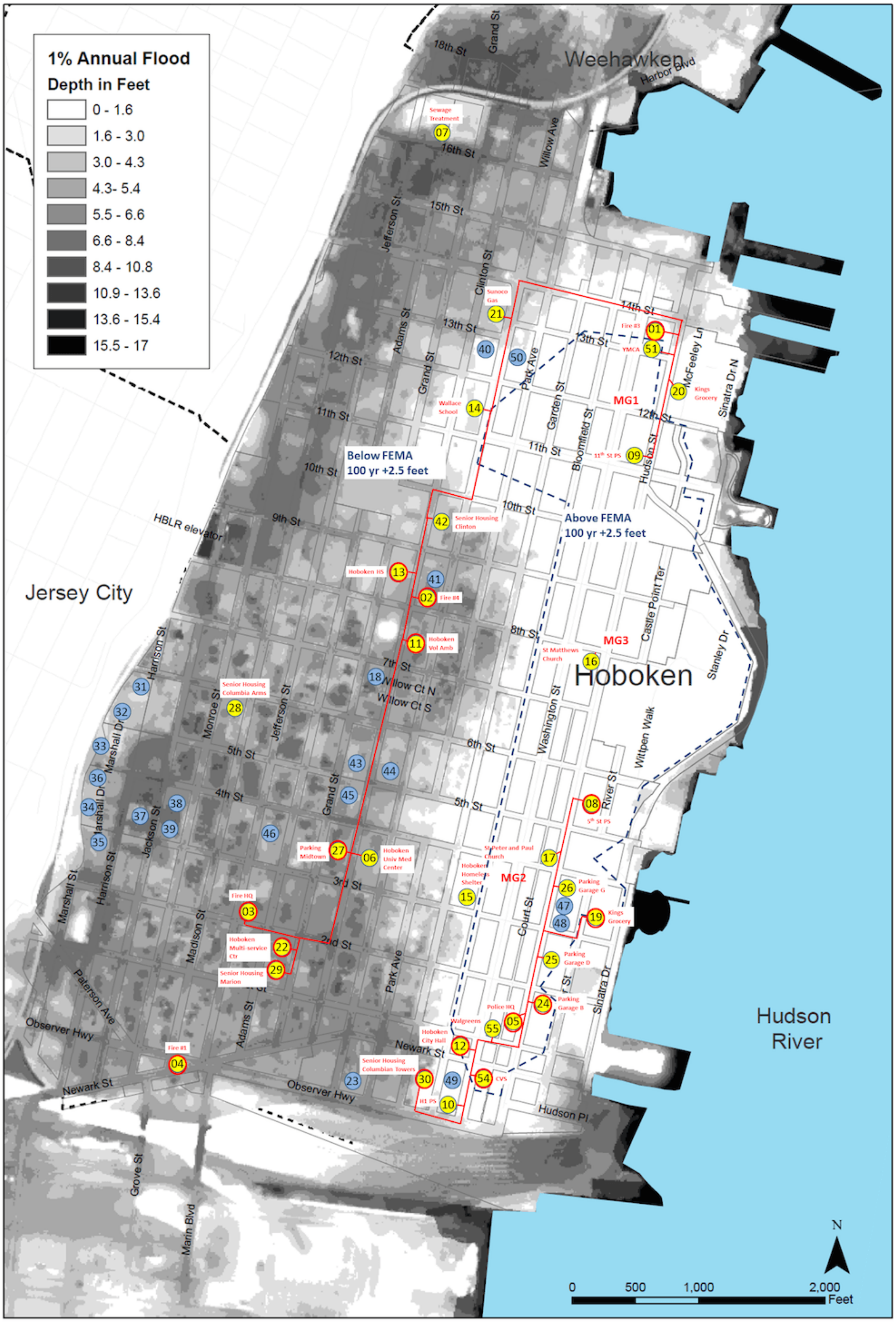


Figure O.6: Geospatial configuration for LBS solution B

Table O.12: Cost breakdown for LBS solution B

Type of Cost	Explanation	Amount
Building Retrofits	Needed at 19 buildings	$2.7M
Control and Communications	Includes 37 gens	$3.2M
Microgrid Infrastructure	The core MV clusters	$4.6M
Microgrid Infrastructure	Additional MV connections & NG gens	$6.8M
Combined Heat and Power	Sized for grid-connected operation	$0.8M
Design and Engineering	25% of subtotal	$4.5M
Contingency	Additional 25% of subtotal	$2.7M
	Total	$25.1M

Appendix P

Google Earth Analysis for the City of Hoboken

Sandia used Google Earth software to create a KMZ file which is a visual of the Hoboken ESDM location of critical buildings, existing generators, future bond generators, potential photovoltaic systems, CHP generators, K-cluster initial electrical feeders, manholes, and transformers. Also included in the file is the TMO option space equipment and materials which are the additional generators, electrical feeder connections, transformers, and manholes. Two overlay maps were included in this KMZ file where one is the FEMA "Stay Dry and Flood Smart" and the other one is various flood levels above sea level created by Sandia.

Using Google Earth

When the KMZ file is opened in Google Earth, there is a panel on the left side with the heading Places. In this panel, there is a folder, denoted by a + sign, called Hoboken ESDM which is the main folder which has all items and overlay maps for the ESDM. Each folder is a layer that can be seen on the map. To turn on the layer, click on the box to the left of the folder heading. A checked box means that layer is on and vice versa. The following are the subfolders under the Hoboken ESDM main folder.

- Buildings
- Equipment Inventory
- Potential Microgrids
- Stay Dry and Flood Smart
- Flood Map

All folders except for the building folder have subfolders that are divided into the 12 K-cluster microgrids. Clicking on one of these subfolders will bring up the main folder category location for that microgrid. For example, to see the existing generators in the first K-cluster microgrid perform the following:

- Expand the folder Equipment Inventory
- Expand the folder Non-ESDM generation
- Expand the folder Existing Generators
- Check the box labeled MG1_Exist_Gen

Buildings

The "Buildings" folder contains the UBS and LBS buildings decided by Sandia and City of Hoboken determined to be critical. Buildings can be visually seen on the map in different layers categorized by Function, Tier, LBS and/or UBS. These will appear on the map as balloons in different colors denoting its function (red=emergency, blue=water, purple=community services, green=shelter, pink=infrastructure) and number for Tier group.

Equipment Inventory

The "Equipment Inventory" folder contains three subfolders labeled "Non-ESDM generation", 'ESDM generation" and "Transformer". The "Non-ESDM generation" folder has the existing generators, future bond generators and potential photovoltaic systems. Generators are represented on the map by a magenta triangle and the photovoltaic systems are represented by a pink polygon. "ESDM generation" is the folder that contains generators for the TMO option space. Sizes for these generators are on the excel spreadsheet used by TMO which is included in the Appendix. The "Transformers" folder contains all the additional transformers needed to create the ESDM microgrid represented by a magenta circle.

Potential Microgrids

The “Potential Microgrids” folder contains all the electrical feeder layouts and additional equipment for the LBS, UBS and TMO option space to connect the K-cluster microgrids. The following is the color code for the electrical feeders:

- Cyan – 13.8kV feeders connecting the buildings together to create the 12 K-cluster microgrids
- Magenta – 480V feeder connection
- Yellow – 13.8kV feeder connecting LBS and UBS buildings
- Purple – 13.8kV feeder optional feeders connecting the K-cluster microgrids together used for TMO optimization

In addition to the electrical feeder layout, additional manholes and transformers are included. Transformers are represented by magenta circles and manholes are represented by dark green solid circles.

The subfolders under the “Potential Microgrids” folder breakdowns the microgrid according to LBS, UBS, Hoboken Housing Authority (HHA) and all the feeder connection options between them. The HHA microgrid is labeled as the folder “Non-LBS”. Within the folders “LBS MV options”, “UBS MV options” and “Non-LBS MV options” are subfolders which show the electrical feeder connections and equipment needed to connect a K-cluster microgrid to another. For example, to see the connections between microgrid 1 and microgrid 2 perform the following:

- Check the box next to the folder “Buildings” to show the UBS and LBS buildings
- Expand the folder “Potential Microgrids” by clicking on the + sign
- Check the box next to the folder “LBS” to show the K-cluster microgrid electrical feeders and equipment
- Expand the folder “LBS MV options” by clicking on the + sign
- Expand the folder “MG1” by clicking on the + sign
- Check the box next to the folder “MG1 to MG2” to show the electrical feeder connections and equipment to connect LBS Microgrid 1 to LBS Microgrid 2.

Stay Dry and Flood Smart

Checking the box next to the "Stay Dry and Flood Smart" folder will overlay the FEMA developed map. Upon checking this box, a set of instruction will be brought up on the screen created by FEMA to navigate the flood map.

Flood Map

The "Flood Map" folder was created by Sandia which provides an overlay of blue solid polygons representing height of flood waters in meters above sea level (blue solid polygons). Subfolders under the "Flood Map" folder are labeled with numbers representing the height of the flood waters above sea level. Checking the box next to one of these folders will visually show the height of the water within the city which is used to determine which buildings will be under water for that condition.

Appendix Q

Original Diagram Files

This document has had various diagram files embedded. For some versions/types of PDF file readers, a full-resolution copy of the original graphics files can be downloaded by clicking on the thumbtack links in Table Q.1.

Table Q.1: Original graphics files.

Link	Description
	Powerpoint version of the CONOPS (Figure 2.6)
	Powerpoint version of the building microgrid connections (Figure 4.3)

Appendix R

Useful Embedded Files

This document has had a supporting document embedded. For some versions/types of PDF file readers, a full-resolution version of an entire document can be downloaded by clicking on the thumbtack link in Table R.1.

Table R.1: Embedded supporting documentation file.

Link	Description
	Sandia-authored Cyber Security Reference Architecture for ICS

Appendix S

Glossary of Terms

Baseline Design: This is a reference point against which are gauged potential improvements suggested by the ESDM. For a site with existing backup generation, this amounts to the observed historical performance, or expected performance based on the system architecture. For a site without existing backups, then the baseline needs to represent some useful comparison – most likely, a program of providing one backup generator per critical load site (which is the conventional approach), which can be compared to the likely ESM architecture resulting from the ESDM.

Critical Load: those loads / buildings that are critical to the mission or function of the facility; these loads usually have dedicated backup generators. Some Type C loads are non-interruptible and will include uninterruptible power supplies (UPS) while other Type C loads can endure short losses of electrical power.

Design Basis Threat: ESDM uses DBT to define the most stringent conditions (threats) which must be met in the system design. These threats may be environmental (such as a hurricane) or man-made (such as a cyber or physical attack).The term is borrowed from the nuclear industry.

Energy Surety Design Methodology: an analysis process developed by Sandia National Laboratories that quantifies and optimizes six key attributes for energy systems (safety, reliability, resiliency, security, sustainability, and cost effectiveness) to develop effective preliminary designs that meet stakeholder requirements. A key concept for ESDM is that energy surety investments are intended to improve performance for extraordinary events like natural disasters or intentional attack, although investments in energy surety can also provide improvement during normal periods, or more conventional emergencies.

Energy Surety Microgrid: Microgrids developed using the ESM methodology demonstrate increased reliability for critical mission loads resulting from the interconnection of electrical generation assets using the existing distribution network; reduced reliance on diesel generated backup power through the use of renewable energy sources during outages; increased efficiency of diesel backup generators through careful coordinated operation across the microgrid system; and operational risk reduction through strong focus on cyber security.

Low Voltage: Equipment that operates at approximately 1kV or less (different standards have slightly different upper bounds).

Medium Voltage: Equipment that operates in the range of approximately 1kV to 70kV (different standards have slightly different upper and lower bounds).

Operator: The stakeholder-designated agency and/or personnel that actually monitor and run the energy systems.

Other Load: Those loads / buildings that will not be powered during islanded, microgrid operations.

Preliminary Design: The ESDM process results in a preliminary design, which describes microgrid functional requirements as well as quantifiably-justified recommendations that will meet the stakeholder concerns. Requirements and recommendations are specified for energy networks, generation, concept of operations, utility connections, controls, and cyber security.

Priority Load: Those loads / buildings that are of high priority ("nice to have"), but that can be switched on or off of microgrids at the discretion of the designated emergency authorities.

Appendix T

Sandia National Laboratories / DOE Contact Information

Name	Organization
Jason Stamp *Design Team Lead*	Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185-1108 jestamp@sandia.gov
Ross Guttromson *Sandia Project Manager*	Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185-1140 rguttro@sandia.gov
Dan Ton *DOE Program Manager*	U.S. Department of Energy 1000 Independence Avenue, SW Washington, DC 20585 dan.ton@hq.doe.gov

Report Distribution

1 Dan Ton
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 Rima Oueid
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 Stephen Marks
City of Hoboken
94 Washington St
Hoboken, NJ 07030

1 Caleb Stratton
City of Hoboken
94 Washington St
Hoboken, NJ 07030

1 Brandy Forbes
City of Hoboken
94 Washington St
Hoboken, NJ 07030

1 Eric Daleo
Governor's Office of Recovery and Rebuilding
PO Box 001
Trenton, NJ 08625

1 Mike Winka
New Jersey Board of Public Utilities
44 South Clinton Avenue
Trenton, NJ 08625

1	MS0671	Jordan Henry, 5628
1	MS0751	Richard Jensen, 6914
1	MS1033	Abe Ellis, 6113
1	MS1140	Ross Guttromson, 6113
1	MS1188	Michael Baca, 6114
1	MS1188	John Eddy, 6133
1	MS1188	Karina Muñoz, 6114
1	MS1188	Alan Nanco, 6114
1	MS1188	Ben Schenkman, 6114
1	MS1188	Mark Smith, 6114
1	MS1188	Jason Stamp, 6114
1	MS0899	RIM-Reports Management, 9532 (electronic copy)

v1.32JES

Sandia National Laboratories