Asia-Pacific Economic Cooperation

Advancing Free Trade for Asia-Pacific Prosperity

APEC Workshop on Improving Electric Grid Resilience to Natural Disasters

APEC Energy Working Group

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PREFACE

This report has been prepared to meet the requirements of the following APEC project.

Project number & title:	**EWG 09 2018S** **APEC Workshop on Improving Electric Grid Resilience to Natural Disasters**
Committee / WG / Fora:	Energy Working Group / Energy Resiliency Task Force
Project Overseer Name: Organization / Economy	Cary Bloyd, Senior Staff Scientist, Pacific Northwest National Laboratory, U.S.A.

The report presents information on the result of the **APEC Workshop on Improving Electric Grid Resilience to Natural Disasters** (EWG 09 2018S). The workshop included discussion of energy security and resilience analysis and design for communities, and a full example analysis done with the attendees for a hypothetical small community (20,000) people. The workshop allowed APEC economies to exchange experience on methods and approaches for evaluating and planning for natural disaster risks to power systems, infrastructures, and communities. The workshop also provided the opportunity to show how Smart Grid, advanced microgrid, and distributed and renewable energy generation and storage technologies can be used to enhance the reliability and resiliency of the electric grid in the APEC region.

Acronyms

APEC	Asia-Pacific Economic Cooperation
CCHP	Combined cooling heating and power
DBT	Design Basis Threat
DER	Distributed Energy Resource
DOE	US Department of Energy
EPRI	Electric Power Research Institute
ESDM	Energy Surety Design Methodology
EWG	Energy Working Group
GIS	Graphical Information System
MW	Megawatt (million watts)
MWh	Megawatt hour
PCC	Point of Common Connection
RAM	Risk Assessment Methodology
RAM-E	Risk Assessment Methodology - Energy
PNNL	Pacific Northwest National Laboratory
ROM	Rough Order of Magnitude
Sandia	Sandia National Laboratories
SEPA	Smart Electric Power Alliance
USA	United States of America

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EXECUTIVE SUMMARY

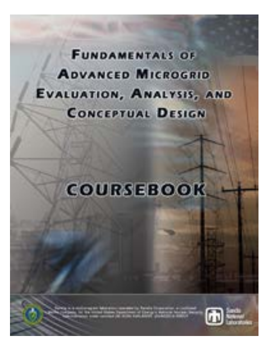
In support of APEC's Energy Working Group, the Energy Resiliency Task Force, the US. implemented a **Workshop on Improving Electric Grid Resilience to Natural Disasters** (Appendix A). The two-day workshop was developed to provide information, training, and capacity-building to participants from APEC economies through interactive exercises and instruction from practitioners engaged in resilience planning and improvement of the electric grid and communities through the use of advanced microgrid concepts and designs. The workshop was designed to help APEC economies and participants build an understanding of:

- Methodologies for evaluating natural disaster risks to power system resources, infrastructure, and communities,
- Climate-driven natural disaster risk screening for grid and community resiliency planning, and
- Integrated natural disaster improvements and response analysis to support grid and community decision-making.

The workshop included discussion of the emerging issues and challenges of energy infrastructure resilience, benefits of the use of advanced microgrids to enhance energy grid and community resilience, as well as training in advanced microgrid evaluation, analysis, and conceptual design.

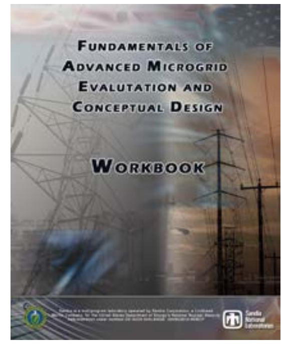
1. APEC Electric Grid Resilience Workshop

The two-day workshop training included many case-studies of resiliency issues and challenges to the electric grid and communities from natural disasters, as well as several exercises in the planning, analysis, and development of advanced microgrids to enhance resilience (Appendix B). The workshop focus was to build an understanding by APEC economy participants on how Smart Grid technologies and capabilities such as integrated distributed and renewable energy resources, smart metering, and smart switching, and automated controls can be included in resiliency design solutions to accelerate cost-effective grid and community resilience planning, design, and implementation against natural disasters.



Over 45 representatives and practitioners from 11 different APEC economies attended and participated in the workshop (Appendix C). Each participant received two bound workshop training manuals. One was a 220-page Course Book that included chapters on background information on resilient design issues and emerging challenges for the electric grid and communities, all the course presentation vugraphs and materials, and reference chapters on renewable energy and distributed generation technologies, reliability analysis, example engineering designs, and community information requests for microgrid designs.

The second manual was a Work Book that contained worksheets of example problems for each chapter in the Course Book as well as materials for a final example microgrid design.



The workshop was broken into eleven separate evaluation, analysis, and design modules as presented in the Course and Work Books. The focus of the course was on helping participants understand and conduct the analysis and design steps required to create conceptual grid resilience designs using distributed generation and Smart Grid technologies to enhance electric grid and community resiliency.

The workshop modules included:
Module 1: Introduction to electric power system, energy assurance, and community resilience
Module 2: Use of advanced microgrids for energy and community resilience
Module 3: Energy Surety Design Methodology
Module 4: Defining system boundaries and grid and community goals
Module 5: Identifying and ranking critical energy and community assets and services
Module 6: Identifying potential threats and community risks
Module 7: Defining community and grid resilience performance goals
Module 8: Performance Risk Analysis
Module 9: Electrical load estimation analysis for sites with limited load data
Module 10: Formulating resilient grid design options
Module 11: Cost Estimating for Grid Improvements

The final part of the workshop was an Example Problem of the design of advanced microgrids for a hypothetical small community (20,000) people. For the example problem, the participants were divided into four groups to work together using the previous course exercises to spend a half-day to develop a conceptual design and preliminary cost and performance analysis for a microgrid. The microgrid designs required consideration of critical loads, shedding of non-critical loads, the use and integration of switching technologies to isolate the microgrid from the main grid to operate islanded, and integration of appropriate distributed and renewable energy generation and storage systems to provide adequate power and reliability for the microgrid during the design outage. Then each team reported out to the whole group on their final analysis and design considerations and costs.

Following the microgrid analysis and design exercises and discussions, the group heard from an expert panel including D.K. Kim from the Asia Development Bank, Mark Paterson, of Strategen, and Dr. Jyuung-Shiauu Chern, the EWG Lead Shepard. Both D.K. Kim and Mark Paterson have extensive experience in advanced microgrid design and implementation in Korea and Australia respectively and discussed opportunities to work with ADB and Australia in future microgrid design and construction efforts.

2. Energy Resilience Workshop Summary Results

Following the presentations, training, the case studies, and breaking into teams to do the example problems, all the workshop participants, including the expert panel, collectively discussed some of the major challenges and issues they considered and the final approaches they took in the example microgrid design effort, as well as what might be needed in the future as far as training and support needed for microgrid implementation training for APEC economies. From the discussions and reviews, four general conclusions were observed. They include:

1. **Overall, the participants responded that the workshop was useful, valuable, and increased their knowledge of resiliency and the use of microgrids.**

   Over 30 participants responded to the end of workshop questionnaire and 83% responded that the topic was relevant/very relevant to their economy, 100% agreed/strongly agreed that the workshop materials were useful, and about two-thirds of the respondents thought their knowledge and skills in the topic increased from low/very low to high/very high during the workshop, which is a significant improvement. Finally, 100% of the respondents thought their understanding of grid and community resilience had increased to medium to very good.

2. **Suggestions of expanding Workshop Training to three days.**

   In the workshop evaluations, about 20% of the respondents thought they needed more time to assimilate the concepts presented in the workshop. Also, several respondents made specific comments that in the 2-day training they felt rushed to comprehend the material, and many requested the training be expanded to 3-days. While the course was originally designed as a 3-day course, many groups have requested the training to be done in two days. In many of those cases, the participants have had specific experience in energy grid operations and security and risk analysis.

   The survey responses suggest that participants from many APEC economies have less experience with renewable energy system integration, advanced control technologies, and less experience on risk assessment approaches, though some economies such as Korea and Australia have an excellent understanding and the use of renewable energy and microgrids. Almost 70% of the APEC workshop participants responded that they had Low/Very Low knowledge of microgrids and how they worked prior to the workshop. This lower level of initial technical understanding and experience about microgrids suggests that additional time should be provided for example problem solutions and discussions. This can be easily done and successfully accomplished in a three-day workshop format by allowing more time to discuss example projects, associated microgrid designs and operations, as well as increasing time for workshop exercises and discussions.

3. **Include more renewable energy integration training.**

In the example community microgrid designs, the four teams chose to consider limited use of available renewable energy resources in their example designs. Each chose to focus on the use of traditional distributed generation resources, i.e. backup generators. None of the teams weighed the high fuel requirements, and large fuel storage requirements for an extended power outage of 7-10 days as something that might be problematic without the use of renewable energy resources.

In final discussions it appeared that the teams were less comfortable with analyzing and integrating renewable energy resources in their designs, even though several APEC economies, such as Australia, Korea, and the US all have significant experience in renewable energy integration with microgrids. Therefore, future efforts should include examples of renewable energy integration and advantages to increase awareness and familiarity in how to include them in them locally during a grid outage are needed.

That could include activities focused on tours of microgrid systems with the ability to operate both grid-tied and islanded, specific training on renewable energy integration into advanced microgrids that can be operated islanded and grid-tied and the benefits and hardware requirements, and inclusion of a module to this training to specifically address renewable energy integration approaches, and resiliency benefits related to natural disasters.

4. **Opportunities exist for economy-specific energy resiliency projects and training.**

Mr. Kim highlighted opportunities for funding from ADB for renewable energy projects focused on supporting grid assurance and resiliency in the Asian region, and suggested APEC economies consider the use of advanced microgrids to enhance renewable energy utility for supporting future grid resilience. Mark Paterson discussed some of the lessons learned and applications of over 50 different distributed generation and advanced microgrid applications in Australia and how they have been used to support local power reliability. Finally, Dr. Chern discussed how important resilience of communities is becoming to APEC economies and the need to improve how energy resiliency can be incorporated into emerging energy improvements to enhance public health and safety as well as APEC long-term robust and resilient economic development.

Therefore, all three panelists suggested future grid modernization efforts in APEC economies should include renewable energy integration to enhance grid resilience, and that opportunities exist for assistance from APEC, ADB, and other APEC economies to support renewable and distributed generation integration for grid resilience.

While none of the economies attending stated they are currently planning any grid resiliency projects with renewables, some opportunities exist that could help accelerate consideration of Smart Grid technologies to enhance grid and community resilience in the future. These could include:1) tours or workshops of existing microgrid projects and applications in various APEC economies to increase awareness of the cost/benefits and regulatory approaches used in different APEC economies, and 2) conduct additional grid resilience workshops to expand overall knowledge and understanding. For example, there are workshops available to provide instruction beyond conceptual designs to create more detailed preliminary microgrid design for direct implementation. All these efforts would help expand the availability of grid resilience design training and renewable energy integration opportunities for APEC economies.

SECTION 1. Emerging Electric Grid Resilience Issues and Challenges

Modern societies are highly dependent on reliable electric power to support community and industrial operations, infrastructure, and services that support both economic vitality and public health and safety. Therefore, concerns are growing of how to protect critical infrastructures so they function effectively during a natural disaster because these events can severely damage infrastructures and power outages that can last for days to weeks (Biringer 2013). The trend in the number of extreme weather events in the US has increased significantly as shown in Figure 1, which has impacted the electric grid, increasing the duration and extent of power outages and tripling the number of customers affected (Campbell 2012). Similarly, the number and damage from natural disasters across APEC and the world has increased by 50% since the 1990's as tracked by Munich Reinsurance.

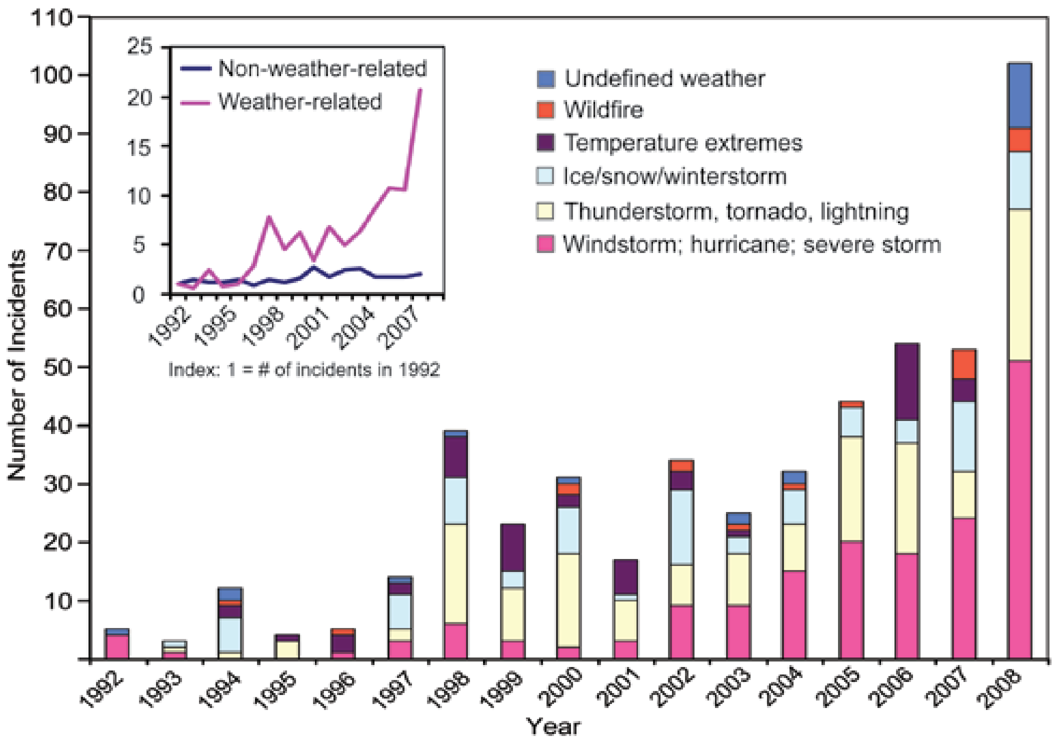


Figure 1. Growth in Number of Natural Disasters in the US.

These trends have not only raised concerns about how to protect and maintain the reliability of the electric power system against natural disasters and extended outages, but have also raised concerns about how to reliably maintain power to support critical community services such as public health and safety, water and waste water, police and fire protection, hospitals, shelters, and communications.

Community resilience has been defined by the 2009 Community Resiliency and Recovery Initiative as - "*A community's or region's ability to effectively prepare for, respond to, and successfully recover from a manmade or natural disaster, by having the ability to quickly: Return citizens to work; Reopen schools and businesses; and Restore the essential services needed for a full and swift economic and social recovery*".

The strong interdependency between the energy infrastructure and community services and critical infrastructure operations suggests that community resilience is therefore directly tied to electric power reliability and robustness. This highlights how important it is for communities to consider options to improve the design, operation, and management of their energy system infrastructure to assure critical infrastructure and critical service operation during natural disasters. Therefore, improving the security and resiliency is a driver in creating a 21st Century grid that can addresses our 21st Century challenges.

1.1. Limitations of Current Approaches for Electric Power Reliability

There are three traditional approaches to enhancing the reliability of the electric power systems and include:

1. The use of building-tied backup generators to provide power during a utility outage,
2. The connection of multiple and redundant power lines to a sector of a community or industrial complex to provide redundant power feeds to minimize power loss if one line fails, and
3. Hardening of electric substations and power lines to better withstand damage from a severe event.

In many cases, a combination of these approaches is often used. Unfortunately, evaluations of the effectiveness of these traditional energy system improvements have shown they are ineffective in addressing major disasters that 1) impact large areas and cause long-term (5-10 day) power outages, and 2) are often very costly (Hightower 2014) (DOE 2018).

For example, failure of backup generators is unfortunately quite common, with operational reliability of only about 60% or less. This is because most backup generators are poorly maintained and improperly tested, so they either do not start or run improperly when needed. Also, they are often not sized properly for the critical loads, and often only have sufficient fuel to operate for less than a day. Without constant refueling, the generators are ineffective in suppling power for an extended outage of five to ten days. Finally, portable generators nominally come in three configurations, emergency generators that can operate up to 100 hours before needing major service, backup generators that can operate up to 400 hours before needing major service, and prime generators designed to operate for approximately 10,000 hours before needing major service. The costs of the generators vary significantly, and therefore emergency generators are often purchased to save money, when a more rugged generator is really needed. Needless to say, the overall operational effectiveness of a low-cost, 100-hour, emergency generator in a seven-day power outage is very low (Nelson, 2018).

Use of redundant power lines to support regional electric power demand is a very common approach to improve regional or local electric grid reliability. With some hardening of poles and substations, this is a common approach for regional-scale energy reliability and resiliency. While this approach works well for common small events, larger and more severe events and disasters often have wide-spread impacts, which cause extensive regional damage of a large number of power lines, power poles, and substations. This reduces the benefits and effectiveness of redundant systems that are impacted by large, regional disasters with regional impact.

Hardening of electrical substations, power poles, and burying power lines have all been used effectively to improve energy system reliability and enhance resiliency.   The biggest concern with hardening is the general cost of the improvements. In many cases, utilities have found that recovery and repair of energy infrastructure and power lines, or turning off the power, can be more cost-effective than hardening hundreds of miles of grid infrastructure. This is because hardening power system elements for disasters that have extremely high winds, or have to survive flooding, mudslides, or extreme fires is often expensive. But, as severe events become more common and storms and disasters become more severe and wide-spread, recovery and repair will be more problematic and energy and community recovery more delayed.

Therefore, some argue that the benefits of the public incorporating resilience and robustness into the energy grid and communities versus the risks of a major disaster do not match the extra costs of current resilience approaches (Hassler and Kohler 2014). They conclude that for the built environment, "*Building resilience and robustness is valuable, in theory. In practice, the cost should not be underestimated. Resilience and robustness are abstract, very costly public goods*." This highlights the reluctance by many to design for resiliency.

To address this challenge, the US DOE and other agencies in the APEC region, including Australia and Korea, have for over a decade funded major efforts to utilize renewable and distributed energy technologies in conjunction with Smart Grid control approaches to improve energy system security and resilience at significantly reduced costs. Advanced microgrids are one operational framework capable of effectively integrating distributed energy and Smart Grid technologies to address the cost and performance challenges of enhanced energy and community resiliency. The following sections highlight ways to utilize microgrids, advanced microgrids, and resiliency nodes, to improve electric grid and community performance relative to natural disasters more effectively and at much lower cost.

SECTION 2. Improving Electric Grid Resiliency Using Advanced Microgrids

An advanced microgrid is commonly defined as - an integrated energy system consisting of loads and distributed energy resources (DERs) operating as a coherent unit, that can operate either in parallel with or islanded from the power grid using advanced controls and protection, whose main purpose is support critical loads during severe power outage contingencies. As shown in Figure 2, advanced microgrids can include collections of buildings connected to the existing distribution feeders that form by isolating portions of the feeders connected to these buildings during a major event using points of common connection (PCCs) and serving these loads with sufficient local generation to be able to supply the loads for the duration of the outage.

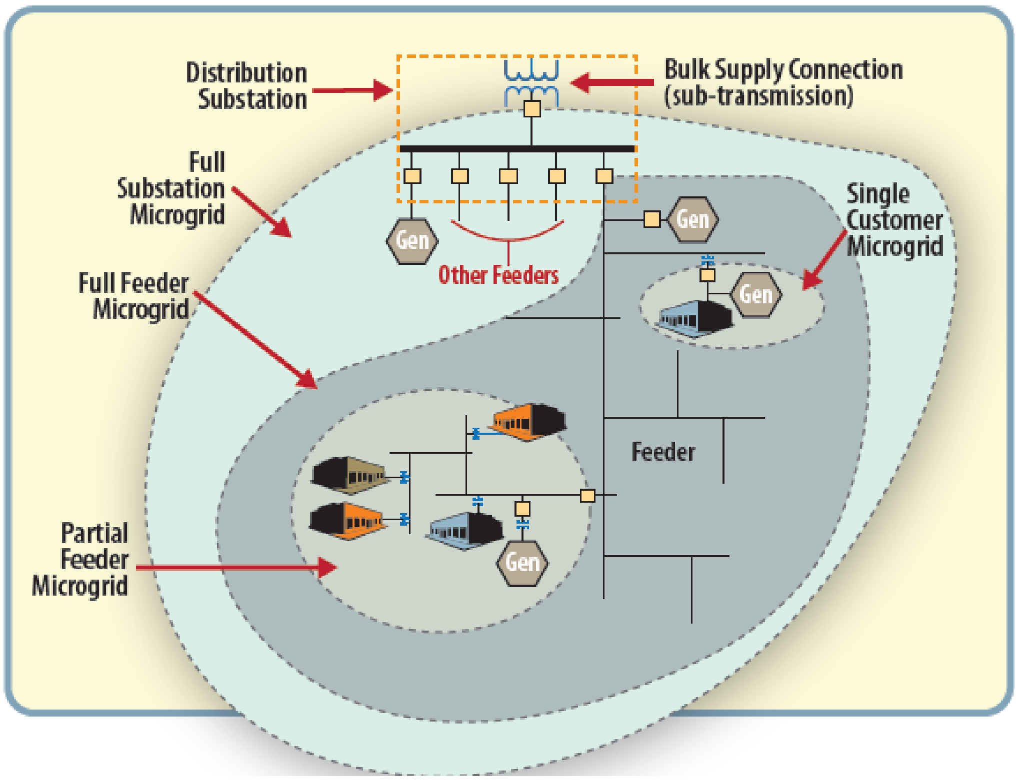


Figure 2. Advanced microgrid size varies depending on distribution feeder use.

With respect to design and operation, an advanced microgrid is always planned with consideration to make optimal use of existing local energy resources, meaning that existing distribution infrastructure elements such as distribution lines, distributed generation, and renewable energy systems are incorporated to support microgrid operations and reduce overall capital and operating costs. Advanced microgrids are therefore designed to supply power to either all the buildings within the microgrid or a set of critical buildings needed. Since it may be cost prohibitive to supply generation to all buildings, it is possible to employ automated switches that disconnect non-critical buildings to optimize generator use and reduce operation costs, while balancing the added cost of the load shedding equipment.

In advanced microgrids, all distributed generation resources - renewables, energy storage, diesel or natural gas generators, etc. - are connected on the local distribution system through one or more points of common connection (PCC)s. As shown in Figure 2, there is flexibility in the size of the advanced microgrid, ranging from a partial feeder, full feeder, multi-feeder, or even a full substation advanced microgrid configurations, depending on local needs.

A major benefit of an advanced microgrid approach over more common stand-alone emergency generators, hardening, or even a standard microgrid that can only operate islanded from the larger power grid, is that with modern control technologies, distributed generation systems can be used when tied to the grid to reduce peak loads, and when islanded from the grid can operate independently during a power outage to safely shed loads and only support local critical loads quickly. This control approach enables renewable energy resources to be fully utilized during a power outage instead of being shed for safety reasons, requires fewer backup generators because of energy use optimization, reduces fuel use and fuel storage needs through optimum generator use and efficient integration of renewable energy resources. By being tied to the existing distribution grid, capital costs are also often significantly reduced.

For these reasons, advanced microgrids are often a cost-effective energy reliability and resiliency option, having the ability to recover design and implementation costs after only a single power outage event. This from both lower implementation costs and the avoided economic losses of community critical operations and services. Cost recovery by an advanced microgrid can be further improved by generating income with Smart Grid controls to better manage distributed generation and renewable resources to routinely support the utility by providing ancillary services – load shedding, frequency support, etc. - as needed.

While grid and utility support is not commonly used by advanced microgrid designs due to regulatory and utility integration challenges, some utilities use advanced microgrids to provide ancillary services routinely with great success. In some APEC economies, advanced microgrids are often operated daily to offset local power reductions in either the summer or winter.

2.1 Advanced Microgrids as Grid and Community Resiliency Nodes

Improvements to the energy distribution system are commonly required when implementing advanced microgrids, including adding improved safety protection schemes, hardening of generator enclosures from wind or water damage to improve reliability, rewiring of distributed generation assets to increase support from a single building to the entire microgrid, as well as the cost of adding power control technologies.

While advanced microgrids are not applicable everywhere, for example at a single remote building location, advanced microgrids are very cost-effective in areas where clusters of critical facilities with critical power reliability needs exist, such as hospitals, military installations, community public health and safety services, economically important industrial campuses. This is also the case in areas with clustered critical services, such as in downtown areas, or regional shopping or banking centers. These type of critical building/service clusters are common in most communities, and therefor are candidates for consideration of implementing advanced microgrids. Utilizing clustered services and infrastructures as locations for advanced microgrid locations create 'resiliency nodes' on the grid and throughout a community.

Energy grid and community resiliency analyses in the US at over 40 communities and installations has shown that as little as 15-20 per cent of the total energy demand is critical, and therefore creating a few 'resiliency nodes' using advanced microgrids can often address most community critical infrastructure and service needs during a natural disaster caused power outage. In smaller cities, commonly only 3-5 advanced microgrids supporting clustered critical services and infrastructures are required, while larger cities may require as few as 15-20 advanced microgrids to create 'resiliency nodes' to meet grid and community resiliency needs.

2.2. Advanced Microgrid Business and Management Models

As APEC economies consider future electric grid resiliency improvements, the discussion above highlights some of the cost and economic advantages of advanced microgrids, commonly called 'smart grid nodes' or 'resiliency nodes.' Based on an APEC economy's grid management and operation, regulatory structure, and funding approach, various business models for the integration of advanced microgrids into a national or regional grid can be used. A recent study by the US Electric Power Research Institute (EPRI) and Smart Electric Power Alliance (SEPA) report, "Microgrids: Expanding Applications, Implementations, and Business Structures", identifies three likely advanced microgrid business and management models. The common business models in shown in Figure 3.

In their report, SEPA summarized the following trends and directions to encourage and utilize advanced microgrids for their resiliency benefits to an electric grid operator based on their particular economy approaches and regulatory structures. These include:

- **Microgrid business models** are evolving along a continuum, from third-party projects to utility-initiated projects. In between, a hybrid, "unbundled" model based on public-private partnerships is emerging, which could offer more flexibility and opportunities for collaboration.
- **Assigning value to microgrids**— monetizing a project's potential value streams is complicated by the tangle of economic and industry factors involved. Clarity on price signals, rate structures, and regulations are needed for the sector to expand. Characterizing and having confidence in value streams for microgrids over time are likewise necessary for investment in these systems.

- **Current technical standards** can provide guidance on microgrid development, but a more detailed and nuanced set of standards is needed to help ensure interoperable designs, communication, and testing practices."

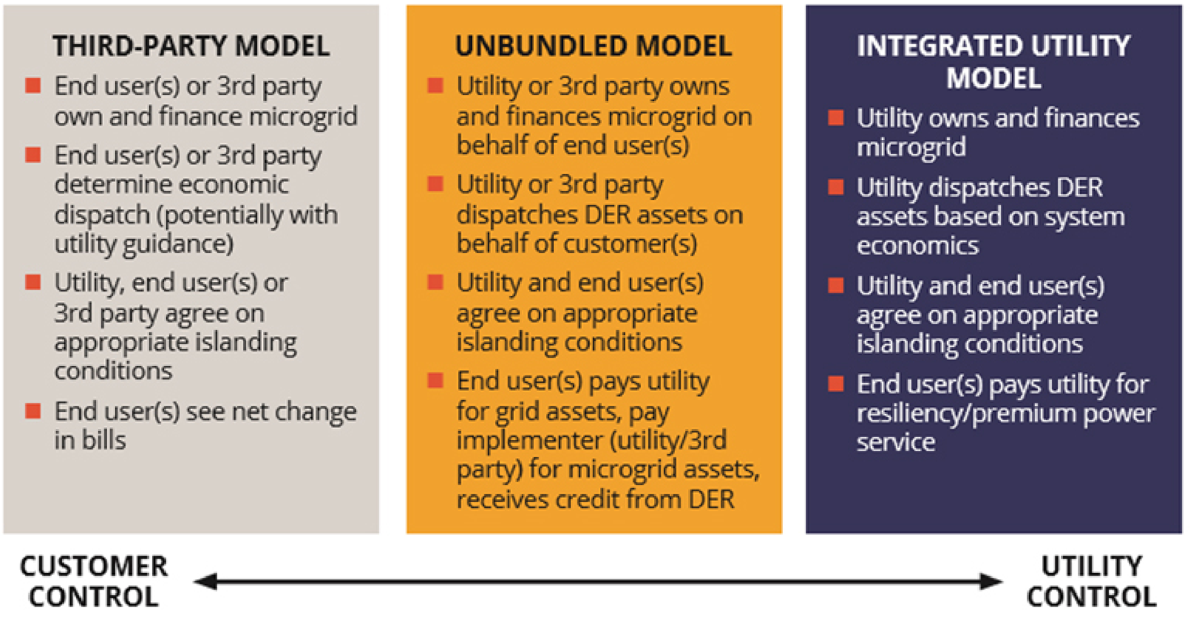


Figure 3. Current Advanced Microgrid Business Models

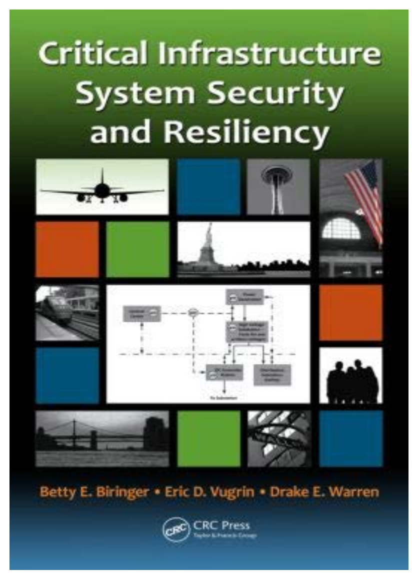
Therefore, while most current advanced microgrid business models being developed across APEC economies are of the Third-Party type, there is an emerging trend of utilities supporting movement to the Unbundled and Integrated Utility business models. But this changes the cost and control strategy and structure of future advanced microgrid implementation. Therefore, the overall acceptance of these improvements in microgrid business models in APEC economies will likely impact the future viability and applicability of advanced microgrids in cost-effectively improving grid resiliency to natural disasters. Therefore, to help make cost-effective improvements to both grid and community resiliency in the future, coordination of technical, operational, and regulatory improvements will likely be needed across all APEC economies.

SECTION 3. Advanced Microgrid Conceptual Design Framework

The previous sections highlighted the need for communities and utility managers to understand and consider how important resilient design, operation, and management of the electric grid is to assuring critical infrastructure and critical community services during natural disasters. Over the past two decades, utility, government, and community groups have come to understand the importance of the security, reliability, and resiliency of the electric grid, and the need to create a 21st Century grid that can address our 21st Century challenges.

In support of the US DOE from 2008 through 2015, Sandia National Laboratories developed and applied an Energy Surety Design Methodology (ESDM) to help installations and communities assess energy improvements needed to improve energy security, reliability and resilience to support local and regional critical community services for a range of extended power outages from severe events and natural disasters. The ESDM is a risk-informed, performance-based, energy system analysis framework designed to enable utilities and municipalities to identify strategic energy needs, quantify power outage durations from severe events, set grid operational goals, and develop cost-effective conceptual designs to meet utility and community. (Hightower 2014) (Jensen 2017).

The ESDM approach is based on Sandia's Risk Assessment Methodology for Energy (RAM-E) developed for the US DOE in the early 2000's. The general RAM approach and its application to critical infrastructure security and resiliency was recently published in a new book (Biringer 2013). A major new element of the ESDM methodology is that it includes consideration of both traditional grid upgrades, but is focused on the use of advanced microgrid approaches to assess the cost-effectiveness and resilience benefits of different energy solutions. The ESDM analysis and design framework was developed to be used in cooperation with installation, utility, and municipality managers and stakeholders to jointly identify the cost/benefits of various conceptual design and operational grid improvement options to meet critical infrastructure and services resiliency goals for extended outages caused by severe disasters.



The basis of the framework is the use of risk-based analysis concepts in conjunction with emerging Smart Grid monitoring and control technologies and new distributed and renewable generation and storage technologies, to assess innovative and cost-effective grid improvement options and create conceptual designs.

Shown below in Figure 4, are the basic analysis steps of the ESDM approach, which include:

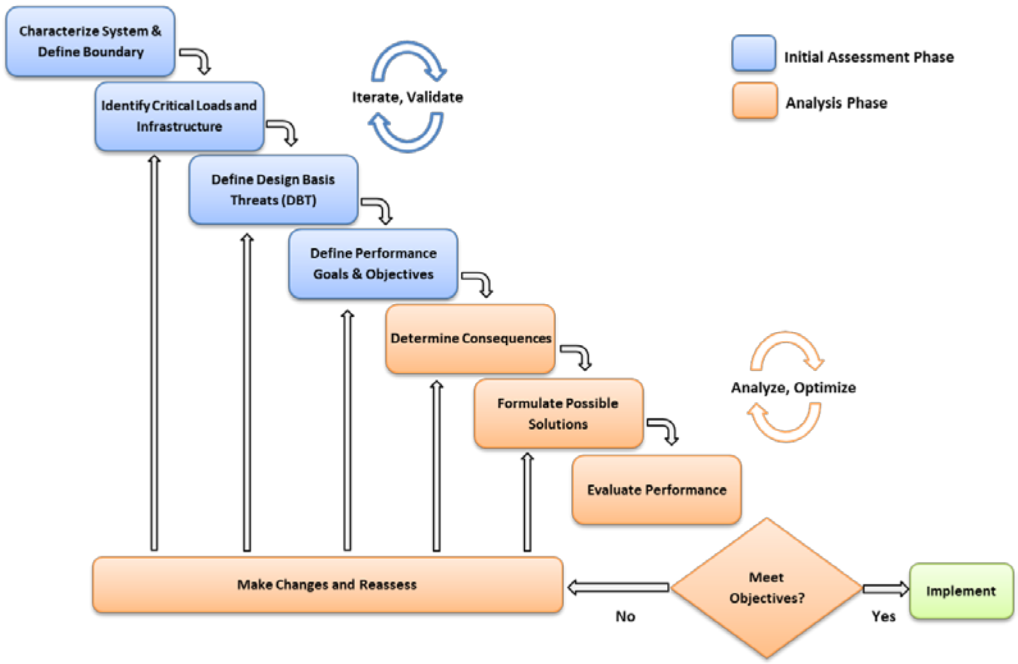


Figure 4. ESDM Energy System Performance Risk Assessment Framework

1) work with utilities and stakeholders to identify critical facilities and services needed,
2) work with utilities and stakeholders to identify credible power outages based on local and regional natural disaster hazard and impact analyses,
3)work with utilities and stakeholders to set energy system performance goals for these events and extended outages,
4) utilize performance risk-based assessments to focus improvements and to quantify upgrade costs and benefits, and
5) assess cost-effectiveness of upgrade options relative to community health and safety performance goals.

The general ESDM approach has been utilized to develop grid conceptual designs and associated rough order of magnitude cost estimates for distribution-level upgrades at more than 40 installations and communities in the US and other countries, including other APEC economies. With the ability to incorporate improvements such as renewable energy technologies, load shedding, energy storage, and combined heat and power within an advanced microgrid framework, the ESDM methodology enables conceptual designs that optimize the use of distributed generation resources and the ability to operate both islanded and grid-tied, providing both capital and operational efficient and cost-effective energy resilience solutions.

With a realistic conceptual energy grid upgrade analysis, design information, and associated cost and performance benefits identified, articulating funding requirements and establishing preliminary and final design specifications help accelerate the development of funding strategies and approaches. Our experience is that a stakeholder developed conceptual designs help accelerate grid improvement planning, implementation, and construction. This analytical, performance-based approach is preferred over jumping directly into a poorly thought out preliminary grid improvement project without knowing critical stakeholder mission and critical service needs, load requirements, and potential operational and power outage duration metrics.

3.1. Overview of the Advanced Microgrid Design Course

To assist utilities and stakeholders in to improve grid and critical community service response to natural disasters, in 2015, Sandia developed a course on the fundamentals of advanced microgrid evaluation, analysis, and conceptual design. The course was designed to provide stakeholders and utilities with a step-by-step process on evaluating community and local grid threats, challenges, and needs based on site-specific cultural, economic, and social energy and community resiliency needs. The course is based on the experience gained in developing advanced energy resilience designs. The course includes:

- General information on the topology, design, and operation of electric grids, so all participants have a working knowledge of grid elements, operations, and designs,
- Information on the definitions and metrics of energy surety, security, and resiliency,
- Use of advanced microgrids to meet emerging electric system operational performance metrics and needs,
- Understanding of advanced microgrids, associated technologies needed, applications, and use,
- Step-by-step instructions on developing energy assurance designs for critical assets, quantifying design threats, setting performance goals, and conducting performance risk analyses of the existing system,
- Cost estimating information to support rough-order of magnitude cost estimates of advanced microgrid designs and construction, and
- Finally, based on the performance risk analyses of an energy distribution system, provide step-by-step options on when and where advanced microgrids provide the best value and where other solutions are more appropriate.

The course also provides information on general lessons learned, analysis and design rules of thumb, and general cost and construction data associated with grid and community resilience upgrades developed over the past decade at over 40 communities and installations.

The course was developed to support a broad range of energy and community planners, energy and community managers, other infrastructure managers, community stakeholders, and engineers to identify and assess grid infrastructure improvement options. The appropriate groups include:

- Utility master planning design teams - for either new master planning or modifications of existing grid and community master plans,
- Community planning teams – for either new development or improvements to existing critical infrastructure or critical services challenges,
- Community critical infrastructure and service managers – focused on either critical mission, infrastructure, or grid improvement operational needs and upgrades,
- Community services and economic development stakeholders – focused on community and economic needs during extended power outages,
- Contingency and emergency operations managers – focused on energy and critical mission assurance needs,
- Energy utility and grid managers and engineers – for evaluating the integration and operation of distributed and renewable energy generation and storage technologies and advanced microgrids to optimize grid performance and cost, and
- Consulting engineers – to help in identifying, designing, and implementing appropriate grid upgrades.

The course was designed to provide these groups with the basic knowledge and understanding of how to coordinate utility, community, and public stakeholder collaboration, cooperatively establish grid and community resilience metrics, and evaluate efficient and cost-effective options to meet identified performance goals.

The following sections of the report discuss the results of an APEC workshop for training of over fifty APEC economy participants in September 2019 in the Philippines on the use of the ESDM approach.   They include discussions on the use of the ESDM training materials and example problems to demonstrate to the participants how to assess and design grid improvements to support grid resilience, as well as important highlights, lessons learned, and suggested future options and directions from this APEC grid resilience workshop.

SECTION 4. APEC Workshop of Grid Resilience to Natural Disasters

On September 19-20, 2019, in Cebu, Philippines, the Philippines Department of Energy and APEC hosted a Workshop on Improving Electric Grid Resilience to Natural Disasters. The two-day workshop was coordinated to provide information, training, and capacity-building through interactive exercises and instruction from practitioners engaged in resilience planning and improvement of the electric grid and communities through the use of advanced microgrid concepts and designs. The workshop was designed to help participants from APEC economies build an understanding of:

- Methodologies for evaluating natural disaster risks to power system resources, infrastructure, and communities,
- Climate-driven natural disaster risk screening for grid and community resiliency planning, and
- Integrated natural disaster improvements and response analysis to support grid and community decision-making.

Approximately 50 representatives and practitioners from 11 different APEC economies attended and participated in the workshop (Appendix C). The workshop training was based on the ESDM analysis and design methodology. Each participant received two course manuals. One was a 220-page Coursebook that included chapters on background information on resilient design issues, course presentations, and reference chapters on renewable energy and distributed generation technologies, reliability analysis, example engineering designs, and community information requests for microgrid designs. The second was a 50-page Workbook that contained worksheets of example problems for each chapter in the Coursebook as well as materials for a final example microgrid design.

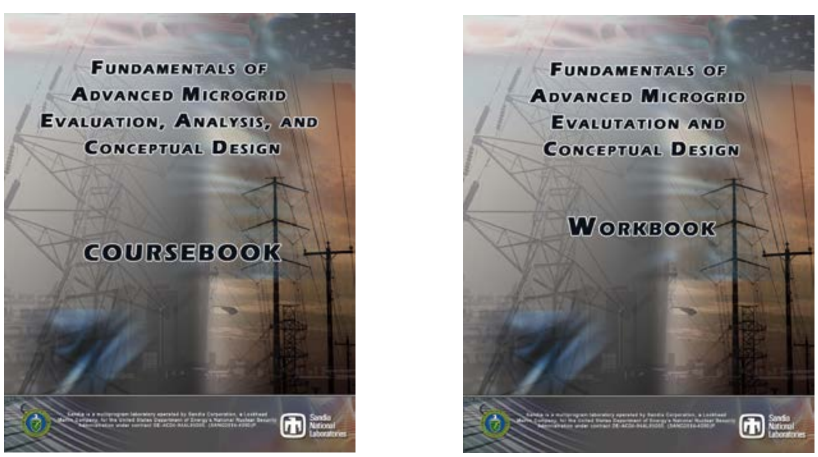


Figure 5. Workshop Course and Work Books

The workshop was broken into eleven separate evaluation, analysis, and design modules that follow each of the ESDM analysis and design steps shown in Figure 4. A summary of the technical content and purpose of each of the workshop modules is presented below.

Sections 1- 3 of this report provide a short overview of the general background information of the first three modules discussed in the workshop:

> **Module 1: Introduction to the electric grid, and energy assurance and resilience**
> **Module 2: Use of advanced microgrids for energy and community resilience**
> **Module 3: Energy Surety Design Methodology**

Following this initial introduction in the morning of Day 1, the afternoon of Day 1 and all of Day 2 of the Workshop were focused specifically on grid threat analysis for different potential natural disasters, identification of critical infrastructure and community service needs and power requirements, and exercises on potential upgrade designs and associated cost analysis. (Appendix B).

4.1. Grid Resilience Analysis and Upgrade Evaluation

Developing a grid upgrade plan for any community requires key stakeholder participation as well as detailed technical analysis to enable success. A foundation of the process requires coordination between expert energy and grid analysts along with community stakeholders. The experience of the analysts will help support data elicitation and normalizing of stakeholder knowledge and opinions, but ultimately it is key stakeholders who define the goals and objectives of any resiliency strategy that will get public support. Therefore, stakeholder involvement including community and facility managers, energy utility managers, key points-of-contact for infrastructure operations and maintenance, critical community services and function managers, public safety representatives, and economic development are vital to successfully defining community priorities and goals and implementing successful grid and community resilience strategies.

Stakeholder groups and participants required for inclusion in a grid resilience assessment were discussed with the Workshop participants. It was pointed out that the Appendix of the Course Book contains example data requests and participant lists for the process. Each Workshop participant was asked to consider what stakeholders might be required as we discussed the different community and grid stakeholder priorities. This forced the participants to think of both the grid and the community needs in the resiliency analysis efforts. We then moved directly into the grid and community resilience analysis.

Module 4: Defining system boundaries and grid and community goals

To make resilience improvements, it is critical to delineate the grid and community boundaries for consideration, because it bounds the scope of what sets of critical functions and facilities are to be considered and places constraints on the analysis and data gathering needed for the preliminary grid resiliency analysis. If it isn't entirely clear what the final critical functions and facilities are and the duration of an event, a wider selection is used as a starting point and narrowed with further analysis as needed. For example, are all police and fire substations or just major substations, or do all hospitals or only regionally significant hospitals need to be considered?

Some services and functions might be regional in nature, such as water and waste water, while others may be more local such as fire protection and public safety. Once these critical facilities have been identified, the associated distribution feeders, existing backup generation, and renewables and energy storage capabilities can be considered as to their possible inclusion in developing energy and community resilience design and upgrade options.

The course example problem presented in the Work Book, provided an example with a city center or downtown area with much of the critical infrastructure and services, but with some outlying critical functions like water and waste water treatment systems, all on different electric feeders. In the class exercise, the participants had to identify which substations and feeders were likely to be important to upgrade for resiliency based on considering themselves as stakeholders and what they might want. This exercise was designed to help them see what community stakeholders might be interested in, where they might likely need to focus resilience improvements, and therefore what grid and community asset information they could best use.

Module 5: Identifying and ranking critical energy and community needs

Critical energy and community services and infrastructures should be identified through interviews and meetings conducted with utility and community leaders and operations managers. The analysis should include both municipal and private controlled assets in order to identify the set of services and assets at risk in a natural disaster so resilience improvements can be made to minimize the impact. Table 1 is a Course Workbook example that provides an idea of the types of community services and critical assets that are commonly considered. The critical assets identified typically map to a smaller number of community services.

For example, in evaluating grid and community resilience, and which buildings/services should be included in a resiliency design, additional weight is given to infrastructure assets that provide different types and levels of service. For example, a pharmacy often includes some food service and banking in the form of ATMs, so can provide additional benefits to resilience than just medications. Similarly, the location and size of an asset also affects how important it is. A large centrally located grocery store is often more important to overall community resilience than a small one in a remote location. Depending on the size of a community or region, either a matrix or community and grid infrastructure GIS data can be used to map community services and critical assets in terms of both their primary and ancillary benefits for use in assessing the relative level of support an asset will supply to the community during an emergency. This is done to help reduce the overall emergency power demand and reduce the cost of the energy grid improvements required.

Table 1. Work Book Example Critical Asset Identification Spreadsheet

	Service	Priorities (H, M, L)	#	Facilities	Priorities of Facilities (H, M, L)	Facility Category Service
1	Special Ops		1	SOP#1		
2	Airport		2	SOP#2		
3	Police		3	SOP#3		
4	Fire/Ambulance		4	Airport		
5	Water		5	Police Station		
6	Waste Water		6	Fire Station1		
7	Fuel		7	Fire Station2		
8	Food		8	Water Treatment		
9	Medical		9	Water Supply		
10	School		10	Wastewater		
11	Other Critical		11	Fuel Farm		
12	Miscellaneous		12	Gas Station		
13			13	PX/Food Court		
14			14	Mini Mart		
15			15	Super Mart		
16			16	Hospital		
17			17	Base School		
			18	High School		
			19	Headquarters		
			20	Public Works		
			21	Hotel		
			22	Bank		
			23	Shelter		

For smaller communities, less than 50,000 people, this additional analysis is often not needed since the critical assets and services are relatively easy to quantify and energy grid resilience improvements are often strait forward. For small communities, a few microgrids, combined with a few individual infrastructure energy asset upgrades and operational and maintenance preplanning, can provide significant improvements in overall grid and community resiliency. For large urban areas, where there are often dozens of critical services to evaluate and hundreds of critical assets to rank and evaluate, a dozen or more community microgrids as well as other individual energy improvements might be needed. In cases like these, advanced visualization tools and resilience modeling are extremely valuable in helping stakeholders and utilities much more quickly and easily visualize and identify energy support issues, deficiencies, options, considerations, and improvements (Jeffers 2017). Asset visualization tools along with the asset ranking criteria noted above, can help quickly identify the best areas to consider "resiliency nodes", areas in a community where a large number of critical assets and services are co-located and where advanced microgrids could be easily developed to support several community functions at once.

As outage durations go beyond a couple of days, the number and types of city services and operations commonly change and increase significantly, and the distribution and control of the assets can change. For example:

- for a two-day outage, in many communities it may not be necessary to have water systems, shelters, food stores, gas stations, or pharmacies open or fully operational. That is likely not the case for outages of a week or greater, where food, medications, dialysis, water, sanitation, and shelters become increasingly more important,
- community services and critical assets associated with fuel, food, banking, pharmaceuticals, etc. are generally provided by the private sector which will need good coordination with public agencies and utilities for large natural disaster to improve overall efficiency, and
- for longer power outages, coordination of public and private sector planning and response becomes both larger and significantly more important.

Therefore, in developing community resilience and energy grid performance goals, it was stressed on how important it is to accurately identify appropriate natural disaster threats and associated durations, since longer-duration threats significantly increase the complexity of community resilience support needs and how public and private sector resources need to be coordinated with grid upgrades to efficiently, and cost-effectively meet community resilience objectives.

With this background, in the APEC Grid Resiliency Workshop, the participants were given an example community (20,000 – 30,000 people) to assess. It represents a small town, or region of a larger city, with an identified distribution of services, population density and demographics, distribution grid assets and substation locations, and renewable energy and other existing distributed generation resources. With this information, and considering the different community stakeholders impacted by a major power outage, the participants used Table1 as a guide in identifying and ranking the primary critical infrastructures, services and grid resources that likely needed to be considered and potentially upgraded.

Overall, there was good agreement among the participants on the number and types of assets and services that needed to be addressed. The participants were also consistent in identifying 4-5 potential main clusters of these critical assets that could likely be integrated into an advanced microgrid to create ‘resiliency nodes’ for focused grid upgrades. Though the general evaluations were similar, not everyone got the exact same answer. This suggests that the use of a range of 15-20 stakeholders to help with a resilience assessment can help ensure that all potential options get vetted and considered.

Module 6: Identifying potential threats and community risks

The term Design Basis Threat (DBT) is borrowed from the probability risk assessment community, and represents an assessment to identify appropriate events the energy system could encounter and needs to withstand. Threats define the conditions that must be met by the system design in terms of assured operational performance – commonly identified in terms of days or weeks of likely energy system outage before the system returns to normal conditions. For example, in terms of an electric power system, there are a range of threats from natural disasters (such as hurricanes, flooding, high winds) or man-made (such as a cyber or physical attacks) that can cause power outages from a few to several days, such as Hurricanes Harvey and Irma in 2017 in the US, or in some cases even weeks or months, such as seen in Hurricane Maria in 2017 in Puerto Rico (New York Power Authority 2017). Based on the local and regional events possible, the grid improvements, such as advanced microgrids, must be designed to function and operate for the defined power outage duration to meet the community’s energy resilience requirements.

A key concept for developing energy resilience performance goals and objectives is that it requires close collaboration between energy utilities, energy resilience analysts, and community officials to quantify the likely power outages expected based on regional events, community needs, and utility recovery and restoration ability. This helps establish key grid operations to maintain critical community operations and services until full power is restored. Typical outage events considered depend on the region, but often include:

- Natural disasters with high impacts such as hurricanes, major floods, tornados, earthquakes, volcanos that can have widespread impacts and durations,
- Natural disasters with medium to low impacts like forest fires, heat waves, ice storms, blizzards and land-slides that have impacts that are more localized,
- Chronic events like blackouts, brownouts, poor equipment reliability, and equipment failures that can cause consistent daily or multi-day power loss, and
- Events from intentional human causes that can have high to low impacts that may be difficult to repair quickly.

The types of threats can then be analyzed based on likely hood of occurrence, likely consequences, existing system resilience, and outage duration to calculate threat risk over a 10-20-year period. Based on experience from over 40 location evaluations, common threat durations commonly considered include:

- 2-day outages – often a minimum outage from low to medium events,
- 5-7-day outage – possible for many major events, with the level of support needed varying depending on the event, but outages of this length often severely stress a community's ability to deliver critical infrastructure operations and services,
- Greater than 7-day outages – possible for major events where catastrophic damage occurs that overstress community infrastructure and services because supplies of food, water, and fuel become depleted. These outages can have major impacts on medical and safety functions like police and fire services, which cause cascading impacts to many types of community and social services.

Threats	Likely hood of event (H 3, M 2, L 1)	Consequence of event (H 3, M 2, L 1)	System resilience to event (H 1, M 2, L 3)	Duration of event (Hrs 1, days 3, weeks 5)	Overall rank scores (Total)

Table 2. Design Threat Analysis Worksheet

In order to define the design threat, the Course Work Book provides work sheets, shown in Table 2, for estimating the correct design outage for different types of outages, based on likely hood, consequences, and duration.

During the APEC Grid Resilience Workshop, Table 2 was used by the participants to estimate the highest ranked design outage events for an example problem, based on high and medium-level natural disasters, local and regional grid reliability data, and historical data to establish a range of expected grid resilience and outage periods.

Overall, there was good agreement among the workshop participants in their ranking of several different potential events and natural disasters. The more chronic and more common events, which had outages of often 1-3 days ranked as very high risk, as did some large natural disasters that could have outages of 5-7 days. This information, along with the critical infrastructure information priorities developed in Module 5, is then used in developing grid resilience improvement location priorities, design outage duration requirements, and grid upgrade options and priorities.

Module 7: Defining community and grid resilience performance goals

Performance goals and objectives set the community requirements that drive grid improvements to ensure that critical community services and facilities energy needs are met during a natural disaster. Performance goals and objectives are therefore needed to establish design requirements and compare various upgrade options for cost and performance. Therefore, performance goals need to recognize 1) the scope of what critical assets need to be protected, as well as 2) what duration these critical assets need to be protected. This is why the critical asset and threat identification efforts are done first.

If the design event is a hurricane, then it might be that the performance goals will require electrical equipment to be functional for a critical asset in a flood zone, and therefore electrical service equipment must be moved above the flood zone in order to avoid being impacted by the hurricane. It is important to define critical assets and associated loads and rank them in terms of importance. These tier rankings help to specify how an advanced microgrid will be designed to function and identify components needed for efficient control and operation (Jensen 2017).

Performance goals can also include sustainability and resiliency metrics such as limiting fuel use, increasing generator equipment efficiency, incorporation of a given amount of renewable resources, lessening the impacts of noise, pollution, or CO_2, in addition to ensuring that the system functions reliably for the designated threats and can maintain safe and secure operations (Baca et al 2014).

Based on the background information established in Modules 5 and 6, performance goals such as critical assets, locations, outage durations, and types of important outages identified, the community can begin to define the critical grid improvement goals and objectives and identify possible resilience improvement options that can meet those goals and objectives.

Based on the information developed from the Example Problem and the data from the Module 5 and 6 Work Sheets, the participants were able to fill out a Module 7 Worksheet that summarized their initial grid and community resilience performance goals in terms of outage durations, primary natural disasters and events to consider, design philosophy, number of likely local refugees, maximum distance to a resilience node, etc. In the example problem, several critical infrastructures were in a flood plain, so most participants chose to find alternative buildings with the same functions in other parts of the community to minimize potential flooding issues in setting their performance goals. This is exactly the type of considerations that must be identified in order to compare different potential design options.

Module 8: Performance Risk Analysis

Of major importance is evaluating the ability of the existing energy components and systems to meet the defined extended outage performance goals and criteria established to establish a baseline for improvement option impact. This is typically done by conducting a simple system performance risk assessment. In general terms, performance risk is defined as the level of system performance loss as a result of the occurrence of some undesired event. Performance Risk can be described as the performance of the grid and community relative to the identified performance goals. Conceptually, larger natural disasters will likely put the grid and community infrastructure at significant risk because of more severe weather, more significant grid damage, and longer power outages due to grid restoration challenges from a wide-spread large disaster.

By using the impact duration of the events identified from Module 6, i.e. 2-day outage, 5-day outage, 10-day outages, along with the system elements to be protected identified in Module 5, and the identified Performance Goals from Module 7, as discussed in the Course Book, this enables Performance Risk to be calculated directly using the event duration and the performance of the critical assets needed during that event (Hightower 2014). This allows a utility or community to directly quantify their existing performance risk for different extreme events. If their performance risk is low, then they will be able to “weather the storm” relatively easily with minimal loss of critical services or operations and therefore their resilience will be high. If their performance risk is high, which often occurs for larger natural disasters, their resilience will be low and significant improvements will be required.

Based on several resilience evaluation studies, the Course Book identifies a group of simple performance parameters that can quickly capture the major impacts of a power outage relative to design goals. The data on these parameters are easy to collect and are easy for both utility engineers and stakeholders to understand and use. Based on this quick and straightforward analysis, teams can quantify Performance Risk as a function of critical buildings, the loads able to be served during a natural disaster and power outage, and the length of time they can be met by the current energy grid configuration or renewable or backup power resources.

The assumption in this approach is that for larger natural disasters, the events are severe enough such that most grid transmission systems will be down for extended periods, and that critical facilities will only be supported by available distributed generation such as backup generators, renewable energy, or distributed generation that can be quickly brought in. From many damage analyses of electric transmission systems during major natural disasters this is generally true. Additionally, because of the design of many renewable energy systems, they often are not available during a major power outage, but this needs to be checked. Also, bringing in additional distributed generation is often problematic following a natural disaster due to logistic and transportation issues. Therefore, access to these additional resources should be carefully considered.

Therefore, Performance Risk can be simply stated as function of the percentage of critical buildings and services having backup energy resources, the percentage of critical loads that can be served, the reliability of the backup generation resources, the duration of the event, and the amount of fuel or renewable operation available. Mathematically this is defined below as:

Performance Risk = 1- (CBS*CLS*RG*(Da/Dn)), *where*

- PR = Performance Risk
- RG = Reliability of backup power generation system
- Da = Operational availability of backup power – up to outage period
- Dn = Event duration (outage period)
- CBS = Percent of critical buildings served by backup power – which critical buildings have access to backup power. If few buildings are served, then consequences and risks will be high.
- CLS = Percent of critical loads served – weights serving the defined critical loads and critical services and buildings. If minimal buildings or loads are covered, the consequences and risks will be high.
- RG = Reliability of generation – weights the maintenance of backup generators or other generation. Low maintenance lowers reliability and risks increase.
- Da/Dn = Ratio of generator fuel available versus outage duration. If the generator fuel tank is small, and/or the ability to refuel the generator is low, then the ration is smaller, unless renewable or other energy resources are available.

Based on power outage evaluations for natural disasters, we have found that when current grid systems can serve 85% or more of the critical buildings, and the critical loads are served 85% or more of the outage duration, communities find that the overall power system adequately supports critical community services and functions without significantly impacting overall public health and safety.

For energy systems that serve less than 70% of the critical buildings and loads for less than 70% of the outage duration, the community health and safety become increasingly stressed. Therefore, energy grid performance risk has notionally been considered as:

- Low Performance Risk – PR <.30 (High Resilience)
- Medium Performance Risk – PR = .30 to .50. (Medium Resilience)
- High Performance Risk – PR >.50. (Low Resilience)

Therefore, the goal of a resilient grid upgrade design is to attain a Performance Risk of at least 0.30. There are often many options to attain that value, and therefore the focus is really on how to reduce the level of risk most cost-effectively or with the greatest flexibility. Often, identifying clusters of critical facilities and services and using advanced microgrids to integrate distributed and renewable energy resources is the most efficient and cost-effective way to improve grid and community resilience. In some cases, facilities are just too far from a cluster of infrastructure or services so they need their own distributed generation resources. This is where different design options have to be considered.

Table 3. Example Performance Risk Worksheet

Asset	Facility	Critical Building Served (CBS)	Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity (Da/Dn)	Other Notes
1	Special Ops	3/3	100%			
2	Airport	3/5	60%			
3	Hospital	1/1	100%			
4	Fire	2/2	100%			
5	Public Works	1/1	100%			
6	Water Supply	1/1	100%			
7						
8						
9						
10						
11						
12						
	Performance Risk					

For the example community in the workshop exercise, information on the location of distributed generation, the size, maintenance, and renewable energy generation resources available were identified. Based on the work sheet information shown in Table 3, a Performance Risk analysis was conducted by all participants. Then a similar Performance Risk analysis was conducted that included improved generator sizes, improving maintenance to increase generator reliability, and increasing fuel supplies. The two analyses showed how important it was to match distributed generation, fuel, renewables, and operations and maintenance improvements to create the most cost-effective resilient grid upgrades and designs.

Module 9: Electrical load estimation analysis for sites with limited load data

Module 9 presented technical information on how to estimate critical building loads if building load data is not available. Based on typical switchgear design approaches and factors for growth, this module presented rules of thumb on what factors to use to estimate critical building loads. The Appendices in the Workshop Course Book provides an example data request form for a gird resilience analysis and upgrade effort that includes a request for building and service load data. But if that data is not available, Module 9 can be used to help engineers estimate critical building loads based on on-site grid components. Because our example problem provided building load data, there were no exercises for this module.

Module 10: Formulating resilient grid design options

This module provided a general discussion of how to formulate and evaluate initial conceptual design options to meet identified performance objectives for critical services and facilities against a set of DBTs. Conceptual design options include development of advanced microgrids or ‘resilience node’ designs where appropriate and feasible. Options also include increasing energy efficiency and use of renewable resources and additional distributed generation resources depending on how feasible various options are.

The expected performance improvements of the conceptual design options are then compared with the baseline system performance according to the performance objectives identified in Module 7 to determine how the conceptual design improves system performance risk or resilience versus the baseline system. Advanced optimization and performance tools as discussed in Appendix B of the Workshop Course Book can be used to map out the optimized performance versus detailed cost of various options to help evaluate the best overall approach based on lowest performance risk (highest resilience) at the most reasonable cost.

In evaluating critical facilities and services needed for grid and community resilience, many critical services are naturally clustered though some are not. Therefore, the Course Book suggests the following considerations be kept in mind when formulating energy resilience upgrade options:

- It is common and often of higher grid reliability and resiliency and of lower overall costs to have from 2-3 to as many as 4-5 clustered services that can be developed into advanced microgrids or ‘resilience nodes’ in small to medium size cities, and 15-20 in a larger city.
- Not all facilities are close enough to other buildings that they can be included in an advanced microgrid. For those buildings, or for a suite of buildings like this across a community, utilizing renewable generation and combined cooling-heating-and power (CCHP), building tied generation, or provisions to bring in additional backup generation – such as installing building pin-and-sleeve connections and having a suite of mobile generators, can be integrated efficiently and cost-effectively and provide high energy and critical mission and service reliability.
- In areas where critical functions are naturally clustered, master planning so that new critical infrastructures or services are incorporated into those existing “resiliency nodes” can help increase community and grid resilience more cost-efficiently.

Finally, in looking at areas of a community where no critical services exist, master planning might want to be modified so that community service capacity can be encouraged in order to provide more cost-effective critical services to isolated parts of the community or where more at-risk constituents live. Also, community development might be encouraged in areas where more resilient grid infrastructure already exists or can be more easily upgraded.

Module 11: Cost Estimating for Grid Improvements

In this module, the Works Shop Course Book provides a simple but commonly used cost estimating approach for making Rough Order of Magnitude (ROM) cost estimates for conceptual designs. In general, costs include initial equipment purchase costs, future maintenance requirements and costs, design costs to create design drawings and outline improvements, engineering costs including review and oversight of the design and construction phases, construction costs including the labor costs to install and testing, and overhead costs and taxes.

To simplify this approach, cost accounting tools have been developed that utilize equipment and construction costs to establish ROM cost estimates (± 30%) based on equipment and construction cost estimating procedures such as RS Means. Once the base equipment costs are estimated, the labor cost estimates are included to determine the overall base costs to install the equipment to estimate the overall construction costs. The construction management oversight costs are estimated to be ~20% of the overall construction costs. The total engineering and design costs are estimated to be ~25% of the construction costs. And finally, a 25% contingency is included to account for the lack of complete information at the conceptual design level.

The Workshop Course Book includes general cost tables for advanced microgrid and grid resilience upgrade equipment to help with the cost analyses. Local labor and construction costs need to be included to help with the cost assessments in local APEC economies.

SESSION 5. Example Grid Resilience Analysis and Design Exercise

The final part of the workshop was an Example Problem for the design of advanced microgrids for a hypothetical small community (20,000) people. For the example problem, the participants were divided into four groups to work together using the previous course exercises to spend a half-day to develop a conceptual design and preliminary cost and performance analysis for an advanced microgrid. The groups had about six different microgrid selection and design opportunities based on the layout of the critical infrastructure and services. Each of the four groups selected a different microgrid and part of the community to analyze.

The microgrid designs required consideration of critical loads, shedding of non-critical loads, the use and integration of switching technologies to isolate the microgrid from the main grid to operate islanded, and integration of appropriate distributed and renewable energy generation and storage systems to provide adequate power and reliability for the microgrid during the design outage. Then each team reported out to the whole group on their analysis and design and considerations.

The example problem is based on an analysis done in cooperation with Northampton, Massachusetts. The publicly released results and analyses with significantly more detail are available from the community consulting engineer project manager (Tourtelotte 2015). In this real-world case, the community had a reasonably low Performance Risk rating for a 2-day outage, but for their final resilience design outage of 10-days their existing Performance Risk was very high. This suggested to them the need to improve distributed generation maintenance, integrate existing renewable resources into critical community nodes, add more renewables to reduce fuel storage demands, add private fuel storage resources to enable operational performance of backup generation for the longer power outage, and add more strategic distributed generation to address grid resilience for additional services needed for the extended outage durations.

Additionally, the community considered the cost of addressing a 21-day power outage and determined, based on cost, that they would initially focus on a 10-day power outage design to support grid improvements, and for events exceeding that, have residents evacuate. Their thinking was that by focusing on being resilient to a 5-10 day power outage, the community health and safety was assured, and it gave the city council and mayor to have the time to assess the situation and make intelligent decisions on what additional disaster support and aid would be forthcoming from state and federal emergency management agencies and utility regional support alliances.

In the Workshop example, similar natural disaster threats had been calculated, approximately a 7-day outage, and similar Performance Risks we calculated for the clustered services each group evaluated. As in the real-life evaluation, each of the teams looked at improving distributed generation operation and maintenance, adding additional critical distributed generation resources, and shedding some non-critical loads. But none of the teams chose to integrate available renewable energy generation resources to reduce fuel use and fuel storage requirements. Other than that, each of the four teams approached the grid resilience solutions similarly and in a technically sound manner.

This comparison shows that the rather simple and straight forward ESDM resilience analysis framework presented can help identify priority grid resource, upgrade, and operation improvement strategies that are effective and support community resilience. The workshop results suggest that this type of 2-3-day training, if done with focused training modules and example problems, can provide participants with a good basic understanding of grid resilience analysis and design issues, challenges, and potential solutions.

In this Workshop, only a few of the groups were able to get to a point of estimating final microgrid and resilience costs for the suggested grid and distributed generation improvements. If they had done that, we believe that the use of existing renewable generation resources would have been factored into the final recommended designs. With more time, each of the teams would have been able to fine tune their conceptual designs.

Based on these initial analyses, potential improvements would be assessed to establish relative cost/benefit tradeoffs. This iterative approach is valuable to community and utility stakeholders in helping them to quickly see trends in needs, and in identifying general funding needs, understanding priorities and needs, and evaluating unique approaches to improve resiliency quickly and relatively easily (Baca 2017) (Jeffers 2017).

With an idea of the general conceptual grid design upgrade options and costs, in an actual application, each of the teams would be able to utilize consulting firms and utility engineers to create more detailed preliminary and final designs for actual implementation.

SESSION 6. Summary, Lessons Learned, and Future Opportunities

At the core of the ESDM resilience framework presented is utilizing key community stakeholders and technical experts to consider and set energy system performance goals for critical community infrastructures and services, while including the social and economic impacts of extended power outages.

During the workshop, participants learned how to use this framework to consider natural disaster and other threats, how to consider important community needs and services including future planning and growth, economic factors, joint public/private cooperation, and coordination of responsibility for system operation to ensure energy resilience. Based on the workshop discussions and evaluations provided by the participants, there were a number of suggestions and lessons learned provided, which are discussed below.

6.1 Workshop Training Summary

Following the presentations, training, the case studies, and breaking into teams to do the example problems, all the workshop participants, including the expert panel, collectively discussed some of the major challenges and issues they considered and the final approaches they took in the example microgrid design effort, as well as what might be needed in the future as far as training. Additionally, they commented on future needs for advanced microgrid implementation and resilience consideration and integration into grid upgrades in APEC economies.

Overall, the participants responded that the workshop was useful, valuable, and increased their knowledge of resiliency and the use of microgrids. Over 30 participants responded to the end of workshop questionnaire and:

- 83% responded that the topic was relevant/very relevant to their economy,
- 100% strongly agreed/ agreed that the workshop materials were useful,
- two-thirds of the respondents thought their knowledge and skills in the topic increased from low/very low to high/very high during the workshop, which is a significant improvement, and
- 100% of the respondents thought their understanding of grid and community resilience had increased to medium to very good following the workshop.

Because almost 70% of the respondents said they started with a low to very low understanding of advanced microgrids and grid resilience, there was a significant increase in understanding of this topic area among participants due to the workshop.

6.2 Workshop Lessons Learned

Two major technical lessons learned were identified by the project participants in their efforts over the two-day workshop. Based on their written comments, they had the following suggestions:

1. **Expand the Workshop training to three days.**

   In the workshop evaluations, over 20% of the respondents thought they needed more time to assimilate the concepts presented in the workshop. Also, several respondents made specific comments that in the 2-day training they felt rushed to comprehend the material, and many requested the training be expanded to 3-days. While the course was originally designed as a 3-day course, many groups have requested the training be done in two days. In cases where we have done this, the participants have had specific experience in energy grid operations and security and risk analysis.

   While some APEC economies, such as Korea and Australia, have an excellent understanding of the use of renewable energy and advanced microgrids, the survey responses by the participants suggested that many APEC economies have less experience with renewable energy system integration, advanced control technologies, and less experience on risk assessment approaches. Almost 70% of the APEC workshop participants responded that they had Low/Very Low knowledge of microgrids and how they worked prior to the workshop. This lower level of initial technical understanding and experience about microgrids suggests that additional time should be provided for example problem solutions and discussions. This can be easily done and successfully accomplished in a three-day workshop format by allowing more time to discuss example projects, associated microgrid designs and operations, as well as increasing time for workshop exercises and discussions.

2. **Include more detailed renewable energy integration training.**

   In the example community microgrid designs, the four teams chose to consider limited use of available renewable energy resources in their example designs. Each chose to focus on the use of traditional distributed generation resources, i.e. backup generators. None of the teams weighed the high fuel requirements, and large fuel storage requirements for an extended power outage of 7-10 days as something that might be problematic without the use of renewable energy resources.

In final discussions, it appeared that the teams were less comfortable with analyzing and integrating renewable energy resources in their designs, even though several APEC economies, such as Australia, Korea, and the US all have significant experience in renewable energy integration with microgrids.

That could be improved through future activities focused on tours of microgrid systems with the ability to operate both grid-tied and islanded, specific training on renewable energy integration into advanced microgrids that can be operated islanded and grid-tied and the benefits and hardware requirements, and inclusion of a module to the current training to specifically address renewable energy integration approaches, and resiliency benefits related to natural disasters.

6.3 Potential for economy-specific energy resiliency projects.

Following the microgrid analysis and design exercises, the group heard from an expert panel including D.K. Kim from the Asia Development Bank, Mark Paterson, of Strategen, and Dr. Jyuung-Shiauu Chern, the EWG Lead Shepard. Both D.K. Kim and Mark Paterson have extensive experience in advanced microgrid design and implementation in Korea and Australia respectively and discussed opportunities to work with ADB and Australia in future microgrid design and construction efforts.

D.K Kim highlighted opportunities for funding from ADB on renewable energy projects focused on supporting grid assurance and resiliency in the Asian region, and suggested APEC economies consider the use of advanced microgrids to enhance renewable energy utility for supporting future grid resilience. Mark Paterson discussed some of the lessons learned and applications of over 50 different renewable generation and microgrid applications in Australia and how they have been used to support local power reliability. Finally, Dr. Chern discussed how important resilience of communities is becoming to APEC economies and the need to improve how energy resiliency can be incorporated into emerging energy improvements to enhance public health and safety as well as APEC long-term robust and resilient economic development.

Therefore, all three panelists suggested future grid modernization efforts in APEC economies should consider renewable energy integration to enhance grid resilience, and that opportunities exist for assistance from APEC, ADB, and other APEC economies to support renewable and distributed generation integration for grid resilience. While none of the economies attending are currently planning any natural disaster grid resiliency projects, based on the panel discussion, some options currently exist to help accelerate consideration of Smart Grid technologies to enhance grid and community resilience.

As suggested by the panelists these include:

- Consideration of tours or workshops of existing microgrid projects and applications in various APEC economies to increase awareness of the cost/benefits and regulatory approaches used in some APEC economies for improving grid resilience,
- Expand this workshop to additional APEC economies, increasing the training to 3-days,
- Develop workshop opportunities for training participants on preliminary microgrid design and implementation that are available through various APEC economies and would help expand grid resilience design capabilities in APEC economies (Stamp 2014), and
- Support for APEC economies to prepare resilient grid designs based on the use of renewable energy to apply for ADB funding grants and opportunities.

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Appendix A: Grid Resilience Workshop Focus

APEC Workshop on Improving Electric Grid Resilience to Natural Disasters
September 19-20, 2019 – Cebu, Philippines

The United States – Philippines co-chaired Asia-Pacific Economic Cooperation Energy Resilience Task Force are supporting a **Workshop on Improving Electric Grid Resilience to Natural Disasters** (EWG 09 2018S). The agenda will include discussion of energy security and resilience analysis and design for communities, and a full example analysis done with the attendees for a hypothetical small community (20,000) people. This size is a good example for smaller cities and regional communities within a large city.

This two-day workshop was developed to provide capacity-building and training on planning and developing conceptual designs for improving grid resilience. The workshop is designed to help APEC economies:

1) identify emerging trends and risks posed by natural disasters,
2) discuss adaptive measures to address these risks and enhance grid and community resiliency;
3) identify evaluation frameworks for enhanced resiliency analysis and design,
4) provide opportunities for participants to conduct example resilience analyses
5) conduct a full conceptual resilience design for a small city with cost and performance analysis, and
6) provide a networking opportunity for APEC members and grid and community resilience experts to discuss ideas for future projects and efforts across APEC economies.

The workshop will bring together representatives and practitioners from APEC economies to exchange experiences on local grid and community resilience issues and challenges, and training and analysis opportunities to enhance grid and associated community resilience and reliability. The workshop will present several case-studies to demonstrate general lessons learned from practical applications of grid resilience analyses and designs. This will include experiences from several APEC economies, including the United States, Australia, and Korea.

The workshop objectives are to build an understanding and an analysis and design capacity within APEC economies on the use and application of grid resilience evaluation and conceptual design methodologies to improve electric power resilience and reliability. Participants will receive a 220-page Course Book and an associated 50-page Work Book that they can keep and use for later reference. The workshop will allow APEC economies to exchange experience on methods and approaches for evaluating and planning for natural disaster risks to power systems, infrastructures, and communities. The workshop will also provide the opportunity to show how Smart Grid, advanced microgrid, and distributed and renewable energy generation and storage technologies can be used to enhance the reliability and resiliency of the electric grid in the APEC region.

Appendix B: Grid Resilience Workshop Agenda

APEC Workshop on Improving Electric Grid Resilience to Natural Disasters

September 19-20, 2019
Bai Hotel Cebu, Cebu, Philippine

Day 1: Introduction to Grid and Community Resilience Issues				
8:30 AM	-	9:00 AM	Arrival & Registration	
9:00 AM	-	9:15 AM	Opening Remarks	Jesus T. Tamang, Director, Philippines Ministry of Energy
9:15 AM	-	9:30 AM	Introduction to the Workshop Objectives and Agenda	Cary Bloyd PNNL, Project Overseer
9:30 AM	-	9:45 AM	Participant Introductions	
9:45 AM	-	10:00 AM	Course overview, Course modules, and course goals and objectives	Mike Hightower, UNM Ben Schenkman, Sandia
10:00AM	-	10:15AM	Electric Grid Resilience from the Asia Development Bank Perspective	Dae Kyeong Kim, Asian Development Bank
10:15AM	-	10:30 AM	Coffee Break	
10:30AM	-	11:00 AM	Module 1 – Introduction to electric power systems, energy assurance, and community resilience	Hightower and Schenkman
11:00AM	-	11:45 PM	Module 2 – Use of advanced microgrids for energy and community resilience	
11:45PM	-	1:00 PM	Lunch	
1:00 PM	-	1:30 PM	Module 3 – Energy Surety Design Methodology	
1:30 PM	-	2:00 PM	Module 4 – Defining system boundaries and grid and community goals	
2:00 PM		2:45 PM	Module 5 – Identifying and ranking critically important energy and community assets and services	
2:45 PM	-	3:00 PM	Coffee Break	
3:00 PM	-	3:45 PM	Module 6 – Identifying system and	

			community threats and potential risks	
3:45PM	-	4:30 PM	Module 7 – Selecting energy system and community-level performance goals	
4:30 PM	-	5:30 PM	Module 8 – Performance Risk Analysis	
Day 2: Example Design				
8:00 AM	-	8:30 AM	Arrival, Coffee, Discussion	Cary Bloyd
8:30 AM	-	9:00 AM	Module 9 – Load Estimation	Hightower and Schenkman
9:00 AM	-	9:45AM	Module 10 – Formulating resilient node and community energy improvement options	
9:45 AM	-	10:00 AM	Coffee Break	
10:00AM	-	10:30 AM	Module 11 – Cost Estimating	
11:00AM	-	2:45 PM	Example Problem – Community energy and resilience evaluation and analysis	All Participants
12:00PM	-	1:00 PM	Lunch	
1:00 PM	-	2:45 PM	Continue Example Problem	All
2:45 PM	-	3:15 PM	Discussion of example analyses and results	All
3:15 PM	-	3:30 PM	Coffee Break	
3:30 PM	-	5:00 PM	Expert panel discussion on grid improvements for community resilience – Concepts and directions	All
5:00 PM	-	5:20 PM	Closing remarks	Dr. Jyuun-Shiauu Chern, EWG Lead Shephard, D.K. Kim, Mark Paterson
5:20 PM	-	5:30 PM	Closeout	Cary Bloyd

Appendix C: Workshop Participants

APEC Workshop on Improving Grid Resilience to Natural Disasters
September 19-20, 2019 – Bai Hotel, Cebu, Philippines

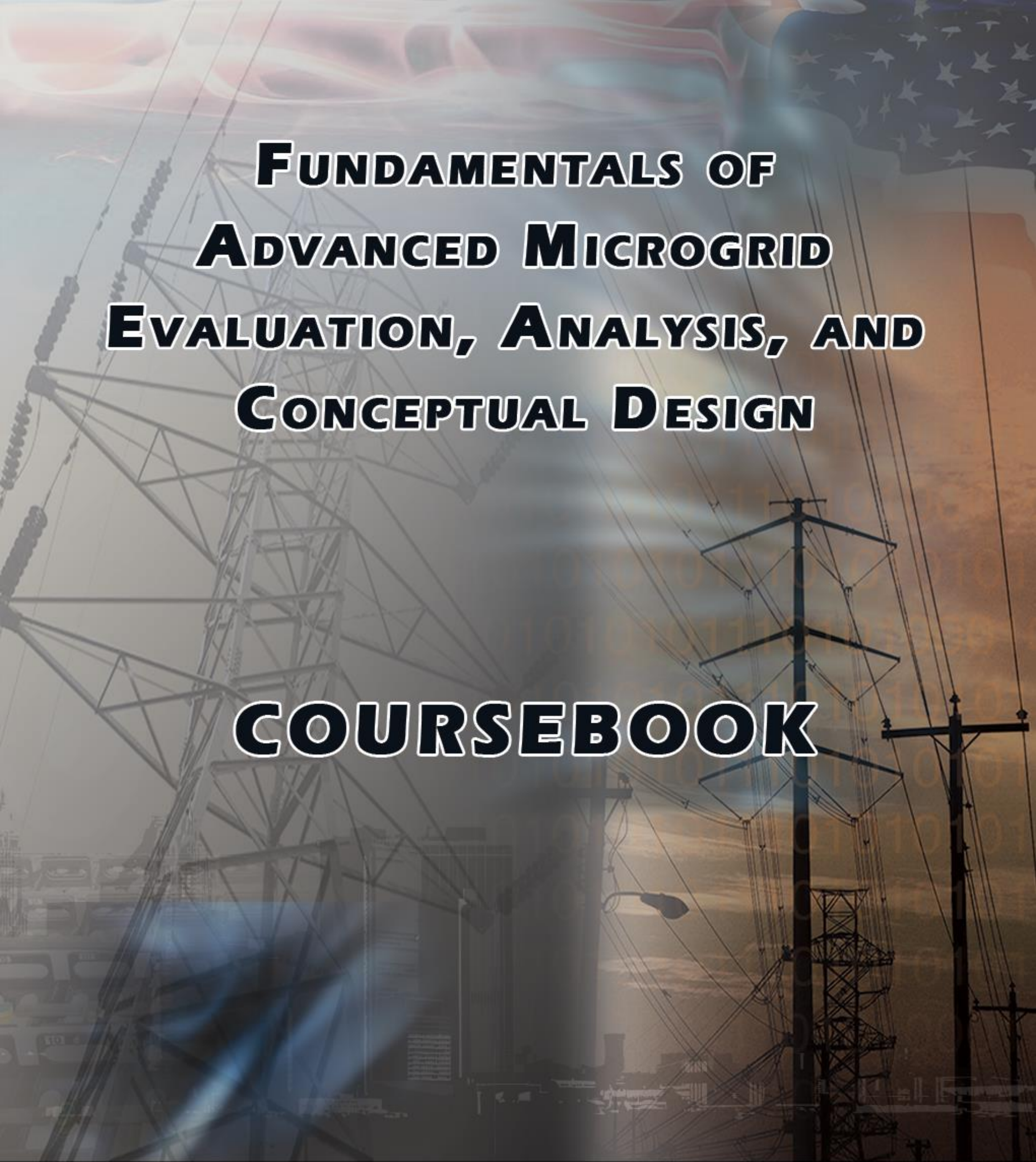
Economy	Last Name	First Name	Company
Australia	Paterson	Mark Donald	Strategen
Chile	Zuloaga Royo	Felipe Alejandro	Ministry of Energy
Chinese Taipei	Chern	Jyuung-Shiauu	Bureau of Energy
Indonesia	Simamora	Pamelaria	Institute for Essential Services Reform
Indonesia	Tampubolon	Argu Praditya	Institute for Essential Services Reform
Indonesia	Hadi	Mochamad Soffin	PLN
Malaysia	Ahmad	Azah Binti	Sustainable Energy Development Authority
Malaysia	Ahmad Ludin	Norasikin Binti	Universiti Kebangsaan Malaysia
Mexico	Romo Ramirez	Sergio	CENACE
Papua New Guinea	Kaupa	Simo	PNG Power
Peru	Barta Navarro	Luis Alberto	Osinergmin
Peru	Cris Caceres	James Washington	Osinergmin
Thailand	Chinabut	Tanaporn	PEA
Thailand	Jansungkalok	Sittanan	DEDE
Viet Nam	Dihn	Duy Phong	Ministry of Industry and Trade
Viet Nam	Tu	Van Hung	Ministry of Industry and Trad
USA	Bloyd	Cary	Pacific Northwest National Laboratory
USA	Hightower	Mike	University of New Mexico
USA	Schenkman	Ben	Sandia National Laboratories
ADB	Kim	Dae Kyeong	Asia Development Bank

Additionally, approximately 30 representatives of the Philippines Department of Energy participated in this workshop.

Appendix D: Workshop Course Book and Work Book

Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design

COURSEBOOK



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Sandia National Laboratories

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Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design

Energy Systems Analysis Department
Sandia National Laboratories
Albuquerque, New Mexico

March 2017

ABSTRACT

In 2008, Sandia National Laboratories (Sandia) developed the Energy Surety Microgrid (ESM) design methodology to provide a structured analysis approach to improve electric power security and resiliency for military installations and communities by using advanced microgrid and Smart Grid approaches and technologies on the local distribution system to enhance safety, security, and reliability at reduced costs. The ESM approach is based on a risk-informed, performance based energy system analysis approach developed in 2001 called the Risk Assessment Methodology for Energy Systems (RAM-E). RAM-E is one of several risk assessment approaches developed by Sandia to enhance specific critical infrastructure security.

Sandia has utilized the ESM methodology since 2008 at over 30 military bases and civilian communities to improve energy system security and resiliency to meet a range of threats and performance goals. As the discussion of microgrids and their potential applications and benefits to communities and the Smart Grid has accelerated, in 20012 Sandia started to develop an energy assurance and advanced microgrid design course to provide organizations, communities, and utilities information on best practices and lessons learned when integrating distributed and renewable generation and storage with advanced microgrids to enhance mission assurance and energy system resiliency for extended outages. The course has been designed to provide a basic understanding of energy assurance and advanced microgrid design concepts that includes both technical discussions and example problems using actual site energy and infrastructure data.

The goal of the course is show how to integrate 21st Century technologies to the electric grid more efficiently and cost effectively to address 21st Century issues and challenges.

ACKNOWLEDGMENTS

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- Department of Energy – Operational Energy
- Korea Institute of Energy Research
- Department of Energy – Energy Efficiency and Renewable Energy – Energy Transition Initiative

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Department of Energy/OE – Dan Ton and Merrill Smith
Department of Energy/EERE – Jennifer DeCesaro and Stephen Walls
Korea Institute of Energy Research – Eugene Song

The following Sandia civil, power, and mechanical engineers have provided valuable input on the course design, course materials, lessons learned, and best practices presented in each of the sections in this course.

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CONTENTS

GLOSSARY OF TERMS

Baseline Performance: This is a reference point to which is gauged potential improvements suggested by the design methodology. 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 microgrid architecture or other improvements developed from the design methodology.

Conceptual Design: An initial system design level that evaluates design options against system performance metrics to establish a rough order of magnitude (+/- 30%) system design for planning, operation, and funding purposes. It provides a reasonable estimate of the major elements, capabilities, and functions that a final design will have. This is generally considered a 15% design by architectural and engineering firms.

Critical Loads: those loads/buildings/services that are critical to the mission or functions; these loads can have dedicated backup generators. These loads nee to be served through the duration of an electrical power outage, regardless of the duration, or until the functions can be transferred to another location or installation. Some critical loads are non-interruptible and will include uninterruptible power supplies (UPS) while other loads can endure short losses of electrical power.

Design Basis Threat (DBT): The design methodology 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. The focus is on credible threats within a regional context, not necessarily only a local context.

Design Basis Outage: The design methodology uses the DBT identification to evaluate the impacts and consequences to a facility, installation, or community. The events and power outages with the highest impacts and consequences are then used as the initial design basis outage. The evaluation is used to compare upgrade performance capabilities to other options and to the performance of the baseline, and to help assess different operational strategies to meet critical infrastructure and mission assurance, and installation and/or the community with high security, reliability, and resiliency.

Energy Surety Design Methodology: (ESDM) is an analysis process developed by Sandia National Laboratories that quantifies six key attributes for energy system performance (safety, reliability, resiliency, security, sustainability, and cost effectiveness) to support critical mission assurance and resiliency. The approach can be used to develop effective conceptual and preliminary designs to meet stakeholder performance 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, while making sure that the energy improvement investments can also support improved energy system performance and cost effectiveness during normal or minor off-normal events.

Energy Surety Microgrid: An advanced microgrid design developed using the ESDM approach to increase reliability of critical mission operations by interconnecting energy generation assets within the distribution network to enhance operational efficiency, reduce fuel use, enhance security and reduce operational risks to a range of credible events.

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.

Non-critical Load: Those loads/buildings that are not directly necessary for critical mission assurance or provide critical mission support. These loads/buildings do not need to be powered for long durations during an extended power outage.

COURSE OVERVIEW AND OBJECTIVES

Today's modern society is highly dependent on the electrical grid and a major outage can have severe consequences. Having a reliable source of power is especially important when it comes to places such as military bases or critical municipal functions where critical mission assurance or public health and safety depends on the ability of the electric power system to support infrastructure operations, including: water and waste water infrastructures for drinking, cooling, and firefighting; police, fire, and emergency response for public safety; hospitals, clinics, and pharmacies for medical treatment; telecommunications, radio, and data services for public information; food and shelter for community support; and transportation, banking, and fuel to enhance recovery.

The 20th century solution for emergency response to power outages at most military bases and municipalities was to utilize backup generation at critical mission buildings, but failure of these backup generation resources is unfortunately quite common. In many cases, these backup generation resources are poorly maintained and do not start or run properly when required. Often, they also do not have a sufficient fuel supply to operate for long periods during and extended outage.

The issue of designing the electrical power system to support critical infrastructure and community services effectively and efficiently during an extended power outage has become an emerging 21st Century problem. This is highlighted in Figure 1, which shows the growing number of power outages observed over the last two decades caused by intentional and extreme weather events. These types of outages have increased both in frequency and duration and have also tripled the number of customers affected by these longer and more severe power outages.

Also of growing concern is that military installations and municipalities have multiple critical functions or services that are interdependent, such that the loss of power or energy to one facility or service will adversely affect other functions or operations. For example, loss of power to a water treatment plant for an extended period could reduce the ability to pump water, impacting not only public health, but also fire-fighting, and water for industrial uses. Therefore, extended power outages can have cascading impacts or lead to a devastating chain of failures of critical services.

This highlights how important it is for military installations and communities to consider options to improve the design, operation, and management of their energy system infrastructure to assure critical mission performance and critical infrastructure and critical service operations for extended outages. Many groups understand the important foundation that the electric power system provides to other critical infrastructures and their operation viability, and energy therefore have suggesting emphasis be placed on increasing the security and improving resiliency of the electric grid as a major driver for creating a 21st Century grid that can address 21st Century challenges.

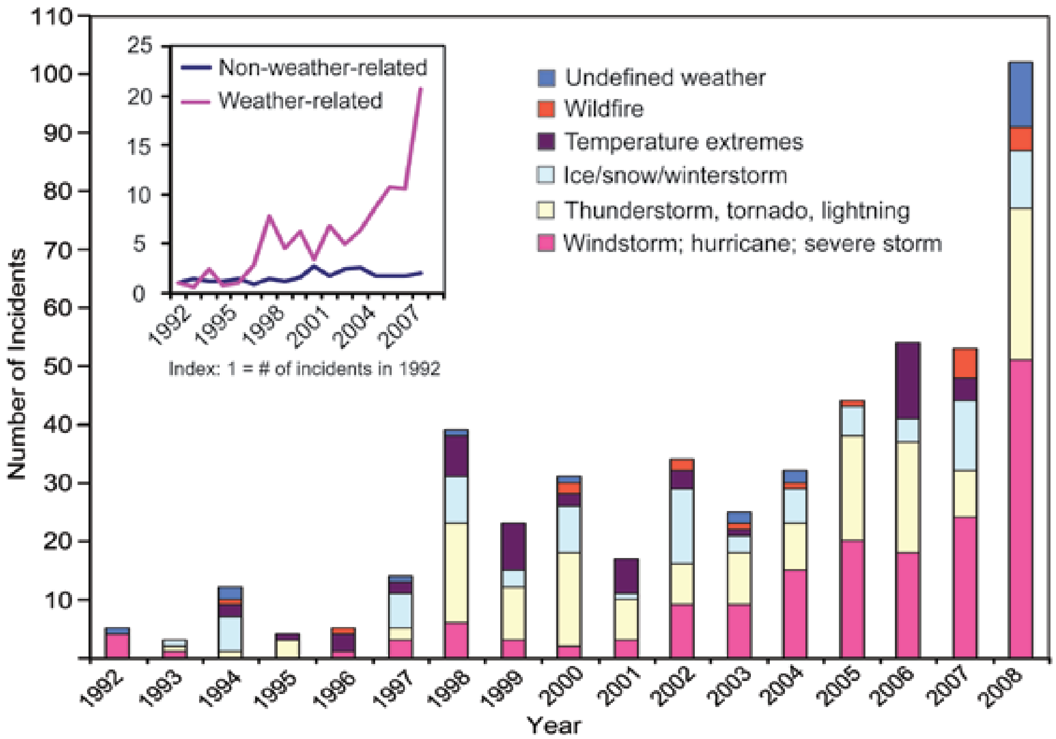


Figure 1. Emerging Electric Power Outage Intensity in the U.S.

To address these challenges, Sandia developed the Energy Surety Design Methodology (ESDM), which is based on a risk-informed, performance-based energy infrastructure evaluation framework. The framework is designed to assist installations, utilities, and municipalities in identifying the cost and performance benefits of different conceptual design and operational improvements that could be made to the electric power infrastructure to meet critical power needs for extended power outages. At the core of this framework is 1) setting energy system performance goals for extended outages or low probability events, 2) conducting risk assessments of various innovative improvement options, such as distributed and renewable energy generation and storage technologies, combined cooling heat and power, energy efficiency, and automated controls and switchgear, to 3) identify how cost-effectively these technologies can be integrated to meet critical mission and service performance needs while supporting overall installation or community health and safety.

While our ESDM approach can be utilized to identify transmission and distribution system improvements, it has been used primarily by third-party operators to assess military critical mission and critical infrastructure energy security and resiliency needs at tactical, contingency, and installation operations and develop conceptual design improvements and associated rough order of magnitude cost estimates for distribution-level upgrades. Integrating these energy security and resiliency improvements within an advanced microgrid framework that enables distributed generation resources to be integrated and operated both islanded and grid-tied, often provides a very capital and operational cost-effective energy resilient solution.

Finally, with a conceptual energy system upgrade design with the cost and performance benefits identified can be used to set funding requirements, establish preliminary and final design specifications, and drive improvement implementation priorities and construction requirements. Therefore, taking the time to visit the proposed site or installation, collecting site data, and establishing critical mission performance goals, is an important first step in creating a secure and resilient energy infrastructure. Jumping into a preliminary energy improvement design, or developing a military base master plan without knowing critical mission and critical service needs, load requirements, and operational metrics, is a sure recipe for operational inefficiencies and failure.

Therefore, this course has been designed to provide a basic understanding of the energy system evaluation design information needs, lessons learned, rules of thumb, and general cost and construction data associated with increasing mission assurance and energy resiliency. These lessons learned have been developed by Sandia over the past decade in the evaluation and conceptual design of energy security and resiliency needs at over 30 military operations and communities. The course is designed to help support many types of energy infrastructure developers, including

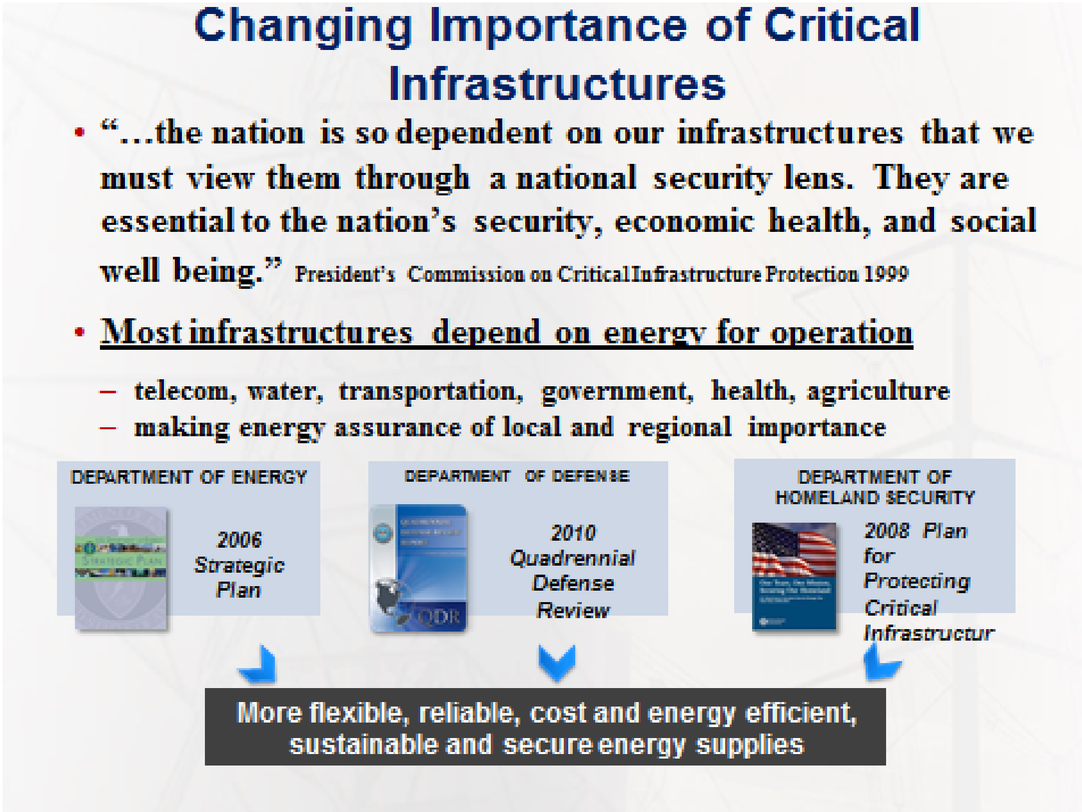
- Master Plan design teams - for either new master planning or modifications of existing installation or other master plans
- Community planning teams – for either new development or improvements to existing energy or critical infrastructure or critical services challenges
- Installation energy and infrastructure managers – focused on critical mission and energy system improvement upgrades
- Contingency and tactical operations managers – focused on energy and critical mission assurance needs
- Energy managers evaluating the integration and operation of distributed and renewable energy generation and storage technologies and advanced microgrids to optimize energy system performance at reduced costs.

This course was also developed to provide energy planners and managers and engineers with a basic understanding and ability to evaluate the costs and benefits of energy system upgrades to support emerging energy system performance metrics such as security, resiliency, and sustainability using advanced distributed and renewable energy technologies, advanced monitoring and control, and new switchgear technologies within an advanced microgrid approach.

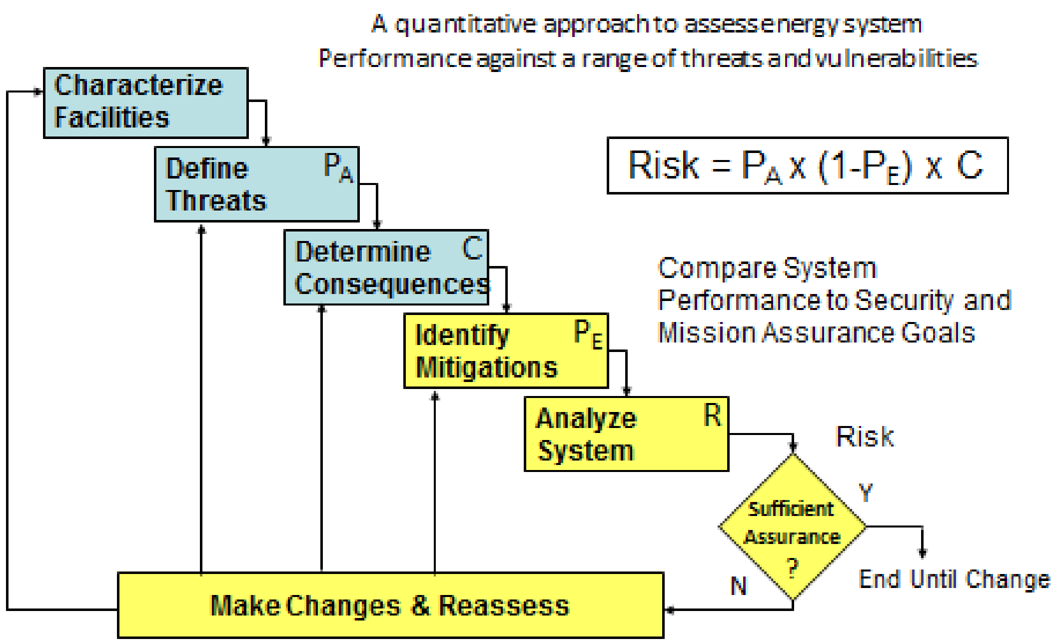
The course provides the following basic information:

- General information on the topology, design, and operation of electric grids,
- Information on the definitions and metrics of energy surety, security, and resiliency
- Use of advanced microgrids to meet emerging electric system operational performance metrics and needs
- Understanding of advanced microgrids, associated technologies needed, applications, and use,
- Step-by-step instructions on developing energy assurance designs for critical assets, quantifying design threats, setting performance goals, and conducting performance risk analyses of the existing system
- Finally, based on the performance risk analyses of an energy distribution system, provide step-by-step options on when and where advanced microgrids provide the best value and where other local solutions are most appropriate.

The course includes example analyses for each design step in the conceptual design process as part of a real world example and case study.



2001 Risk Assessment Methodology – Energy (RAM-E)



Circa 2005 DoD and Utility Electric Power Security and Reliability Concerns

- Practice of providing power security based on back-up generators was problematic
  - *Frequently over-sized and under-maintained, low probability of start (<60%)*
  - *Dedicated to one building or facility*
  - *Operations for extended periods problematic*
- Stating 9's of reliability – did not adequately factor in the erosion of critical mission capability for extended outages
- Safety requirements forced renewable energy technologies to go offline during a power outage
- Several large events highlighted that energy assurance was not impacted only by intentional events – Fires in the west with multi-state outages, large eastern multi-state outages due to weather
- Sandia started looking at advanced microgrids as a likely energy assurance solution

The 2010 QDR Provided Guidance on Energy Security and Energy Assurance Assessments For DoD

- Defines Energy Security

  "Energy security for the Department means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs"

- Directs facilities to:
  - Address energy security while simultaneously enhancing mission assurance
  - Conduct a coordinated energy assessment to prioritize critical assets
  - Promote investments in energy efficiency
  - Ensure that critical assets are prepared for prolonged outages: natural disasters, accidents, attacks

Sandia Advanced Microgrid Experience

Conceptual Designs/Assessments	Small Scale Microgrid Demos	Large Scale Microgrid Demos	Community Evaluations
• Philadelphia Navy Yard – FY11, DOE OE/PIDC • Camp Smith – FY10, DOE FEMP • West Point FY12, DoD/DOE • Indian Head NWC – FY09, DOE OE/DoD • Ft. Sill – FY08, Sandia LDRD • Ft. Bliss – FY10, DOE FEMP • Ft. Carson – FY10, DOE FEMP • Ft. Devens (99th ARG) – FY09, DOE OE/DoD • Ft. Belvoir – FY09 DOE OE/FEMP • Cannon AFB – FY11, DOE OE/DoD • Vandenberg AFB – FY11, DOE FEMP • Kirtland AFB – FY10, DOE OE/DoD • Maxwell AFB – FY09, DoD/DOE • Soto Cano – 2012, DoD/OSD • Creech AFB – 2012, DoD/OSD • Bagram – 2013, DoD/OSD • 29 Palms – 2014, DoD/ESTCP	• Maxwell AFB – FY09, DoD • Ft. Sill – FY08, DoD w/ SNL served as advisor	• SPIDERS JCTD – FY11, DOE/DoD • Camp Smith • Ft Carson • Hickam AFB	• Hoboken • NJ Transit • Northampton, MA • Kauai/Oahu • New Orleans • Kentucky

Power Outages Can be Regionally Significant

Major outages are lasting for 5- 14 days, but these duration electric power outages are not commonly designed for

Sandia National Laboratories

DoD Instruction 4170.11 – March 2016

- Pertains to all phases of administration, planning, programming, budgeting, operations, maintenance, training, and materiel acquisition activities that affect the supply, reliability, and consumption of facility energy.
- Directs facilities to improve Energy Resilience:
  - *The DoD Components shall take necessary steps to ensure energy resilience on military installations. DoD Components shall plan and have the capability to ensure available, reliable, and quality power to continuously accomplish DoD missions from military installations and facilities. UFC 3-500 (Reference (r)) provides guidance to assist in the determination of power availability, reliability, and quality definitions that will impact design criteria for energy resilience.*

Why are Conceptual Designs so Important?

- Conceptual Design – 15% design
  - Threat/outage analysis, critical facilities selection, critical mission priority selection, mission interdependencies evaluation, reliability analysis, operation/control/cyber strategy, performance risk analysis, resiliency analysis for renewables and fuel logistics, ROM cost analysis
- Preliminary Design – 30-50% design
  - MDT, DERCAM, HOMER, Cat, USACE, NAVFAC, A&E's, other industry optimization assessment tools
- Final Design - 60-100% design
  - A&E's – pads, trenching, PID, coordination study, etc.
- Construction and Implementation
  - 1391, RFI, RFP, Operational Testing, Authority to Operate

A good conceptual design is an important element of a successful critical mission energy assurance strategy

1. ELECTRIC POWER SYSTEMS AND ENERGY SURETY

This module provides a general overview of the design and operation of the electric power grid, emerging concerns of energy reliability and security for extreme events, and emerging energy system design metrics.

Concerns of a long-term electrical grid failure due to either natural disasters or human caused deliberate attacks continue to grow. Today's modern society is highly dependent on the electrical grid and a major outage for extended durations can have severe consequences for organizations with critical missions that support or protect citizens. Having a reliable and secure source of power is especially important when it comes to places such as military bases, critical community infrastructures, or critical industrial needs. While the current electric system has served us well for almost a century, the system of long transmission lines and large transformers and substations are vulnerable to a number of threats and are difficult to repair or replace quickly. To keep system reliability high, redundant systems and transmission and distribution system lines have been developed and interconnected at load centers. But even these redundant systems can be damaged in some region-wide events such hurricanes or floods. Therefore, reliance on this large centralized electric system has lead to significant regional outages over the last several decades, with significant regional and national economic impacts in many cases.

Backup generation is often utilized at many critical mission buildings to help offset outages of the current electric grid, but these resources often have not been designed nor maintained to support longer-term outages envisioned from expanding types and levels of threats and disruptions. Furthermore, many military bases and communities have multiple critical functions and roles where the loss of power in part of the base or community can adversely affect other critical functions and can lead to a devastating chain of events that would impair mission performance or public health and safety.

Relative to other infrastructures, a major electrical power outage will likely have the most severe consequences to critical mission functions at military base or communities during mission critical operations. This is because most operations and missions are increasingly dependent on energy supplies and electric power for critical operations such as data centers, command and control centers, critical services such as water supply, wastewater treatment, and emergency operations, telecommunications and computer systems operations, and other specific critical industrial operations. Currently, when the main grid loses power, facilities rely on their individual building tied backup generation for support. Generators along with Uninterruptible Power Supplies (UPS) are typically located only in places where they are essential for continuous critical mission. If a generator fails, which is not uncommon, the building that the generator is allocated to will remain without power and the critical mission likely will be affected.

Although it is rare that a typical power failure lasts longer than a couple of hours, this is not the case for natural disasters such as hurricanes, floods, tornadoes, or an intentional event, where an outage can last for weeks and where portions of the system can be unavailable for even longer periods of times. This is a significant issue since most facilities with backup generation are not prepared for long term outages. Fuel for generators is typically stored to be capable of lasting a maximum of a few days without external refueling from central storage sites as well as storage tanks for individual generators.

Given the interconnectedness of many critical missions, this means that the loss of power at one facility can adversely affect functions or operations at other locations, potentially leading to a chain of events that could have a devastating impact on overall critical mission assurance.

Therefore, the importance of the energy infrastructure, the scale and range of potential impacts on critical mission operations at a base from a power outage, and the fact that current backup energy systems at most installations are not designed for extended outages, are the major reasons why the energy infrastructure, as well as other critical infrastructures, should be considered when considering improvements to support the assured performance of critical mission operations. This is exactly the intent of the directions provided in the U.S. Department of Defense 2010 Quadrennial Defense Review on energy security evaluations and needs.

Energy System Attributes and Associated Metrics

The emerging attributes needed by the electric power system have been discussed by various federal and industry working groups for almost a decade. In reviewing the general thoughts and discussion from the DoD, DOE, and DHS, it is clear that all three agencies would like to see the energy system become more “flexible, reliable, cost and energy efficient, sustainable, and secure”. In general Sandia has identified the general metrics for these attributes in the table below.

While safety is not a major attribute identified by DOE, DoD, and DHS, safety is an inherent requirement by both utilities and the public. Therefore, we believe that the six attributes in Table 1 and the associated metrics

Table 1. Sandia Identified Energy Surety Metrics

Attribute	Metric
Safety	Safely supplies energy to the end user at all times
Security	Maintains power in a malevolent environment
Reliability	Maintains power when and where needed
Sustainability	Assures long-term resource availability
Cost Effectiveness	Produces energy at an affordable consistent cost
Resiliency	Ability to withstand and recover from extended events

Safety, ensures that energy is provided to the end user in a safe manner. This means that the energy system must function well during unplanned outages and developed with safety as a top concern.

S*ecurity* makes a power system more robust to various cyber and physical threats, including terrorist attacks. This can be accomplished through hardening of the energy infrastructure or having more redundancy in in distributed energy systems.

R*eliability*, reflects a power system's ability to meet its mission-critical electric demands. Although it may be impossible to ever achieve 100 percent reliability for all buildings and functions during an extended outage at a reasonable cost, the ability to serve critical power needs for a military base or a community are necessary for public support and safety. This can be accomplished in many ways, including use redundant power systems.

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 future resources. Sustainability can be improved with the use of renewable energy that is used as a secure on-site energy resource, such as PV, geothermal heat pumps, combined heat and power, etc.

C*ost effectiveness* deals with being able to provide high reliability and secure electric power at an affordable cost. Affordability includes evaluation of the costs of different energy infrastructure upgrade options relative to the benefits of mission assurance, higher reliability, and extended outage capability improvements.

R*esiliency,* means a grid that can adapt to large-scale events or disasters 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 focus on short-term reliability needs to be replaced with a resiliency approach, one that looks at the grid not strictly as a flow of electrons but as a grid that serves, 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 would improve upon the traditional reliability approach to grid operations in a key way, be more responsive and adaptive. That is to say, able to react predictively to threats, adjust operations prior to forecast threats, and recover quickly after an event.

All of these attributes can be defined slightly differently, but most definitions are consistent with Table 1. For Example, general definitions of energy security and resiliency from public laws and directives include:

- Energy security
    - Public Law 112-81 - "*The term 'energy security' means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements.*"
- Mission assurance
    - Public Law 112-81 - *"prioritized to provide power for assets critical to mission essential requirements on the installation in the event of a disruption.."*
    - DODD 3020.40 - Mission assurance*. "A process to protect or ensure the continued function and resilience of capabilities and assets—including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains—critical to the execution of DoD mission-essential functions in any operating environment or condition.* **"**
- Energy resilience
    - Presidential Policy Directive 21 - *"Resilience is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."*
    - Army new ES3 - "*Resilience: The capability for systems, installations, personnel and units to respond to unforeseen disruptions and quickly recover while continuing critical activities."*
    - DHS 2013 – *"Resilient infrastructure assets, systems, and networks must be robust, agile, and adaptable. Mitigation, response, and recovery activities contribute to strengthening critical infrastructure resilience."*

Grid Improvement Options to Address Energy Surety

There a number of ways to improve the energy surety of the current electric grid as shown in the table below. This could include building additional transmission and distribution systems to provide energy supply redundancy, hardening transmission and distribution systems to make them more resistant to storms or attacks, adding additional onsite energy generation and storage systems to protect critical buildings or services and critical mission functions, or by the use of microgrids. So while there are multiple options, the focus is to balance the costs and benefits of different improvement options.

Component Hardening (Protection)	Increase Component Redundancy (Mitigation)	Accelerate Outage Response (Response & Recovery)	Distributed Resources (Mitigation, Recovery)
Harden substations – guards, guns, gates, barriers	Redundant transmission lines	Real-time monitoring of substations and transmission lines	Distribution switch gear improvements to more easily move power around
Harden substation equipment	Redundant substations	Fast response, fast reconstruction	Local energy generation
Harden transmission and distribution lines	Increase connectivity	Maintain spares, extra equipment, pre-planned work around	Renewables and/or alternative fuels
High costs, events beyond design basis	High costs, regional outage issues	High costs, regional outage issues	Medium costs, outage duration issues

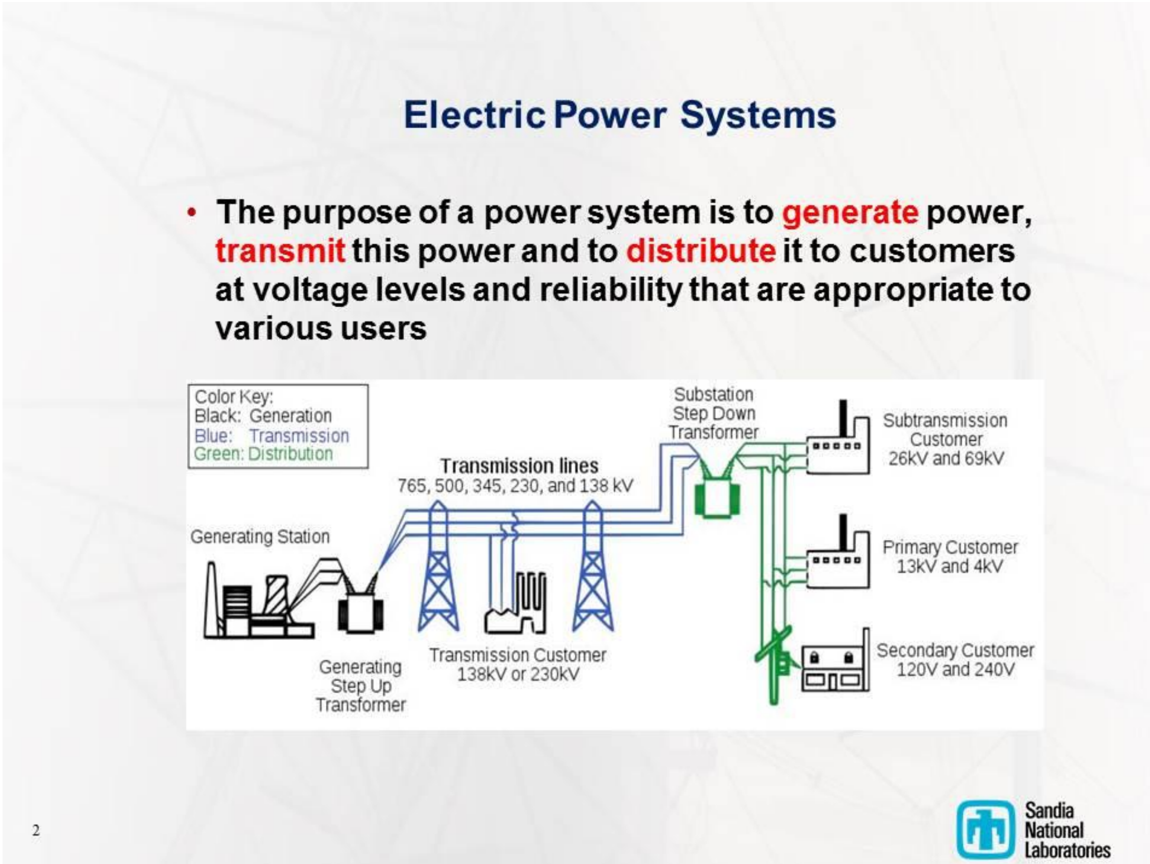
For example, the *safety* attribute can be addressed by ensuring that no new safety hazards are introduced with the interconnection of generation and/or addition of renewable energy to the existing electrical system. This is often done by disconnecting from the grid during a power outage and islanding the critical parts of the base distribution grid into a type of microgrid. *Sustainability* can be improved by including renewable distributed generation such as solar or wind power and minimizing the dependency on fossil fuels were appropriate. Because of reliability issues with many renewable energy technologies, integration with other distributed generation resources and energy storage systems are often needed to meet overall system reliability needs.

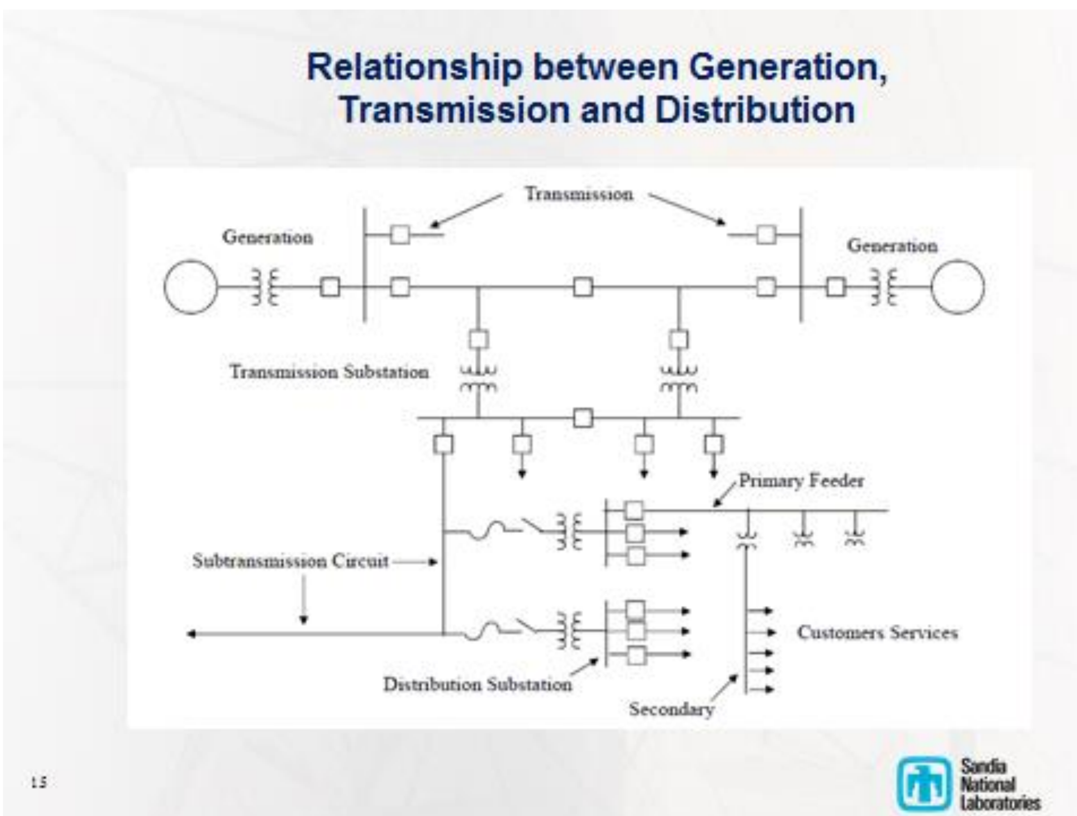
From a *reliability, security, and cost-effectiveness* standpoint, many energy system improvement options focus on integrating proposed upgrades within the context of the existing energy transmission or distribution system. While transmission hardening and redundancy are possible, the associated costs could be prohibitive, and there would continue to be a discussion of "how hard is hard enough". Use of existing on-site electrical distribution feeders, backup generators, and switchgear can reduce implementation costs, reducing reliance on remote substations and transmission lines, and is often more secure and more easily protected. The increased use of on-site distributed generation can be easily focused to support *resiliency* for specific critical mission needs and facilities, without significant new grid infrastructure but instead improved local distributed generation integration, management, and control.

Since the late 1990's, Sandia research into optimizing for the identified energy surety metrics has shown that advanced microgrids with distributed generation is often one of the most cost effective and resilient approaches to improving the surety of the electric grid in providing critical mission and critical services assurance for military bases or communities. Sandia designates an advanced microgrid with the energy surety attributes defined above as an Energy Surety Microgrid (ESM).

In this course, Sandia provides a technical approach to evaluate an energy system based on the identified energy surety metrics and assess improvement options to meet site-specific energy system performance goals. In many cases, microgrids can be an integral part of an overall community energy surety improvement program. The following course modules, we provide specific evaluation and conceptual design guidance approaches for utilizing microgrids with other energy system improvement options to support improved energy system *safety, security, reliability, sustainability, and resiliency cost-effectively*.

1.1 Module 1 – Electric Power Systems





Typical Voltage Levels for Loads, Distribution and Transmission Systems (USA)

Low Voltage Systems:

120 / 240
208 Y/ 120
480 Y/ 277

Primary Distribution Voltage Systems:

2.4 kv	13.2 Y / 7.62 kv
4.16 Y/ 2.4 kv	13.8 kv
12.47 Y/7.2 kv	34.5 Y/19.92 kv

Transmission Voltage Systems:

46 kv	161 kv
69 kv	230 kv
115 kv	345 kv
138 kv	500 kv

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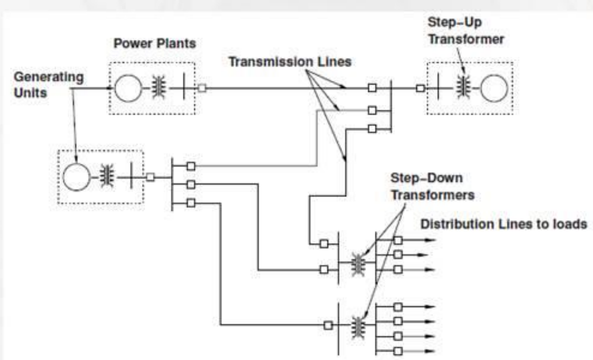
Electric Power Systems

Transmission System



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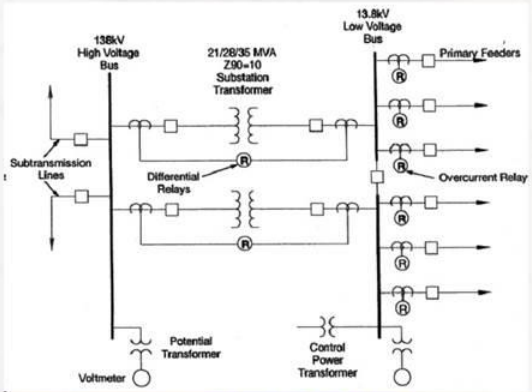
Distribution Substations



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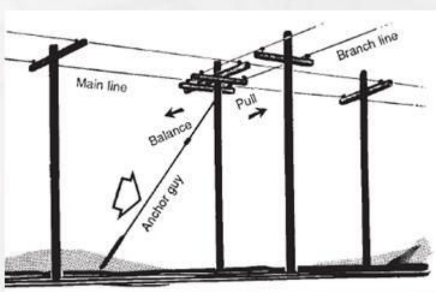
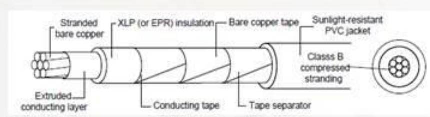
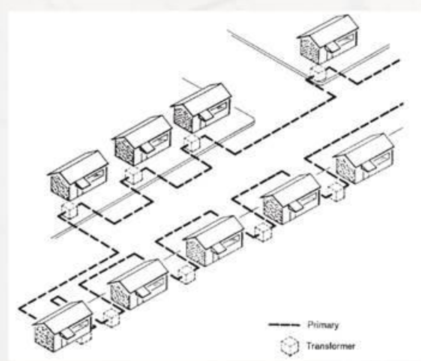
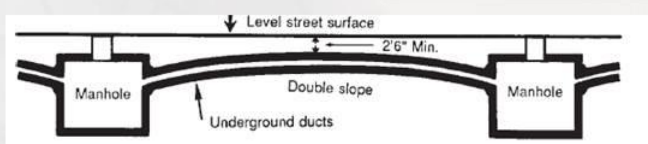
Power Lines and Transformers









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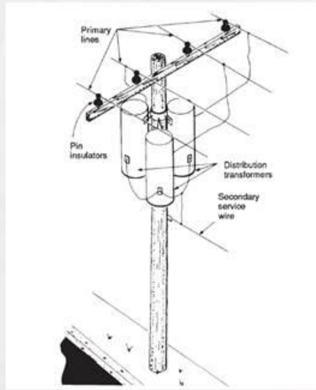
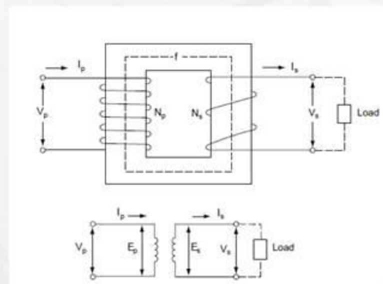
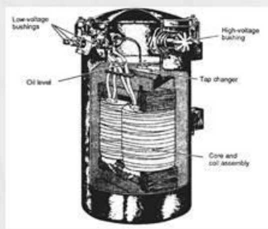
Substation and Building Transformers







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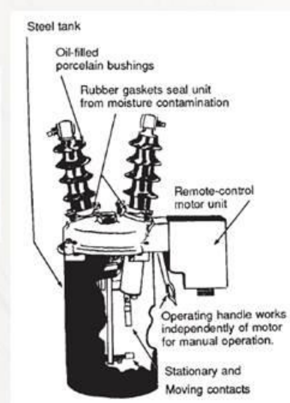
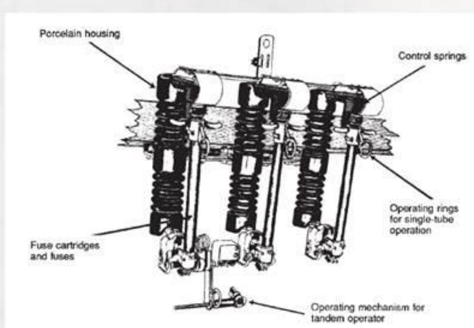
Switching Devices





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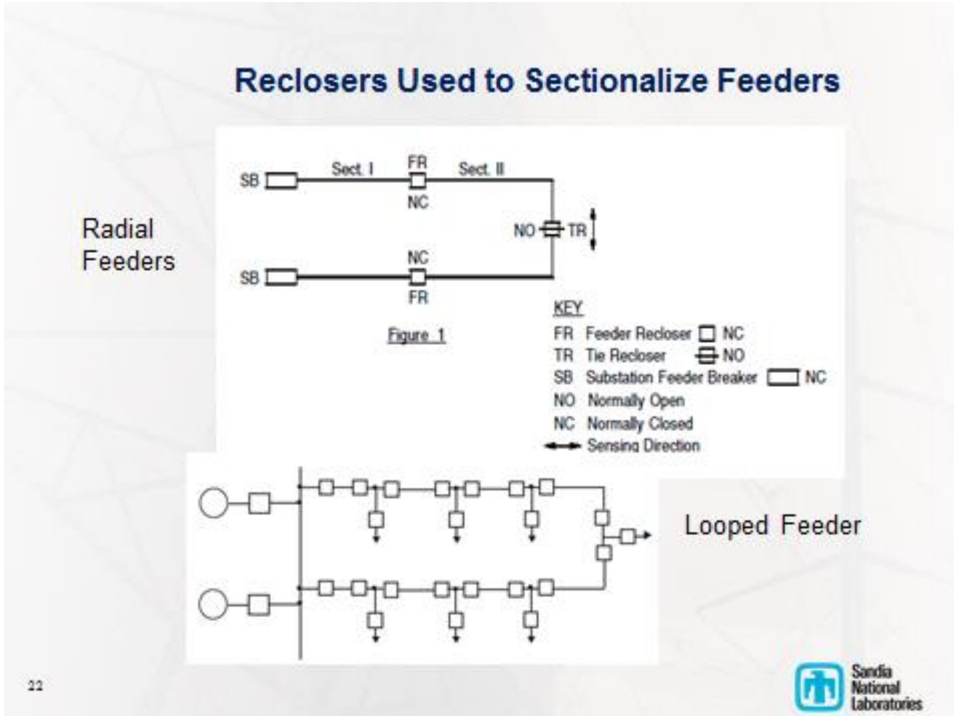
Reclosers Used to Sectionalize Feeders
Radial Feeders
SB
Sect. I
FR
NC
Sect. II
NO
TR
Figure 1
KEY
FR Feeder Recloser NC
TR Tie Recloser NO
SB Substation Feeder Breaker NC
NO Normally Open
NC Normally Closed
Sensing Direction
Looped Feeder
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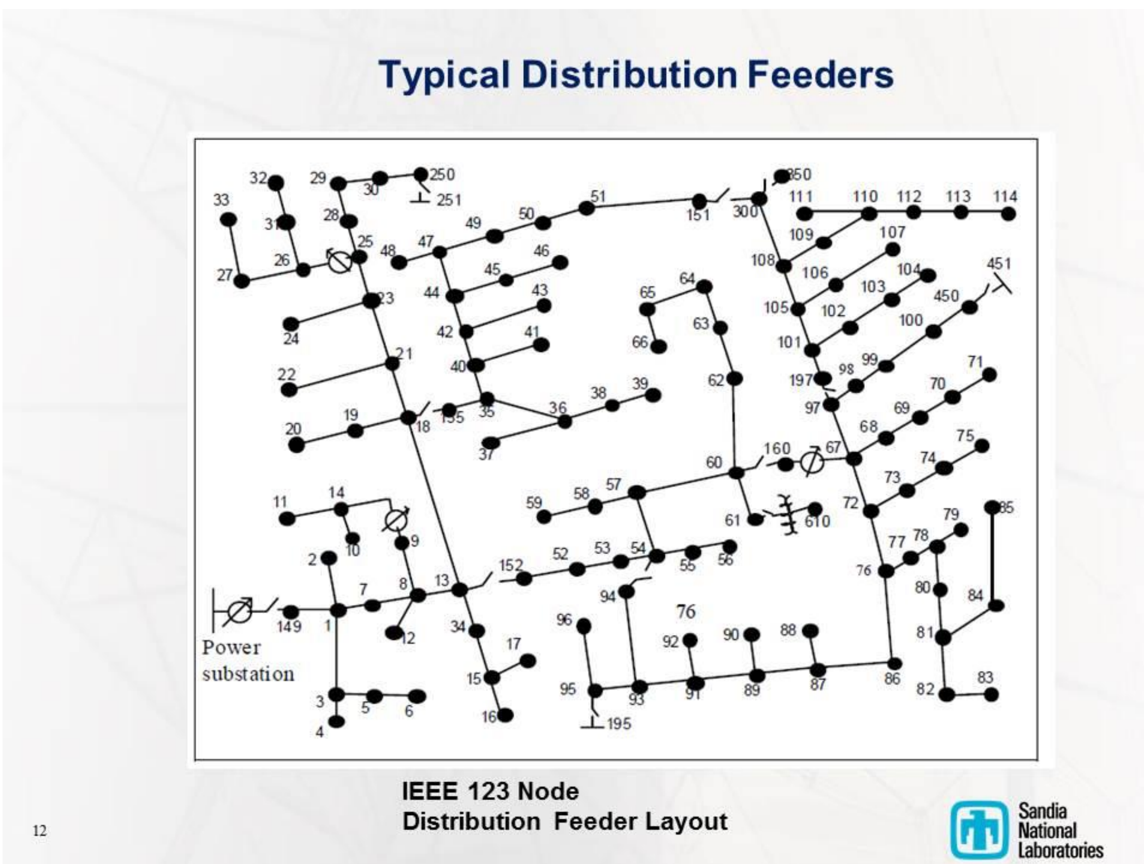
Typical Distribution Feeders
Power substation
IEEE 123 Node
Distribution Feeder Layout
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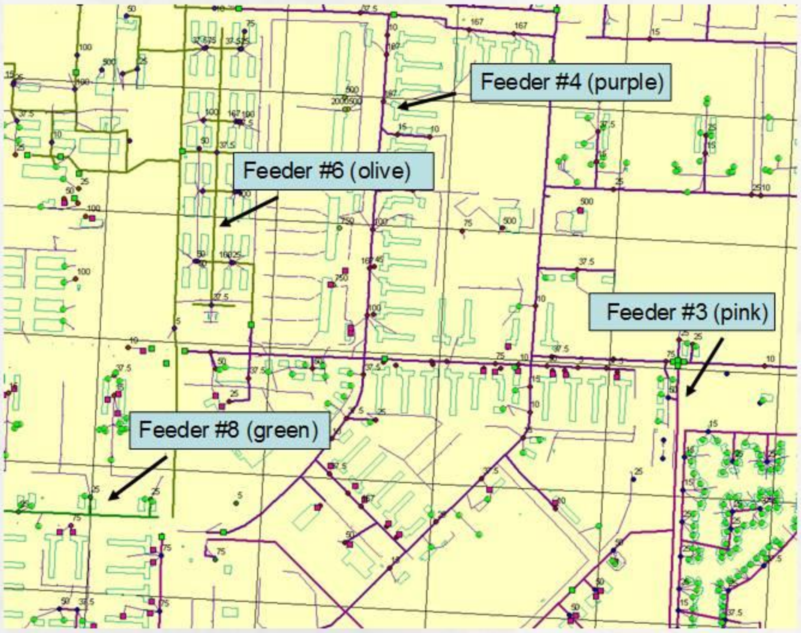
Example (One Line) Feeder Layout



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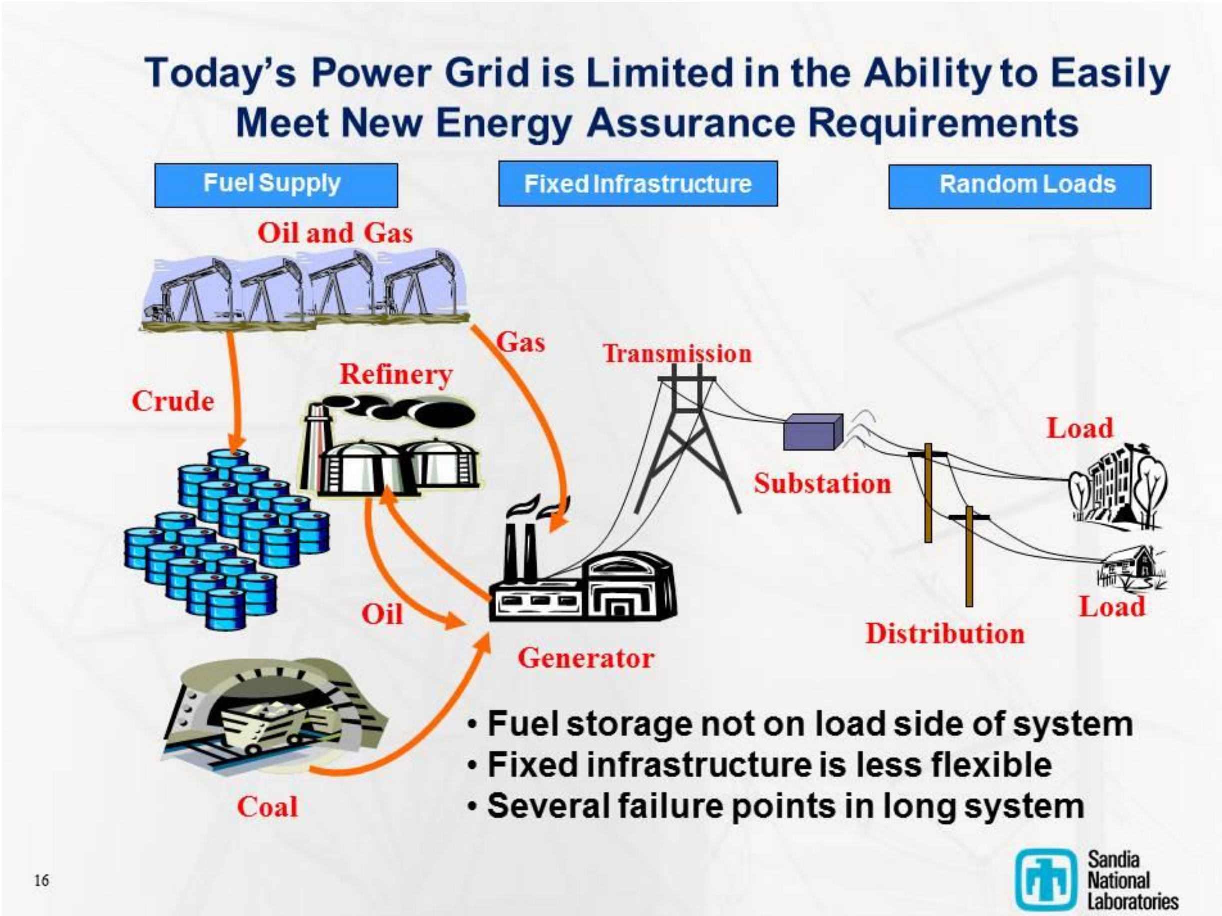
1.2 Emerging Energy Assurance Drivers and Metrics



Energy Surety Metrics

Energy Surety – Safe, secure, and reliable energy supply for sustained system operations and assured system and mission performance

Performance Characteristic	Definition and Metrics
Safety	Safely supplies energy to end user
Security	Protection of energy supply infrastructure
Reliability	Provide energy when and where needed
Sustainability	Can be maintained for long durations with minimal impact on resources
Cost Effective	Provided at affordable cost
Resiliency	Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions

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New Energy Surety Definitions

- **Energy security**
  - **Public Law 112-81** - *"The term 'energy security' means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements."*
- **Mission assurance**
  - **Public Law 112-81** - *"..prioritized to provide power for assets critical to mission essential requirements on the installation in the event of a disruption.."*
  - **DODD 3020.40 - Mission assurance.** *"A process to protect or ensure the continued function and resilience of capabilities and assets—including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains—critical to the execution of DoD mission-essential functions in any operating environment or condition. "*
- **Energy resilience**
  - **Presidential Policy Directive 21** - *"Resilience is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."*
  - **Army new ES3** - *"Resilience: The capability for systems, installations, personnel and units to respond to unforeseen disruptions and quickly recover while continuing critical activities."*
  - **DHS 2013 –** *"Resilient infrastructure assets, systems, and networks must be robust, agile, and adaptable. <u>Mitigation, response, and recovery</u> activities contribute to strengthening critical infrastructure resilience."*

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Energy Assurance Challenges



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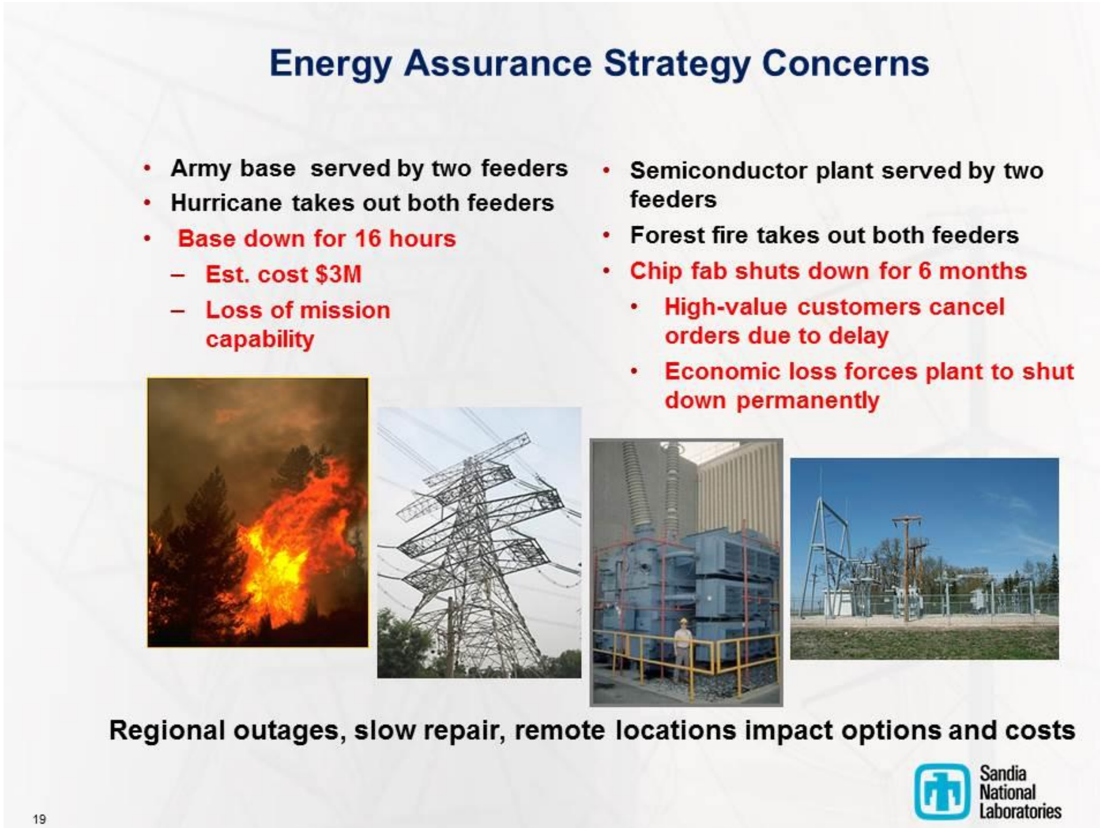

1.3 Module 1 – Lessons Learned and Tips

Module 1 - Lessons Learned, Tips, Best Practices

Line Voltage	Nominal Line Length	Nominal Line Load	Operating Line Load
480 v	480 yds	300 kW	250 kW
4 kV	4000 yds	1 MW	750 kW
13.5 kV	2.5 mi	10 MW	7 MW
34 kV	7 mi	35 MW	22 MW
46 kV	9 mi	50 MW	40 MW

Distribution line sizes

- impact maximum length and loads that can be carried
- Impact number and size of substations required

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Energy Reliability/Availability Values

Application	Energy Availability	Energy Unavailability	Downtime per year
Unreliable power	<0.96	>0.04	350 hr/14.6 days
General utility operations	0.99	0.01	87.6 hr/3.65days
	0.999	0.001	8.76 hr
High utility redundancy	0.9999	0.0001	0.87 hr/52 min
Non-utility high reliability	0.99999	0.00001	0.087 hr/5.2 min
	0.999999	0.000001	.52 min/31 sec
	0.9999999	0.0000001	.31 sec

Utility nomenclature of 9's of reliability or availability

Example Availability, Reliability, and Cost Calculation

Option	Availability	Reliability 14-day	Costs
Baseline	0.99999780	0.99811376	NA
Option 1 – Redundant utility substation	0.99999800	0.99878546	$20 M
Option 2 – Small central power plant	0.99999901	0.99924114	$4-5 M
Option 3 – Collection of shared existing backup generators	0.99999999	0.99995592	$3-4 M

Notice – reliability #s are lower than availability

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2. MICROGRIDS AND ENERGY SURETY BENEFITS

This module provides an overview of the application and use of microgrids, and microgrid components and their function and use. This module is intended to provide non-power engineers with background information on how the electric gird is commonly constructed and used and how microgrids are being designed to safely and reliably use distributed and renewable energy and storage resources to support utilities and help provide power for communities during extended outages. In many microgrid applications, the existing electric power infrastructure can be utilized with some modifications of electrical system components to insure worker safety and appropriate system functions and operations.

This module includes:

- A general discussion of microgrids and how they can support energy surety needs in communities, and
- Information on various microgrid applications and associated components commonly utilized and their functions.

What are microgrids?

Microgrids are defined as an interconnected sets of loads and energy resources that can operate at the distribution level as a single entity.

Essentially all microgrids integrate energy generation and storage and renewable energy resources onto the electrical distribution system to function as a small power grid or as a small distributed or virtual power plant. This makes microgrid operation of generation resources more efficient and cost effective, managing the use of these resources only when needed, rather than operating individual systems for each building at low power use. They also provide higher reliability power since distributed generation is integrated rather than being only building-tied, enabling better use and management of generation resources. If for example, a generator breaks down and cannot operate, other generators will pick up the load, which is not the case for building-tied generators.

So distribution-level grids can vary in size and scale. The table below highlights the general size differential between a national grid, microgrids, and nanogrids. Microgrids are essentially between 1-20 MW in size and normally utilized at distribution level voltages ranging from 480V to 12-40 KV and at three-phase power. The size uses depends on the application, whether a military installation, enduring base, tactical or islanded operation, or industrial campus.

Grid Definition	Generation Size	Commonly Considered Size	Common Attributes
U.S. Grid	~1 Tera watts (1x 10^{12} watts)		High to medium voltage, 69kVa- 700 kVa
Microgrid	1 x 10^{-6} (US Grid) 1 x 10^{6} watts ~1 MW	1 MW-10 MW	Medium voltage 4 kVa - 34 kVa, three-phase, 4-20 buildings
Nanogrid	1 x 10^{-9} (US Grid) 1 x 10^{3} watts ~1 kW	5kW-200 kW	Low voltage 120/208/480 V, often single phase, 1-2 houses or buildings

Microgrid capabilities and elements

Although the concepts behind microgrids have been around for a long time, the understanding of what a microgrid should consist of in terms of its capabilities and elements has greatly evolved over time. There are two major types of microgrids as shown in the table below.

- Standard Microgrids
- Advanced microgrids

A third type, essentially the same as the advanced microgrid is the Smart Grid Node, often discussed by utilities as an option utilities are interested in pursuing.

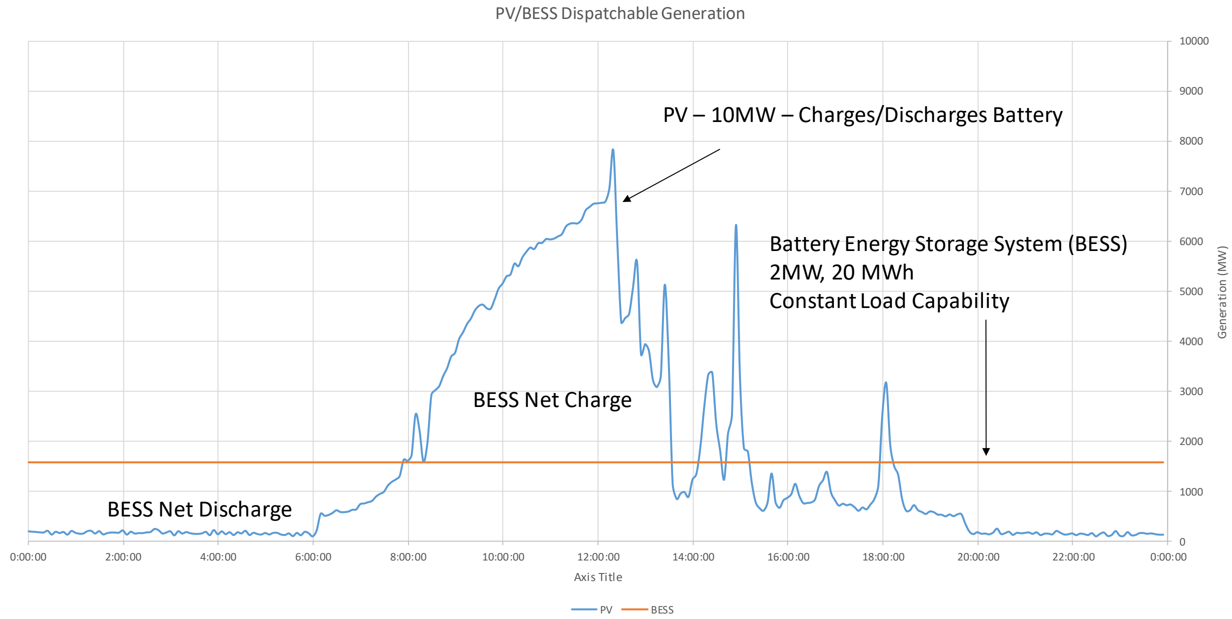
Standard Microgrids

Standard microgrids have been operated successfully for decades at large industrial parks and university campuses, especially where combined heat and power are needed. But these microgrids generally operate with no or minimal connection to the larger grid. For islanded microgrids, all distributed generation resources, renewables, energy storage, diesel or natural gas gen-sets, etc. are tied to the local distribution system, but the microgrid is not tied to the larger sub-transmission system or transmission grid. Therefore, standard microgrids often operate as a stand-alone or islanded system, and the microgrid performs all generation and load management. This is a common approach at college or industrial campuses, where heating and cooling loads or industrial process create significant heat to also generate enough on-site thermoelectric power to satisfy local demands and grid power is not really required. Islanded microgrids also occur in many small islands or remote areas where there is no transmission grid to connect to.

STANDARD MICROGRID	• Operates where there is no large grid or operates generally islanded from the larger grid • Often used with a central power plant or CCHP plant to balance power supplies and demand locally (universities, industries) • Minimal grid interaction or support
ADVANCED MICROGRID	• Can operate islanded or grid-tied • Can integrate distributed and renewable generation and manage and control power demand and distributed resource allocation • Supports optimal use of distributed energy resources during both power outages and for grid support
SMART GRID NODE	• Same functional capabilities as an advanced microgrid • Control capabilities to federate with other microgrids, if needed • Grid-tied operations are coordinated through the grid operator to support grid operations and performance, and provide ancillary benefits to the grid

In other than Combined Cooling Heating and Power (CCHP) applications, islanded microgrids are often an expensive option because the use of local distributed and renewable generation resources often requires extensive energy storage systems to be able to maintain high quality and high reliability power without the support of a large grid. In islanded microgrids, all operations and maintenance (O&M) costs are born by the microgrid operator, with fuel costs often being higher than for a large utility unless the economies of combined heat and power are integrated within the islanded microgrid system.

If an all-renewable islanded microgrid is required, then the costs can be even higher. This is because the use of intermittent renewables such as wind and solar have extra generation and extensive energy storage requirements to provide the high reliability and high quality electric power needed. This need is highlighted below for a 2 MW fully solar PV powered microgrid system design.



Example PV/BESS Dispatchable Generation System

If the only source of generation is PV, the capacity of the PV system and Battery Energy Storage System (BESS) would need to consider the possibility of days with low or a lack of solar irradiance. Thus, the total PV output needs to support not only a full 24-hour demand, but also needs a battery that can support the full power demand for a potential one or two-day power outage. Essentially, the BESS supplies generation to the system when the PV is unavailable, and is charged with the excess power provided by the PV, when available, so the total system can act as dispatchable generation, similar to a diesel or natural gas generator.

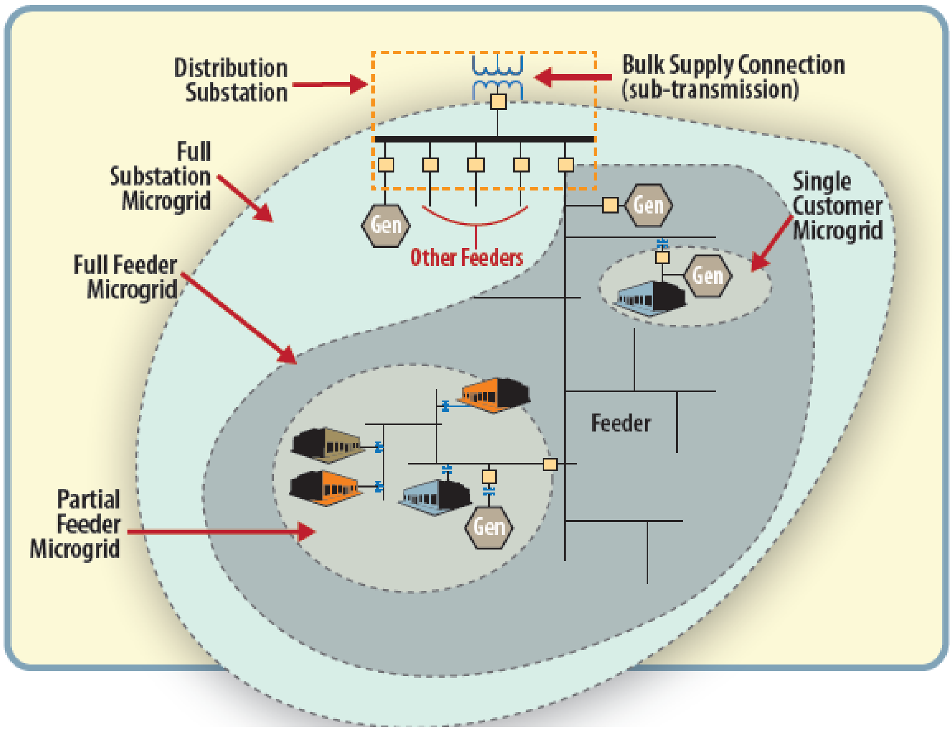
Advanced Microgrids

Advanced microgrids utilize automated electrical switchgear and computer controls to be able to operate either islanded or grid-tied. This enables the microgrid and its distributed generation resources to separate from the grid during a power outage to meet local power needs, but also operate the generation resources when grid-tied to reduce peak power demands or provide power to the grid to support the utility in addressing transmission congestion, powerline damage, etc. Sandia has developed many advanced microgrid designs at over 30 military sites and communities. The use of advanced microgrids has many benefits, including:

- Improved energy assurance for critical mission needs,
- Enhanced energy resiliency in extended power outages,
- Improved utilization of distributed and renewable generation,

- Reduce grid congestions and provide other ancillary grid services, and
- Reduce size and costs of emergency generation needed.

In advanced microgrids, all distributed generation resources - renewables, energy storage, diesel or natural gas gen-sets, etc. - are connected together on the local distribution system, as well as connected to the sub-transmission system through a point of common coupling (PCC). As shown below, you have flexibility in the size of the microgrids, from a partial feeder, full feeder, or even a full substation microgrid, depending on local needs.



Advanced Microgrid Approaches

The major operational benefit of an advanced microgrid is that the distributed generation can operate when tied to the grid to reduce peak load, etc., but also operate together during a power outage to safely support local critical loads. In this way, energy costs are minimized by using often lower cost utility power most of the time, but using the renewable and distributed generation resources when appropriate – power outages, peak shaving of power demand to lower energy costs, etc. This optimizes the operation of the distributed generation and lowers operational costs. This is often the lowest cost, highest reliability approach, supporting 20-40% of renewable penetration without expensive energy storage.

There is often minimal operations and maintenance cost associated with advanced microgrids since the existing distribution system infrastructure is often used. This approach has the most flexibility in managing loads and generation resources as situations vary, improves local energy assurance and resiliency in both short and extended power outages, enhances the utilization of renewables to provide emergency power, and enables load shedding and other grid services with distributed and renewable generation. Advanced microgrids can be a relatively inexpensive option, often paying for themselves in a single major power outage because of the avoided economic loss of critical operations or services, by reducing costs through load shedding, and by generating income by providing ancillary services to the local utility when needed.

A microgrid essentially works as an integrated energy system consisting of loads and distributed energy resources (DERs) operating as a coherent unit, either in parallel with or islanded from the power grid, and either utilizing elements from the existing grid (power lines, transformers, switches, etc.,.) or operating as a separate unit which can tie to or be isolated from the power grid. An advanced microgrid should have capabilities designed to make the microgrid operate with flexibility and efficiency. Some important capabilities include:

- Flexibility in placement and technologies associated with generation resources including distributed generation, renewables and energy storage by development of plug-and-play capabilities. Plug-and-play also provides for reduction of engineering costs of these resources and increased reliability through their shared use among multiple facilities within the microgrid. This is compatible with a range of different sizes of generation resources in the microgrid.
- Power quality and reliability are enhanced through intentional islanding and autonomous control of generation resources.
- Robustness of the system is enhanced through the ability of generation resources to share all energy resources to meet the needs of the loads. The microgrid provides for continuous operation during loss of the utility grid, and compensates for loss of generation resources by sharing loads between units.
- Because the total generation is matched to the microgrid load, with a slight excess for contingencies, the generation resources are run more efficiently so only the backup generation required for the microgrid is utilized, so less yearly emissions during power outages will occur.

Generation resources (also can be referred to as distributed energy resources (DERs)) are distributed to enhance reliability by minimizing disruptions during power outages and providing distributed power to critical resources when islanded. If generation resources are designed to carry continuous loads, they can supply these loads and any excess can be sold back to the utility to balance costs while grid connected. Generation resources can also be potentially used as peak shaving devices. Generation resources can include diesel and gas engines, microturbines, fuel cells, PV, wind, biomass, etc. depending on the capabilities and interests of the particular site.

Microgrids are designed to distribute existing and new generation resources among critical buildings to meet critical energy needs. They therefore require the following types of alterations of the existing utility grid to implement the microgrid:

- *Additional transformers /breakers /controls to existing generator resources (backup generators, PV etc.)* – step up voltage levels of backup generators to designated feeder levels if necessary and apply microgrid monitoring and controls of voltage and power levels of the generator resources
- *New generation resources (generators, PV, etc.)* – add sufficient new generation resources to supply required critical microgrid load demand when the microgrid is islanded from the utility grid; recommended that microgrids have enough generation such that the loss of any generation resource within the microgrid will not entail loss of load which provides so called 'N-1' redundancy to the microgrid
- *Static Switch/Main Breaker* – main isolation device (point of common coupling) to form the microgrid and allow it to be grid tied or islanded (note – there can be multiple isolation devices, between a microgrid and the utility grid depending on how the microgrid is designed)
- *Sectionalizing Switches/Breakers* – can be used to isolate non-critical loads within microgrid when generation is available; can also be used to sectionalize microgrid into zones of protection for larger sized microgrids
- *Energy Storage* – additional resource used as needed to protect non-interruptible loads and provide ride through capability until distributed generators start up; can also improve system performance such as absorbing sudden changes in PV so that generators limit the amount of ramping in response to PV fluctuations
- *Microgrid controls* – set of centralized and distributed controls to monitor and control generation resources, isolation devices (breakers, switches) to switch the microgrid between grid tied and islanded operation as well as deploy the generator resources efficiently to reduce fuel use by being responsive to load conditions
- *Protection* – microgrid system protection against fault conditions to isolate generation devices from the system during the microgrid operation
- *Building load reconfiguration* – in some microgrid designs, the critical load needs for a microgrid can be reduced by reconfiguring building loads to sectionalize critical and non-critical loads within the building so that microgrid is only required to supply a portion of building loads rather than entire building loads
- *Load Shedding* – in some microgrid designs, isolation devices can be installed to isolate less critical loads within a microgrid when sufficient generation is not available to meet all the load within the microgrid

- *New Feeders* – in some microgrid designs, it may be more economical to install a new dedicated microgrid feeder connecting critical buildings together rather than using the existing utility grid because the amount of non-critical load far exceeds the critical load so would be cost prohibitive to use the existing utility grid to form a microgrid
- *Feeder rearrangement* – in some microgrid designs, instead of installing a new dedicated microgrid feeder it may be possible to reconfigure the connections of an existing utility feeder so that mainly critical loads are on the microgrid feeder and the non-critical loads are on other feeders, so that this feeder can be made into a microgrid without a prohibitively large amount of generation required to meet loads

An advanced microgrid includes at least one point of common coupling (PCC) where the portion of the load on a feeder containing the microgrid can be grid-tied or islanded from the utility feed using either a main breaker or static switch which can open and close, providing signaling to microgrid generator controls. The microgrid generation resource controls interact with the generation resources isolation devices (breakers, paralleling switchgear, automatic transfer switches (ATSs) etc.,) as well as other devices involved with system protection and isolating non-critical loads within the microgrid if they exist during operation of the microgrid and transitions between grid tied and islanded modes of operation.

The use of electrical energy storage is needed to keep non-interruptible loads from experiencing short duration outages during the transition between a microgrid going from grid tied to islanded mode. Without electrical energy storage, these loads will experience a short duration outage (example 10-60 seconds) in which microgrid generation resources are starting up and synchronizing to the microgrid. Critical loads which are non-interruptible are usually equipped with Uninterruptible Power Supplies (UPS) to provide 5 or more minutes of backup power to these loads such as telecom or computer server equipment. The power is rated to ride through the time necessary for backup diesel generators to start and recharge the batteries if the outage is sustained.

A microgrid can be designed to allow ride through of all critical loads if additional UPS units are considered. However if an entire building requires non-interruptible loads, then a larger scale electrical energy storage unit may be required to prevent these loads from getting interrupted during short transitions.

Large-scale energy storage can also be used in a system to balance out the expected fluctuations associated with renewables such as wind and PV. When renewable penetration exceeds 20% or more of the generation, it is often appropriate to install some energy storage in a microgrid to prevent the non-renewable resources (diesel or natural gas generators, microturbines, etc.) from being excessively ramped up and down to balance frequency shifts as renewables vary, which can lower the lifetime of these units. Engineering studies can be done to optimize the amount of energy storage required to balance out wind and PV resources, with a factor of 10% battery unit size for each unit of renewable power included in the design, where renewables are over about 30% of the total load capacity.

Building load reconfiguration refers to if and how the existing emergency connections of critical buildings are made and what further adjustments can be made to assign criticality. Buildings with backup generation generally have an automatic transfer switch which closes the generator onto a portion of the building loads during emergency situations. If it is determined that a larger portion of a critical building should be supplied by the microgrid than currently exists, then existing switchboards and/or panelboards will have to be retrofitted or expanded to accommodate the new load requirements. Or if a new critical building is added to a microgrid, it might be helpful to reconfigure the building so that only the critical loads are connected to the microgrid to limit the amount of generation required.

Non-critical loads can be shed when an advanced microgrid is in islanded mode by installing remotely operable main breakers on the incoming building feeds, which will isolate these buildings when the microgrid is in islanded mode. If the microgrid is designed to handle all loads within its jurisdiction, these retrofits won't be required, but instead additional generation will be needed to cover these additional loads.

If it is too cumbersome to create a microgrid within an existing distribution feeder system, it may be possible to reroute a portion of the non-critical loads along the existing radial distribution feeder to other feeders. This will allow the microgrid to island from the utility during power outages to supply mostly critical loads, so generation requirements are reduced. It also may be more efficient to develop a separate dedicated microgrid feeder isolated from the utility by one or more PCCs in which only critical loads are attached to reduce the amount of generation required for the microgrid.

The suitability of these options all depend on the relative cost effectiveness of the number of switches needed, the amount of additional generation needed, or the length of the isolated feeder. We have seen cases were each of these options in different scenarios is more cost effective.

In microgrids, all the generation resources required are located within the military installation. Having the distributed generators inside a military facility automatically improves the system security since it would be more difficult to physically obtain access and cause damage to the system. Having the generation on-site increases reliability due to the reduction of single points of failure due to the interconnection of generators in a microgrid since the failure of one generator does not necessarily mean that critical load will go unserved.

By utilizing the interconnected distributed generation and storage more efficiently, there are cost saving possibilities that come with back feeding the grid to reduce costs as needed by the utility, and reducing diesel consumption during islanded mode. Some of the ancillary benefits available with advanced microgrids are noted in the table below.

Ancillary Service	Value of Service ($ per kWhr)	Required Response (minutes)
Frequency Regulation	High	1
Spinning Reserve	Medium	1-10
Auto Response	Medium	10-20
Manual Response	Low	30-60
Non-spinning Reserve	Very Low	10
Replacement Reserve	Very Low	30

The highest ancillary utility value with a microgrid is frequency regulation as well as load shedding during times when transmission congestion support rebates for shedding load. With many microgrids being designed with 5-10 MW of integrated distributed generation, load shedding of those magnitude of loads have been profitable for several microgrid operators.

Example Advanced Microgrid Sequence of Operation (SOO)

Although we can't specify the sequence of operations associated with a microgrid without knowing the type of microgrid it is (Type 1, 2 as described above), as well as how it is specifically configured including its size as well as the conditions upon which it will operate; it is possible to describe some generic features of the sequence of operation that most microgrids will follow. We will pick a simple example to illustrate the sequence of operations for microgrids.

Below is an example of microgrid which operates predominantly as a type 1a/1b (non-grid tied, no or small amount of renewables) or but can in heavy load circumstances be operated as a type 2a/2b (grid-tied, no or small amount of renewables):

- The microgrid provides power to all critical mission loads within its area and isolates non-critical loads during islanding mode when utility power is lost.
- The microgrid predominantly operates isolated from the grid but can be operated grid tied to provide peak shaving capabilities during heavy load conditions.
- When the microgrid is isolated, generators come on line to pick up loads and restore power.
- If renewables exist, they are at a low penetration level (<20%) so no additional energy storage is required for the microgrid. Any critical loads requiring UPS are assumed to already be provided for in existing buildings.
- Isolation devices exist to remove non-critical buildings from the microgrid when it is islanded from the utility during power outages.

The following diagrams (Fig. 1 – Fig. 4) illustrate the basic steps involved in forming an islanded microgrid from a grid-tied collection of buildings. The first step (Fig 1) illustrates the a feeder with a microgrid with a point of common coupling (PCC) main breaker dividing the upstream non-microgrid portion of the feeder from the downstream microgrid portion of the feeder. The microgrid consists of a collection of critical mission buildings in blue and non-critical buildings in yellow. The critical mission buildings have none, one, or more generation resources (DERs) attached to them. The generation resources are de-energized when the microgrid is grid-tied. Initially the PCC is closed allowing critical and non-critical buildings to be fed from the utility. For peak shaving, the PCC would remain closed and the appropriate generators (necessary to compensate for the peak loads during peak conditions) will start up and synchronize with the utility in parallel, and run for the duration necessary to compensate for the system load peak conditions.

In step 2 (Fig. 2), when the feeder loses power through a system fault which effects the feeder which the microgrid is attached to, next the feeder and microgrid become de-energized. Depending on the type of fault, a main substation breaker or upstream breaker will open to isolate the feeder from the utility power (i.e. the fault may have occurred on the microgrid feeder or another upstream feeder which affects the main substation). Next the microgrid main breaker (PCC) opens to isolate the microgrid portion of the feeder from the main substation to prevent the generation in the microgrid from backfeeding upstream faults in the utility system for safety purposes. The microgrid main breaker also sends signals to open up non-critical building feeds to prevent them from connecting to the microgrid when the generation resources are started up in order to limit the microgrid generation to critical loads. A more sophisticated microgrid control scheme could allow non-critical loads to remain in service and only become isolated when sufficient generation is not available. Microgrids can exist which don't discriminate between critical and non-critical loads, if they have enough generation resources to supply all of the loads. During this period prior to generation resources getting started up (~30 seconds), the critical buildings will be without power, so any uninterruptable loads will have to be supplied by backup sources, such as UPS units. The entire microgrid can be kept from temporary outages with enough UPS to supply the microgrid while the generation resources start up.

In step 3 (Fig. 3), once the generation resources sense a loss of utility power, they start up to pick up their individual building loads. Any remaining generation capacity from these generators is available for other critical loads. IEEE 1547 requires that renewable resources remain powered off for a minimum of 5 minutes, so any renewables will be available to add to the generation resources after that.

Finally, in step 4 (Fig. 4), the generators are synchronized sequentially to the microgrid portion of the feeder until all the generators are on the bus and all critical buildings in the microgrid are provided with power, with each generator output increasing as they are synchronized to large loads. At this point, the amount of generation provided by the generation resources can be adjusted for more efficient utilization, either manually or through an automated process. For example if the load doesn't require one or more of the generation resources (DERs) to be available, they can be shut off to make the other resources more fuel efficient.

When utility power is restored, the steps to undo the microgrid occur in the reverse of those just described. When the power returns, the generation resources at each building sense that power is restored and are individually offloaded from the microgrid in a seamless fashion, preventing any load interruptions. When all critical buildings are up and running, a signal is sent to the non-critical buildings to close their isolation devices and re-energize these buildings.

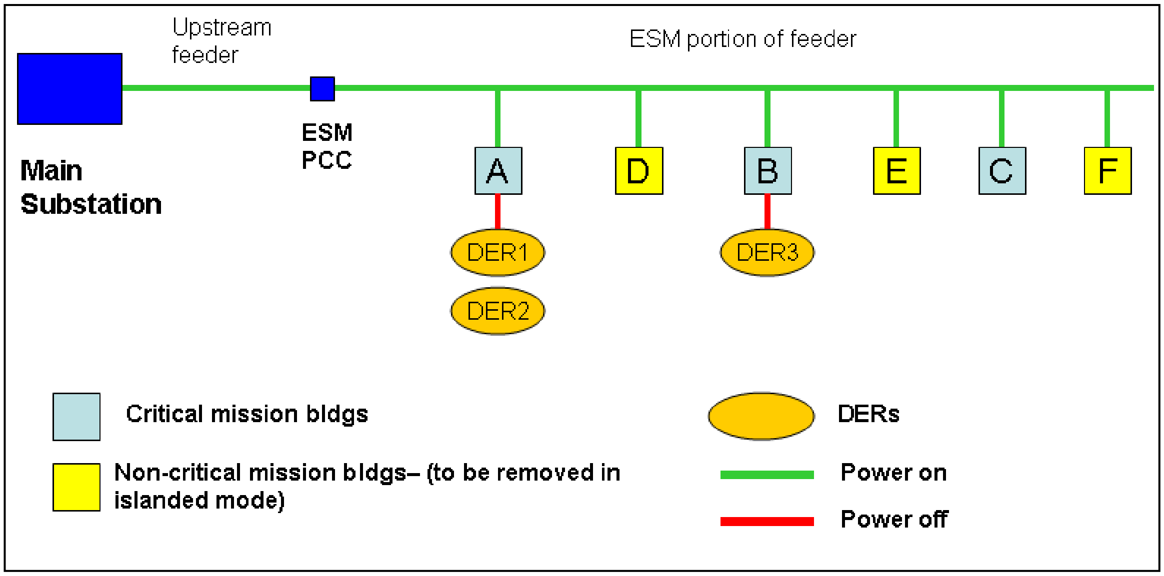


Figure 1. Step 1 – Feeder and microgrid are grid connected (DER – generation resource such as diesel or gas generator)

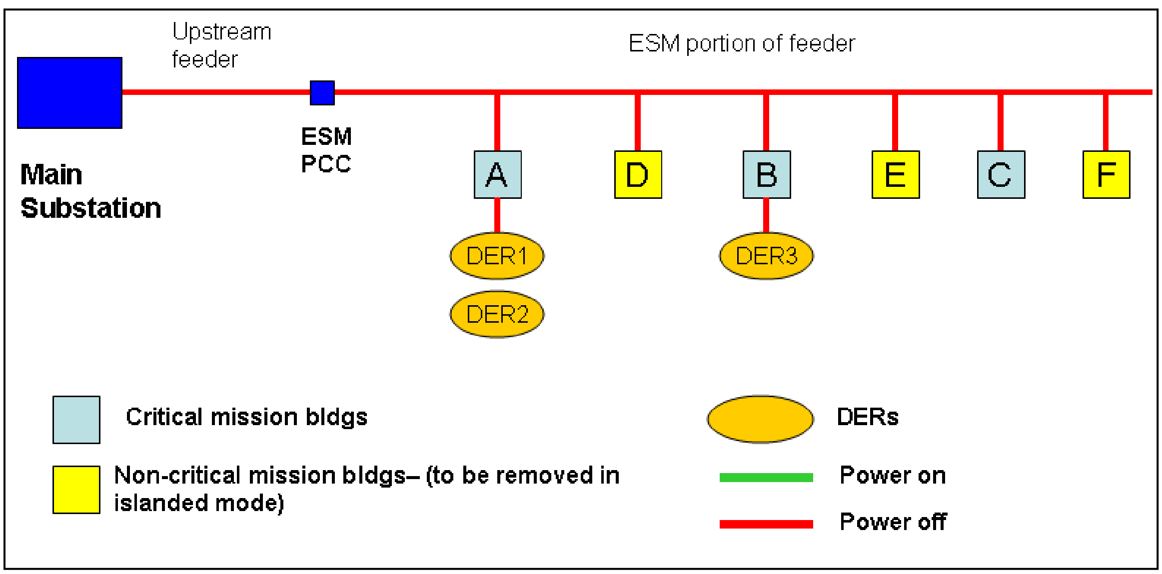


Figure 2. Step 2 - Loss of utility power to Feeder and microgrid (ESM)

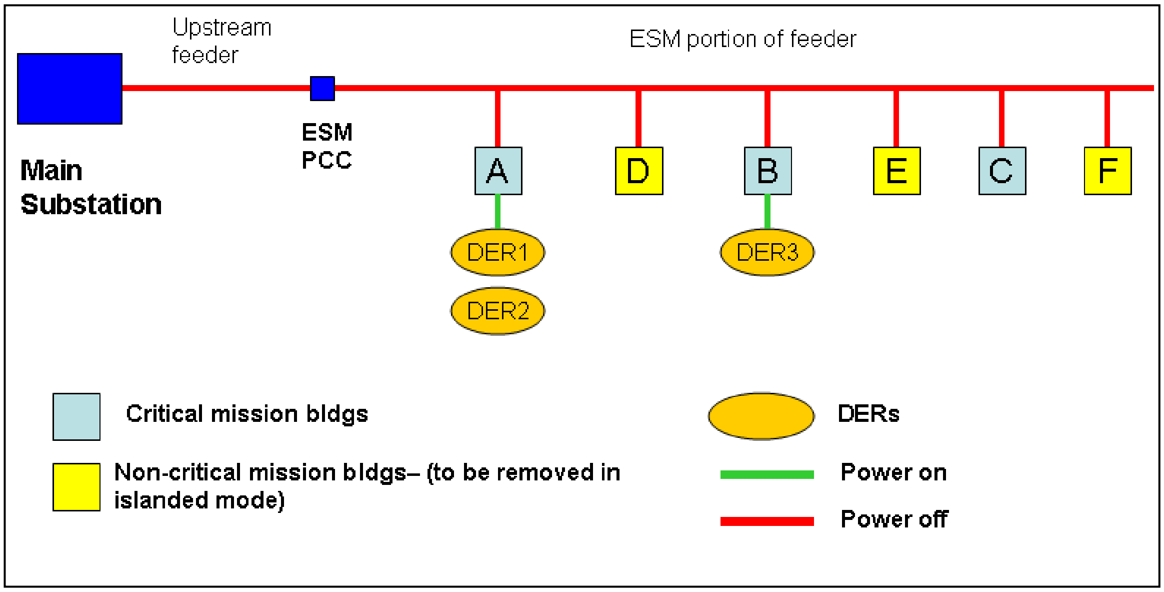


Figure 3. Step 3 – Generation resources (DERs) start up to pick up critical buildings; non-critical buildings are kept offline

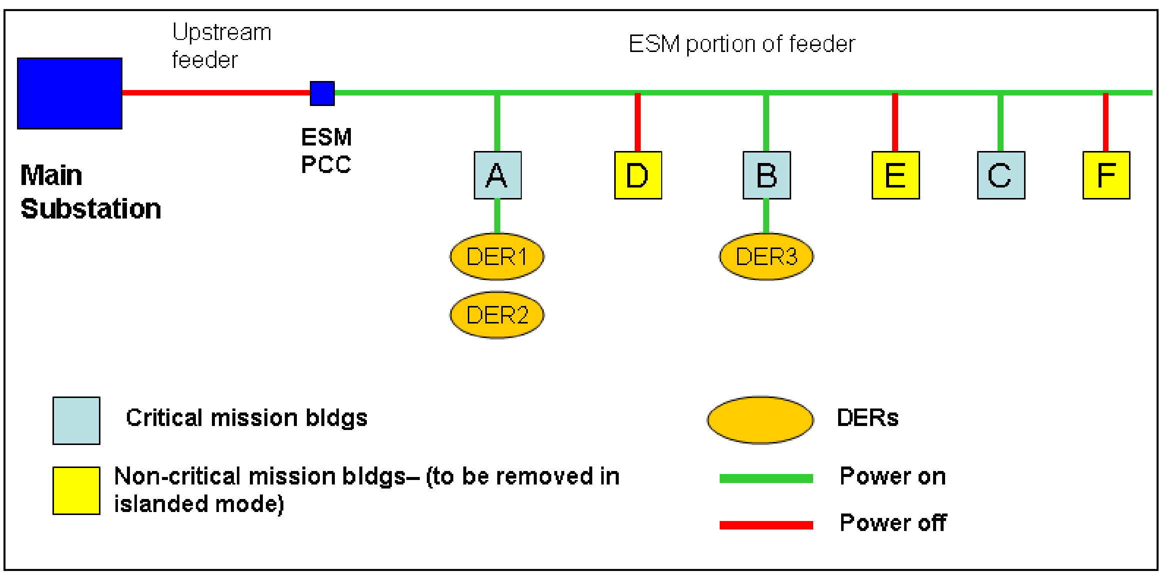


Figure 4. Step 4 – Generation resources sync together to form microgrid supporting critical buildings

A slightly more detailed set of steps for the microgrid to go from grid-tied to islanded mode and back again is listed below (note as mentioned that a microgrid may have more than one main breaker-PCC depending on the arrangement):

1.) Utility power is lost, upstream fault clearing devices open to turn off power to all buildings connected to the affected feeder which the microgrid is attached to; all renewable resources are taken off the grid as well

2.) The main breaker (PCC) senses a power loss and opens up

3.) The main breaker sends a signal to each building to open up main breakers to non-critical loads and receives confirmation that breakers are off (15-45 seconds)

4.) Each generation resource automatic transfer switch (ATS) determines that there has been a loss of utility power

5.) Each ATS starts the generation resources in isochronous mode to pick up their local loads (30-60 seconds depending on the generator type)

6.) Microgrid controls allow each ATS to communicate their status with each other

7.) Voltage and frequency is measured at each ATS and communicates to other ATSs in the microgrid

8.) When the voltage and frequency between two ATSs are within a window, i.e. they are in sync, the bypass switch on the ATS is closed (30-60 seconds for all generators to sync together)

9.) The generators then go into a frequency droop mode in which the predetermined power and voltage setpoints are altered based on the generator size (percent droop) and are controlled by the microgrid generator controls unless the user changes the setpoints from the main microgrid control algorithms

10.) All the generators will run together as long as the microgrid network provides the frequency that the generators need to be at

11.) After 5 minutes from the power loss, renewable resources isolation devices will reclose and be available for the microgrid

12.) At some point, the utility power returns and its fault device is cleared restoring power to the feeder with the microgrid

13.) Controls are used to change the frequency of the generators to match the grid

14.) When the synchronizing conditions are satisfied, the main microgrid breaker (PCC) closes, restoring grid power to the critical buildings in the microgrid from the utility

15.) Generators will soft unload and eventually stop

16.) The closed main breaker (PCC) sends signals to close the isolating devices and restore power to all non-critical loads

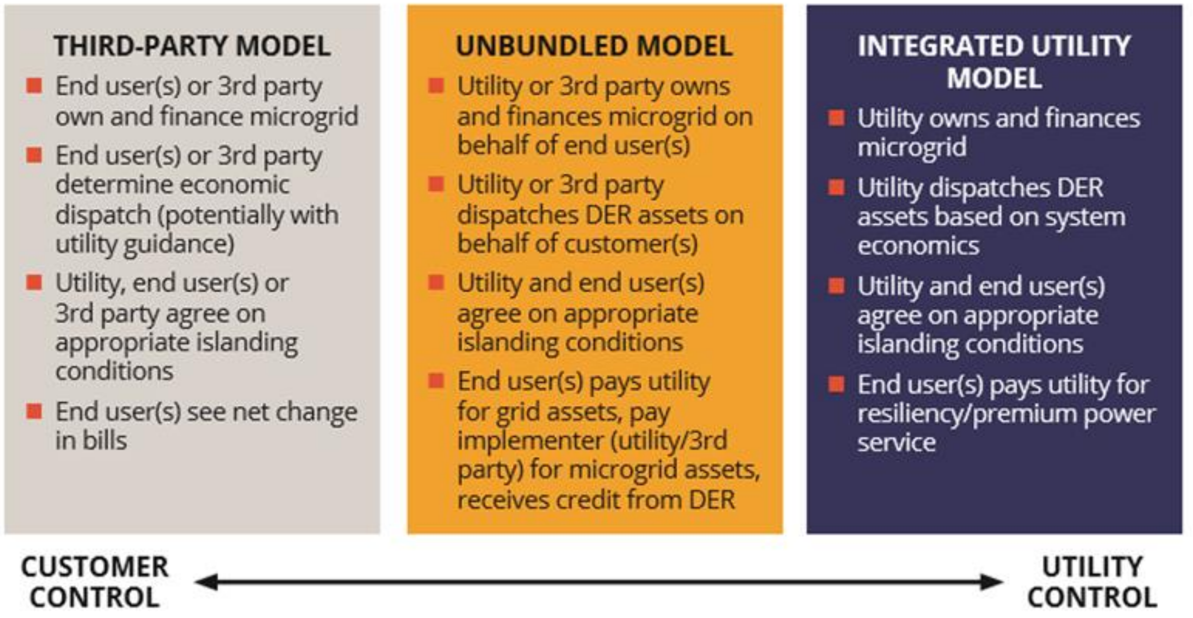
When utility power is restored the steps to undo the microgrid occurs in the reverse of these steps. When the power returns, the generation resources at each building sense that power is restored and they are individually offloaded from the microgrid in a seamless fashion, so no load is interrupted. When all critical buildings are up and running a signal is sent to the non-critical buildings to close main breakers and re-energize these buildings.

It is also possible to have a microgrid with generation resources normally operating in parallel with the utility or grid tied or a microgrid which is normally isolated from the power grid which can connect to the grid under certain circumstances. The main difference between this example and a microgrid operated in normally parallel, would be that designated generation resources would be continually operating connected to critical loads. Therefore, in Step 1 (Fig. 2.1), when utility loads become disconnected, the generation resources will continue to feed critical loads without interruption but the rest of the steps to form the isolated microgrid will occur. There may be generation resources which are normally off in grid tied mode but start up to be available only when the microgrid is islanded. As before, if sufficient generation is supplied to the microgrid, non-critical loads will not have to be isolated from the microgrid.

Microgrid Business Models

For the past decade the Electric Power Research Institute (EPRI) has been investigating the role of microgrids within the Smart Grid initiative and to address emerging energy resiliency issues associated with the current national grid, as highlighted by Super Storm Sandy. The following information has been excerpted from the highlights of a recent EPRI and Smart Electric Power Alliance report, ***"Microgrids: Expanding Applications, Implementations, and Business Structures".*** It summarizes the following:

"To date, most existing microgrid installations have taken place in more isolated campus situations, for example, at universities or military bases. Greater application of microgrids may allow for greater integration of the increased flexibility and diverse capabilities of distributed energy resources (DERs), although the specific costs and benefits still need to be considered. Specific takeaways from the EPRI-SEPA report focus on the potential of microgrids to provide a range of customer and grid solutions for greater integration of DERs and some of the challenges that lie ahead.



- **Microgrid business models** are evolving along a continuum, from third-party projects to utility-initiated projects. In between, a hybrid, "unbundled" model based on public-private partnerships is emerging, which could offer more flexibility and opportunities for collaboration.

- **Assigning value to microgrids**—and monetizing a project's potential value streams—is complicated by the tangle of economic and industry factors involved. Clarity on price signals, rate structures, and regulations are needed for the sector to expand. Characterizing and having confidence in value streams for microgrids over time are likewise necessary for investment in these systems.

- **Current technical standards** can provide guidance on microgrid development, but a more detailed and nuanced set of standards is needed to help ensure interoperable designs, communication and testing practices."

While most current microgrid business models are of the Third-Party type, there are discussions of the utilities supporting movements to the Unbundled and Integrated Utility business models.

2.1 Module 2 – Microgrids, Advanced Microgrids, and Applications

Module 2 – Microgrids and Energy Reliability and Cost Benefits

- Topics will include
  - What is a microgrid?
  - Categories and functionality of microgrids
    - Standard
    - Advanced
  - Attributes of advanced microgrids
    - Safety, security, reliability, cost effectiveness, resilience, maintainability
  - Capabilities of advanced microgrids
    - Flexibility, redundancy, expandability
    - Peak shaving, load shedding, renewables integration, power quality management, energy efficiency
  - General operation of a microgrid

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Mathematically - What is a microgrid?

Grid Definition	Generation Size	Commonly Considered Size	Common Attributes
U.S. Grid	~1 Tera watt (1×10^{12} watts)		High to medium voltage, 4 kVa - 700 kVa
Microgrid	1×10^{-6} (US Grid) 1×10^{6} watts ~1 MW	500 kW-20 MW	Medium voltage 4 kVa - 34 kVa, three-phase, 4-20 buildings
Nanogrid	1×10^{-9} (US Grid) 1×10^{3} watts ~1 kW	1-200 kW	Low voltage 120/480 V, often single phase, 1-2 houses or buildings

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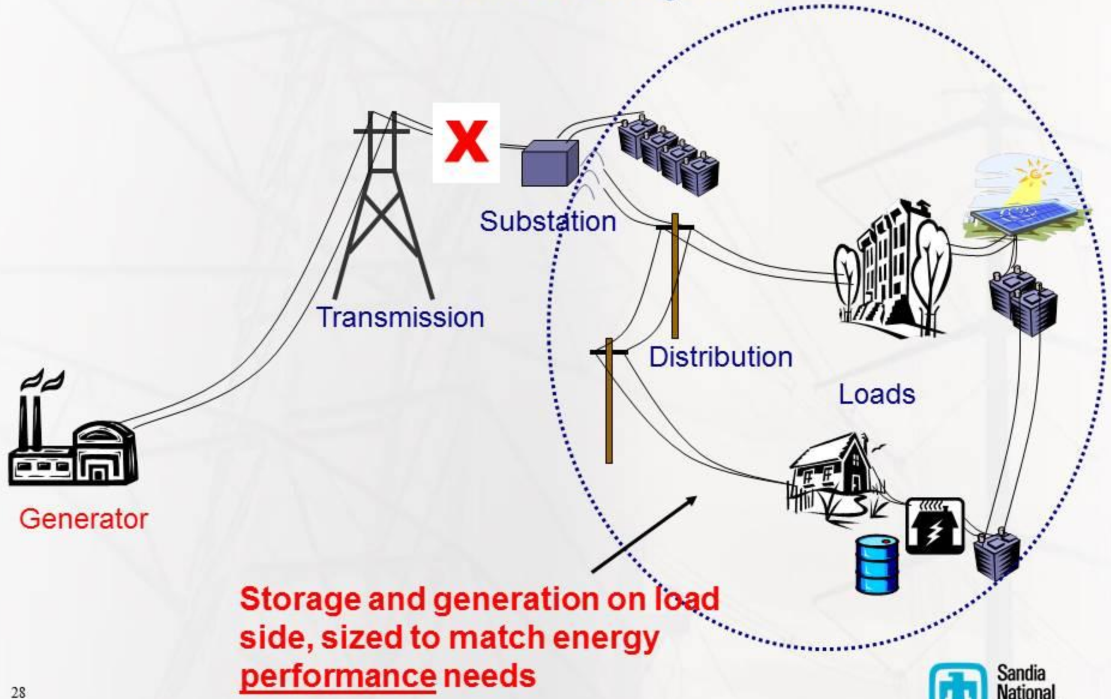
Microgrids are Generally Associated with the Energy Distribution System



Functionality and Types of Microgrids

STANDARD MICROGRID	• Operates where there is no large grid or operates generally islanded from the larger grid • Often used with a central power plant or CCHP plant to balance power supplies and demand locally (universities, industries) • Minimal grid interaction or support
ADVANCED MICROGRID	• Can operate islanded or grid-tied • Can integrate distributed and renewable generation and manage and control power demand and distributed resource allocation • Supports optimal use of distributed energy resources during both power outages and for grid support
SMART GRID NODE	• Same functional capabilities as an advanced microgrid • Control capabilities to federate with other microgrids, if needed • Grid-tied operations are coordinated through the grid operator to support grid operations and performance, and provide ancillary benefits to the grid

Advanced microgrids are the building blocks for Smart Grid Nodes, which in turn is one of the major power utility building blocks for the Smart Grid

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Advanced Microgrid Definitions

- **Smart Grid**
  - **Energy Independence and Security Act of 2007** - *"..which together characterize a Smart Grid: (1) Increased use of digital information and control technology to improve reliability, security, and efficiency of the electric grid, (2) Dynamic optimization of grid operations and resources, with full cyber-security, (3) Deployment and integration of distributed resources and generation, including renewable resources, (4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources, (5) Deployment of "smart" technologies…for metering, communications concerning grid operations and status, and distribution automation (6).. smart appliances…, (7) …advanced electricity storage..(8) ..consumer timely information and control options, (9) Development of standards for communication and interoperability of … equipment connected to the grid, including the infrastructure serving the grid, (10) Identification and lowering of unreasonable barriers to adoption of smart grid technologies, practices, and services.".*
- **Advanced microgrid**
  - **Lincoln Labs, Microgrid Study, April 2012 -*"A DoD installation microgrid is an integrated energy system consisting of interconnected loads and energy resources which, as an integrated system, can island from the local utility grid and function as a stand-alone system."***
  - **IEEE 1547.4, "*2011 Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*". The term Distributed Resource Island Systems, sometimes referred to as microgrids, is used for electric power systems that: 1) have DR and load, 2) have the ability to disconnect from and parallel with the area EPS, 3) include the local EPS and may include portions of the area EPS, and 4) are intentionally planned. DR island systems (microgrids) can be either local EPS islands or area EPS islands.**

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DOE Microgrid Exchange Group
Advanced Microgrid Attributes and Benefits

Advanced Microgrid Key Attributes

1. Interconnected loads and generation (multiple distributed energy resources)
2. Ability to operate in island mode or grid-connected mode
   a. Seamlessly connect and disconnect
   b. Maintain load and generation balance
3. Local control
   a. Acts as a single controllable entity to the grid
   b. Provides a point of common coupling for safety
   c. Utilizes advanced communication/control technology with cyber security

Advanced Microgrid Benefits

1. Enhances the integration of distributed and renewable energy resources
2. Increased reliability
3. Promotes energy efficiency
4. Increased consumer participation
4. Locally controllable power quality and quantity
5. Enables Smart Grid technology integration

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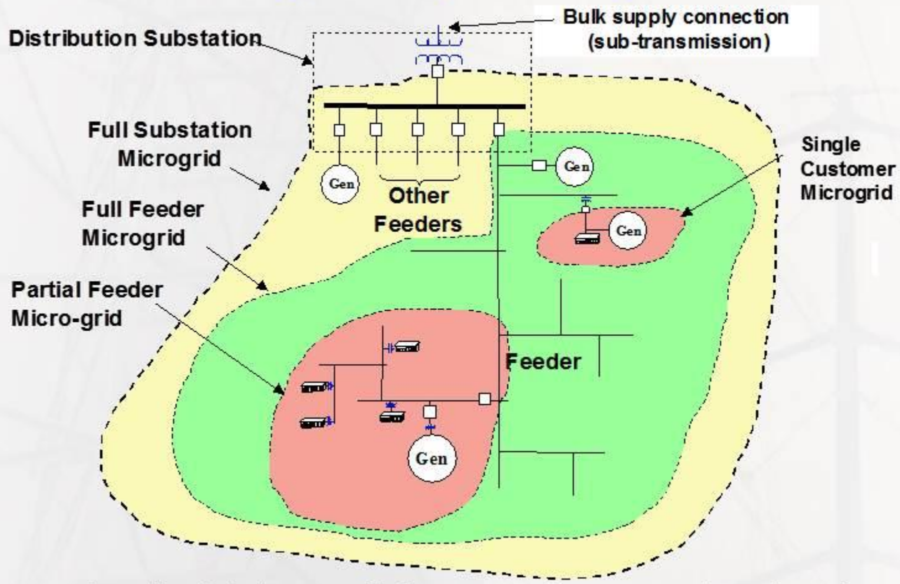
Microgrids can Address Energy Surety Challenges



Applicable to small, large, and even regional scale energy infrastructure security and reliability

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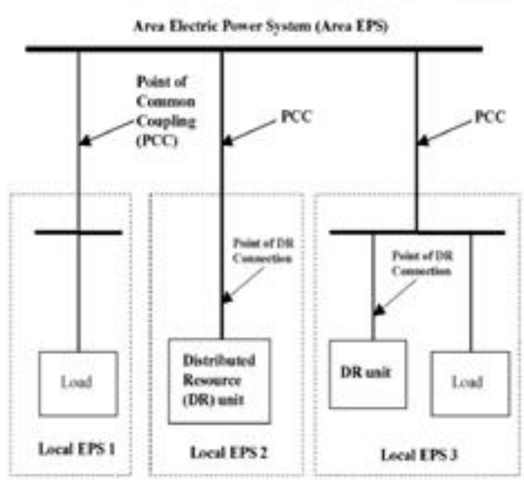
Microgrid Point of Common Coupling (PCC)



Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs.

Figure 1—Relationship of interconnection terms

Reference: 1EEE Std. 1547

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Unique Elements of Advanced Microgrids

- Point of Common Coupling (PCC) – One or more devices (breakers, switches) which island the microgrid from the utility power
- Power Lines – Overhead and/or underground distribution network - may or may not utilize existing utility distribution system
- Switching devices – Breakers, reclosers, load break switches, manual switches, automatic transfer switches, etc. involved in switching and isolating microgrid elements
- DERs – Local generation and storage units including renewables to supply power to the microgrid – can use exsiting resources
- Other elements –
  - Controls – Local and remote monitoring and controls
  - Protection – Relaying used to isolate system faults specific to microgrid
  - Cyber security – Implementations to secure microgrid controls and data

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Capabilities and Benefits of Microgrids

- **Peak shaving – normally islanded microgrid can be paralleled with utility to reduce system peaks and lower energy costs**
- **Load shedding – less critical microgrid loads can be shed if microgrid generation is not available**
- **Enhanced renewable, storage and CHP integration – microgrid designed to allow use of renewables, energy storage and CHP resources more eficiently**
- **Power quality – Energy storage and other devices can be used to increase quality of microgrid power**

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Capabilities and Benefits of Microgrids

- **Efficiency** – Microgrid can be designed to integrate with building efficiency and load reduction control devices
- **Transmission and Distribution Deferral** – Microgrid can defer costs of transmission and distribution assets to meet critical load demand
- **Demand Response** – Microgrid can operate during peak demand periods offsetting utility demand charges
- **Ancillary Services such as Voltage Regulation** – Microgrid can supply additional generation to augment system voltage levels through system

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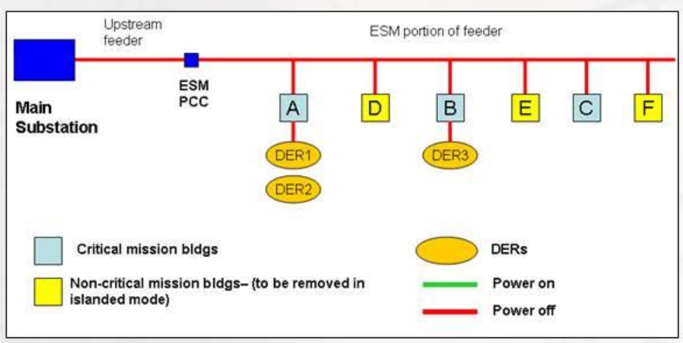
Example Microgrid Operation



Step 2 - Loss of utility power to Feeder and microgrid (ESM)

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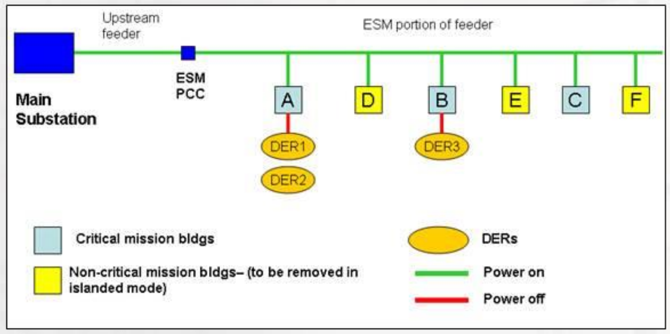
Example Microgrid Operation



Step 1 – Feeder and microgrid are grid connected (DER – generation resource such as diesel or gas generator)

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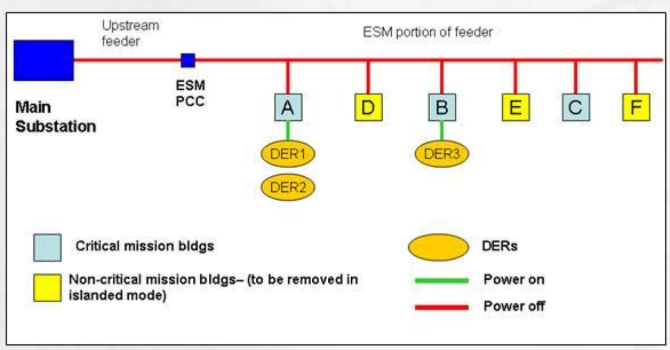
Example Microgrid Operation



Step 3 – Generation resources (DERs) start up to pick up critical buildings; non-critical buildings are kept offline

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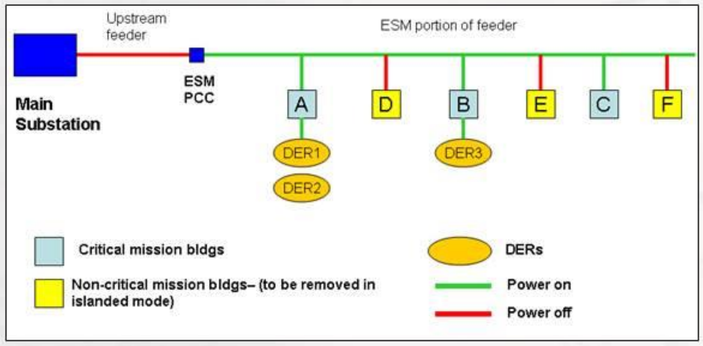
Example Microgrid Operation



Step 4 – Generation resources sync together to form microgrid supporting critical buildings

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Emerging Microgrid Business Models

THIRD-PARTY MODEL	UNBUNDLED MODEL	INTEGRATED UTILITY MODEL
▪ End user(s) or 3rd party own and finance microgrid ▪ End user(s) or 3rd party determine economic dispatch (potentially with utility guidance) ▪ Utility, end user(s) or 3rd party agree on appropriate islanding conditions ▪ End user(s) see net change in bills	▪ Utility or 3rd party owns and finances microgrid on behalf of end user(s) ▪ Utility or 3rd party dispatches DER assets on behalf of customer(s) ▪ Utility and end user(s) agree on appropriate islanding conditions ▪ End user(s) pays utility for grid assets, pay implementer (utility/3rd party) for microgrid assets, receives credit from DER	▪ Utility owns and finances microgrid ▪ Utility dispatches DER assets based on system economics ▪ Utility and end user(s) agree on appropriate islanding conditions ▪ End user(s) pays utility for resiliency/premium power service

CUSTOMER CONTROL ← → UTILITY CONTROL

Microgrid business models are evolving along a continuum, from third-party projects to utility-initiated projects. In between, a hybrid, "unbundled" model based on public-private partnerships is emerging, which could offer more flexibility and opportunities for collaboration.

Assigning value to microgrids—and monetizing a project's potential value streams—is complicated by the tangle of economic and industry factors involved. Clarity on price signals, rate structures, and regulations are needed for the sector to expand. Characterizing and having confidence in value streams for microgrids over time are likewise necessary for investment in these systems.

Current technical standards can provide guidance on microgrid development, but a more detailed and nuanced set of standards is needed to help ensure interoperable designs, communication and testing practices.

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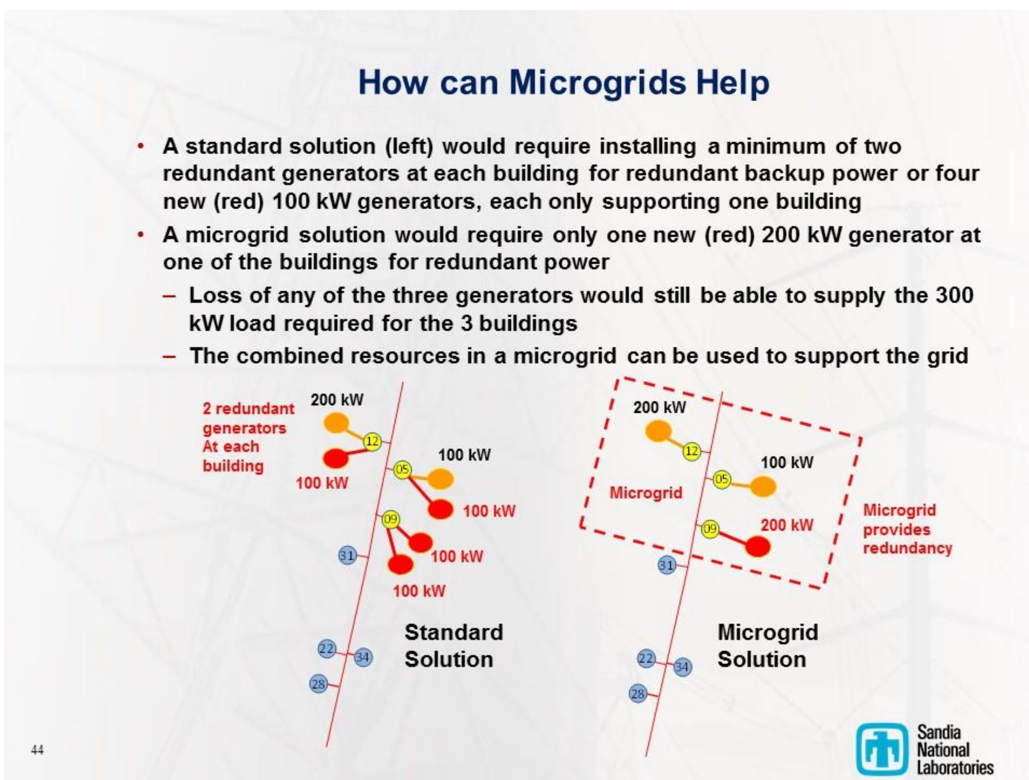
2.2 Microgrid Lessons Learned and Best Practices



Component Availability and Redundancy Impacts on Overall System Reliability

Component Availability	Component Unavailability	Units in Parallel (Redundancy)	System Unavailability
60%	0.40	2	$(0.4)^2$ =0.16
		3	$(0.4)^3$ =0.06
		4	$(0.4)^4$ =0.026
		5	$(0.4)^5$ =0.01
95%	0.05	2	$(0.05)^2$ =0.0025
		3	$(0.05)^3$ =0.0001
		4	$(0.05)^4$ =0.000006

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Generation Needs with and without a Microgrid

- Generator reliability – 60%, 85%, and 95% (based on maintenance)
- Generators required for 99.5% energy reliability – (unavailability 0.005)
  - 60% reliability - 6 generators
  - 85% reliability - 3 generators
  - 95% reliability - 2 generators
- 10 buildings – 20 generators at 95% reliability (good maintenance), 30 at average maintenance
- Generators required for a 10 building microgrid – same load, same size
  - 11-12 (good to average maintenance)

DoD generators

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Advanced Microgrid Designs and Use Master Planning Application Examples

Ft. Carson 2 MW Microgrid for Critical Mission Connect 2 MW to Mission critical corridor and add new critical missions to corridor

Boston Seaport 20MW Coupled Microgrids

Philadelphia Navy Yard Redevelopment 80MW of New Load with 5 Microgrids vs. Major Transmission Upgrades

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Operational Energy Can Benefit from Implementing Advanced Microgrids

- Bases reviewed had central power plants, but often covers only ½ to ¾ base load - therefore utilize generators

Base Load	Critical Load	Backup Generators	Total Generator Capacity	Building Tied
3 MW	1.5 MW	12	2.5 MW	Most
22 MW	10 MW	300	90 MW	Most
75 MW	30 MW	360	70 MW	Most

- Generators often running 24/7, 14% to 70% capacity
- Maximum contingency generator is 200 kW max
  - Bases purchase much larger generators for efficiency, often 50 to 100 different makes/models, don't meet UFG guidelines – ATS, paralleling
  - No standard fuel tank sizes – ½ day to 3 day, refueling an issue
  - Fuel storage an issue – often only 1-3 day supply, wrong tank sizes

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Advanced Microgrid Implementation Lessons Learned

- Can Include 30-50% renewables energy with storage and distribution system upgrades and planning
  - Renewables need to be sized and segmented depending on feeder or substation application, and
- Ability to quickly shift between ‘grid tied’ and ‘islanded’ can add major safety, reliability, and resiliency benefits to customers
- N+1 generation redundancy is simple with microgrids with also high reliability
- Full utilization of microgrid benefits for cost reduction require close coordination with utilities:
  - Utilities are often limited in power and renewables they can/want to accommodate
- Critical loads often only 25% of total system load, distributed on several feeders
  - Suggests applications with multiple small microgrids to reduce complexity and accelerate implementation

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Summary of Advanced Microgrid Operations

MICROGRID	CIRCA	POINT OF COMMON COUPLING	INTERCONNECTED GENERATION AND LOAD		DISCONNECT /RECONNECT[3] sec	POWER RELIABILITY	POWER SECURITY	ANCILLARY BENEFITS USED		
			GEN	LOAD				DEMAND SUPPORT	UTILITY BACKFEED	RENEWABLES INTEGRATION
Ft. Greely	1960	Substation	8MW	3MW	Man, <60 sec	x	x	x	x	-
Ft. Detrick	1985	Feeder	4MW	2MW	Man, <60 sec	x	x	x	-	-
Ft. Greely	2005	Feeder	10MW	3MW	Man, <60 sec	x	x	-	-	-
Ft. Bragg[1]	2005	Feeder	5MW	3MW	Auto, <10 sec	x	x	X	-	-
Ft. Bliss	2012	Feeder	1.5MW	1MW	Auto, <10 sec	x	x	X	-	25%
Ft. Detrick	2012	Feeder	4MW	2MW	Auto, <10 sec	x	x	-	-	-
Ft. Carson	2013	Feeder	3MW	1.5MW	Auto, <10 sec	x	x	-	-	30%
Ft. Bragg[2]	2015	Feeder	5MW	3MW	Auto, <10 sec	x	x	x	-	-
Ft. Detrick[2]	2016	Feeder	20MW	15MW	Auto, <10 sec	x	x	x	-	40%
Tinker AFB	2000	Substation	80MW	15MW	Man, <90 sec	x	x	-	x	-
Pearl/Hickam	2013	Feeder	1.2MW	1MW	Auto, <10 sec	x	x	X	-	20%
29 Palms	2014	Feeder	8 MW	5 MW	Auto, <10 sec	x	x	-	-	20%

1 – Decommissioned
2 – Under planning/construction - Ft. Bragg (ESTCP), Ft. Detrick (IMCOM)
3 - – 60 sec needed for high value ancillary services

Current advanced microgrid operational focus is on energy security and reliability, but not taking full advantage of ancillary use and associated cost benefits.

Positive Advanced Microgrid Operation Observations

- **No major technical implementation and operation challenges identified**
  - No safety issues observed in transitioning between grid-tied and islanded modes
  - All control systems support ~10 - 60 second transition to islanded operations, critical circuits on UPS systems, all controls meet cyber security requirements
  - Renewable energy technologies were utilized and effectively integrated with other generation resources
  - Advanced microgrids can effectively support base demand/response and utility grid support/ancillary services

Microgrid capabilities have matured significantly in past decade.

Advanced Microgrid Observed Best Practices

- Simple controls and well trained and experienced operators increased microgrid utilization
- Enhanced energy metering at a site consistently increased microgrid use for utility support
- All sites have implemented many simple strategies - circuit-level UPS systems, VFDs, etc. – which has minimized large-scale energy storage requirements
- Renewable energy systems greater than 1 MW partitioned to support feeders or connected to substations, were more easily integrated and utilized
- Microgrids designed to consider longer-term outages and associated changes in critical missions provide greater energy resiliency

These practices need to be propagated across the Army.

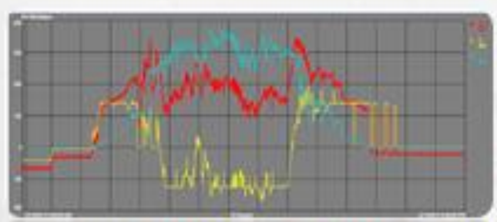
Current Advanced Microgrid Operational Challenges

- **Microgrid control challenges**
  - Training of site staff on microgrid control and operation is often insufficient
  - Because of control complexity, many microgrids are operated less than once a year
- **Renewable energy integration challenges has limited extensive use**
  - Lack of price advantage in some locations
  - Utility push back because of intermittency
  - Inability to partition and balance energy output – design and contracting reasons
  - Renewables systems often not designed to match energy infrastructure, site loads, etc. due to different policy drivers
  - Concern about cost of energy storage and impact on system cost effectiveness

These challenges are hindering microgrid benefits and utilization.

Microgrid Operational Challenges (cont'd)

- **Utility demand response/ancillary services challenges**
  - Only 30% of microgrids were used regularly for demand response or peak shaving
  - Lack of metering and microgrid control complexity is limiting ancillary support
  - Most utilities discourage grid support due to lack of performance data
- **Cost effectiveness challenges**
  - Current microgrid costs are ~ $0.20-$0.30/kWhr vs. $0.06-$0.16/kWhr for grid power
  - Designs are often N-2 or N-3 load redundant
  - Environmental issues often impact selection of generation mix for grid tied operations



Utility (PNM) Advanced Microgrid Operational Data

Ancillary Service	Value of Service ($ per kWhr)	Required Response (minutes)
Frequency Regulation	High	1
Spinning Reserve	Medium	1-10
Auto Response	Medium	10-20
Manual Response	Low	30-60
Non-spinning Reserve	Very Low	10
Replacement Reserve	Very Low	30

A major opportunity is that advanced microgrid response times are compatible with utility ancillary service needs and more microgrid grid-tied data is now available

Recommended Strategies and Policies

(Prioritized by potential impact)

- Diversity of advanced microgrid design approaches reviewed suggests that design and operation standards are needed
  - Establish design, use, and interoperability protocols
  - Similar approach being pursued by the Tactical Microgrid Standards Consortium and efforts could be leveraged
  - Will eliminate inappropriate microgrid development
- Take a much more proactive approach to encourage utilities to incorporate Army advanced microgrids as part of utility Smart Grid initiatives
  - Get Army leadership involved in utility discussions of microgrid operational requirements for utility acceptance – leverage and expand EITF efforts
  - Provide data to utilities on Army and other advanced microgrid operational performance and control strategies compatible with utility needs
  - Establish a conceptual architecture, standard design methodology, and operational approaches that improve the ability to plan, implement, and integrate advanced microgrids with a local utility

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Recommended Strategies and Policies (cont'd)

- Improve installation energy infrastructure such as metering, installation of critical panel boards, microgrid controls, etc. in new and updated construction
  - Example : Accelerate IMCOM Directive 2014-10 – Advanced Metering of Utilities
  - Utilize infrastructure modernization rather IMCOM funding sources to accelerate improvements
- Microgrids should be operated grid tied and islanded several times/year
  - Improves operational training and experience, creates significant data base of operational and cost performance data, accelerates overall knowledge
- Provide training in sizing and integrating distributed and renewable generation for cost effective energy benefits
  - Training is needed for renewable energy providers and microgrid designers on integrating renewables and storage to optimize cost/performance/security benefits

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3. DEVELOPING MICROGRID CONCEPTUAL DESIGNS

This module provides a general overview of the Energy Surety Design Methodology developed and used by Sandia to assess the vulnerability and performance of energy systems. The ESDM methodology approach has been adapted for application to advanced microgrids for improving energy assurance and resiliency for tactical, contingency, and installation military applications and both on-grid and off-grid communities and cities. This section highlights the specific system analysis and design steps, a discussion of the role of each step, and how these fit together to provide the information needed to develop and and rank different advanced microgrid conceptual design and operation options.

This module includes:

- A general discussion on the Sandia Energy Surety Design Methodology and how the approach can be utilized for evaluating microgrid applications, and
- Discussions of specific microgrid design steps and sequence

Overview of the Energy Surety Design Methodology

The Energy Surety Design Methodology is intended to be applied to energy systems with the specific focus of detailing specific changes to the system that will increase energy and installation or community security and resiliency. The goal is to establish how to preserve and quickly restore customer specified critical loads, and to increase the reliability of power to critical loads to support critical mission assurance for extended outages.

The methodology makes use of one or more outage scenarios or events identified by the customer. A DBT is a profile of the type, composition, and capabilities of an adversary or event. The event can be natural event, such as a hurricane or ice storm, or it can be manufactured, such as a cyber or physical attack on infrastructure. The DBT provides boundaries on the environment in which the system must operate, and with performance objectives and goals identified by the customer, establishes the microgrid design and operational requirements that must be met.

As discussed previously, Energy Surety, as has been a principal at Sandia for almost two decades, and includes elements of reliability, security, safety, cost, sustainability and resiliency. The methodology addresses each component of surety assessment in the following way:

Reliability - Reliability is the probability of getting power to a particular load when needed. Additional metrics are employed that aid in the determination of how the reliability can be characterized such as adequacy (the ability of the source of power to meet the demand), and security (the ability of the system to continue performing it's job under a contingency situation).

Security - As described in the context of surety, security addresses both physical and cyber security. Unless otherwise dictated within a DBT, security will not be degraded but may be enhanced. All solutions added to the system will preserve existing levels of security.

Safety – Safety is a major element that cannot be degraded. The safety of the existing system will be preserved and any new solutions added will have the same level of safety to the public and operators that previously existed.

Cost Effectiveness - The cost of several viable solutions should be evaluated against the performance and resilience requirements and goals for the system. This allows the customer to evaluate the tradeoffs between cost and performance to select the best solution.

Sustainability (Environmental Impact) - Environmental issues should not be degraded and should be enhanced if and when possible using available renewable energy resources.

In addition to a focus on energy surety, the design methodology specifically acts to increase resilience through a focus on analytical and performance-based design and evaluation approaches that include:

Critical Load/Services - The importance (or criticality) of loads or functions served by the system define the level of consequences. The importance of these loads is identified during evaluation in relation to customer defined system performance goals.

Risk Based Analyses - Risk based solutions include elements of reliability (or vulnerability), threat (which is defined per the DBT) and consequences. The importance (or criticality) of operations, functions, buildings, etc. are quantified during risk evaluation to assess the level of operations relative to customer defined performance goals.

Graceful Degradation - The designs chosen are made to reduce loads in a piece by piece manner, in a way that places a priority on preserving critical loads.

Reduced restoration time – Identifies options to locate distributed energy generation and storage resources that support the ability to accelerate restoration of the electric system.

Reduced frequency of power outages - A natural effect of increasing resiliency of the electric grid will be a system that is more robust to extreme changes in the operating environment and is impacted less by different events and maintains power and services to most customers.

Mitigation of consequences to specific threat classes – focuses consequence mitigation efforts on identified energy system performance goals so that outage scenarios are proactively addressed.

This design methodology as applied in this application is to radial or looped distribution systems and specifically microgrid applications. While the approach can be used for transmission systems, the scale, scope, complexity, performance objectives, and analytical requirements are quite different.

Analysis Elements and Focus

The following elements are included in an energy surety evaluation and design:

1. Support differentiated reliabilities of loads for high consequence low frequency events
2. Increase resiliency to specific identified threat classes
3. Quantify resiliency and reliability and exposure of specific loads
4. Offers focused solutions
    a. For specific system infrastructure improvements (rate based)
    b. For specific load owning entities (private)
    c. For community service, emergency response entities.
5. Quantify benefits in resiliency and reliability to the solutions identified
6. Perform cost benefit trade-offs for the solutions identified
7. Decision method acceptable resiliency and reliability metrics are – related to community identified electric system performance goals
8. Decision methods and support tools are used to help determine appropriate options

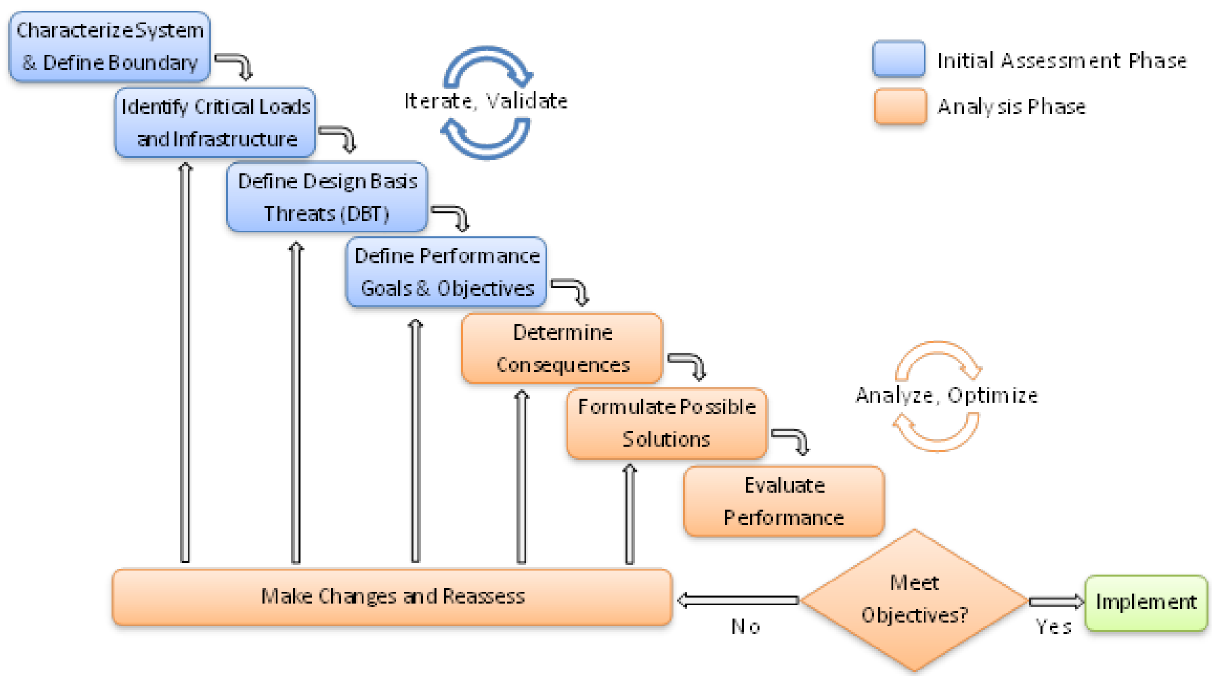
The analysis includes the following analytical elements to help quantify options:

1. Includes risk by assigning numerical values to the criticality of each load
2. Account for the uncertainty associated with the threat by using methods to assign numeric values to the criticality of individual assets within the system with respect to specific threats and outage durations
3. Provides ranking criteria, such as power availability and cost, that can be analytically determined to rank options against each other with respect to a resiliency and cost tradeoff
4. Utilizes a Design Basis Threat evaluation approach to rigorously define the threats under which the evaluation takes place

5. Considers interdependencies between the electric infrastructure and other critical infrastructures (e.g. communications, transportation, physical security, emergency services, etc.)

Energy Surety Design Steps

The following steps noted in the figure below are utilized as part of the ESDM, amd utilized in applying the ESDM to microgrids. If the steps are followed closely, at the end of the evaluation various microgrid design options can be compared directly for cost and performance benefits relative to community identified energy system performance goals.



Microgrid Evaluation Approach

The discussion below highlights the details of each evaluation step.

1. Characterize the mission critical needs and boundaries of the system and therefore the stakeholders needed and their responsibilities
   - Establish system size, characteristics, likely critical missions, roles and responsibilities, support needs, and therefore boundaries to be evaluated – regional, local, integrated installation/community, etc.
   - Establish stakeholders to be involved or consulted based on above

2. Utilize stakeholders as appropriate to identify mission critical loads:
- Based on critical missions and roles, identify critical services and loads
- Identify interdependencies among critical loads and other critical infrastructures
- Utilize previous or existing mission studies
    - Mission Essential Vulnerability Assessment (MEVA)
    - Continuity of Operations (CONOPS)
    - Restoration Priority Lists
- Map physical locations (map/building)
- Identify needed duration before operations transfer can be accomplished – hours, days, months

3. Define Critical Energy Infrastructure (such as switches and transformers)
- Build upon the component lists developed by the utility/public works
- Identify critical generators, storage, switches, breakers, buses, etc.

4. Work with stakeholders.to create/identify the Design Basis Threat (DBT) document(s) that should be applied and identify impacts and consequences.
- Start with a generic historical data
- Validate with stakeholders to assess potential energy system outage durations and impacts
- Could be multiple DBTs for hurricane, ice storms, peak heat, flood, CIP, etc.
- Could have multiple response scenarios and multiple design

5. Obtain utility and stakeholder input for defining initial performance goals from a critical mission, installation, city, county, business, etc. perspective in terms of:
- Duration of operations, types and functions of service operational requirements, level of capability needed, interactions and cooperation through interagency agreements
- Support System Status Awareness and critical mission resiliency (including distribution, transmission, and ISO) with Emergency Operation Procedures
    - Staging of equipment
    - Reconfiguring network
    - Protection
    - Recovery procedures
    - Communications and telemetry needed to support awareness/operations?
- Future infrastructure plans and impact on outage duration and consequences
- Constraints (environmental, regulatory, safety, etc.)

6. Create a Performance Risk Analysis that shows the risk of each element in the system by analyzing existing infrastructure and loads against the DBT(s), design

outages, and impacts. This results in baseline system response to events in the DBT relative to the initial system performance goals.

7. Determine what modifications to the system should be considered as high level options to enhance system performance to meet initial performance goals.

- Hardening of individual facilities, distributed and renewable generation and storage at individual facilities, networking of generation assets (microgrids), etc.
- Combinations of all these approaches might be appropriate due to locations, etc.
- Further gathering of detailed electrical system information
  - Electrical feeds (one line, building breaker, etc.)
  - Electrical characteristics
    - Daily and seasonal KW and KVAR
    - Example profiles could include:
      - High resolution for a few days
      - Hourly for a year
    - Peak load, average load, min load (KW/KVAR)
    - Interdependencies
    - Level of criticality
  - Identify reliability/resiliency measures already in place
  - Determine any qualifications (e.g. load is critical in spring, but not summer fall and winter).

8. Using high level options found in (7), engineer potential solutions and prove technical and operational feasibility and ability to meet identified performance goals

- This is done using best practices for safety, reliability, construction, operation
- Assess costs of each option
- For each option considered, evaluate the performance risk to make sure that system performance is appropriately enhanced and the risks reduced.

9. Compare engineered solutions and determine the cost/performance (Pareto) type frontier, and with input from the stakeholders, identify the best viable options.

- The Pareto frontier compares cost vs. performance for multiple options to identify the most efficient and cost effective solutions.
- This is can be done with engineering judgment if the number of cases is small
- Provides a cost/benefit tradeoff analysis for stakeholders to use to assess options and reassess performance goals.

10. Compare reliabilities of baseline and engineered solution cases and costs to system goals.

- If the costs and the performance of the upgrades are acceptable, move forward.
- If the costs and performance of the upgrades are not acceptable, iterate on process by reducing the DBT, reducing performance goals, or looking at alternative solutions.

General Energy Assurance and Microgrid Conceptual Design Phases

The evaluation steps for microgrid evaluations generally consist of three phases. They include:

- Phase I: Assessment of the current energy infrastructure, identifying critical functions, services and loads, and defining the expected threats and durations.

  This is usually accomplished by developing a Project Working Group (PWG) by teaming with the local utility, community, installation, and mission stakeholders to identify critical and priority building and facility functions, and with their help determine the expected energy demand for various outage durations (design basis threats), the energy reliability required, and the energy supplies, renewables, and energy storage needed.

  This essentially establishes the expected system performance goals and threats.

- Phase II: Assessment of options to reconfigure existing or new energy resources to enhance critical mission energy needs.

  In this phase, based on the critical and priority buildings, operations, and services identified by the PWG, a range of upgrade options are considered to meet the expected performance objectives and design threats.

  This includes preliminary cost estimates for system upgrade options. Upgrade options typically considered include:

  - Hardening the system to prevent outages,
  - Use of additional backup generators to provide redundancy and improved utilization of backup generation,
  - Networking of distributed and renewable generation resources in either campus microgrids (does not interact with the grid) or advanced microgrids (that can operate grid-tied or islanded), and
  - Combinations of each depending on the reliability, security, resiliency, and cost of different options and assorted combinations.

- Phase III: Evaluate upgrade options and develop conceptual designs to meet energy supply, reliability, and restoration needs cost effectively.

  In this phase, preliminary information on integrating hardware improvements, control system improvements, distribution system modifications, and renewable and distributed generation resources integration and the potential cost and performance benefits are evaluated.

  This phase includes the use of a range of consequence modeling tools, power reliability modeling tools, and system cost and performance analysis tools to provide more detailed understanding of how the system would perform.

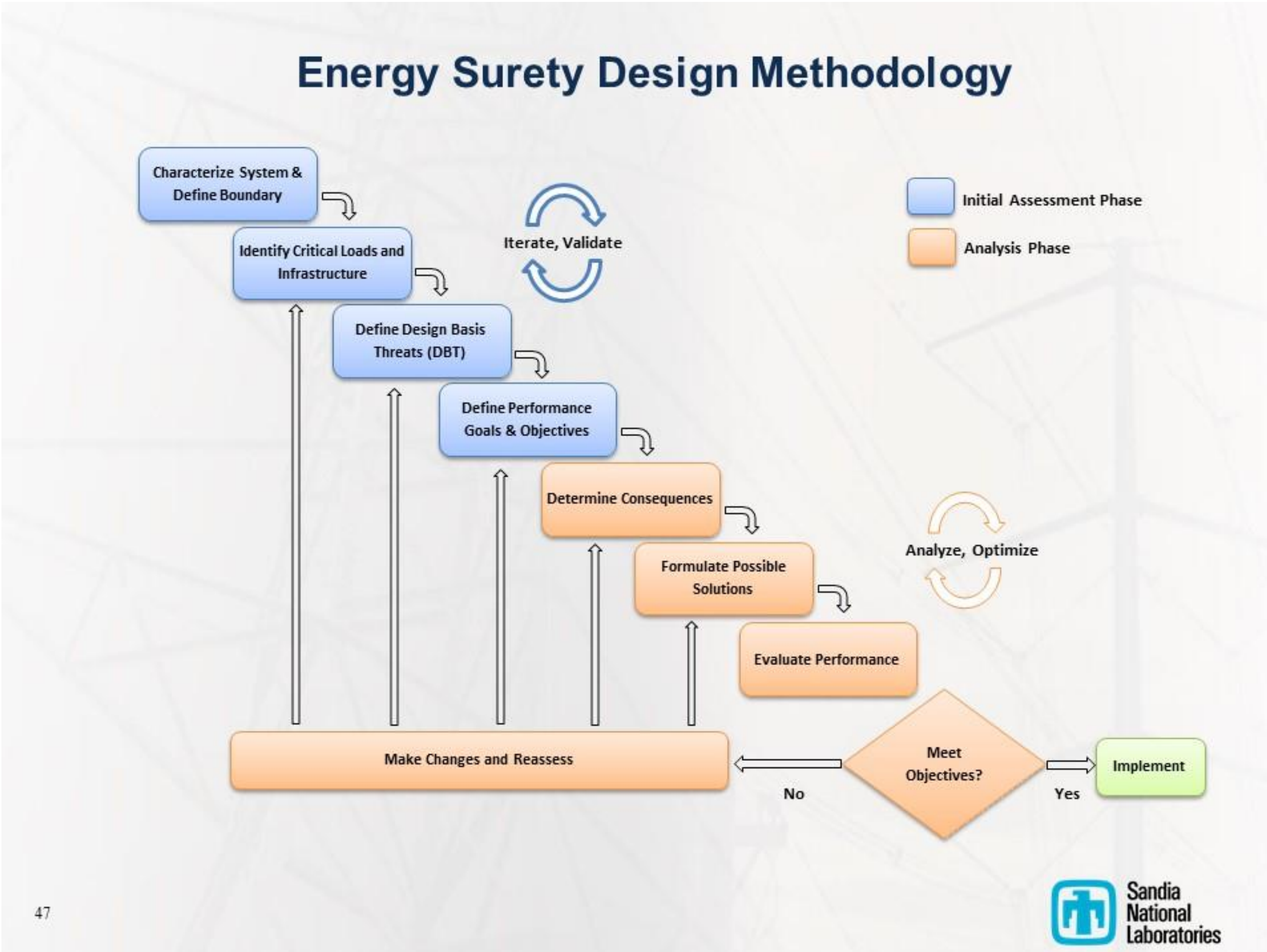
  The need for this step depends on the complexity of the system and the design approach. For example, optimization analyses for only a few buildings that cannot be networked or buildings that would be hardened can often be effectively analyzed through simple analytic approximations.

Outcome of an Energy Surety Design

The outcome of an Energy Surety Design includes two important elements. The first is a Conceptual Design at about a 10-15% design level. This provides a general description of the major design and construction elements, best locations to enhance energy surety, and suggestions of the elements and operational scenarios to be included. The conceptual design provides an architectural and engineering company enough information to develop an optimized preliminary engineering design (50% design level) for final consideration and selection. The preliminary model can then be used to establish a detailed engineering design for construction and implementation.

The second element is as cost analysis that allows the evaluation of the trade space between performance goals and costs. This provides an initial estimate of the relative cost/system performance tradeoffs of the initial performance goals. This helps provides community leaders and installation managers with estimates of the budgeting and funding needs and expected performance benefits. It establishes a general baseline of what might be doable and at what cost. This can be used to reevaluate the proposed performance goals and objectives, try other options, or establish appropriate funding requests.

3.1 Module 3 – Energy Surety Design Methodology and Microgrids



Conceptual Energy Surety Design

- Covered in this Course
  - How to use the Energy Surety Design Methodology to conduct an initial energy surety assessment
    - Including consideration of microgrid and other energy improvement options
  - Provides the first step in looking at understanding and energy system performance goals and impacts on energy improvement needs and associated costs
  - Conceptual designs provide a 15% design that can be used to provide direction for:
    - Expected operational issues and challenges,
    - Additional planning needed and financing needs,
    - Discussions with community stakeholders and utilities,
    - Providing planners and engineers with a starting point for likely options for use in developing final designs, selecting locations, considerations, etc.

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Preliminary and Final Energy Surety Designs

- <u>Not covered in this course</u>
  - Development of conceptual designs into preliminary (30-50%) and final (90%) designs
  - Those require advanced modeling and analysis, detailed engineering analysis, operational considerations and design, and management and control needs and technology selection, etc.
    - Some modeling approaches discussed in Appendix B for the DOE Microgrid Design Toolkit
  - Construction and operation coordination with key stakeholders, construction management
    - Local building codes
    - Government (city, state, regulatory, etc.) requirements
    - Public or private utility coordination
    - Financing
    - Operational testing or ownership transfer

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4. CHARACTERIZE MISSION CRITICAL NEEDS AND BOUNDARIES

This module provides a general discussion of how to establish the initial energy system boundaries to be evaluated in the microgrid design as discussed on the ESDM methodology steps in Module 3. This step requires deliberation and discussion of the general critical missions, their power needs, general types of events and outages that should be considered, and what are the major critical functions and capabilities needed from the electric grid by the community/installation during an outage.

It is critical to establish the critical missions and boundaries for consideration, because it can limit the scope of what sets of critical functions and facilities are to be considered. This can help to constrain the amount of analysis and data gathering needed to design the upgrades, but may limit the consideration of important interdependencies. If it isn't entirely clear what the final critical functions and facilities that should be considered and for what duration, a wider scope can be used initially and then narrowed with further analysis. The wider scope will often require the initial inclusion of a broader range of stakeholders, which reduces the chances of missing major mission critical facilities or important critical mission support activities.

This initial characterization effort therefore <u>begins to help establish appropriate system-level thinking</u> needed to begin to consider performance goals and objectives for the energy system, and over what ranges and infrastructures and for what durations they should be considered. This module includes:

- Background information on how this step should be conducted,
- What stakeholders should be considered, and
- An example problem of initial system characterization of
    - mission critical energy needs,
    - associated important mission support energy needs,
    - physical and electrical boundaries to be considered, and p
    - erformance needs and stakeholders to include in the evaluation.

4.1 Module 4 – Defining Energy System Boundaries

Module 4 – Characterizing Mission Critical Needs, Energy System Boundaries, and Stakeholders

- Initially determine the boundaries of the size and scope of the system to be assessed
  - Military base, city, town ,or village energy system
  - Distribution system configuration – feeders, substations, switchyards, one-line diagrams, etc.
- Determine the key stakeholders who should be involved in the process
  - City government or base commanders, mission owners
  - City or base public works
  - Utilities (power, gas, water, communications)
  - Regulatory agencies
- Identify general energy performance goals and power outages,
  - operational strategies expected to operate under,
  - cost and funding mechanisms being considered
  - Types of events to consider

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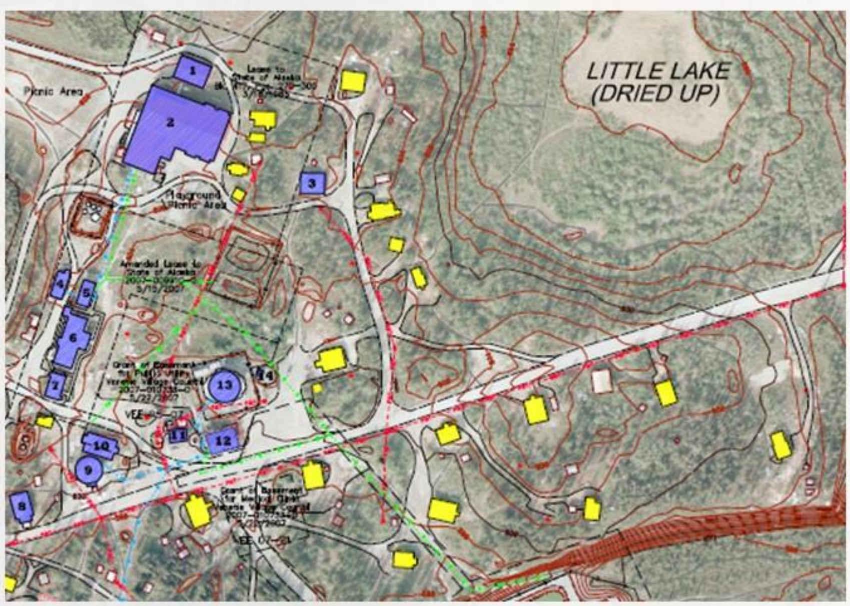
Example of a Village Electrical Distribution System



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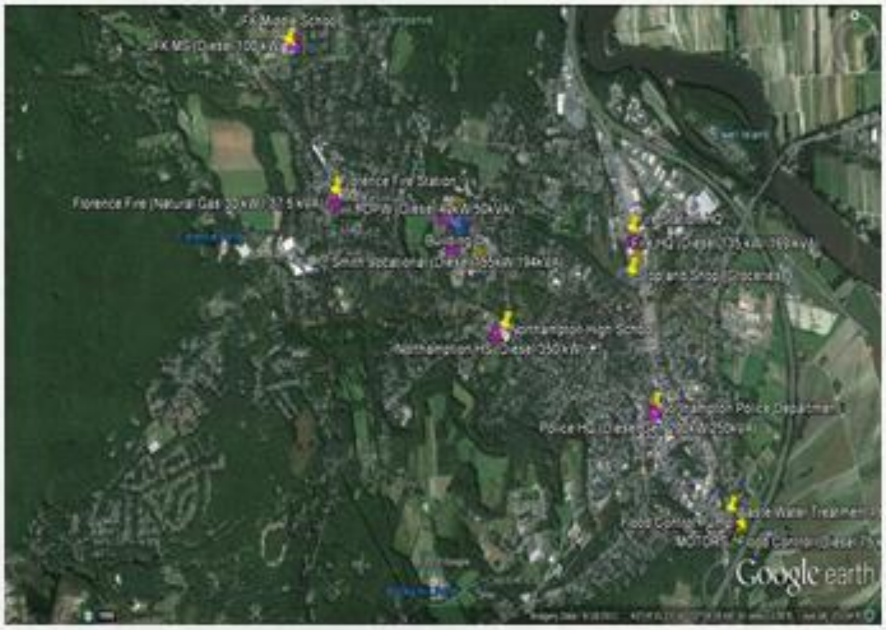
Municipal Boundary Selection



Local or regional critical facilities

Operational Bases and Connection to Host Nation Power

Where to connect, who pays for the connection costs, and two-way, power sharing agreements

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Identifying General Energy System Performance Considerations

- What are likely outages – what has occurred in the past – lessons learned from past outages, what performance might be needed?
- What does the city/community/base want to be able to do during an extended outage, cover all power needs or only for critical loads?
- Is this going to be an economic development opportunity for regional energy reliability, is this for local energy security?
- What funding mechanisms are available and do they have incentives to include certain capabilities or technologies?

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Module 4 Exercise

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5. IDENTIFYING CRITICAL ASSETS AND SERVICES

This module provides a general discussion of how to establish those critical loads and infrastructures that need to be included in the energy surety design evaluation and the opportunities for microgrid applications. This step requires integration with key stakeholders and discussions of the general needs of the microgrid, ranking of the major critical functions and capabilities needed from the electric grid by the community during an outage, as well as honing in on the needs for different potential outages. This begins to further establish the system boundaries, operations, and critical infrastructures to be included in the final design. This module includes:

- Background information on how this step should be conducted, and
- An example problem of critical infrastructure evaluation

As part of an energy assurance and microgrid conceptual design assessment, we ask cities and installations to identify critical needs, critical operations, and critical functions that they believe need to remain in operation for a range of events that could vary in severity and duration. Though actual performance goals and resiliency capabilities needed for a city or installation differs, addressing general categories of operational performance goals and city service considerations are common. General services that need to be considered are presented below.

Energy and infrastructure system considerations and examples

In general, a city or installation might have different operational performance goals for a one-day outage versus a five-day outage. For example:

A one-day outage response or microgrid design might focus on infrastructures like:

- making sure major intersections and traffic lights are operating,
- making sure city hall and police and fire station energy needs are met, and
- making sure hospitals are running on their standby generators for part of the day.

This might also focus on temporary solutions that can be handled quickly and easily with portable technologies, such as portable gen-sets.

A five-day outage might require a focus on a totally different set of needs that would not be initially identified as critical, but would become critical during an extended outage. This might require focusing on not only a different set of operations and infrastructures, but also on a different set of solutions. For example:

A five-day outage might focus on more permanent energy solutions or a combination of permanent and the temporary solutions that support having people shelter in place for the duration of the outage or event. This might include:

- Less emphasis on energy for transportation needs and traffic lights since few people might be driving,
- Increasing importance of energy for critical infrastructures not typically important for a one day outage -
    - providing fuel or energy to hospitals whose generators might have run out of fuel,
    - operation or partial operation of water and waste water utilities so people are not living in unhealthy conditions and there is an ability for firefighting,
    - meeting the energy needs of businesses that provide important community services including grocery stores, pharmacies, and gasoline stations for at least some period during each day,
- making sure city hall, emergency operation centers, police, and fire station energy needs are met,
- provide energy for shelters, schools, and community centers where people can go for assistance
- provide energy to at-risk polpulations – senior housing, etc. if warranted
- making sure energy is available for communications hubs, radio, TV, etc. so citizens/soldiers can stay informed of the latest developments and information on the outage.

Energy and infrastructure system consideration priorities

Below is a summary of city or installation operations, infrastructures, and services that should be considered when looking at critical mission assurance for primary and support efforts for extended outages from natural disasters or other low probability but high consequence events. The categories that should be considered include:

- energy system hardening or resilience,
- critical water (for public health and firefighting), waste water (for public health) and associated treatment operations and pumping needs, as well as storm water pumping infrastructure,
- communication infrastructure - radio and TV stations, though not all would be required,
- emergency response infrastructure - police, fire, ambulance, emergency response operations center (city hall), and related emergency communications for these functions,

- community health and public safety – hospitals, at risk patient care centers, pharmacies, ambulance services
- community services – grocery stores, gas stations, shelters, schools as shelters, etc.,
- transportation services - traffic control, railway operations and control, aviation operations and control as appropriate, and
- other infrastructure needed to support identified major critical community or business operations.

These elements should always be considered but might not be appropriate in all cases, depending on the range of threats and the performance expected of the energy system that will support the military or city services and operations identified as critical by each city or installation.

5.1 Module 5 – Identifying Critical Assets and Services

Module 5 – Prioritizing Critical Assets and Services for Normal and Emergency Operations

In this module you will learn how to:

- Define energy system resiliency and performance goals to meet city need during
  - normal conditions and emergency conditions
- Characterize an energy system and identify microgrid boundaries based on the energy system topology
- Identify critical services and priority facilities that are needed to support identified energy system performance goals
- List critical facilities services needed for various types of normal and emergency conditions

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Example of Critical Services to Consider at a Military Installation

Military Services	Auxilliary Services
Command HQ	Public Works
Consoldidated Comm	Fire Station
Training	Medical Clinic
Communications	Dining
Information Sys	Military Housing
Command Post	Fuel Storage
Control Tower	Base School
Base Ops	Water Treatment
Control Tower	Water Pumps
Airfield	Waste Treatment
Laboratory	
Armory	

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Example of Critical Functions Lists and Differences

Facility/Description	MEVA list?	CRP Priority list?	CRP Shutdown list?	Standby generators? kW	UPS
	Critical	I		Yes, 300 & 250	Yes
Airfield pavements	Critical	I		Unknown ATT	
20604 – Cmnd Post & Com Ctr	Critical	I		Yes, 100 & 300	yes
328 – FAA control tower	Not listed	I		Unknown ATT	
1032 – POL Facilities	Sensitive	I		No (left blank)	
	Sensitive	I	Yes, 4th 10%		
20220 – Law Enforcement	Critical	II		Yes, 30	yes
1200 – Base Hospital	Sensitive	II		No?	
1038 – Fire Station #2	Not listed	II		Yes, 17.5	
30116 Fire Station #3	Not listed	II			
20210 Fire Station #11	Not listed	II			
1017 – Cmnd/Ctrl	Critical	II	Yes, 4th 10%	Yes, 155 kW	
20684 – CE	Not listed	II		Yes, 100 kW	
419 – Tech Library	Not listed	II	Yes, 3rd 10%		
638 – Fire Station #5	Not listed	II		Yes, 30 kW	
xxxxxxxx	Cr	Not listed		Yes, 200 kW	yes
1043 – ANG	Cr	NL	Yes, 4th 10%	No?	
1004 – xxxxxx AFB west	Cr	NL		Yes, 80 kW	yes
30158 – xxxx AFB SE	Cr	NL		Yes, 80 kW	yes
29010 – xxxx AFB south	Cr	NL		Yes, 80 kW	yes
498 – xxxxx AFB far west	Cr	NL	Yes, 3rd 10%	Yes, 80 kW	yes

Will need working group review to finalize priorities for mission assurance

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Example Hierarchy of Critical Infrastructures

Critical Infrastructure Hierarchy

Tier 1	Tier 2	Tier 3
• 911 • Emergency Comm System • Emergency Operations • Water Pump Control Center • Hospitals • Command and Control • Special Ops • Data centers	• Drainage Pumps • Shelters • Fuel Storage • Other Medical Centers • FM and AM Broadcasts • Sewer Pumps • Water Purification • Airports • Public Works/bulk fuel	• Evacuation Sites • Banks • Pharmacies • Gas Stations • Sewer Treatment • Grocery Stores • Fire Stations • Police Stations
Critical/Non-Interruptible	Critical/Interruptible	Discretionary

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Example of Stakeholder Rankings of Critical Assets Needed for a a 2-day and a 5-day Power Outage

Asset	Building or Asset Name	Group A	Group B	Group C
1	Public Works Garage	■	■	■
2	Fire Department - HQ	■	■	■
3	Police Department - HQ	■	■	■
4	WTP + Low Lift Pump	■	■	■
5	WWTP	■	■	■
6	Radio Towers and System: Fire/Police	■	■	
7	High School (Emergency Shelter)	■	■	
8	WWTP Flood Control System	■		■
9	Flood Control - Remote Sewer Pump System			■
10	Municipal Building	■		
11	Food and Gas		■	
12	Fuel Company		■	
13	Cell Towers		■	

Building additions for a 5-day outage

Note: Stakeholders have different views, and some critical functions are missing

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Module 5 Exercise

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6. IDENTIFICATION OF DESIGN THREATS AND OUTAGES

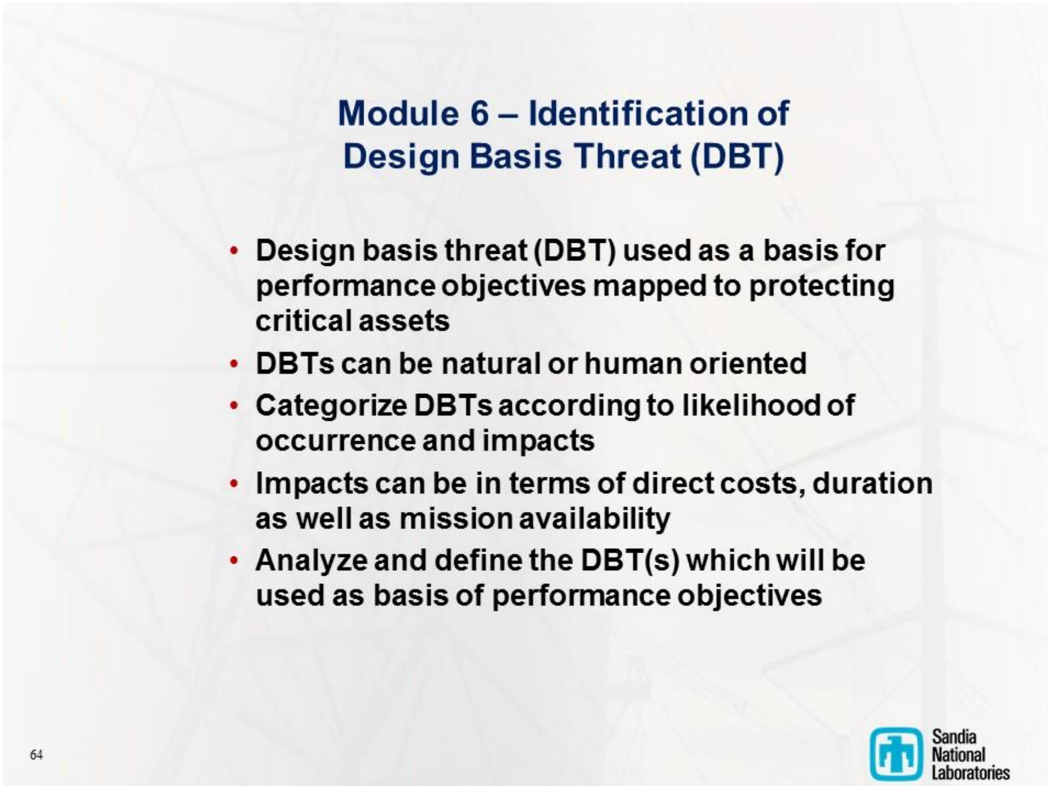
This module provides a general discussion of how to identify potential design basis threats (DBTs) and utilize this knowledge to evaluate which DBTs have the highest likelihood of occurrence and impacts in order to develop performance objectives for system improvements to mitigate the identified DBTs. 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. A DBT is a profile of the type, composition, and capabilities of an adverse threat. The adverse threat can be natural, such as a hurricane or ice storm, or it can be manufactured, such as a cyber or physical attack on infrastructure.

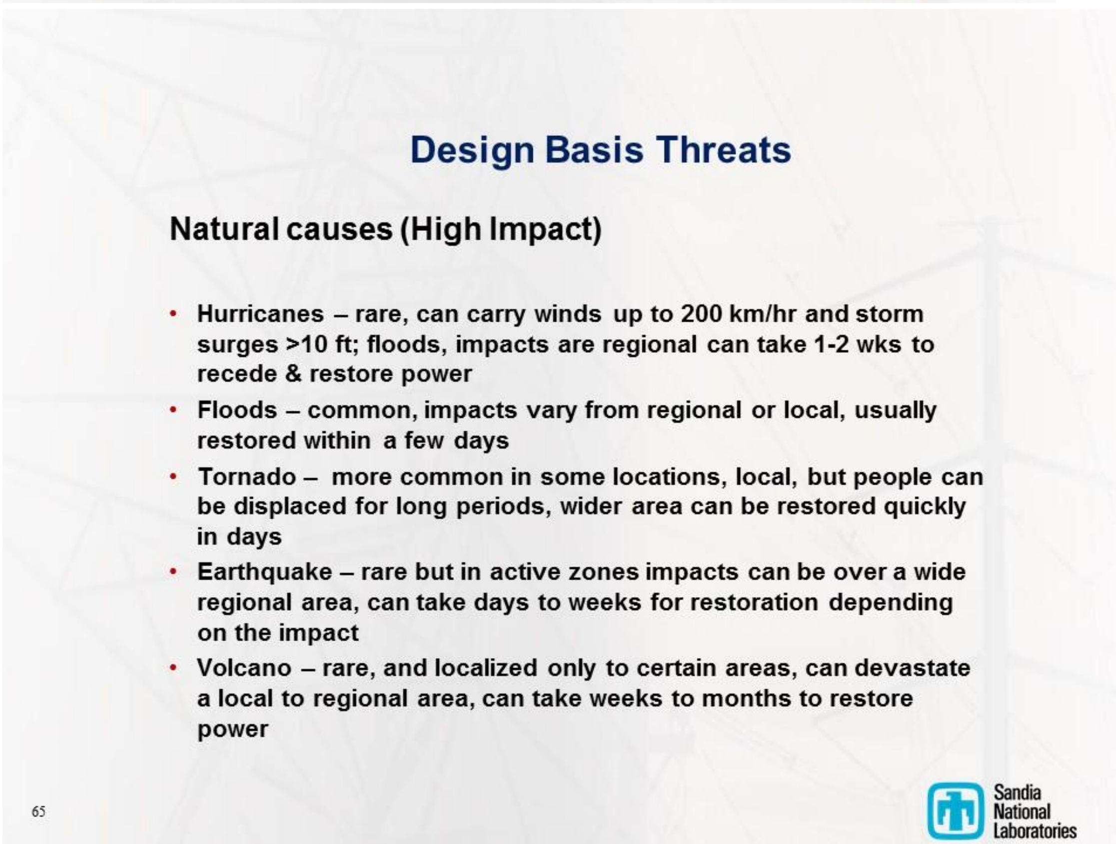
The DBT provides boundaries on the environment in which the system must be made more resilient. It is a cooperatively developed analysis that defines the threat (such as a hurricane, flood, or cyber-attack), providing a basis for the design. The module provides examples of different classes of design basis threats. A given DBT will impact a system for both the consequences of the threat in terms of power loss, equipment loss, economic losses as well as potential impact to public safety. Additionally, a given DBT will have a duration associated with how long the threat is expected to last, and how long it will take to restore the system and recover from the threat. For our applications, this would correspond to the total duration of the associated power outage.

While it is helpful, it is not necessary to determine the impacts and duration of a DBT in great detail, since in many cases the data for such an analysis may not be available. However it is important to understand what the key threats are, and to make some attempt to rank these threats and determine which ones should be specifically designed for or prioritized over other threats, and which ones will be less severe than other threats. Natural DBTs in particular are regional in nature and therefore will vary depending on location. For example, coastal areas are more prone to hurricane threats, while dry areas with forest cover are more prone to forest fires.

Following establishment of DBTs for a given community or installation, stakeholders can analyze local and regional threats and from the likelihood and consequences associated with them can calculate credible design basis outage durations. This then provides an estimated outage value to use as part of the system performance goals. Based on efforts at over 30 installations and communities, Sandia provides in this module DBT ranking criteria that have been used by stakeholders to collectively develop design outages. The criteria include event likelihood, consequences, resilience of the system to the event, and the duration of a nominal event, is demonstrated in the Module exercise.

6.1 Module 6 – Identification of System Design Threats





Design Basis Threats

Natural causes (Medium to Low Impact)

- Explosion/fire – usually localized and impacts for short durations, local power outages only for area where fire occurs
- Fires - rare, in susceptible areas, can entail evacuations of whole areas, and take weeks to restore power depending on the damage
- Heat wave – not uncommon, in susceptible areas, but people are generally mobile, at risk people do need support or shelter, don't usually entail large scale power outages
- Ice Storms/Blizzards – not uncommon, occur in susceptible areas, can take out local to small regions for days until storm clears and power can be restored often from tree damage to lines
- Land Slide - rare, particular areas, like explosions takes out local areas but doesn't cause widespread power outages

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Design Basis Threats

Unintentional causes (High to Low Impact)

- Blackouts – rare, high impact over a wide region, depends on the overall security and adequacy of generation and transmission grid assets, main outage usually occurs over a few hours, but can take days to weeks to fully restore power to all areas
- Brownouts – less rare than blackouts, usually moderate impact over wide regions, more common in high demand periods like summer and winter, depend on generation and transmission availability, sometimes planned during high demand periods, take localized areas out in a rotating basis until overall demand decreases
- Human Error – rare, impact usually localized, takes out particular line, generator or equipment where error occurs, doesn't usually impact overall system
- Equipment Failure - rare, impact usually localized, takes out equipment which failed, system protection usually isolates the failure to localized areas impacts

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Design Basis Threats

Malevolent (High to Low Impact)

- **Cyber Attack – rare, largely dependent on cyber protections and monitoring implemented, impact can be local to regional depending on the sophistication of the attack, restoration depends on mitigating the attack in order to restore the system**
- **Physical Attack – rare, dependent on physical protections, can cause human injury as well as an outage, impact depends on nature of physical attack**

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Ranking DBTs

- **Example metric scale used to rank various DBTS**
  - Likelihood of event (High = 3; Medium = 2; Low = 1)
  - Consequence of event (High = 3; Medium = 2; Low = 1)
  - Resilience to the event (High = 1; Medium = 2; Low = 3)
  - Duration of event (Hours = 1; Days = 3; Weeks = 5)
  - Total score – higher means greater DBT of concern
- **Hurricane**
  - Likelihood (low); Consequence (high), Resilience (low), duration (weeks); overall score = 12
- **Heat Wave**
  - Likelihood (high); Consequence (low), Resilience (medium), duration (hours); overall score -7
- **Conclusion – Hurricane higher impact DBT**

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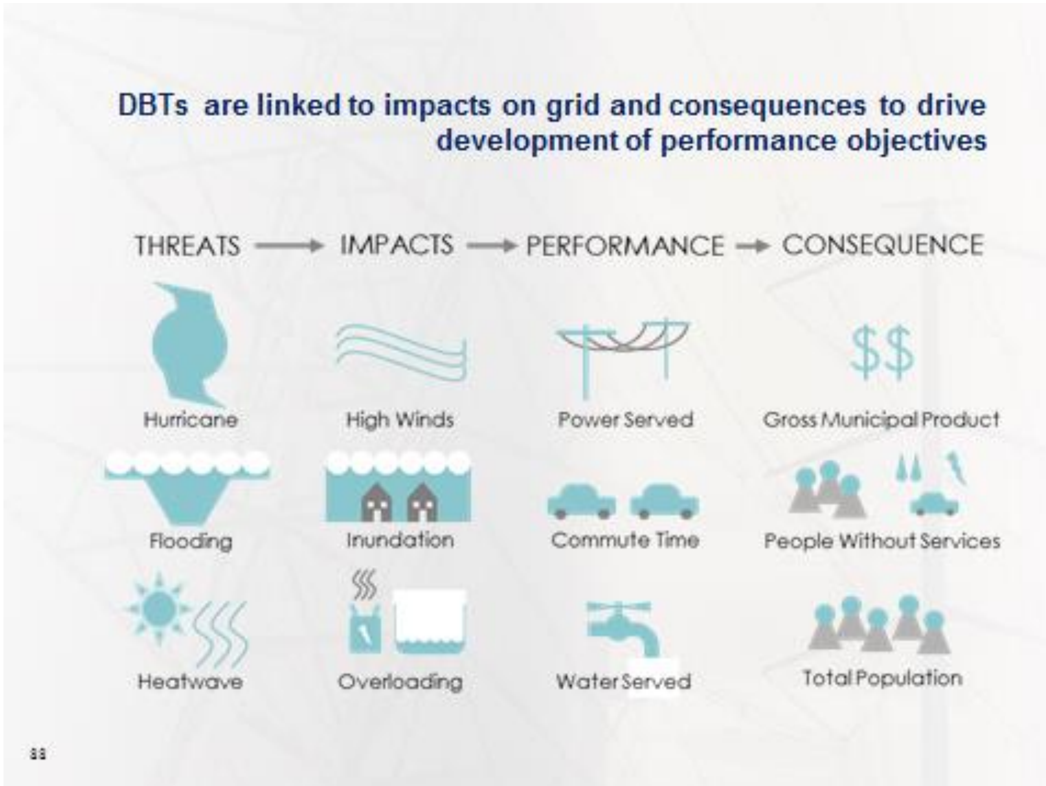
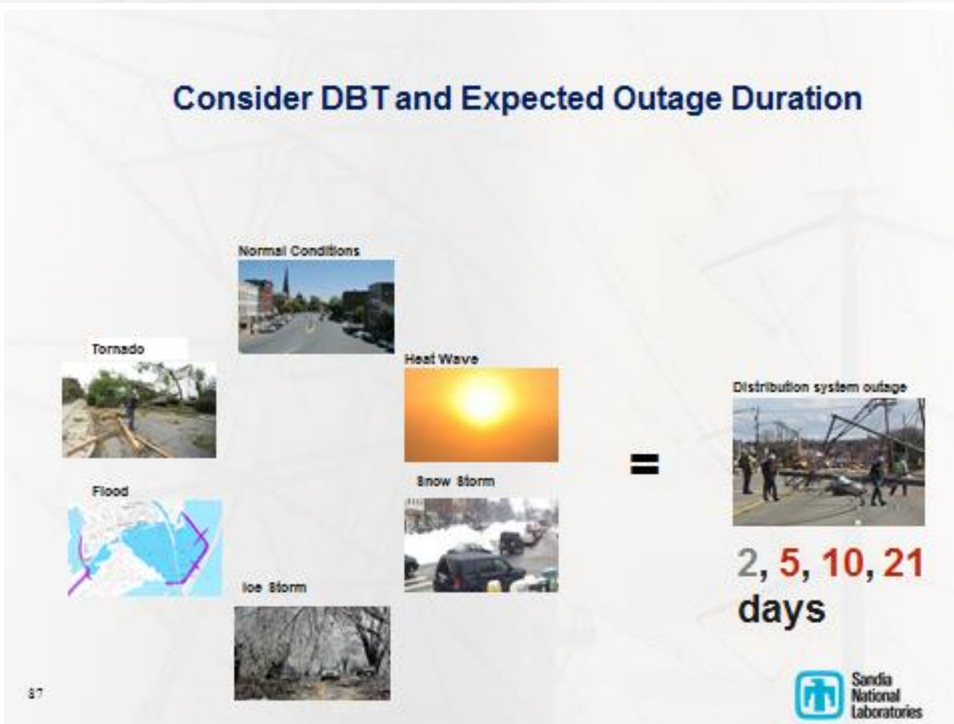

DBTs are linked to impacts on grid and consequences to drive development of performance objectives
THREATS → IMPACTS → PERFORMANCE → CONSEQUENCE
Hurricane
High Winds
Power Served
$$
Gross Municipal Product
Flooding
Inundation
Commute Time
People Without Services
Heatwave
Overloading
Water Served
Total Population


Consider DBT and Expected Outage Duration
Normal Conditions
Tornado
Heat Wave
Distribution system outage
Flood
Snow Storm
Ice Storm
=
2, 5, 10, 21
days
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6.2 Module 6 – Lessons Learned and Best Practices

A couple of best practices that appear to provide universal benefit to the conceptual design process for the desing outage duration or the design basis threat includes:

- When looking at threats, consider things that have occurred regionally as one basis for a design threat.
- Include a broad range of stakeholders in the evaluations, if broken into multiple groups, you will likely get some consensus and some outliers. The consensus results can bring in camaraderie, and the outliers can be taken forward and evaluated from a cost benefit analysis that seems to temper the opinions and reduces the focus about non-credible threats.
- Outages of 4-7 days seem to be the most commonly selected outage duration for most design basis threats.

7. DEVELOPING PERFORMANCE GOALS & OBJECTIVES

This module provides a general discussion of how to establish initial system performance goals and objectives for identified critical services and facilities against identified DBTs and associated design outages. The performance goals and objectives set the requirements that the set of system improvements must meet to be able to protect critical services and facilities performance if identified DBTs were to occur. Performance goals and objectives are initially determined and then modified and expanded as conceptual design improvements are developed and the relative feasibility and performance of various options is evaluated.

The performance goals can be affected by both the scope of the system being considered and by the types of DBTs considered. For example, it will be easier to implement performance goals for a small subset of buildings in a city or military base, than an entire city or military base. It will also be easier to meet performance goals based on withstanding storm damage than for withstanding severe hurricanes since the impacts will likely be smaller, of shorter duration, and likely more localized.

Performance goals identify the baseline of how the system is designed to operate during a major power outage. Therefore, performance goals need to recognize the scope of what critical functions and facilities need to be protected as well as for what duration these assets need to be protected. If the DBT is a hurricane, then it might be that the performance goals will require electrical equipment to be functional in critical buildings in a flood zone, and therefore electrical service equipment must be moved above the flood zone in order to avoid being impacted by the hurricane.

Also enough backup fuel sources such as diesel must be kept to ensure that all the designated critical buildings can be supplied with power for the duration of the design power outage. This might require either innovative fuel storage, use of renewables, or reducing the time a critical function or services is needed. If certain loads cannot be disrupted for even short periods, such as transition from utility power to an islanded microgrid, then these loads must be additionally backed up by storage devices such as UPS systems or batteries that will keep the required equipment powered up during the transitions.

Performance goals also include sustainability and resiliency metrics such as limiting fuel use (very important in tactical system applications), increasing generator equipment efficiency, incorporation of a given amount of renewable resources, lessening the impacts of noise, pollution, or $CO2$, in addition to ensuring that the system functions reliably for the designated threats and can maintain safe and secure operations.

7.1 Module 7 – Setting Performance Goals

Module 7 – Performance Goals and Objectives

- Based on mission requirements and DBT impacts:
  - Critical services to be maintained
  - Critical buildings supporting these services
  - Duration of DBT (2 day, 7 day, 2 week etc.)
- Specify electrical and physical requirements necessary to meet DBT
- Requirements should be metric based
- Electrical requirements may include power availability metrics, power quality and redundancy necessary to meet DBT

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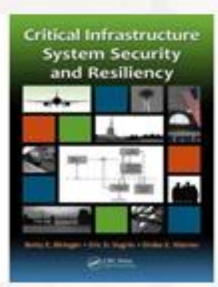
Resilience Science at Sandia

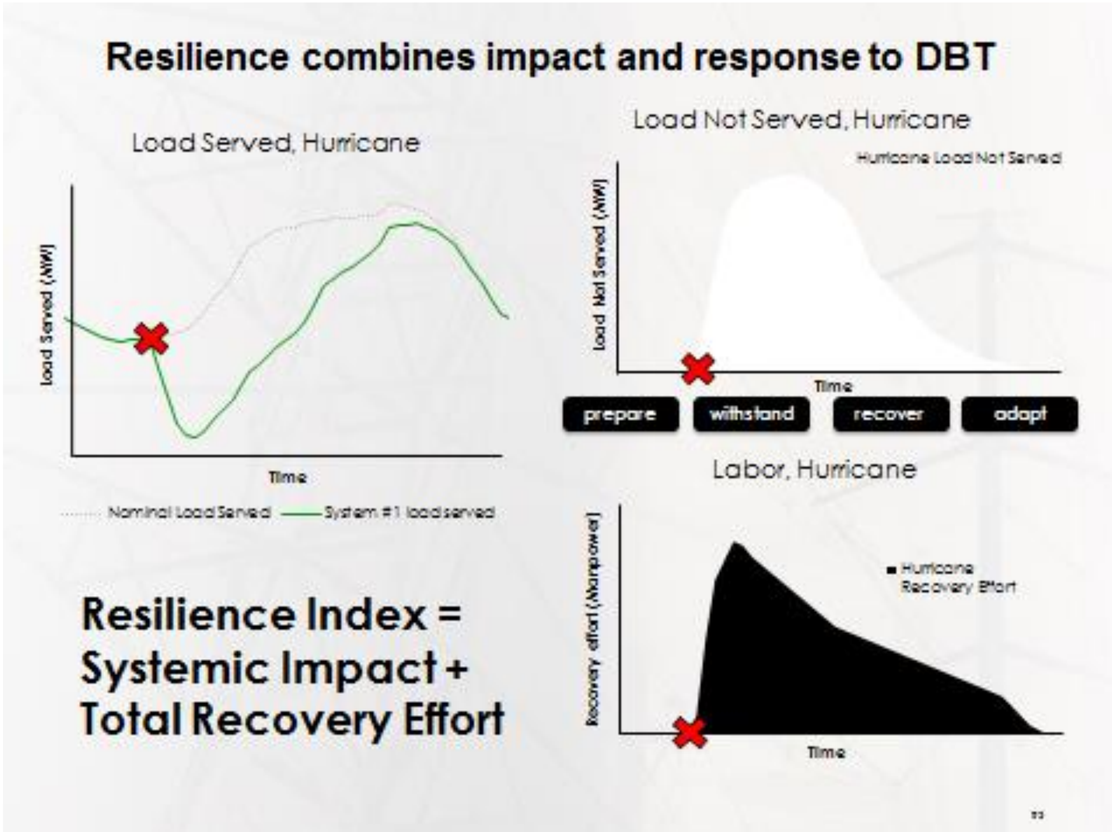
Presidential Policy Directive 21:
The term "resilience" means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

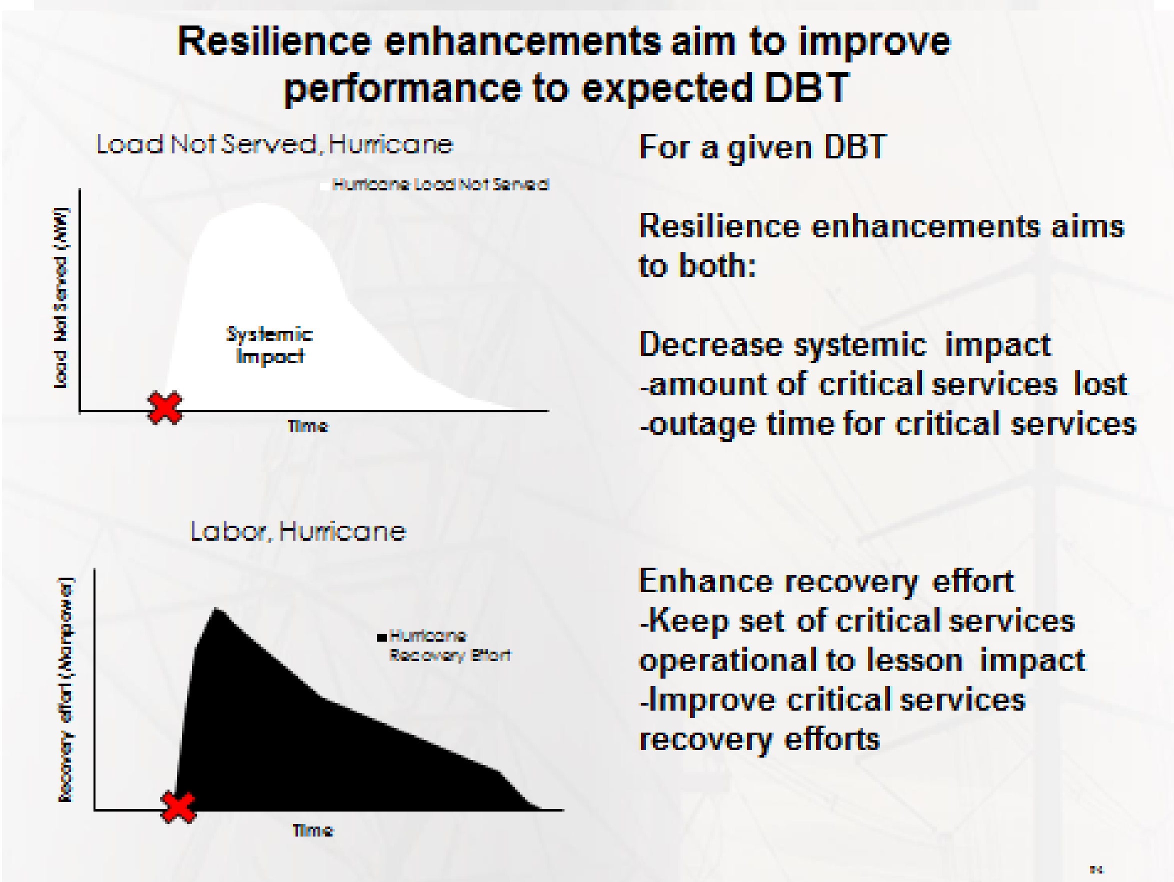
$$SI = \int_{t0}^{tf} [TSP(t) - SP(t)]\,dt. \qquad TRE = \int_{t0}^{tf} [RE(t)]\,dt.$$

SI = System Impact
SP = System Performance
TSP = Total System Performance

RE = Recovery Effort
TRE = Total Recovery Effort




Resilience combines impact and response to DBT
Load Served, Hurricane
Load Served (MW)
Time
Nominal Load Served
System #1 load served
Load Not Served, Hurricane
Hurricane Load Not Served
Load Not Served (MW)
Time
prepare
withstand
recover
adapt
Labor, Hurricane
Recovery effort (Manpower)
Hurricane Recovery Effort
Time
Resilience Index =
Systemic Impact +
Total Recovery Effort


Resilience enhancements aim to improve performance to expected DBT
Load Not Served, Hurricane
Hurricane Load Not Served
Load Not Served (MW)
Systemic Impact
Time
Labor, Hurricane
Recovery effort (Manpower)
Hurricane Recovery Effort
Time
For a given DBT
Resilience enhancements aims to both:
Decrease systemic impact
-amount of critical services lost
-outage time for critical services
Enhance recovery effort
-Keep set of critical services operational to lesson impact
-Improve critical services recovery efforts

Questions to consider in developing performance objectives

- What areas and assets are most likely to lose power in the case of these events?
- What other infrastructure services will be impacted due to loss of power?
- What are the consequences of these projected infrastructure service outages on the critical infrastructures?
- What are the grid enhancement options that will improve resilience for these critical infrastructures? How would these options be designed to work with the existing system?
- For the resilience gained, what is the cost? How would the cost/benefit play out over short, medium, and long terms?

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Resiliency and Performance goals

High Level Resilience Performance Goals:

- Ability to prepare for, adapt to, and recover rapidly from changing, non-normal events defined by DBT
- Metrics will include how each critical infrastructure services will be improved and function to meet DBT
- Metrics include defining time needed for critical services to meet DBT (e.g. 2, 3, 7 days)
- Metrics can be non-electrical such as sheltering people without access to lifeline services, for how long, and at what consequence during DBT event
- Consider upstream and downstream supply-chain impacts and interdependencies of infrastructures

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Linking performance goals to metrics

- Assess adequacy of existing backup systems for various tiered assets both in terms of reliability, as well as backup fuel, and supply chains
- From DBT analysis, number of days required to serve critical functions is a key metric to meet resiliency
  - Adequate fuel storage and supply must be provided
- Critical functions and missions will drive metrics of what is required to improve resilience to DBT
  - Requirements include how many facilities in each critical service are needed and the level of resiliency
- Requirements for resiliency improvements may differ depending on the tier level of the asset
  - Some building may require non-interruptible power to portions of loads
  - Some buildings may require redundant generation through additional backup generation or advanced microgrids

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Example Performance Goals

- **Preliminary Design Basis Threat (DBT)**
  - **Design Basis Threat – Hurricane with surge/flooding**
- **Critical buildings to protect from DBT**
  - **50 buildings identified as Tier 1 – 4 in terms of criticality**
- **Preliminary Performance Goals**
  - **Design implementation options must be physically located at least 2.5' above 100 year flood plain (≥ 12.5' above sea level), which is the flood level designed for**
  - **Design options are focused on electric power solutions as they support critical facilities, infrastructures and city operations; not the operations themselves**
  - **Design options with newly installed backup power (via. microgrids, backup generators, etc.) must remain available for 5-7 days**

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Example Performance Goals

- Preliminary Performance Goals (continued)
  - Design options are focused on electric power solutions as they support Tier 1-3 critical infrastructure operations; not the operations themselves
  - Fuel supplies as well as supply chains must maintain 72 hours of fuel storage for entire system backup storage
  - Design options with power units must meet or exceed the manufacturer recommendations for reliability for well maintained backup generators
  - Energy storage and renewable resources may be included to the extent they are cost effective
  - Ensure all Tier 1 assets have either redundant backup generation or included in advanced microgrids
  - Ensure a select number of Tier 2 & 3 assets in non-inundated areas have either adequate backup generation or included in advanced microgrids as a resilience metric

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Module 7 Exercise

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8. ENERGY SYSTEM PERFORMANCE RISK ANALYSIS

Of major importance is to evaluate the ability of the existing backup system to meet the defined extended outage performance goals and criteria envisioned and established. This is typically done by conducting a system performance risk assessment. In general terms, performance risk is defined as the level of system performance loss as a result of the occurrence of some undesired event.

Performance Risk, **PR**, can be described using a product model:

PR = L * C *where* **PR** = Performance Risk
L = Likelihood of an event occurring
C = Consequences of the event

Performance Risk is often notionally presented as shown in Table 1. Here, highly likely events with low consequences are often considered to have low risks, while unlikely events with high consequences, such as a long term power outages, would be considered to have medium to high risks to system performance.

Table 1. Nominal Performance Risk Levels Based on Event Characteristics

EVENT		Consequences		
		Low	Medium	High
Likelihood	High	L	M	H
	Medium	L	M	H
	Low	L	L	M

This performance risk framework for ranking events and consequences helps provide some insight on where contingency planning or operational improvements would be most beneficial.

For an energy system, Sandia has defined the design threat duration, i.e. 2-day outages or 5-day outages as the likelihood, since the duration identifies how likely they will occur. This enables the **PR** to be calculated directly by identifying the impacts or consequences C, of the power outage on the critical function operations and facilities previously identified in the Performance Goals and Objectives.

Based on previous Sandia energy system evaluation efforts, we have identified critical performance parameters we believe generally capture the potential consequences of a given power outage. Sandia bases energy system performance risk assessment on how well the energy system can meet critical infrastructure functions and services during a given power outage. Based on this approach, Sandia has defined the **PR** for a given outage as a function of the critical buildings and loads served and the length of time they can be met by the energy system. The performance Risk, **PR**, is therefore defined as:

PR = 1-(CBS*CLS*RG*(Da/Dn)), *where*

PR = Performance Risk
CBS = % Critical Buildings Served
CLS = % Critical Loads Served
RG = Reliability of generation system
Da = Operational availability – up to outage period
Dn = Operational duration needed (outage period)

CBS - Percent of critical buildings served by backup power – which critical buildings have access to backup power. If few buildings are served, then consequences and risks will be high.

CLS – Percent of critical loads served – weights serving the defined critical loads and critical services and buildings. If minimal buildings or loads are covered, the consequences and risks will be high.

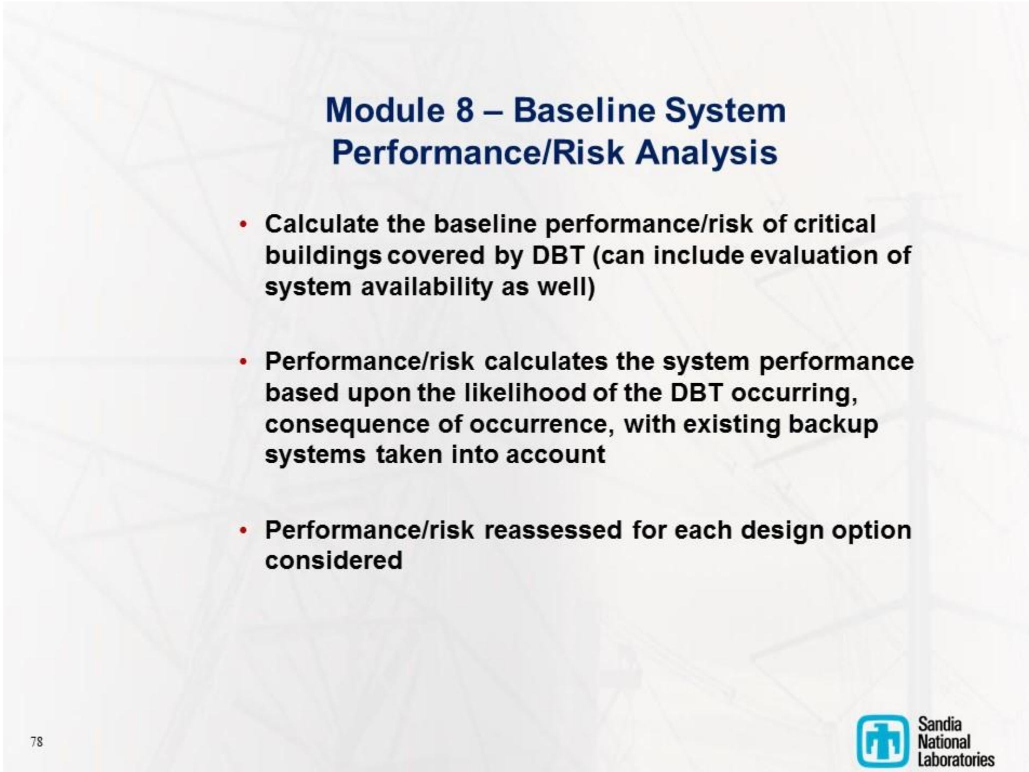
RG - Reliability of generation – weights the maintenance of backup generators or other generation. Low maintenance lowers reliability and risks increase.

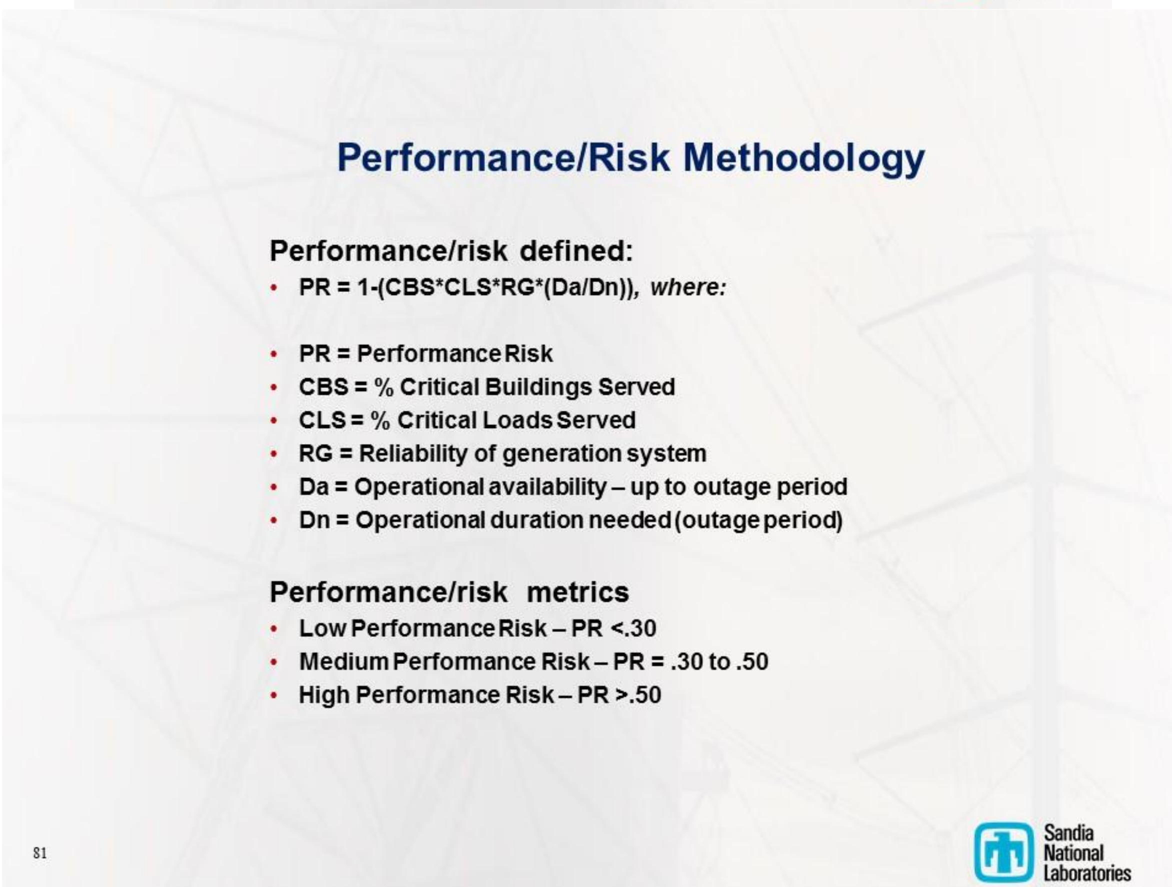
Da/Dn Ratio of generator fuel availability versus outage duration. If the generator fuel tank is small, and/or the ability to refuel the generator is low, then the risks can increase for longer power outages, unless renewable or other energy resources are available.

Based on customer outage evaluations for some major natural disasters, we have found that when backup power systems can meet 85% or more of the critical buildings, and loads served for 85% or more of the outage duration, the overall power system can adequately provide power to support critical community services and functions without significantly impacting overall public health and safety. For energy systems that meet less than 70% of the critical buildings and loads served for less than 70% of the outage duration, the community health and safety become increasingly stressed. Therefore, in general we have quantified energy system performance risk notionally as:

Low Performance Risk – **PR** <.30
Medium Performance Risk – **PR** = .30 to .50
High Performance Risk – **PR** >.50

8.1 Module 8 – Performance/Risk Analysis





Performance/Risk Methodology

- CBS - Percent of critical buildings served – which are the critical buildings with backup power systems. If few buildings are served, then consequences and risks will be high.
- CLS – Percent of critical loads served – which weights serving the defined critical loads for the critical services and buildings. If minimal loads are covered, the consequences and risks will be high.
- RG - Reliability of generation – weights the maintenance of backup generators. Low maintenance lowers reliability and the risks will be high.
- Da/Dn - Ratio of generator fuel availability versus outage duration - If the generator fuel tank is small, and/or the ability to refuel the generator is low, then the risks can increase for longer power outages, unless renewable or other energy resources are available.

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Example Performance/Risk Analysis (2 Day Outage)

Asset	Facility	Critical Building Served (CBS)	Generator Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity
1	Public Works Garage	2/2	100%	.8	At least 2 days
2	Fire Department HQ	2/2	100%	.8	At least 2 days
3	Police Department HQ	1/1	100%	.8	At least 2 days
4	Water Treatment Plant	1/1	100%	.8	At least 2 days
5	Waste Water Treatment Plant	1/1	60%	.8	At least 2 days
6	Radio Repeaters/Police and Fire	2/2	100%	.8	At least 2 days
7	High School	2/2	75%	.8	At least 2 days
8	Flood Control	1/1	100%	.8	At least 2 days
	Total	100%	91.9%	80%	100%

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Example Performance/Risk Calculation (2 Day Outage)

Performance/risk defined:

- PR = 1-(CBS*CLS*RG*(Da/Dn)), *where:*

- CBS = % Critical Buildings Served (all served = 1.0)
- CLS = % Critical Loads Served (based on which have generators = 0.91)
- RG = Reliability of generation system (0.8 – not tested under load)
- Da = Operational availability – (2 days available)
- Dn = Operational duration needed (2 days needed)
- Da/Dn = 1

Performance/risk

- PR = 0.27 which is <.30 so Low Risk

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Example Generator Reliability and Fuel Use Assessment

Asset	Building or Asset Name	Tested at least Monthly	Tested under Load	Adequate Generation Capacity*	On-Site Fuel supply
1	Public Works Garage	Y	N	Y	>5 days
2	Fire Department HQ	Y	N	Y	~3 days
3	Police Department HQ	Y	N	N	~5 days
4	Water Treatment Plant	Y	Y	Y	~40 days
5	Waste Water Treatment Plant	Y	N	N	~8 days
6	Radio Repeaters/Police and Fire	Y	N	Y	~5 days
7	High School	Y	N	N	~2 days
8	Flood Control - Main	N	N	N	~2 days
9	Flood Control Remote Pumps	-	-	N	0 days
10	Waste Water Remote Pumps	N	N	N	7 days
11	Municipal Building	Y	N	Y	>5 days
12	Grocery and Gas Station	-	-	N	0 days
13	Fuel Supplier	-	-	N	0 days
14	Communication towers	-	-	Y	3-5 days
15	High School	-	-	Y	1-2 days
16	Junior High School	-	-	N	>5 days
17	Hospital	Y	-	Y	~5 days

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Example Critical Facility Backup Generator Data

Facility	Gen Capacity (KW)	Peak Measured Facility Load (KW)	Peak Use Relative to Rated Capacity (%)	Internal Tank Capacity (gallons)	External Tank Capacity (gallons)	Total Fuel Capacity (gallons)	Daily Fuel Use (gallons)	Total Supply (days)
A	350	235	67	-	500	500	420.8	1.2
B	400	169	42	1000	NA	1,000	320.8	3.1
C	7.5	0	0	20	NA	20	0	-
D	300	30	10	-	500	500	92.6	5.4
E	750	248	33	-	500	500	486.2	1.0
F	80	31	39	145	NA	145	79.0	1.8
G	150	38	25	850	NA	850	86.4	9.8
H	1750	410	23	1800	8,000	9,800	844.5	11.6
I	600	232	39	NA	5,000	5,000	449.4	11.1
J	1500	300	20	NA	10,000	10,000	653.9	15.3
K	125	0	0	154	NA	154	0	-

Estimating Backup Generator Demand and Fuel Use

- Generator demand determined by measured generator peak use (if available) or just Generator nameplate data
  - Example – Generator A 350 kW; 235 kW measured demand so 235 kW used as peak demand
- Generator fuel use is calculated by dividing the fuel tank size by the fuel demand
  - Example – Generator A 235 kW demand translates to 420 gallons/day, so 500 gallon tank will last 1.2 days
- Manufacturer specifications can be used to get information on generator fuel use in gallons/hour or gallons/day depending on the demand required which is converted to make calculations (See Appendix A)

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Estimating Backup Generator Demand and Fuel Use

- Backup generator fuel storage calculations determine if storage adequate for performance requirements or if additional storage is needed
- Backup generator fuel storage also depends on existing centralized fuel storage for cities or bases
- For example – 12K fuel tank with an estimated 4K gallons/day fuel use for critical generators can supply generators for additional 3 days beyond calculations from individual day tanks
- Performance requirements should account for how often and when (e.g. @½ full) both bulk fuel storage and day tanks are replenished
- Performance requirements should also account for fuel supply and delivery during both normal and emergency conditions and what contingency and backup plans exist to supply fuel during extended outages

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Module 8 Exercise

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8.2 Module 8 – Best Practices and Lessons Learned

There have been several lessons learned from out energy surety and advanced microgrids at all operational, installation, and community levels. These include:

- Outages longer than a few days require significant fuel storage that is not easily coordinated in most applications
- JIT fuel delivery really equates to Just in Trouble for most significant threats
- Improved generator maintenance can have a significant impact on energy security and resiliency values
- Shelter, food and water needs at many bases is as severe as fuel issues.

9. LOAD ESTIMATION TECHNIQUES

This module provides a general discussion of how to perform load estimation for conceptual design development. In most cases, city or military base equipment is primarily powered by an electric utility and may have backup power resources if it is deemed critical for power outages. As such, the main metering concern of the utility is to gather sufficient information for billing. For many residential and commercial customers this will entail gathering monthly energy use data, and for larger industrial customers both monthly energy use and peak demand data. Though there has been a trend towards the increased use of advanced metering of facilities to provide 15 minute – 1 hour energy use and demand data, widespread implementation of these meters is still limited and sporadic.

For microgrid conceptual designs, it is necessary to have a solid understanding of what the expected peak loads as well as range of loads will be, since the microgrid can and in many cases is operated islanded from the utility, and therefore the power to loads depends on the collection of distributed generation resources supplying the islanded microgrid. Knowledge of the expected range of loads as well as the peak drives the amount of generation required to operate the microgrid to be designed to meet the expected peak demand of these facilities as well as to operate efficiently.

Unfortunately in many cases, given the lack of adequate metering, individual building energy use (kWh) and demand (kW) data is unknown. Usually demand and energy use for individual distribution feeders at a monthly level is metered and known, and the individual transformer ratings to buildings connected to the feeders is known. This module presents techniques to estimate critical building loads in order to adequately size generation with additional redundancy for additional reliability to meet these expected loads with limited data. It may be necessary to install meters on critical facilities to supplement these estimates at some point during the microgrid design process in order to increase the confidence that enough generation is being provided to meet the microgrid design loads for the critical buildings included within a microgrid. Otherwise generators will likely be oversized to ensure that they can meet expected loads, and thus will operate less efficiently than if they were properly sized for the actual loads.

9.1 Module 9 – Load Estimation Techniques

Module 9 - Load Estimation Techniques

- Load estimation involves estimating load demands in order to develop microgrid conceptual design
- Good load demand information is critical to knowing what generation and auxiliary microgrid equipment is needed to develop microgrid conceptual designs
- Loads can be further subdivided into tiered categories according to criticality which will determine how the microgrid will respond to these loads, such as critical, sensitive and non-critical loads

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Characterize System Feeders and Loads

Identify critical facility loads and associated feeder connections associated with performance objectives

- Physical locations (map/building)
- Energy Infrastructure (electrical feeders, natural gas pipes, building one lines, water pipes, drainage, etc.)
- Feeder and building controls and monitoring
- Outage records (frequency, duration of events)
- Electrical characteristics
  - Daily and seasonal KW and KVAR
  - Sample load profiles
    - High resolution for a few days
    - Hourly for a year
  - Peak load, average load, min load (KW/KVAR)
  - Level of criticality

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Characterize System Feeders and Loads

- Map where critical facilities connect to existing feeders
- Determine critical and non-critical loads on feeders
- If feeder and load data does not exist, demand estimates need to be made from whatever data exists
  - Feeder monthly and yearly peak demand (kW) and energy use (kWh) from meter records and load profiles
  - Building monthly and yearly peak demand (kW) and energy use (kWh) from meter records and load profiles
  - Feeder cable rating (kVA)
  - Feeder and building connected transformer (kVA)
- Generation requirements sized to meet or exceed peak demand (kW) expectations for set of buildings served

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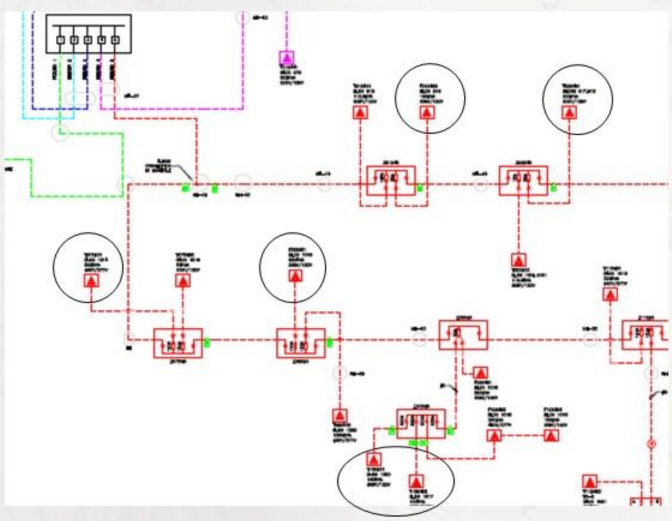
Example Electrical One-Line Diagram



Critical Buildings

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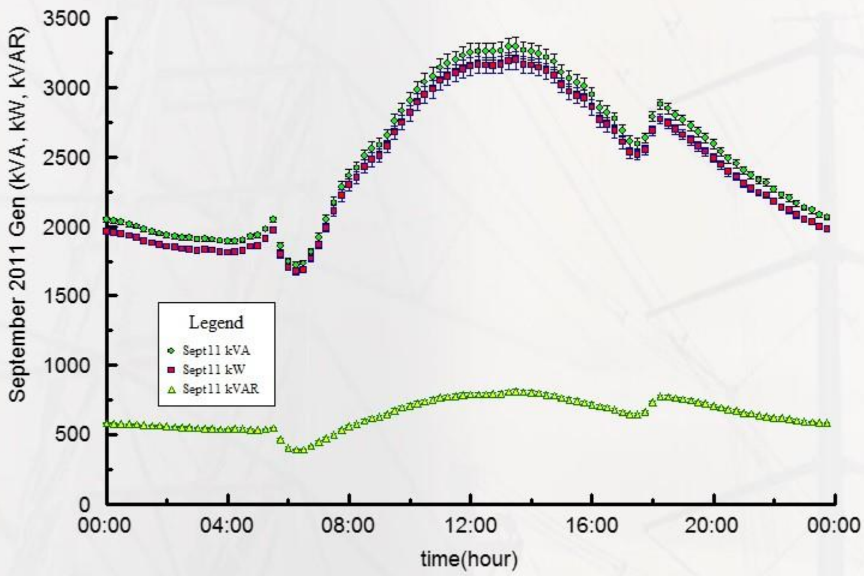
Example System Load Profile



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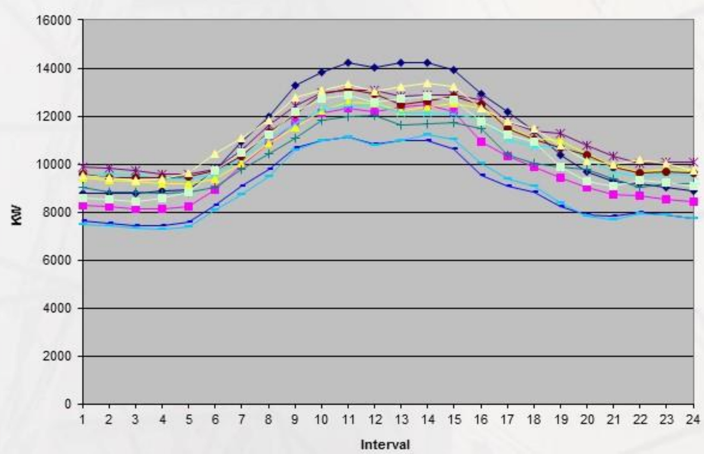
Example Building Load Profile



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Estimating Peak Demand

- Estimates are made to size generator requirements to expected peak feeder and building demands
  - Feeder and building peak demand (kW) can be estimated from monthly and yearly energy use (kWh) by calculating an average demand and multiplying it by a demand factor
  - Example – Building monthly energy use : 50,000 kWh
  - Building average demand/hour : 50,000 kWh /(30*24) = 69.4 kW
  - Demand Factor: 1.5
  - Peak Demand estimate = 69.4*1.5 = 104.1

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Estimating Peak Demand

- Peak demand for buildings can also be estimated from feeder demand or energy use data and building transformer kVA ratings
  - Start with feeder peak demand (kW) data or demands estimated based on feeder energy use data (kWh) using methods of previous slide
  - Determine connected kVA of all transformers on feeder (add the kVA of all transformers on feeder
  - Divide peak demand by connected kVA to estimate % load of each transformer
  - Example – Feeder demand 10 MW; Connected load 40 MVA
  - Average connected load – 10 MW /40 MVA = 0.25 W/VA
  - Building A - 500 kVA
  - Building A load estimate – 500 kVA* 0.25 W/VA = 125 kW

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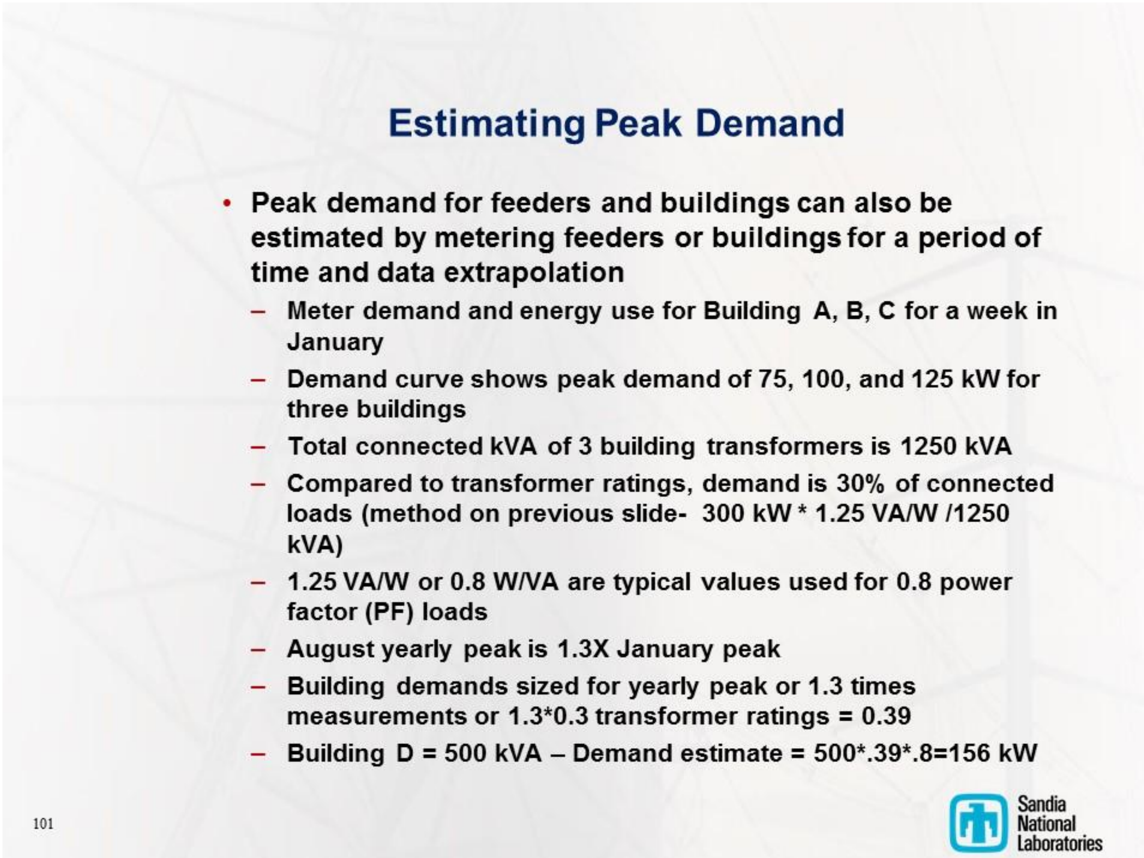


9.2 Module 9 – Load Estimation Lessons Learned

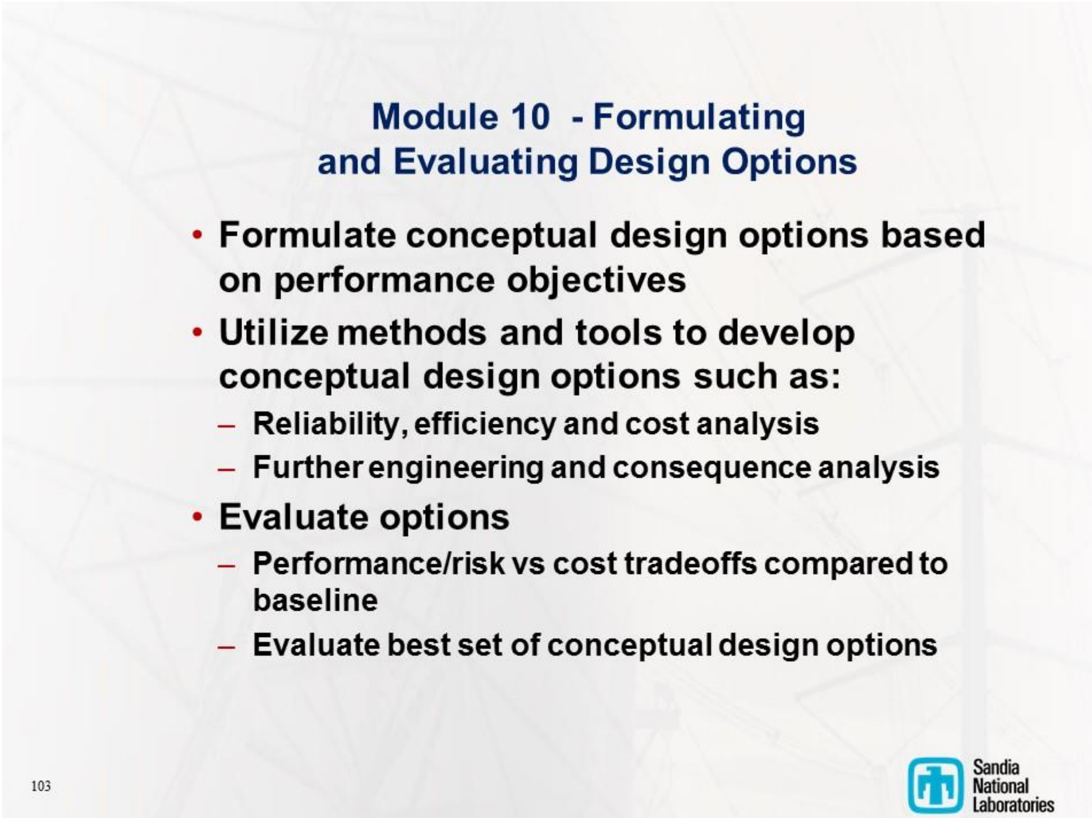
Regardless of the number of bases and sites we have worked with, it seems that often load and building data are not fully available and the load estimation techniques identified in this section are often needed to begin some preliminary designs while additional metering and monitoring is conducted. In general, the rule of thumb is that the building load is one-third the transformer rating.

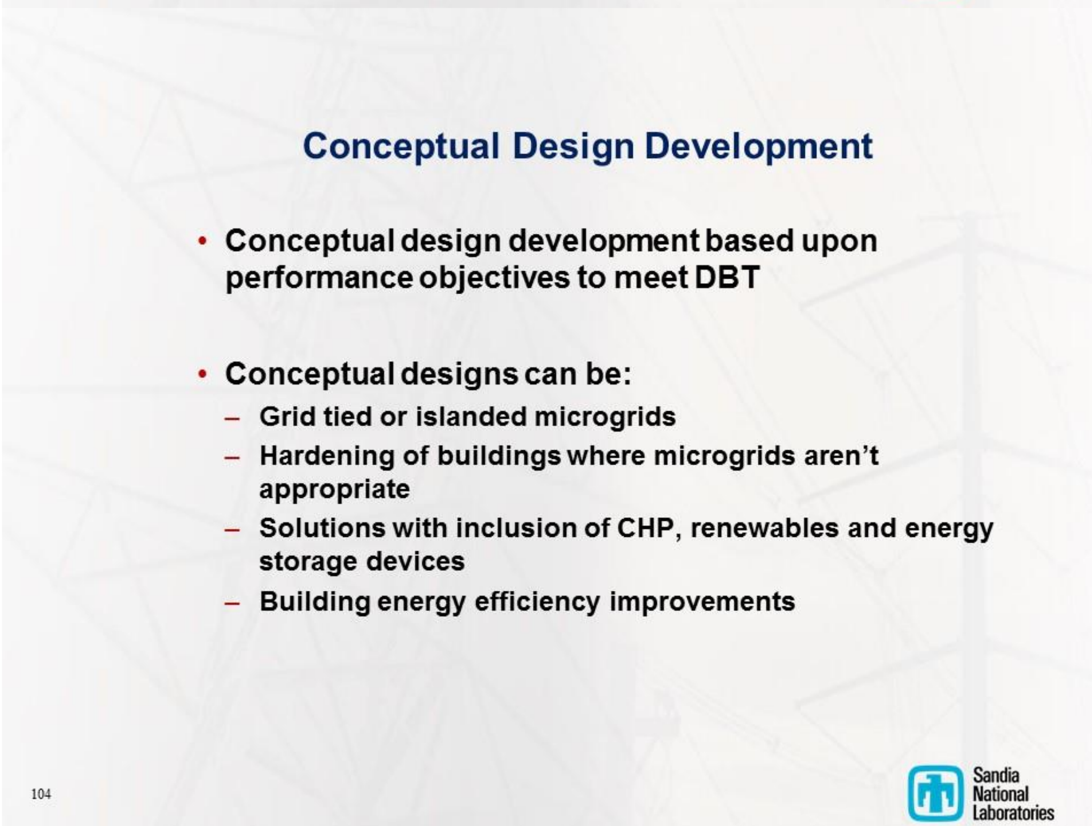
10. FORMULATING AND EVALUATING DESIGN OPTIONS

This module provides a general discussion of how to formulate and evaluate initial conceptual design options to meet identified performance objectives for critical services and facilities against a set of DBTs. Conceptual design options include development of conceptual microgrid designs where appropriate and feasible. Options can also include increasing system resilience, energy efficiency and use of renewable resources and energy storage devices at a local facility level as well as with microgrids as determined by the analysis of how feasible various options are.

The expected performance improvements of the conceptual design options are then compared with the baseline system performance (without improvements) according to the performance objectives to determine how the conceptual design improves system performance versus the baseline system. Advanced optimization and performance tools as discussed in Appendix B can be used to map out the optimized performance versus detailed cost of various options to help evaluate the best set of candidate microgrid options that provide the highest performance at the most reasonable cost.

10.1 Module 10 – Formulating and evaluating design options





Conceptual Design Development

- Use system one-line diagrams and building layouts to locate critical buildings on existing feeders
- Identify areas of city or base where critical buildings can be clustered together
- Identify locations of existing backup generators, energy storage or renewables associated with these critical buildings

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Characterization of Energy and Critical Infrastructures for Mission Assurance

It is necessary to visit the site and characterize the existing electrical and other critical infrastructures to provide sufficient information in order to develop conceptual design improvements

- Characterize electrical system infrastructure including building and feeder loads
- Characterize other critical infrastructures as applicable (gas, water, telecom) to mission assurance
- Characterize existing backup systems (generators, UPS systems, fuel storage etc.)
- Utilize Appendix E information request form as a template for collecting information
- Utilize E-size drawings of infrastructures to highlight things identified for support of mission assurance and resiliency – helps visually identify possible synergies

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Example Critical Facilities within a City

Common for facilities to be spread out across a large area and found on different feeders

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Example Infrastructure and Load Data

Location	Function	Peak Load in kW	Date
00328	FAA Contro Tower	246	12/22/2009
00570	Battle Space Lab	294	1/26/2011
01038	Fire Station #2	33.8	12/19/2008
01043	ANG - No Data		
01062	ANG - No Data		
01055	ANG - No Data		
01900	EOC	80	6/22/2010
01032	POL Facilities	56.32	12/9/2009
01005	Fire Station	117.1	8/4/2009
01200	MUSAF Medical Clinic	456.8	8/3/2010

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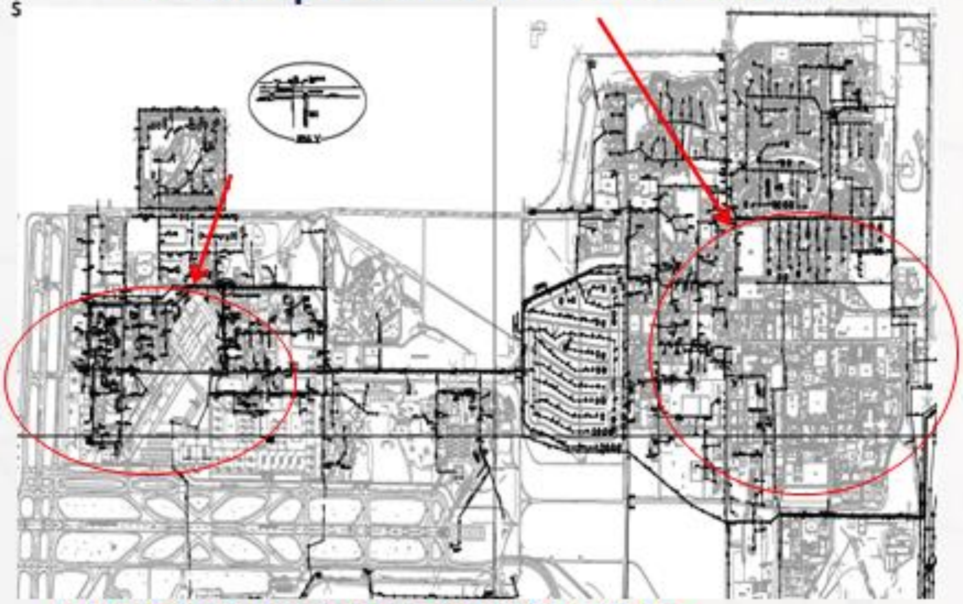
Common Critical Mission Facility Locations on Multiple Subtations and Feeders



Landfill 3 miles away and on different substation

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Identify Critical Buildings and Backup Generators

Critical Building   Substation   Generator

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Conceptual Design Development

- Come up with initial clusters of buildings as candidate microgrids based criteria of whether they are located on the same feeder to close to each other
- Some buildings may not be close enough to any other critical buildings so may be better served by enhancing the reliability and resilience locally

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Example Identifying candidate microgrids

Facility/Description	Critical list?	Standby generators? kW	UPS	SS -- Feeder
Potential Microgrid				
Headquarters	Not listed	None		A – 1
Military Unit 1	Sensitive	None	Yes	A – 1
Military Unit 2	Sensitive	None	Yes	A – 1
Fire Station	Not listed			A – 1
Hospital	Not listed	None		A– 1
Potential Microgrid				
Command Center	Critical	Yes, 100 & 300	yes	B – 4
Police Station	Not listed	Yes, 100		B – 4
Control Tower	Sensitive	Yes, 365		B – 4
Armory	Critical	Yes, 200	yes	B – 4
Airfield Lights	Not listed	Yes, 2 x 200		B – 4

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Conceptual Design Development

- Conceptual design microgrids are developed using a combination of both existing and new generation to meet loads
- Conceptual design microgrids can include energy storage and renewables
- Conceptual designs are developed so that combination of generators can supply peak load requirements in the absence of any single generator (N-1 requirement)

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Microgrid Conceptual Design Example making Generation exceed Peak Loads

- Generation
  - New generation – 5 -200 kW microturbine modules
  - Existing generation - 2 – 250 kW and 2 -200 kW generators
  - Capacity 1900 kW
- Loads
  - Peak Load – 1600 kW
- Loss of any single generator will still meet peak load requirements

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Example Microgrid Conceptual Design Considerations

- Critical building peak load exceeds generation available
  - Add extra generation
  - Shed non-critical loads
  - Install dedicated microgrid feeder

- Critical buildings in microgrid sparse
  - Building share backup generation
  - Add redundant backup generation to critical building

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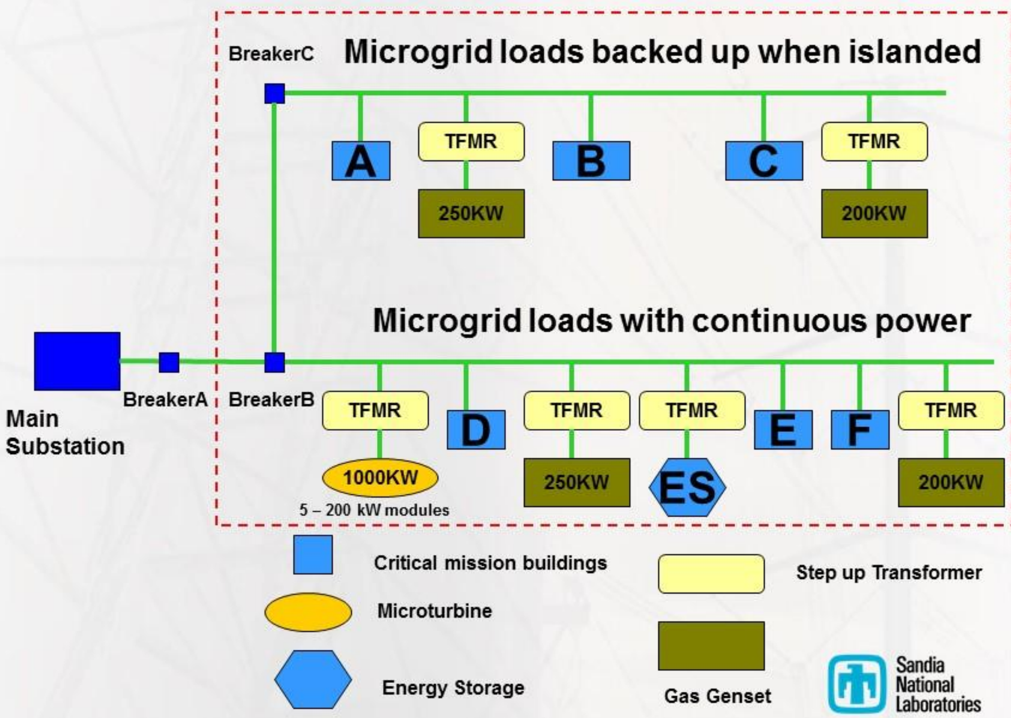
Example Microgrid Conceptual Design



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Performance/Risk Analysis of Conceptual Designs

Do performance risk to compare conceptual designs to baseline system performance

Recall - Performance/risk defined as:

- **PR = 1-(CBS*CLS*RG*(Da/Dn)),** ***where:***

- **PR = Performance Risk**
- **CBS = % Critical Buildings Served**
- **CLS = % Critical Loads Served**
- **RG = Reliability of generation system**
- **Da = Operational availability – up to outage period**
- **Dn = Operational duration needed (outage period)**

Performance/risk metrics

- **Low Performance Risk – PR <.30**
- **Medium Performance Risk – PR = .30 to .50**
- **High Performance Risk – PR >.50**

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Example Conceptual Design Performance/Risk Calculations

Option	Primary Upgrade	P/R	Critical Asset Availability	Fuel Supplies Needed	Estimated Cost	Benefits
1	Pin and Sleeve at all facilities, some rewiring, and purchase additional portable generators	0.06	.9963	1700 gallons	$745K	Allows each building to be provided with a portable generator if needed. Minimizes redundant generators
2	Redundant generators at each building, some rewiring	0.05	.9975	800 gallons	$1190K	Redundant generator at each building, has its own fuel supply so less refueling needed
3	Pin and sleeve with PV integrated at 5 buildings	0.05	.9964	1500 gallons	$1450K	Option 1 with renewable energy at several critical builidngs
4	Pin and sleeve with PV	0.05	.9964	1500 gallons	$1000K	Option 3 but using PPA for PV

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10.2 Module 10 – Lessons Learned

In evaluating critical facilities and services needed for energy system and installation or community resilience and critical operations security, many critical services natural cluster into and some do not. Therefore the following considerations should be kept in mind when evaluating for energy and mission assurance:

- It is common and often of higher energy reliability to have 4-8 small microgrids at larger installations, and 2-3 microgrids at smaller installations
- Not all facilities are close enough to other buildings that they can be included in a microgrid. For those buildings , or for a suite of buildings like this across a base or community, building tied generation, provisions to bring in additional backup generation – such as installing building pin and sleeve connections and having a suite of mobile generators, can be integrated efficiently and cost-effectively and provide high reliability.
- In areas on an installation where critical functions are naturally clustered, master planning so that other critical infrastructures or services are incorporated into a “resiliency node” utilizes a microgrid much more efficiently.
- Finally, in looking at areas of the installation or community where no critical services exist, master planning might want to be modified so that those areas can get a microgrid and “resiliency node” established to provide more cost effective critical services.

11. COST ESTIMATION

The cost estimates include several costs. This includes the initial equipment purchase costs, future maintenance requirements and costs, the design costs necessary for a design firm to survey the electrical system, do supporting analysis and create design drawings to outline the changes in the existing grid necessary to implement the design, engineering costs include all of the additional support to review and oversee the design and construction phases, and the construction costs including the labor costs to install and test the equipment, and any overhead costs associated with a general contractor assigned to oversee the construction.

To simplify this approach, cost tools which use equipment costs to help identify estimates of the other cost categories based on construction and engineering cost estimating procedures such as RS Means can be used. Once the base equipment costs are estimated, the labor costs estimates are included to determine the overall base costs to install the equipment. The construction management oversight costs are estimated to be ~20% of the overall equipment costs. The engineering and design costs are estimated to be ~12.5% each of the construction equipment costs. A 25% contingency is included to take into account the lack of complete information at the conceptual design level. Therefore, the cost estimate approach is:

- Calculate equipment, installation and labor costs – construction baseline costs (C)
- Calculate additional construction management costs (0.2*C)
- Calculate design cost (0.125*C) and engineering cost (0.125*C)
- Sum the overall design, construction and engineering costs and multiply by 0.25 to get ranges of costs
- Additionally add any overall facility overhead costs to these estimates (e.g. 10%)

For example, if it is determined that the overall costs for procuring and installing equipment including labor for a small project is $1000K, then the construction management costs can be estimated to be $200K. The design and engineering costs are estimated to be $125K each. Therefore the overall minimal costs for this ESM will be $1450K, and the range of costs including a contingency will be ~$1450K - $1810K. Additional facility overhead costs if known or estimated can be added to these cost ranges.

This approach shows that ~45 – 80% of additional costs (not including facility overhead) on top of construction equipment procurement and implementation costs should be expected to install these upgrades. Cost estimates for electrical equipment and labor includes the following:

- Electrical equipment and installation cost data can be obtained with estimate resources such as RS Means,
- For equipment not included in these, published reports or equipment manufacturers can be consulted for additional cost information,
- Regional Davis-Bacon labor wage rates can be used to modify the basic installation costs for the equipment,
- An additional labor productivity adjustment of 15% for construction costs is included to take into account any additional costs associated with safety and security requirements and training needed to work on city utilities, and
- Labor overtime is not included in the estimates.

In the case of a conceptual design, since many of the details of a final design and construction need to be more fully scoped, this approach provides a rough order of magnitude (-30% to +30%) estimate of the likely range of costs associated with the project energy system upgrades identified.

The table below provides some 2015 costs updated in 2017 of typical microgrid equipment costs. The list focuses on equipment costs, and using the analysis above can be used to estimate design, engineering, and construction costs for various energy and infrastructure improvement and resiliency options. These values can be used to help begin the estimation of the cost of upgrades, understanding that equipment cost can vary by region or change rapidly depending on supply, and construction costs are very region and site specific. But most installation operations managers know the relative impacts to cost from local construction and supply issues and how the proposed cost factors can be modified for site-speciific conditions.

Equipment Cost Table

Equipment	Cost $
OH Cable	$150/ft
UG Cable	$300/ft
Transformers	$40/KVA
HV Breakers	$100k/Unit
Reclosers	$30k/Unit
HV Switches	$20k/Unit
LV Breaker	$50K/Unit
Manhole	$15k/Unit
Pin & Sleeve	$100k/Unit
Controls	$100k/generator
Diesel Generator	$500/kW
Natural Gas Generator	$1000/kW
PV	$2300/kW
Wind	$1000/kW
CHP (Control Heat & Power)	$2500/kW
Batteries	$2000/kWh
Fuel Tank	$1.5/gallon
Retro fit Buildings	$750/kW
Natural Gas Fuel	$10/MMBTU

11.1 Module 11 – Cost Estimation

Module 11 -Cost Estimation

- **This module covers how to estimate project costs including:**
  - Equipment costs – combination of procurement and installation (including construction) costs associated with the microgrid equipment
  - Design costs – costs for A&E to perform a detailed design as well as a portion of the engineering analysis necessary to design a microgrid
  - Engineering costs – costs to do detailed engineering analysis of the performance and controls for the microgrid
  - Overhead costs – costs associated with other entities such as city or military personnel, regulatory agencies, etc. necessary to install the microgrid
  - If overhead costs are not known, these costs are factored into the 25% contingency cost factor to estimate overall costs for a project

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Elements of Cost Estimation

To simplify the cost calculation, the cost components are broken down into the following categories:

- Installation Costs – costs to procure and install all equipment involved in conceptual designs including construction firm overhead costs
  - Cost for construction overhead for installation can be optionally be calculated separately from equipment procurement costs and then tabulated as long as this is done consistently throughout the estimation process
- Design and Engineering Costs – costs for detailed A&E firm design plans, and engineering involved in installation, testing and final implementation of conceptual design. Estimated to be 25% of the total installation costs
- Contingency Costs – Additional 25% contingency added to account for unanticipated costs associated with the conceptual design such as base or city planning related costs.
- Overall Construction Costs – Sum of installation, design and engineering as well as contingency costs. Approximately 1.5X of installation costs
- If any of these costs are more directly known, for example design costs are $350K, from an estimate from an A&E firm, these costs can be substituted for this formula used to estimate these costs.

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Installation Costs

- Installation costs include the following cost components
  - Distribution Infrastructure Costs
  - Generator Costs
  - Cyber Security and Controls Costs
  - Retrofit Costs (if needed)
  - CHP, PV and Energy Storage (if included)
  - Labor for installation

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Distribution Infrastructure Costs

Distribution infrastructure costs are all costs associated with connecting clusters of buildings together using underground or overhead conductors. This includes:

- Cabling – costs of conductors (overhead (OH) or underground (UG))
- Trenching and Conduits – trenching, duct bank and conduit costs for UG cables; OH conductors would be costed for pole structures
- Manholes – access to buildings and connections for UG systems
- Transformers – it may be necessary to install transformers to connect building loads to the microgrid if existing transformers cannot be used; transformers are also needed to step up voltages from generators to medium voltage levels

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Generator Costs

Generator costs are all costs associated with providing N-1 redundant generation to individual buildings or clusters of buildings. This includes:

- **Generators – Natural gas, diesel, microturbines, fuel cells, etc. which supply the main energy source to the microgrid**
- **ATS – Automatic transfer switches to connect and disconnect backup generators from critical building loads**
- **Parallel Switchgear – In some cases more expensive parallel switchgear is required to connect multiple generators together**
- **Additional Fuel Storage – Additional fuel tanks to supply diesel fuel to diesel engines for longer duration outages; can also use propane storage for natural gas engines; some engines are rated for other sources like JP or biofuels during emergency conditions**

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Retrofit Costs

Retrofit costs are all costs associated with upgrading building service equipment to meet the DBT, such as raising equipment for flood conditions.

This includes:

- **Relocation of Service equipment – Switchboards, panelboards, transformers, and wiring to be above the DBT for the building**
- **New Equipment – if equipment cannot be relocated, additional or duplicate equipment must be provided**
- **Demo/Restructuring – Any costs associated with demolition and restructuring of the existing building structure in order to be able to supply power to meet the DBT**

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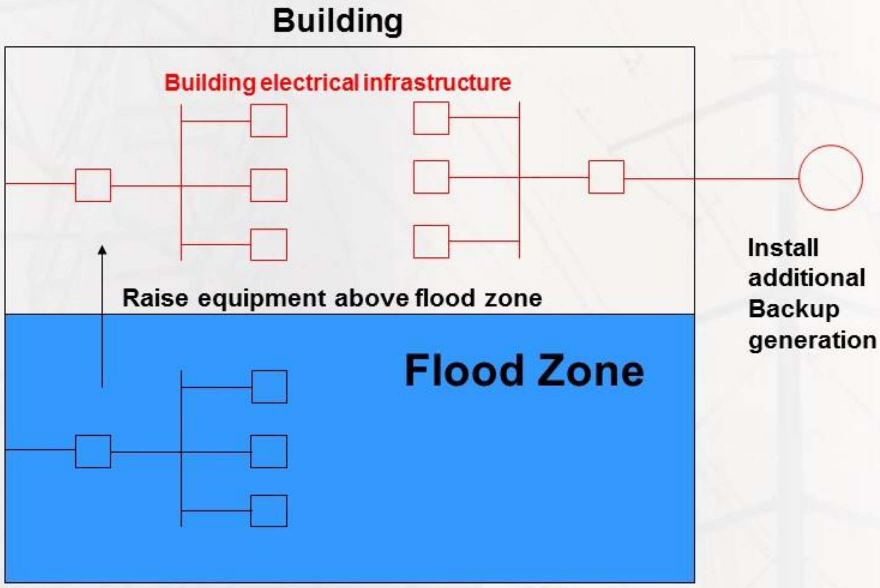
Example of Retrofits



CHP, PV and Energy Storage Costs

CHP, renewables and energy storage are all costs associated with utilizing any of these opportunities with the conceptual designs to provide additional benefits.

This includes:

- CHP – combined cooling, heating and power; excess heat of building used to supply building heating and cooling relieving electrical requirements and making system more reliable
- Renewables – use of renewables to offset generation use to reduce fuel requirements and emissions
- Energy Storage – use of energy storage to provide non-interruptible power to certain loads or other applications such as smoothing PV and ramp rates of generators to make system more efficient

Example CHP Benefit Analysis

Location	CHP Size (kW)	Peak Electric Load (kW)	Electric Savings ($2013)	Natural Gas Savings ($2013)	CHP NG Costs ($2013)	O&M Costs ($2013)	Net Savings ($2013)	Installed System Cost ($2013)	Payback (Years)
Bldg A	**100**	**142.7**	**$70.6k**	**$33.0k**	**$73.9k**	**$8.0k**	**$21.7k**	**$221.0k**	**11**
Bldg B	**37.5**	**56.4**	**$40.7k**	**$16.7k**	**$30.0k**	**$6.1k**	**$21.3k**	**$81.0k**	**4**
Bldg C	**15**	**20.7**	**$9.9k**	**$5.6k**	**$9.0k**	**$1.5k**	**$5.0k**	**$27.0k**	**6**
Bldg D	**100**	**142.7**	**$62.6k**	**$33.0k**	**$75.2k**	**$8.0k**	**$12.4k**	**$224.9k**	**19**

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Example PV Benefit Analysis

Service	Usable PV Output (kW)	System Cost	Energy Value	Payback: (years)
Bldg A	**550**	**$2635k**	**$156.6k**	**10.5**
Bldg B	**360**	**$1724k**	**$102.5k**	**10.5**
Bldg C	**300**	**$1437k**	**$85.4k**	**10.5**
Bldg D	**240**	**$1150k**	**$68.4k**	**10.5**
Bldg E	**210**	**$1006k**	**$59.8k**	**10.5**

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Cyber Security and Control Costs

Cyber security and control costs are all costs associated with providing cyber security and controls to individual buildings or clusters of buildings. This includes:

- **Control infrastructure – Costs to install communications infrastructure necessary for microgrid controls (including monitoring, cyber security and protection)**
- **Control Center – Laptops, pagers, etc. with different levels of access to monitor and control microgrids**
- **Generator Controls – Local as well as overall supervisory controls involved with synchronization, startup and outputs of generators and isolation devices**
- **System Protection – Devices involved in detecting and clearing faults which may occur within microgrids**

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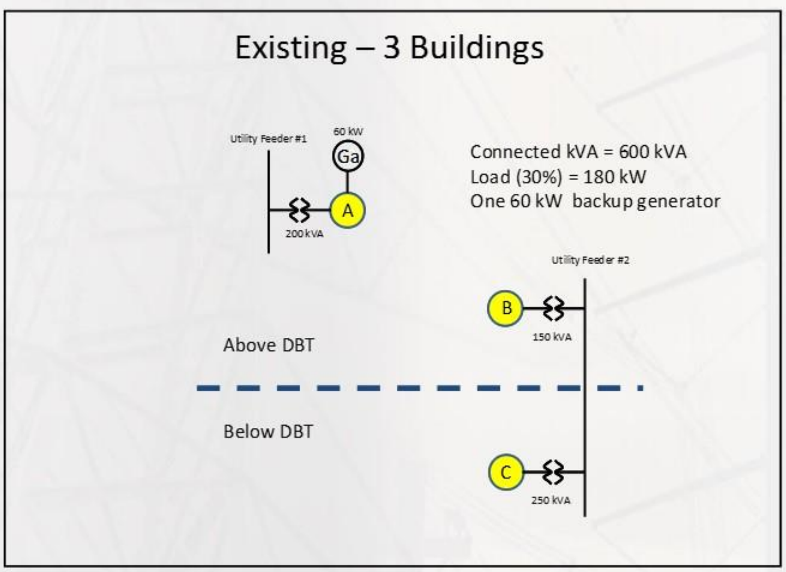
Example System



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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**	

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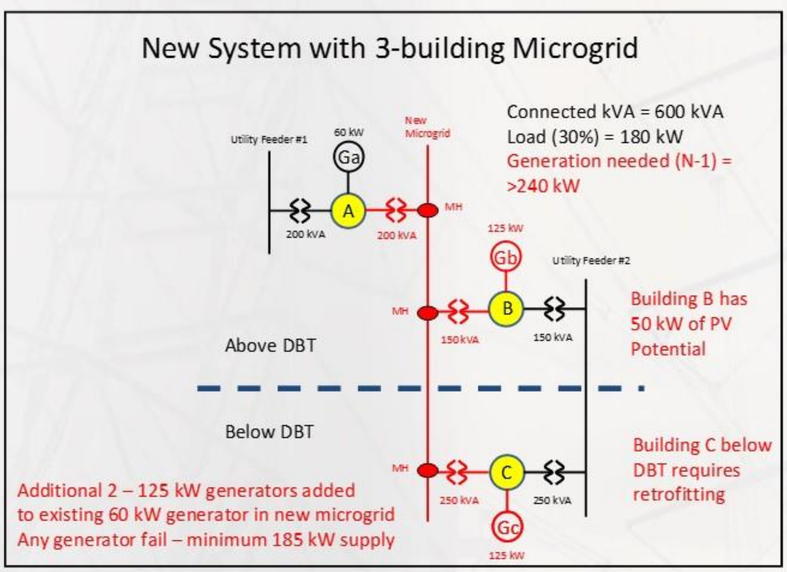
Example System with Microgrid



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General Cost Table

Equipment Cost Table

Equipment	Cost $
OH Cable	$150/ft
UG Cable	$300/ft
Transformers	$40/KVA
HV Breakers	$100k/Unit
Reclosers	$30k/Unit
HV Switches	$20k/Unit
LV Breaker	$50K/Unit
Manhole	$15k/Unit
Pin & Sleeve	$100k/Unit
Controls	$100k/generator
Diesel Generator	$500/kW
Natural Gas Generator	$1000/kW
PV	$2300/kW
Wind	$1000/kW
CHP (Control Heat & Power)	$2500/kW
Batteries	$2000/kWh
Fuel Tank	$1.5/gallon
Retro fit Buildings	$750/kW
Natural Gas Fuel	$10/MMBTU

Based on RS Means 2015 data and 2017 updates

Cost calculations for Example Microgrid

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

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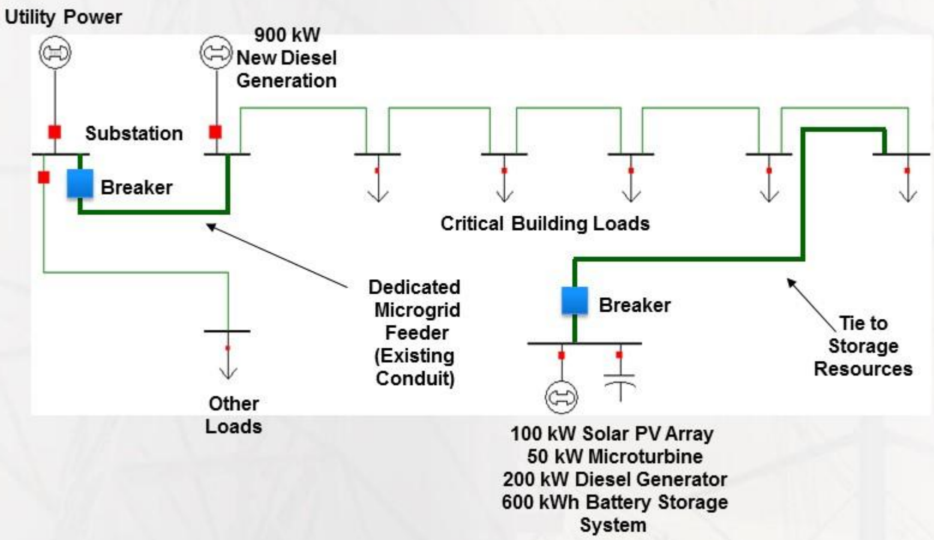
Another Example Microgrid



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Cost Spreadsheet with Engineering, Design and Contingency Costs

Equipment	Equipment and Installation costs ($K)	Constructio n OH (20%) ($K)	Design OH (12.5%) ($K)	Engineering OH (12.5%) ($K)	Total Costs ($K)	Total Costs with Contingency (25%) ($K)
Microgrid Breaker	100.0	20.0	12.5	12.5	145.0	181.3
Underground Feeder	530.0	106.0	66.3	66.3	768.5	960.6
Microgrid Controls	375.0	75.0	46.9	46.9	543.8	679.7
Misc Equip	250.0	50.0	31.3	31.3	362.5	453.1
Total w/o Generation	1255.0	251.0	156.9	156.9	1819.8	2274.7
Generation						
1600 kW New Generation	1200.0	240.0	150.0	150.0	1740.0	2280.0
Total w/generation	2455.0	491.0	306.9	306.9	3559.8	4554.7

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12. SYSTEM RELIABILITY AND AVAILABILITY

This module provides a general discussion of power system reliability and availability, how they differ and how to calculate system reliability and availability from component reliability and availability.

Reliability of a power system is the ability to provide sufficient power especially during critical conditions. Although achievement of complete 100% reliability of a system may be impractical due to the prohibitive costs associated with supplying redundant power networks or backup equipment and supplies to all facilities, the reliability of the electrical distribution system on a military base still can often be significantly improved to meet critical mission operational needs with appropriate risk-based evaluations and energy infrastructure modernization.

Reliability

The definitions for reliability (as well as availability discussed later) are based on the IEEE Gold Book:

> *Transmission and Distribution Committee of the IEEE Power Engineering Society (2004) IEEE Std 1366™-2003: IEEE Guide for Electric Power Distribution Reliability Indices*

For engineering purposes, reliability is defined as:

> ***Reliability:*** *The probability that a device, or system, will perform its intended function without failure under stated conditions for a stated period of time.*

Mathematically, reliability is a function of time, expressed as *R*(*t*). Let *T* be a random variable representing time to failure of a component or system. Then, *R*(*t*), by definition, is the probability that *T* is greater than a specified time, *t*.

$$R(t) = Pr\{T > t\} = \int_t^{\infty} f(x)\,dx$$

Here, *f*(*x*), is the failure probability density function describing the probability of occurrence of outcomes of the random variable *T*, and *t* is a specified time (which is measured starting from *t* = 0). In other words, *R*(*t*) is the probability that the device, or system, will **not** fail on or before *t*. Therefore, reliability can also be written as:

$R(t) = 1 – \Pr\{T \leq t\}$,

where $\Pr\{T \leq t\}$ is the probability that the device, or system, will fail on or before time t. $\Pr\{T \leq t\}$ is commonly referred to as the device, or system, probability of failure, $F(t)$.

$R(t) = 1 – F(t)$

Methods such as fault tree analysis can be used to identify and evaluate components of a systems probability of failure, then this relationship can be used to compute the reliability of the system.

The most common failure probability density function used in reliability analysis is the exponential density. Empirically, the exponential density has been found to accurately characterize time to failure of many components and systems that are well maintained and are operating in the usable portion of their lifespan (i.e., not start up and not end of life). The usable portion of a system's life is generally a long period. A common characteristic of a component or system in this stage of its lifecycle is a constant failure rate, λ. During this period, failures occur at random times. The units of λ are failures/time period. The time period could be seconds, minutes, hours, days, etc. and is generally chosen to provide appropriate scaling for λ. The parameter λ completely characterizes the exponential density function.

$f(t) = \lambda e^{(-\lambda t)}, 0 \leq t \leq \infty$

The mean value of the exponential density is found by integrating t times $\lambda e^{(-\lambda t)}$ from 0 to infinity. The result is the mean time to failure (MTTF) and is equal to 1/λ. For a repairable system, the mean time to failure is also equal to the mean time between failures (MTBF). In terms of the exponential failure density function, reliability is easily found to be:

$R(t) = e^{(-\lambda t)}, 0 \leq t \leq \infty$

Since the single parameter λ completely characterizes the exponential failure density function, some engineers like to use the MTBF as a measure of component or system reliability. This can, however, lead to confusion and errors because it leaves out the fact that reliability is also a function of time. $R(t)$ always decreases with increasing time, regardless of the form of the failure probability density function. Two systems with the same MTBF could have different reliabilities if the time period specified by t is different for each system.

When conducting a reliability analysis, it is important to note four key elements of the definition:

- First, reliability is a probability. This means that failure is regarded as a random phenomenon: it is a recurring event, and we do not express any information on individual failures, the causes of failures, or relationships between failures, except that the likelihood for failures to occur varies over time according to the given probability density function describing the occurrence of outcomes of *T*.
- Second, reliability is predicated on "intended function". Generally, this is taken to mean operation without failure. However, even if no individual part of the system fails, but the system as a whole does not do what was intended, then the system has failed.
- Third, reliability and failure probabilities apply to a specified period of time. In practical terms, reliability means that a system has a specified chance that it will operate without failure on or before time *t*. Units other than time may sometimes be used. The automotive industry might specify reliability in terms of miles. The military might specify reliability of a gun for a certain number of rounds fired. A piece of mechanical equipment may have a reliability rating value in terms of cycles of use. The specification of the time period used in the reliability analysis is critical. Evaluations of system availability will be made for the standard period of one year. Definitions and methods for calculating availability are made in the relevant sections below.
- Fourth, reliability is restricted to operation under stated (or explicitly defined) conditions. This constraint is necessary because it is impossible to design a system for unlimited conditions. For example, the failure modes of a system under normal operating conditions are likely different from those when the system is being operated under stress, outside of intended operating conditions. For the Site C power system reliability analysis, we assume the entire power system is operating under normal, expected conditions … not subject to adversarial attack.

In reliability analysis, it is also critical to establish the failure rates for the different elements that make up the system. Mistakes at this point would obviously result in incorrect reliability calculations. Failure rates are generally established based on empirical evidence derived from historical observations of measured time between failures of different components. As discussed below, failure rates are taken from the IEEE Gold Book standard.

Availability

The availability of a component or system refers to the probability at a given point in time that the component or system will be available for service. It can be defined as follows:

> ***Availability:*** *The probability that a device, or system, will perform its intended function at a stated instant of time for a stated period of time.*

The availability of a system or component is distinct from the reliability of a system or component. As we have discussed, reliability takes into account only the mean time to failure (MTTF) equivalent the mean time between failures (MTBF) of a component which are both equal to 1/λ, where λ is the failure rate of the component in failures per year. The availability of a system also takes into the account the mean time to repair and/or replace (MTTR) a piece of equipment after a failure and is termed r:

> r = average downtime per failure (hours per failure) = mean time to repair or replace a piece of equipment (MTTR) after a failure

The availability of a component is then defined as the mean time between failures divided by the mean time between failures plus the mean time to repair:

$$A_C = \text{availability of a component} = MTBF/(MTBF + MTTR)$$

Since r=MTTR in hours, and MTBF=1/failure rate=1/λ in years the MTBF is equivalent to the standard used of 8760 hours/year or MTBF = 8760/λ.

So the expression can be converted to:

$$A_C = (8760/\lambda)/(8760/\lambda + r)$$

The expression can be further reduced to:

$$A_C = 8760/(8760 + \lambda r)$$

As we discussed previously the reliability can be defined as:

> ***Reliability:*** *The probability that a device, or system, will perform its intended function without failure under stated conditions for a stated period of time.*

Since reliability takes into account only the failure rates of a component or system, it measures how reliable the component or system will be for a given period of time considered. As discussed previously, for longer periods of time considered the reliability will necessarily decrease at a rate dependent upon how long the reliability analysis period is specified. The comparative reliability of different components will depend upon the failure rate λ of a component since reliability is defined as:

$$R(t) = \exp(-\lambda t),\ 0 \le t \le \infty$$

By contrast availability takes into account both the failure rates of a component or system, as well as the mean time to repair components in a system to calculate the availability of a component or system.

To demonstrate how reliability and availability are calculated as well as to show how they can differ significantly both in reliability and availability consider the following three components with associated failure rates λ, and repair times r below:

Component A: λ=1 failure/year; r=1 hour

Component B: λ=0.01 failure/year; r=1 hour

Component C: λ=0.01 failure/year; r=100 hour

Component A represents a component which fails approximately 1X/year and requires a mean time to repair of 1 hour. Component B and C both have equivalent failure rates of 1X/100 years but Component B only requires 1 hour to repair where Component C requires 100 hours to repair when it fails.

Calculating the reliability of each of the components for a time frame of one year gives the following values:

$R_{CompA}(\text{year}) = 0.3679$

$R_{CompB}(\text{year}) = R_{CompC}(\text{year}) = 0.9900$

The reliability of component B and component C will be the same since they have the same failure rates. Calculating the reliability values for these components for 1 week instead of one year gives the following values:

$R_{CompA}(\text{week}) = 0.9810$

$R_{CompB}(week) = R_{CompC}(week) = 0.9998$

Notice that the reliabilities of the components are significantly higher for shorter time periods considered for all components.

The availability of the components using the failure rates and repair times for 1 year considered gives the following values:

$A_{CompA}(year) = 0.999886$

$A_{CompB}(year) = 0.999999$

$A_{CompC}(year) = 0.999886$

Notice in this case, the availability values for this equipment are much higher than the reliability values. Again availability measures how likely a component or system will be in service at a given time while reliability measures how likely a failure will have occurred for a given time frame. Also notice that the availability of Component A and Component C are equivalent even though the failure rates and underlying reliability of Component A is much less than Component C. Similarly the calculated availability of Component C is much less than Component B because the repair time for Component C is much longer than Component B (100 hours versus 1 hour).

The reliability of a component or system depends only on the failure rates of the component or system and is highly dependent on the time frame used for the analysis. The availability of a component or system depends both on the failure rates and repair times of a component or system. Since availability is typically considered for a specified time period usually a year or 8760 hours (also considered in this analysis) it is not related to time frame used in the analysis, since a standard period of one year is typically used to evaluate availability.

In general the reliability of a system will be disproportionally affected by components with relatively high failure rates, while the availability of a system will be disproportionally affected by components with a combination (multiple) of high failure rates and/or long repair times.

Both in public discourse and in the literature, discussion is made that a system has so many “9s of reliability” and/or with such and such improvements a new set of “9s of reliability” to the system have been made. Care has to be taken however as to whether reliability or availability is really what is being addressed. Often times what is actually meant is that the system has increased availability not necessarily more reliability with such and such improvements. This is important to stress because reliability is defined for a specific time frame, while availability is usually defined for a prescribed period of time, typically a year. For a given component or system and underlying assumptions, availability values will be invariant, while reliability values will depend on the time frame considered.

Analysis of both availability and reliability of components, subsystems and systems are important to analyze for different reasons, because they provide different pieces of information about a system. Reliability analysis in general will show how likely it is *for a designated duration of time* that a component, subsystem or system will undergo a failure of any type to take the component or system out of service. Availability analysis will show how likely a component, subsystem or system will be available for service *at a given period of time*.

12.1 Module 12 – System Reliability and Availability

Module 12 – System Reliability and Availability

- This module covers the definition as well as concepts of reliability and availability and how individual component reliability and availability can be calculated to estimate how different system configurations affect system reliability and availability to develop microgrid conceptual designs
- Component reliability and availability can be used in more detailed stochastic modeling of system reliability and availability such as Sandia developed tools like PRM and TMO introduced in later modules
- The module covers backup generator reliability, a major component in microgrid reliability because backup generators are the primary way that city and military base facilities currently supply backup power during emergencies, and are foundational to microgrid systems as well

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Reliability and Availability Defined

- <u>Reliability</u> is defined as the probability that an item will perform its required *function* under *stated conditions* for a specified period of *time*
  - Related to mean time between failures (MTBF)
- <u>Availability</u> is defined as the ratio of the time the system is up, or operational, to the total time it is required or expected to function
  - Uptime / (Uptime + Downtime)
- As reliability increases, so does availability
- A system can have high availability even if it is not very reliable
- Often people talk about reliability, when they are really referring to availability

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Availability for Series and Parallel Systems

- In a series configuration, failure of any component results in the failure of the entire system

$$A_{System} = \Sigma A_i$$

- In a parallel configuration, failure of all the components results in the failure of the entire system

$$A_{System} = 1- \Sigma (1-A_i)$$

- The same concepts apply to reliability as well

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Examples of series and parallel systems

- Assume system has three components, a PV system (A = 99.5%), a battery (A = 98.7%), and a generator (A = 97.3%)
  - If all three components are in series
    $A_{system} = (0.995)*(0.987)*(0.973) = 95.55\%$
  - If all three components are in parallel
    $A_{system} = 1- (1- 0.995)*(1- 0.987)*(1- 0.973) = 99.9999\%$

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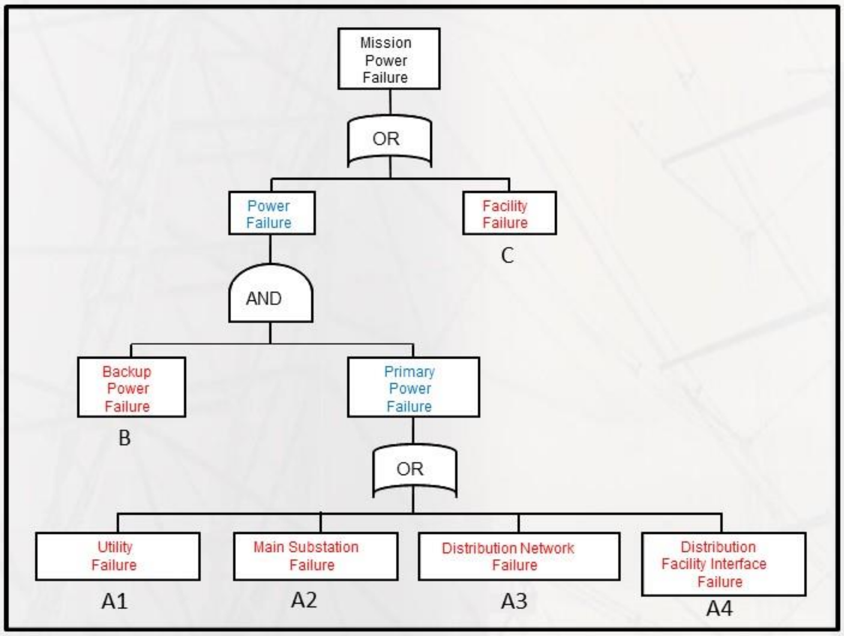
Fault Tree Analysis can be used to aid development of Reliability and Availability



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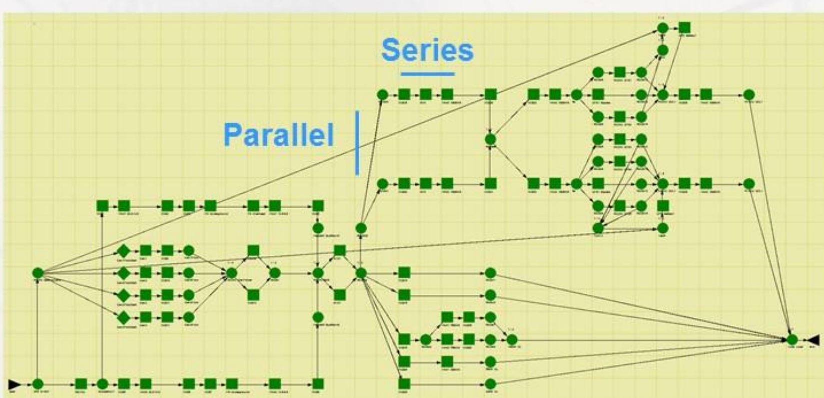
Reliability and Availability Calculations for Larger Systems



Mathematical calculation of parallel and series connections of system components

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Example Availability Calculation for Small System

Item	Failures/year (λ)	MTTR (hours) r	Downtime (λr)	Count	Component Availability (year)	Total Component Availability (year)
Small Test System						
Diesel Generator Packaged	0.25371	23.14	5.870849	1	0.99933026	0.99933026
Fuel Storage Tank	0.00404	18.13	0.073245	1	0.99999164	0.99999164
ATS	0.05117	4.1	0.209797	1	0.99997605	0.99997605
UPS	0.00402	6.00	0.024120	2	0.99999725	0.99999449
Belowground Cable (480V, 12 kV)/1000 ft	0.00579	6.77	0.039198	8	0.99999553	0.99996420
Switchgear	0.00812	27.56	0.223787	2	0.99997445	0.99994891
Cable Termination (480V, 12 kV; each)	0.00037	0.75	0.000278	36	0.99999997	0.99999886
Subsystem Unavailability						0.00079549
Subsystem Availability						0.99920451

Diesel generator availability/year = uptime/(uptime + downtime)
= 8760 / (8760 + 5.87) = 0.99933

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Example Availability, Reliability, and Cost Calculation

Option	Availability	Reliability 14-day	Costs
Baseline	0.99999780	0.99811376	NA
Option 1 – Redundant utility system	0.99999800	0.99878546	$20 M
Option 2 – Small microgrid	0.99999901	0.99924114	$4-5 M
Option 3 – Collection of shared backup generators	0.99999999	0.99995592	$3-4 M

Notice – reliability #s are lower than availability

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Generator Reliability

- Generator reliability depends on maintenance and load testing
- Assessing generator reliability is done by assessing how well generators are maintained according to manufacturer specifications, including if they are tested under load as well as the type of generator used (standby, continuous, prime)
- Some assumptions:
  - 95% availability if tested weekly under 30% load or more
  - 80% availability if tested weekly not under load
  - 60% availability if not tested or under maintained
- Generator availability assessment as well as fuel supply calculations are used in performance/risk evaluation of a system

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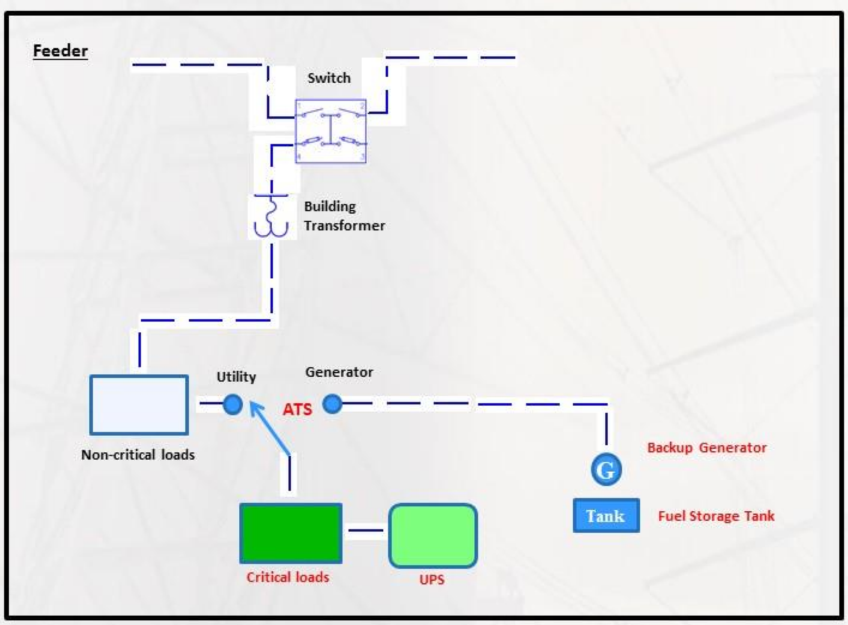
Typical Backup Generator Layout



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Basic Generator Characteristics

- Three Class of Generator Ratings
  - Standby
    - Guaranteed to run for 72 hours (3 days)
    - Maintained approx. every 100 hours (5 days)
    - Generally generators under 300kW fall into this category
    - Can be converted to continuous with alterations to cooling system and alternator
  - Continuous
    - Used to supply power at a constant load continuously
  - Primary
    - Used to supply power with variable loads continuously
    - Most expensive
  - Continuous and prime power rated generators still require maintenance and overhauls after a set number of manufacturer specified hours (e.g. 750 hours)

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Common Electric Power Security and Reliability Concerns

- Current practice of providing power security often relies on back-up generators
  - Frequently over-sized and under-maintained
  - Low probability of start when needed
  - Dedicated to one building or facility – does not share power with other facilities
  - Operations for extended periods often problematic
- Supply redundancy often not effective
- Stating 9's of availability – does not factor in the erosion of critical mission capability for extended outages

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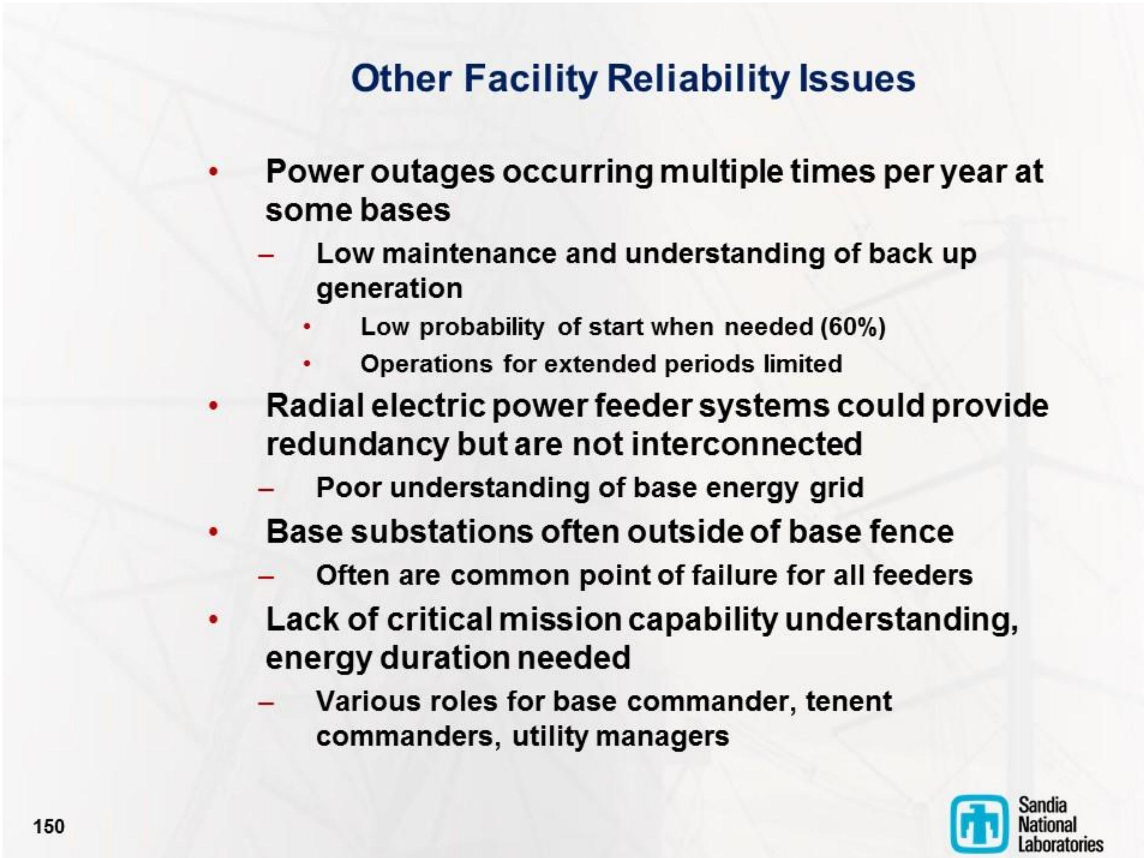

12.2 Module 12 – Lessons Learned

Reliability is a major performance metric that all system are being designed to meet. Depending on the criticality of the mission function, energy reliability or availability is expected to be in the 99% or higher reliability. Most often Tier 1 activities are looking at 99.9% or even 99.99% or better system reliability. Therefore, making sure one can adequately calculate a reliability or performance reliability is necessary. From our work we have seen the following major things that should be considered:

- The lowest reliability element (normally generation) drives the reliability. Therefore good maintenance of generators is paramount in regards to energy assurance.
- There are several ways to calculate reliabilities – use of IEEE Gold Book values, analytical models like RAPTOR. Use the appropriate tool for your size microgrid.
- Energy storage in terms of fuel is an important need for high resiliency, but electrical storage needs can be significantly minimized with a balanced approach of distributed and renewable generation sources.

APPENDIX A. DISTRIBUTED ENERGY GENERATION AND STORAGE RESOURCES

This module provides a general overview of distributed generation and energy storage devices commonly considered for microgrid applications.

Types of Distributed Energy Resources

- Overview of types and uses of DERs
  - Distributed generation
    - Diesel generators
    - Gas generators
    - Microturbines
    - Fuel Cells
  - Renewables
    - PV
    - Wind
    - Others (geothermal, biomass)
  - Energy Storage
    - UPS
    - Batteries
    - Others

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Diesel Generators

- 26% - 33% Energy Efficient
- Most Common DER used for back up power
- Power ratings are from the kW up to MW
- Three types
  - Emergency – 100 hrs ops
  - Standby – 300 hrs ops
  - Prime Power – 10,000 hrs ops
- Cost range ($0.25 - $1)/Watt
- Reliability varies
  - No maintenance – 0.60
  - Monthly no load – 0.85
  - Weekly under 30% load – 0.95

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Diesel Generator Fuel Use and Efficiency

Diesel Generator Fuel Use

Gen Rating (kW)	Fuel Used (gal/hr) Based on % Loading 25%	50%	75%	100%
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4.0
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5.0	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11.0	14.4
230	5.3	8.8	12.5	16.6
250	5.7	9.5	13.6	18.0
300	6.8	11.3	16.1	21.5
350	7.9	13.1	18.7	25.1
400	8.9	14.9	21.3	28.6
500	11.0	18.5	26.4	35.7
600	13.2	22.0	31.5	42.8
750	16.3	27.4	39.3	53.4
1000	21.6	36.4	52.1	71.1
1250	26.9	45.3	65.0	88.8
1500	32.2	54.3	77.8	106.5
1750	37.5	63.2	90.7	124.2
2000	42.8	72.2	103.5	141.9
2250	48.1	81.1	116.4	159.6

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Diesel Generator Efficiency

Gen Rating	Efficiency Based on % Loading 25%	50%	75%	100%
60kW	22.9%	28.7%	29.5%	29.9%
100kW	25.6%	31.5%	31.2%	31.9%
150kW	22.6%	29.7%	30.4%	31.6%
200kW	24.6%	31.1%	33.5%	32.8%

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Gas Generators

- 24% - 30% Energy Efficient
- Combined Cold and Heat Power (CCHP)
- Lower Emissions
- Power ratings are from the kW up to MW
- Cost range ($0.60 - $1.20)/Watt – 1.2-2X costs of equivalent diesel generator

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Microturbines

- Similar to a steam plant
- Spin as fast as 500,000 rpm
- CCHP
- Low Emissions
- Energy efficiencies range from 25% - 35%
- Cost Range ($1.50 - $2.00)/Watt

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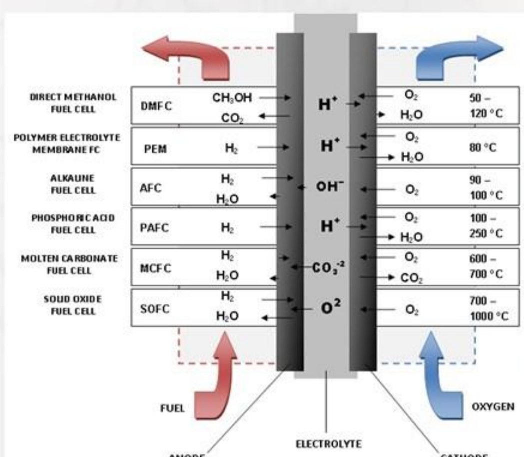
Fuel Cells



- Types
  - Solid Oxide (SOFC)
  - Proton Exchange Membrane (PEM)
  - Alkaline (AFC)
  - Direct Methanol (DMFC)
  - Molten Carbonate (MCFC)
  - Phosphoric Acid (PAFC)
- CCHP
- 30% - 70% Energy Efficient
- Low Emissions and Noise Pollution
- Cost Range ($4.50 - $6.00)/Watt

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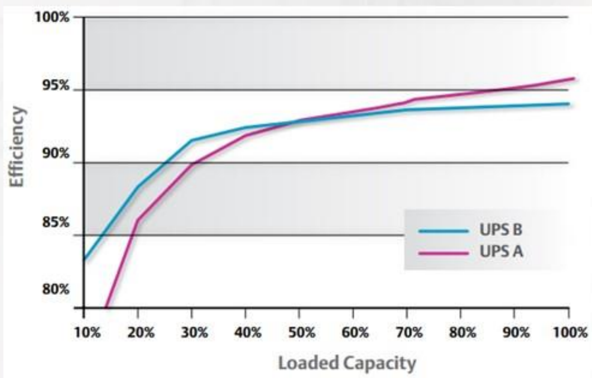
Uninterruptible Power Supply (UPS)

- Commonly put in series of a critical load
- Voltage and power disturbance ride through is typically 5-20 minutes
- Increases reliability and power quality for the load it is connected too



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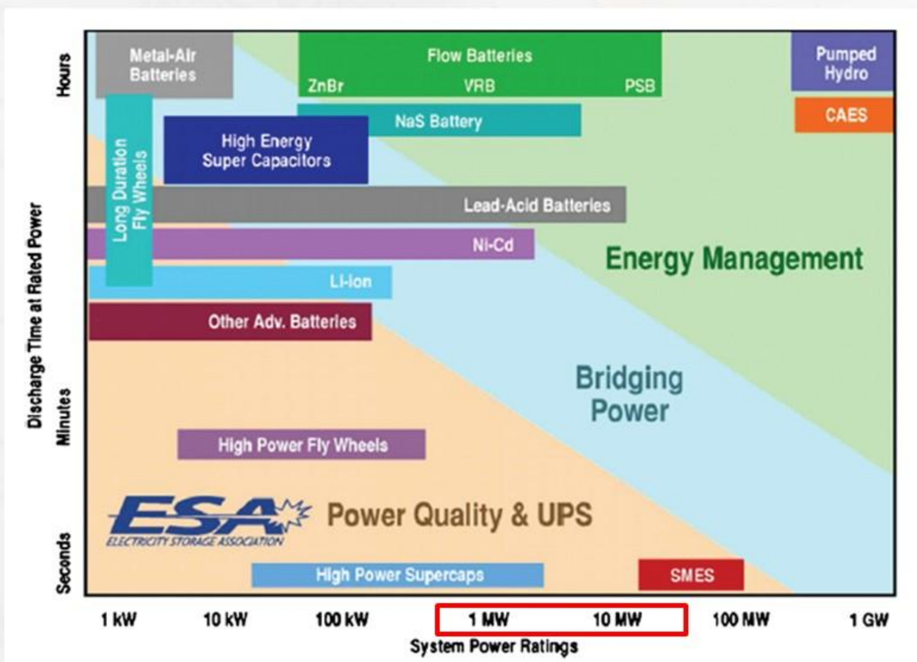

Typical Microgrid Size (1-10 MW)

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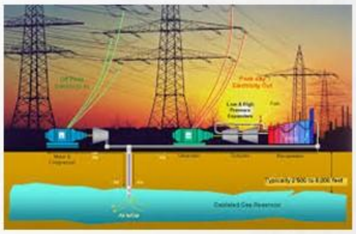
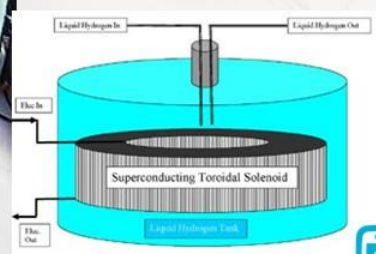
Other Energy Storage



- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Flywheel
- Capacitors
- Superconducting Magnetic Energy Storage (SMES)



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Photovoltaics

- Rooftop or Ground
- Fixed or Axis
- Concentrated
- 10% - 30% Energy Efficiency
- Capacity Factor approximately 15%-20%
- Cost range ($2.8 - $5)/Watt

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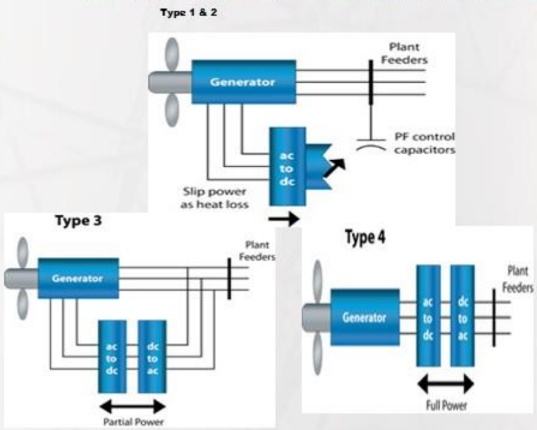
Wind Turbines



- 4 types of Wind Turbine
  - Type 1 (Induction Gen w/ fixed rotor resistance)
  - Type 2 (Induction Gen w/ variable rotor resistance)
  - Type 3 (Doubly-fed induction Gen)
  - Type 4 (Full converter Gen)
- Energy Efficiency is approximately 75%
- Capacity Factor is approximately 20%-40%
- Cost Range ($1.50 - $3.00)/Watt

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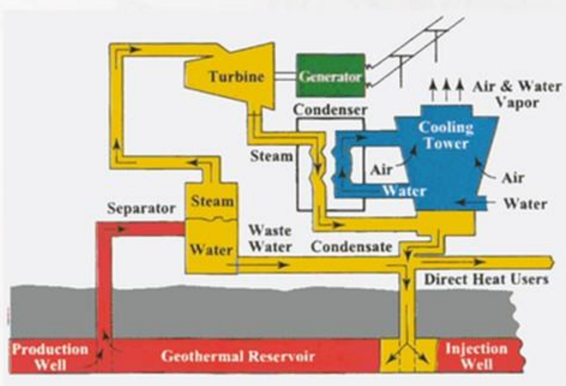
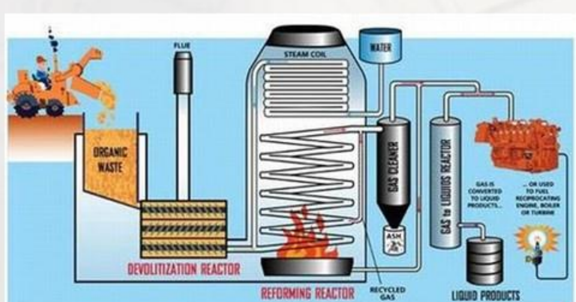
Other Renewables



- Geothermal
- Biomass
- Stirling Engine
- Hydroelectric (Tidal, River)



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APPENDIX B. MICROGRID ADVANCED ENGINEERING ANALYSES

This module provides a discussion of advanced microgrid analysis capabilities developed by Sandia to optimize conceptual microgrid designs to get to a preliminary or 50-60% microgrid design. This is usually a point where the design can be handed over to an engineering firm to develop the final drawings and construction plans for a the microgrid or set of energy assurance improvements.

Power Flow Analysis

For successful operation of a power system, several requirements are essential during normal operation. One requirement is that the generating sources be sufficient to compensate for all loads plus losses within the system. Generation to load balance is required to maintain system frequency because there is little energy storage in the system. Another requirement is that voltage magnitudes should remain as close to rated values as possible at all buses. This will not only avoid any equipment damage but will also decrease the likelihood of voltage collapse. Ensuring that all generators operate within their power limits and that transmissions lines and transformers are not overloaded are also requirements of the successful operation of a power system. A power flow study, also referred to as a load flow study is a common tool used for AC analysis of a power system in steady state and to ensure that all requirements discussed above are met during the planning stages of a power system. A power flow study is also used to study system behavior with increasing load and to aid in real-time applications such as network optimization, state estimation and VAR planning. There are commercial software power flow analysis tools available for finding a power flow solution.

A power flow models different levels of system generation and load as well as effects of equipment disruptions on the system, and the changes to the system which result. After each change in generation or load or disruption event the model of the system is solved and compared to the initial system. The model records:

- Changes in power flow between regions due to the differences in generation, load or disruption
- Changes in the overall voltage profile of the system as a result of the differences or disruption
- Changes in the overall system generation as a result of the differences or disruption

The power flow model ensures that the system is designed so that generation meets load requirements both when the system is grid tied as well as islanded in a microgrid configuration. The microgrid generation should be designed with redundancy meaning that the loss of any single generator in the system will not result in the loss of load. The power flow model also ensures the system voltages, and power flow conditions do not exceed equipment limits such as cable carrying capacities and system parameters such as voltages between 0.95-1.05 per unit, to ensure the system with perform as designed. If conditions do occur, that exceed these limits, the conceptual design must be modified so that the system meets the necessary performance requirements.

Consequence Modeling Analysis

To further optimize the utilization of building energy resources and evaluate ideas that have the potential to increase energy security, consequence analysis modeling can be used. Consequence analysis involves:

- Defining problems using a system dynamics approach, characterizing the significant dynamics of a system related to power system applications.
- Defining a system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioral model capable of reproducing, by itself, the dynamic situation being modeled. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and flow/ causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights.

Systems dynamics modeling uses time series of flows and accumulations of flows are central to the process. For energy reliability analysis applications, power and energy accumulations are tracked to evaluate power and energy characteristics of the generators and loads in critical buildings.

For example, in one application of consequence modeling, we can model how to efficiently implement PV, energy storage and gas or diesel generators within a microgrid. The model inputs a time series of building load data and dispatches a predefined suite of generators required to meet that load. The model tracks numerous aspects of generator performance, including generator ramp rates, fuel consumption, fuel tank refills, and generator efficiency. The model can then input expected PV characteristics such as outputs based on solar inputs for a particular area, and finally include energy storage dynamics for particular battery technologies. The combined model can then be used to size an appropriate amount of energy storage to PV use, to operate generators efficiently with a high level of utilization (>70%) using energy storage to balance out the expected fluctuation in PV outputs when available to optimize the use of PV, energy storage and backup generators in a system. Consequence modeling can be used in many other applications such as implementing peak shaving and power wheeling in a microgrid, utilization of cogeneration by balancing heating, cooling and electrical loads in a system, integration with other renewables such as geothermal or wind, as well as other examples where system dynamics approaches are useful.

Performance Reliability Model (PRM) Analysis

The Performance Reliability Model (PRM), a Sandia developed tool, is very useful to develop the ESM conceptual design options. The PRM was developed to help understand the impact that loss of power has on critical missions at military installations in terms of probability and expected behavior. The model allows for comparison between different energy system configurations by simulating the behavior of each over thousands of years to evaluate key tradeoffs, costs and performance indicators. PRM is essentially a power flow model with extra features included to model additional power flow metrics over extended periods of time. The model takes inputs such as system configuration, energy assets, etc. and calculates applicable metrics of interest such as:

1. Critical Load Unserved: Although generators are designed to cover the critical load of the building to which they are assigned, startup failures are common. If part or the entire critical load goes un-served, even if for only seconds, the results can be serious. To understand the risk and how a microgrid can mitigate it, one must determine the frequency with which a load goes un-served (number of times/year), the average duration the load goes un-served (hours) and the amount of critical load that goes un-served (kWh) for each of the following three scenarios:

    - Generators serving individual buildings and loads (not in microgrid)
    - Generators interconnected in a microgrid configuration
    - Generators interconnected in a microgrid configuration with additional generation provided by renewables and/or other energy sources

    Once this has been done, the benefits of each scenario can be better understood.

2. Utility Energy Usage Deferred: A renewable energy installation defers energy usage from the grid during normal operations (when the system is not operating as a microgrid), with larger installations translating into less dependency on the

grid and therefore greater savings. Annual cost savings can be projected based on average rates of usage and how much can be deferred (kWh/year).

3. Diesel Consumption Deferred: A renewable energy installation can also defer backup diesel generation during utility grid failure. The amount of diesel fuel saved will depend on the capacity of the renewables-powered generator and also on the number and duration of utility grid failures per year. The number of deferred gallons of diesel fuel can be estimated to calculate cost savings per year.

4. Carbon Emissions Deferred: The atmospheric release of carbon and other greenhouse gases has been a primary driver of renewable energy research and development. Adding renewables to a microgrid installation may help lower a facility's carbon "footprint," especially for those facilities that rely heavily on diesel-powered generators and draw their electricity from a utility that generates most of its electricity from fossil fuels. The amount of carbon emissions deferred can be calculated in tons per year for both grid-connected and island microgrid operations.

5. Improved Energy Availability: Improved energy availability is a key feature of the microgrid, because – if configured as intended – all energy generated by the microgrid feeds into the grid.
Not only does a microgrid allow for more efficient generator operating ranges (from 70 to 80 percent instead of from 20 to 50 percent) but additional power can be directed at loads that are noncritical but "nice to have." Given the flexibility enabled by its control fabric, a microgrid can support various loads depending on time-varying base needs or mission requirements.

Optimizing microgrid conceptual designs using TMO

TMO (Technology Management Optimization) is Sandia-developed software that uses a metaheuristic 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.)

How PRM and TMO interact

PRM helps understand the impact that loss of power has on critical missions with conceptual microgrids in terms of probability and expected behavior. The model allows for comparison between different energy system configurations to evaluate key tradeoffs, costs and performance indicators. The model takes inputs such as system configuration, energy assets, etc. and calculates applicable metrics described in the introduction. This model is used as an external evaluator as an input to TMO. These models were used in conjunction to optimally determine several design parameters for microgrids. TMO is designed to help decision makers optimally manage high-value, long-lived, highly technical equipment over the lifetime of a system. TMO users define choices that affect the performance parameters of the system. TMO then performs an optimization of the system, using input from the PRM, and analyzes how these user-defined choices affect the relevant performance parameters of the system. TMO can then be run using a multi-objective optimizer approach, resulting in a set of solutions.

Appendix B- Advanced Engineering Analysis

- This Appendix discusses advanced engineering analysis which can be performed to augment the microgrid conceptual design process in order to obtain more optimal microgrid conceptual designs that match performance goals
- The engineering analysis includes:
  - Power flow analysis
  - Consequence analysis
  - PRM and TMO analysis

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Power Flow Analysis

- Analysis to determine potential problematic microgrid behavior
- Power quality, voltage sags, frequency regulation, transformer inrush, cold load pickup, etc.
- Development of a notional microgrid one-line diagram
  - Determination of switching to form the microgrid MV backbone
  - Designation of PCCs
  - Designation of generators
  - Prioritization of buildings load served in microgrid (critical, priority, nice to have, etc.)

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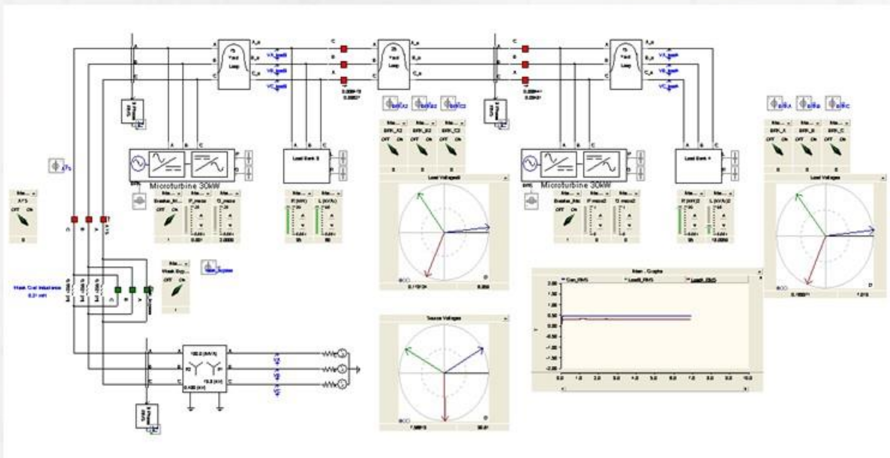
Example Power Flow Model



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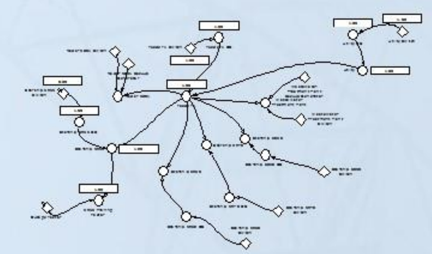
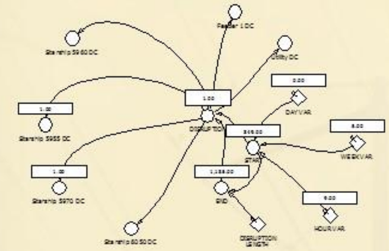
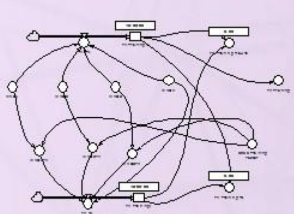
Consequence Modeling



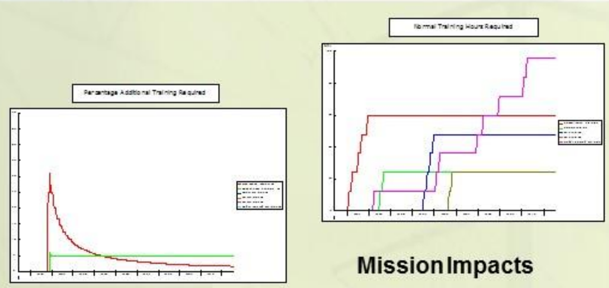
Electric System Model



Interruption Control Model



Mission Consequence Model



Mission Impacts

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Consequence Analysis

- Defining problems using a system dynamics approach, characterizing the significant dynamics of a system related to power system applications .
- Defining a system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioral model capable of reproducing, by itself, the dynamic situation being modeled. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and flow/ causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights.

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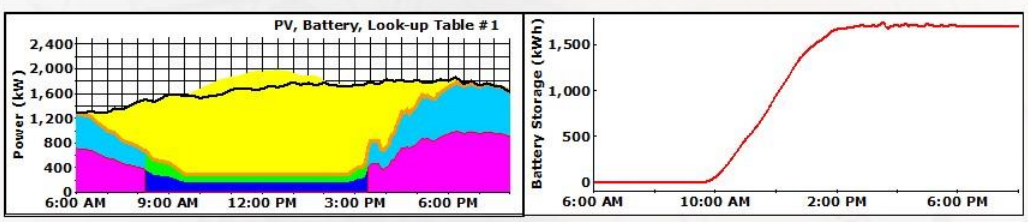
Example of Consequence Modeling



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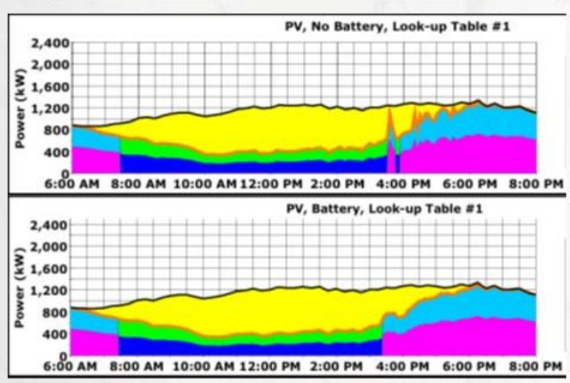
This system has too much PV energy and would require expensive amounts of energy storage.



With less PV, adding appropriate amounts of storage reduces renewable energy intermittency issues. More load would reduce the PV penetration levels. →

Optimizing Use of Energy Storage, PV and Diesel Generators

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Performance/Reliability Model (PRM)

- The purpose of the PRM is to statistically quantify the behavior of a candidate microgrid design in terms of performance and reliability
- This information is used by TMO to tune the design according to the design options in order to maximize performance and reliability while minimizing cost
- PRM operation:
  - Samples utility outages according to a distribution (e.g. at a rate of ~4/year) for thousands of years
  - Microgrid is simulated during each outage and statistics are collected
  - Uses an event-driven simulation for better calculation efficiency
  - Once the standard error of the mean (SEM) of the primary statistic is below the desired threshold, the simulation stops and returns the analysis
- Required Information:
  - Electrical layout, including transmission/distribution line data
  - MTTF and MTTR for grid elements, transmission lines, other relevant equipment
  - Generator efficiency curves and other data
  - Load profiles (both critical and priority)
  - PV and wind profiles, etc.

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Evaluate Options

- Compare performance/risk and cost estimates for each option
- A spreadsheet or Pareto chart representation can assist evaluation of options
- Performance risk modeling can be assisted with tools like Sandia Performance Reliability Model (PRM) for grid dynamic analysis
- Pareto chart representation can be developed with tools like Sandia Technology Management Optimization (TMO) to evaluate options

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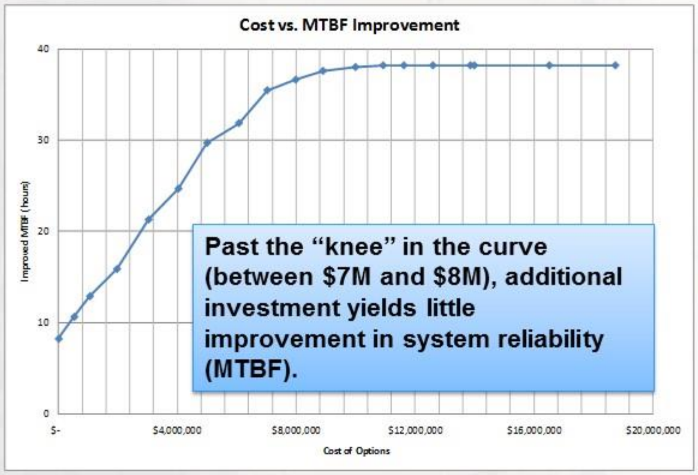
Cost vs. Performance

- Each dot in graph represents a combination of improvements yielding an optimal overall system MTBF for a given cost constraint.
- Availability improvement follows a similar curve



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Technology Management Optimization (TMO)

- Software that computes planning roadmaps
- Tradeoffs are treated objectively and defensibly
- Solves user-defined problems: timeframe, objectives/constraints, options/suboptions are all user-defined
- Microgrid optimization

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Performance/Risk and Cost Analysis

- Performance/Risk
  - Determination of performance/risk for each option
  - Comparison of options with baseline system
  - More detailed performance/risk can be done by examining component and system reliability and availability and using engineering tools to perform more detailed calculatiosn
- Cost
  - Estimation of microgrid component costs for each option
  - Include additional costs associated with additional design, engineering, and installation of microgrids

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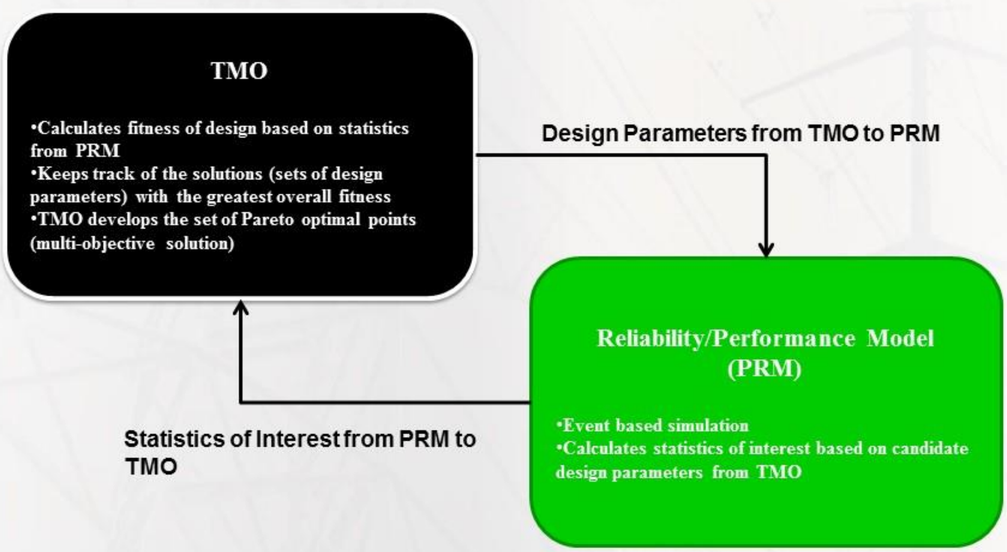
Optimizing Microgrid Design Performance



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Evaluate Best Set of Conceptual Design Options

- Determine options which meet DBT according to specified performance objectives
- If best performing options are cost prohibitive, determine which options will most closely align with performance objectives at least cost
- Consider other factors in the evaluation such as the time necessary for design and installation of the options and feasibility in obtaining stakeholder support for each option as well

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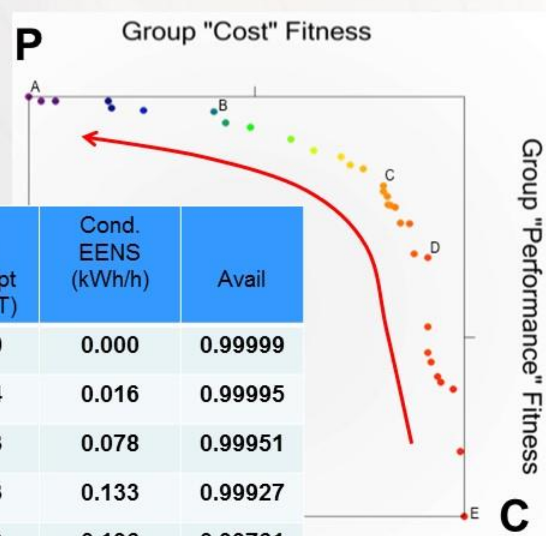
Example Pareto Chart comparing Performance and Cost

A= highest cost and performance
E = lowest cost and performance



Sol	Cost ($M)	Freq Interrupt (% DBT)	Cond. EENS (kWh/h)	Avail
A	7.55	0.000	0.000	0.99999
B	6.70	0.154	0.016	0.99995
C	6.12	1.423	0.078	0.99951
D	5.84	2.113	0.133	0.99927
E	5.65	7.250	0.196	0.99761

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APPENDIX C. MICROGRID CONTROL AND CYBER SECURITY

This module provides a general discussion of additional sets of analyses can be done after an initial conceptual design has been developed. Additional analyses includes analysis of the types of system control and cyber security implementations, incorporating energy efficiency into the overall analysis, and understanding existing policies that may impact legal and economic factors involved with the feasibility of various conceptual design options evaluated.

Microgrid Communication Network Analysis

The 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. Network infrastructure equipment must be located in accordance to the DBT requirements and have provisions for backup power when the 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.

Energy Management System and SCADA

The energy management and SCADA systems together provide monitoring, control, and optimization functionality for a 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 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 and IEEE 1547 standards. The EMS must provide manual and automated start capabilities to initialize an 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.

Recommendations

All parameters and measurements should be archived using data historian functionality and should be used heuristically by the EMS system to further optimize microgrid 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 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.

A given 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).

Generator Controls

When generation in the form of diesel or natural gas generator sets is part of a 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. Diesel and 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.

Photovoltaic Array Control

Photovoltaic energy options can provide clean renewable energy that augments diesel and 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 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).

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.

Loads

Microgrid loads represent the critical buildings and facilities stakeholders 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.

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.

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.

Controls Summary

The control architecture for a 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.

Control System Cyber Security Analysis

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

- The microgrid will be used in emergency situations and may be critical to continuity
of emergency operations.
- The 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 microgrid. In addition to referenced best practices, additional rigor should be applied to strengthen defense in-depth for the microgrid control system. Best practices for securing ICSs often leverage network segmentation; 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 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.

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 a microgrid control system and incorporated where possible:

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

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 below are a list of typical control system defense-in-depth strategies that are recommended for a microgrid conceptual design. These high level recommendations are documented in NERC CIP standards, NISTIR 7628, and NIST 800-82.

Typical high-level defense-in-depth measures recommended for the microgrid control systems:

<u>Policy / Procedural:</u>

- 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.

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
- 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 its importance to the overall security posture and potential to reinforce the defense-in-depth practices listed above.

Microgrid Control System Segmentation

To further enforce defense-in-depth and expand on industry standard best practices, segmentation strategies within a 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, 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) 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.

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.

By leveraging network segmentation within the control system network itself like this, 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 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 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 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.

Cyber Security Summary

The goals of the cyber security measures to be implemented for the 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 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.

Policy Analysis

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, 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 (ROWs)

Right of Way (ROW) issues are concerned with the use of utility, city or military facility infrastructures two interconnect power systems between two different adjacent facilities. ROW considerations come in to play whenever the microgrid conceptual design will require the installation of new, independent infrastructure to provide electric service through connections between these facilities to share power during normal or emergency conditions with microgrids. The ability to utilize ROWs will depend on military base or city regulations, as well as state regulations that apply, and if legal and possible will require negotiation to achieve with the ROW owner, whether it is a utility, city or military base. ROW issues don't come into play if the microgrid is constructed using the existing utility infrastructure, or doesn't involve connecting power directly between two different facilities bypassing the normal utility powered feeder. Depending on the design, some microgrids will have ROW issues and others will not.

Retail Wheeling

Retail wheeling involves transferring and selling power from one entity to another across an independent power system. In a microgrid, retail wheeling occurs when the microgrid, or portions of the microgrid generation, is designed to be capable of operating grid tied and supplying excess power back to the utility. Retail wheeling agreements need to be negotiated with the local utility as well as state electric power regulators.

Renewable Energy and Combined Heat & Power

Incentives may be available for CHP and fuel cell (FC) systems with recovery and productive use of waste heat that are located on-site. Incentives may be sized based, fuel savings or by amount of heating and cost deferred, as well as other incentive mechanisms.

Owning and Operating Infrastructure

A determination has to be made as to who will own and operate the microgrid which connects to an existing electric infrastructure. Some of the considerations that need to be addressed 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?
2. Can the microgrid operator own resiliency infrastructure on private property?
3. In the situation of multiple owners of resiliency infrastructure equipment (private or public),
how will the state regulating entities 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 to explore can include:

- State Energy Savings Programs: State government programs may authorize government entities to make energy related improvements to their facilities, paying for the costs of these improvements through the resulting energy savings.
- 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.
- Power Purchase Agreement: Portions of the microgrid costs could be contracted 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 microgrid owner 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 microgrid owner, being able to negotiate lower energy rates:
- Investment tax credits: The Federal Government provides investment tax credits (ITC) at various rates for investment for PV and 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.
- SRECs: Solar renewable energy credits (SRECs) provide incentives to offset the costs of the generation of renewable solar energy. The incentives are often expressed in terms of $’s/MWh of generation provided by the solar resource.

Additional Microgrid Analysis

- Other types of analysis are necessary to develop conceptual designs have not been covered in the course
- These analysis are done in conjunction with the other conceptual design processes covered and can also be aided by advanced engineering analysis tools
  - Controls
  - Cyber security
  - Policy
  - Energy efficiency

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Control Analysis Issues

- Analysis of best control strategies for communication and energy management system
- Determine the operating modes of the microgrid including transition between islanding and restoration
- Define requirements for how microgrid elements are controlled (generators, switches, loads)
- Determining best infrastructures and communication protocols to use
- Determining system protection requirements
- Determine system metering and monitoring requirements

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Example Communication Methods

- **Dedicated fiber-optic link.** Substations and control centers are increasingly using fiber-optic links for dedicated, secure communications. Dedicated fiber-optic links provide speed and reliability that enables real-time communication.
- **Continuous-carrier power line communications carriers.** Used by some utilities for automated meter reading systems. The power line communications carrier signal is lost if the connection to the utility is lost, so this signal could be effective for inverter anti-islanding control. Drawbacks are high cost, low bandwidth, and high power demand.
- **Broadband-over-power-line.** This approach takes advantage of existing power-line infrastructure to communicate data, but this technology has faced technical issues, including interference with other radio spectrum users and interference from loads. Some systems have gone to digital multiple-carrier modulation scheme to mitigate radio interference issues.
- **Ethernet.** Provides communications within buildings, but must be connected to a wide-area-network technology, such as cable television. Wide-area networks do not have sufficient reliability to support protection functions.
- **Wireless metropolitan area networks.** This is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL. It is often used in urban environments to transmit 2 km without line-of-sight antenna configurations and up to 10 km with unobstructed path.

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Categories of Control Functions

- **Frequency control – such as for islanding steady state, transient, requency smoothing and ride through, load shedding**
- **Volt/VAR control – such as for grid connected and islanding Volt/Var controls**
- **Grid-connected-to-islanding transition – such as for intentional and unintentional islanding following outage event**
- **Islanding-to-grid-connected transition – such as restoration of connections back to grid following outage event**
- **Energy management – example grid-connected and islanded energy management for efficient operation of resources**
- **System Protection – Relay protection to detect and clear fault events**
- **Load Shedding – option to shed non-critical load if sufficient generation is unavailable**
- **Ancillary services – grid connected real and reactive power services such as for peak shaving**
- **Black Start – starting the microgrid up when generation is offline**
- **User interface and data management – All local and remote monitoring and control of the microgrid(s)**

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Microgrid Controls

- Microgrid controls are paramount to grid stability since:
  - Effective inertia of a microgrid is significantly lower than larger utility grid
  - Higher penetration of renewable energy possible
  - Good power quality is harder to produce and maintain
- Microgrid controlled and monitored assets include:
  - Natural gas generators
  - Network-capable PV inverters
  - Controllable switches
  - Smart meters

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Microgrid Controls

- Control network requirements
  - Network connectivity provided to all microgrid control and monitoring components
  - Must satisfy low latency requirements for control
  - Must provide a highly reliable information channel
- Control system must have provisions for remote access, HMIs for monitoring and manual control, and manual switch-over for microgrid testing

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Microgrid Control Hierarchy

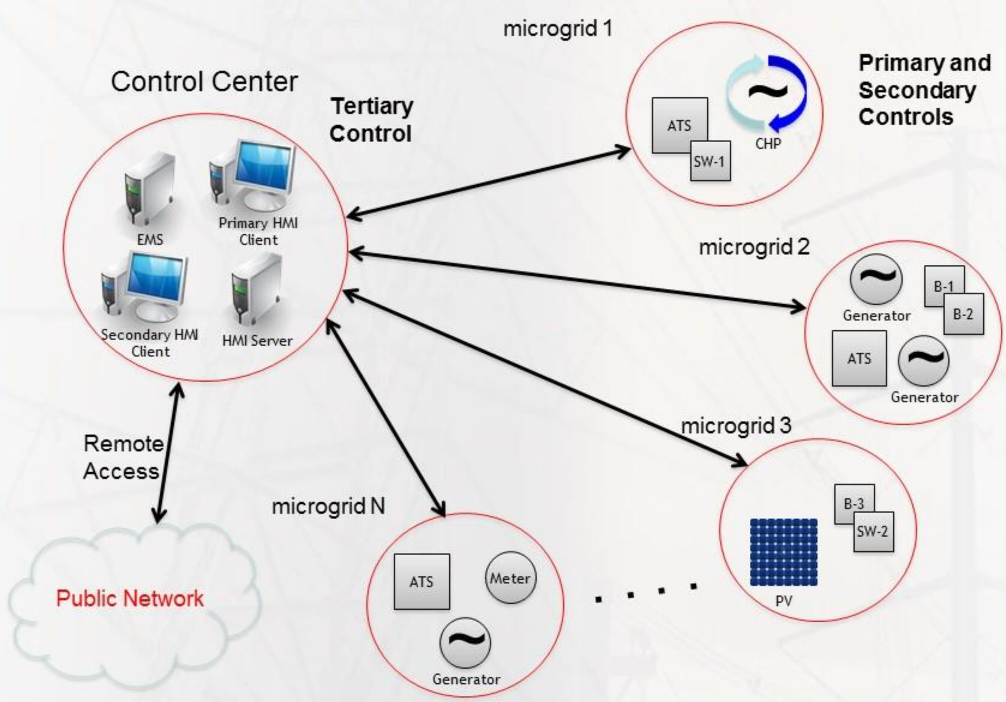
The hierarchical levels of microgrid controls can be categorized as primary, secondary, and tertiary.

- **a) *Primary control* is the level in the control hierarchy that is based exclusively on local measurements, which includes islanding detection, output control, and power sharing (and balance control) at the level of a generator or automated switching device.**

- **b) *Secondary control*, the energy management system is responsible for the overall microgrid operation in either the grid-connected or islanded mode.**

- **c) *Tertiary control* is the highest level of control and sets long-term and "optimal" set points depending on the host grid's requirements. Tertiary control can also be used to coordinate multiple microgrids interacting with one another as well as interactions with the utility.**

Example Control Architecture



Cyber Security Information Protections

Three well recognized properties of information protection:

- ***Confidentiality*** is the property of a body of information that it is available to only authorized entities and not otherwise disclosed. The confidentiality of a piece of information is enforced by ensuring that every access is properly authorized. Information cannot provide confidentiality; confidentiality must be enforced by some mechanism designed to provide it. A loss of confidential information may not directly affect a system but can cause major problems in other ways.

- ***Integrity*** is the property of a body of information that it has not been altered by any unauthorized entity or mechanism. The integrity of a piece of information is enforced by ensuring that it has been changed by only authorized entities. A system's integrity depends on the correctness and reliability of its operating systems, the completeness and correctness of its hardware and software, the consistency of its data structures and processes, and the stored data itself. In a formal security model, integrity is interpreted to mean protection against unauthorized modification or destruction of information.

- ***Availability*** is the property of a body of information that it can be acquired by an authorized entity as needed. Mechanisms that provide availability are normally required to meet timeliness and reliability requirements. Infrastructure control systems and their subsidiary information systems must generally meet information availability requirements no less stringent than those of the infrastructure itself.

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Cyber Security Considerations

- **Traditional design and implementation of industrial control systems is not sufficient for implementing secure microgrids**
  - **Microgrids are designed to be used in emergency situations and will be critical to continuity of emergency operations**
  - **Microgrids must function during active attack by a capable adversary**
- **Additional rigor can be applied in addition to defense-in-depth strategies incorporated from industry standards**
  - **NIST 800-82 - Guide to Industrial Control Security**
  - **NIST 800-83 – Guide to Malware Incident Prevention and Handling**
  - **NISTIR 7628 – Guidelines for Smart Grid Cyber Security**
  - **NERC CIP – Critical Infrastructure Protection Standards**

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Common Cyber Security Best Practices

- Authentication / Encryption - The use of 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
- 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.
- Redundancy / Spares - Ensuring that critical components are redundant and are on redundant networks.
- 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.
- 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.

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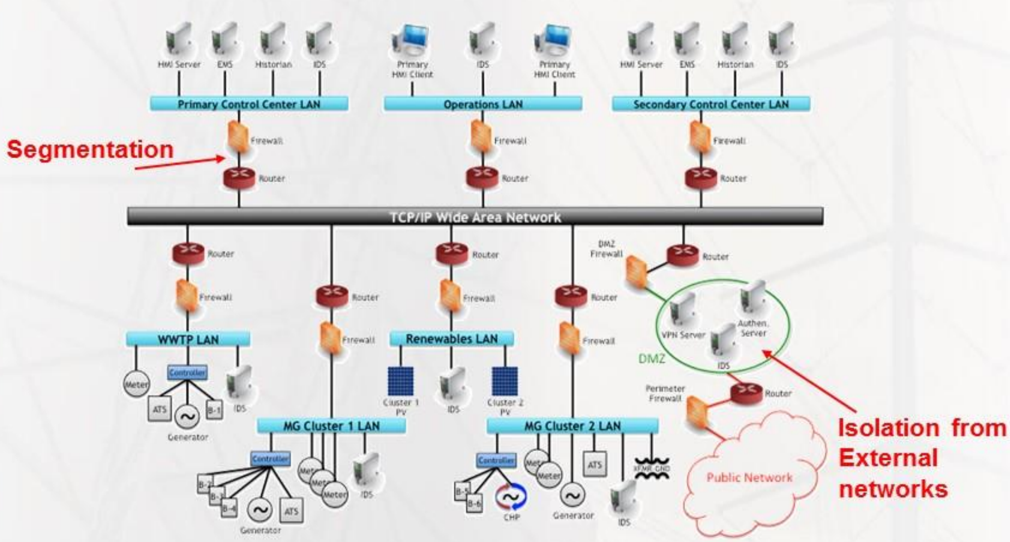
Example Cyber Security Architecture



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Building Efficiency Analysis

- **Efficiency improvements**
  - **Examination of how building efficiency can reduce load requirements**
  - **Efficiency measures can be integrated with microgrids**
  - **Examples**
    - Solar Hot Water (SHW) - Solar thermal collectors convert solar radiation into useful thermal energy. These systems can be designed to work directly or indirectly. A direct system heats water or air directly for immediate use whereas an indirect system heats a working fluid that stores the thermal energy and then transfers the heat to water or air when needed
    - Lighting Retrofits - Lighting retrofits aim to provide cost effective and reliable opportunities to reduce energy consumption through lighting while maintaining adequate light levels
    - Heating, Ventilation, and Cooling (HVAC) Upgrades -Updating HVAC systems to increase the efficiency as well as saving
    - Building envelope improvements - improvements to reduce energy losses including improvements in R-value insulation levels for walls, windows and roofs

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Policy Analysis

- **Policy analysis includes evaluation of**
  - **Current regulations for integrating microgrids and distributed energy resources into utility grids**
  - **Are there Right of Way (ROW) restrictions for connecting power between facilities**
  - **Environmental regulatory issues such as for emissions, noise, EM radiation, etc. and permitting requirements for operation**
  - **Policies for retail wheeling of microgrid generation for uses such as**
    - **Grid tied operation – demand response**
    - **Peak shaving**
    - **Selling renewables (reverse metering)**

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Policy Analysis

- **Policy analysis includes evaluation of**
  - **Policies for ownership of microgrids and interconnection with existing utilities**
    - **Negotiation with utilities, cities, bases on how microgrid is operated, where and what access each has**
    - **How public and private entities with buildings within the microgrid interface**
  - **Finance considerations such as rebates associated with use of CHP generation, renewables or energy storage and analysis of these potential savings**
  - **Any other incentives may exist to reduce costs**
  - **Government or private funding mechanisms for financing microgrids**

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APPENDIX D. MICROGRID CONFIGURATION OPTIONS

This module illustrates schematically some generic microgrid configuration options at a building level which can be considered in designing microgrids. This includes consideration of whether to build a microgrid at a medium voltage (MV - 600V – 34,500V) or low voltage (LV – 600V and below) level, and whether the microgrid should be connected to an existing utility feeder or utilize a dedicated microgrid feeder which may connect to a utility system.

A LV microgrid has the advantage of not requiring step up transformers for generators, but the disadvantage that due to lower voltage levels, cabling costs are higher due to higher amperage and limitations of how far the microgrid generators and loads can be connected (usually less than 1000 feet).

A MV system can be extended over 10's of miles but requires transformers to connect generators together in the microgrid. Additionally for MV microgrids, the microgrid can be built using the existing utility feeder as a backbone or alternatively a dedicated microgrid feeder can be designed to feed critical loads supplied by the microgrid. The advantage of connecting to the utility feeder is that no additional costs are incurred to connect the microgrid together since it is done with the existing feeder. A disadvantage is that often critical loads on a feeder are interspersed with collections of non-critical loads which must be supplied by the microgrid or additional load shedding controls and switchgear must be added to shed non-critical load when the microgrid is operated.

An advantage of a dedicated microgrid feeder is that only critical loads need to be connected to the microgrid so additional load shedding schemes are not needed. Additionally, since it is not directly connected to the utility feeder, it may be easier to implement since it requires less coordination with the utility to construct. A disadvantage is that a dedicated microgrid feeder must be built adjacent to existing utility feeders so it is more costly. Additionally, there must be overhead or underground corridors available to run the dedicated microgrid feeder.

Microgrid generators can be directly connected to buildings or buildings can be provisioned with pin and sleeve type connections to allow quick connections to buildings during an extended outage to allow more flexibility.

The module includes several microgrid connection diagrams of how microgrid generators can be connected to existing building service panels and automatic transfer switches to permit them to be utilized in microgrids.

Microgrid Configuration Options

- This Apendix covers some design considerations for microgrids at both the medium and low voltage levels such as
  - Utilizing an existing medium voltage feeder to build a microgrid
  - Alternatively building a dedicated medium voltage microgrid feeder to supply identified critical facilities during emergency situations
  - Or developing microgrids at low voltage levels (600V or below) instead of at medium voltage if buildings are adjacent to one another
- The module shows some sample connection diagrams on how existing backup generators can be reconfigured to connect into both medium and low voltage microgrids

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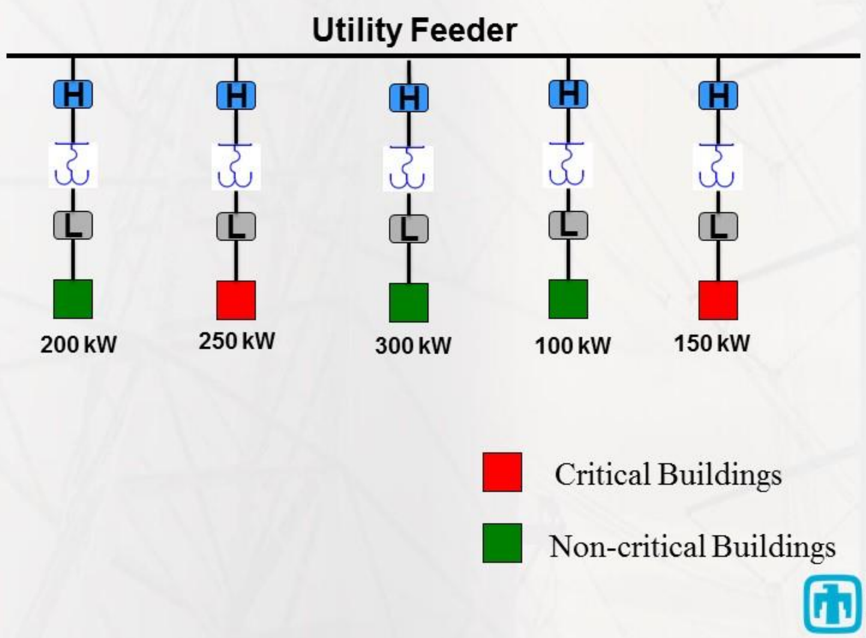
Example Feeder Layout where Microgrid Conceptual Design will be developed



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Option -Design Microgrid using Utility Feeder

- Requirements:
  - Ability to utilize utility system to form microgrid
  - Can be manual or automatic
  - Attractive sites must be found which satisfy building needs and utility requirements for operation
- Pros
  - Less costly than MV microgrids independent of utility
  - Microgrid provides more reliability than individual backup generator through redundancy & can serve multiple buildings
- Cons

  May alter automated/manual sectionalizing schemes
- Issues, Risks and "Show Stoppers"
  - Who owns, operates microgrid and how does it interface with utility
  - Regulatory, permitting, right of way (ROW), private business issues
  - Should we consider only emergency or also grid tied with possibility of wheeling

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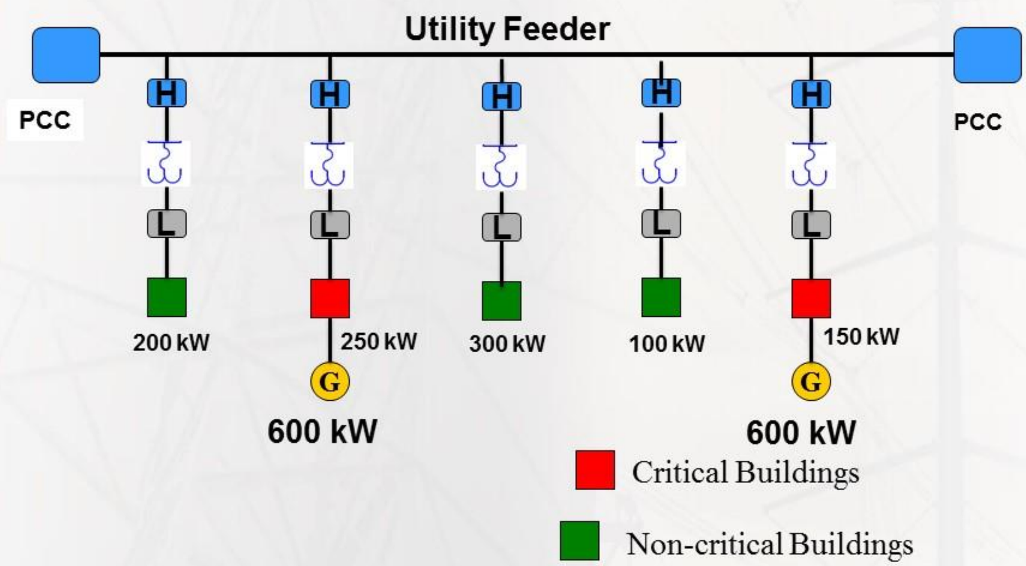
Microgrid using Utility Grid



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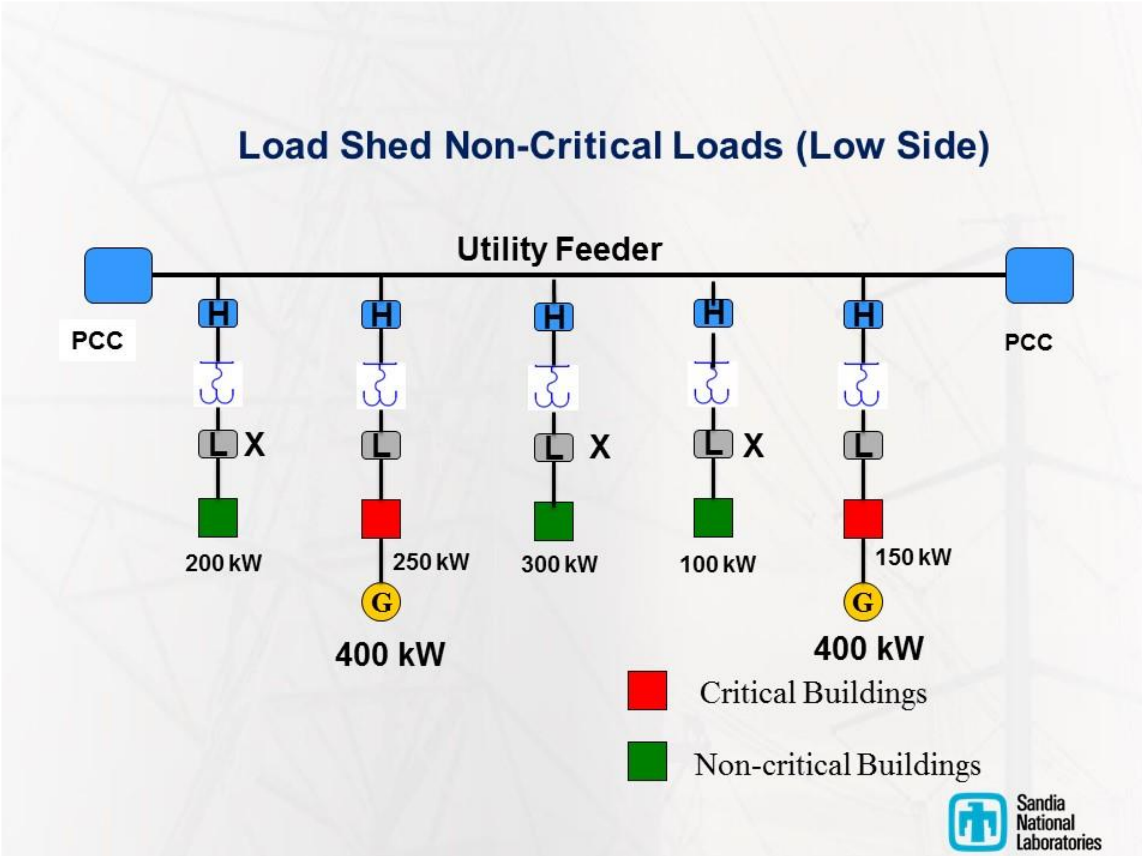
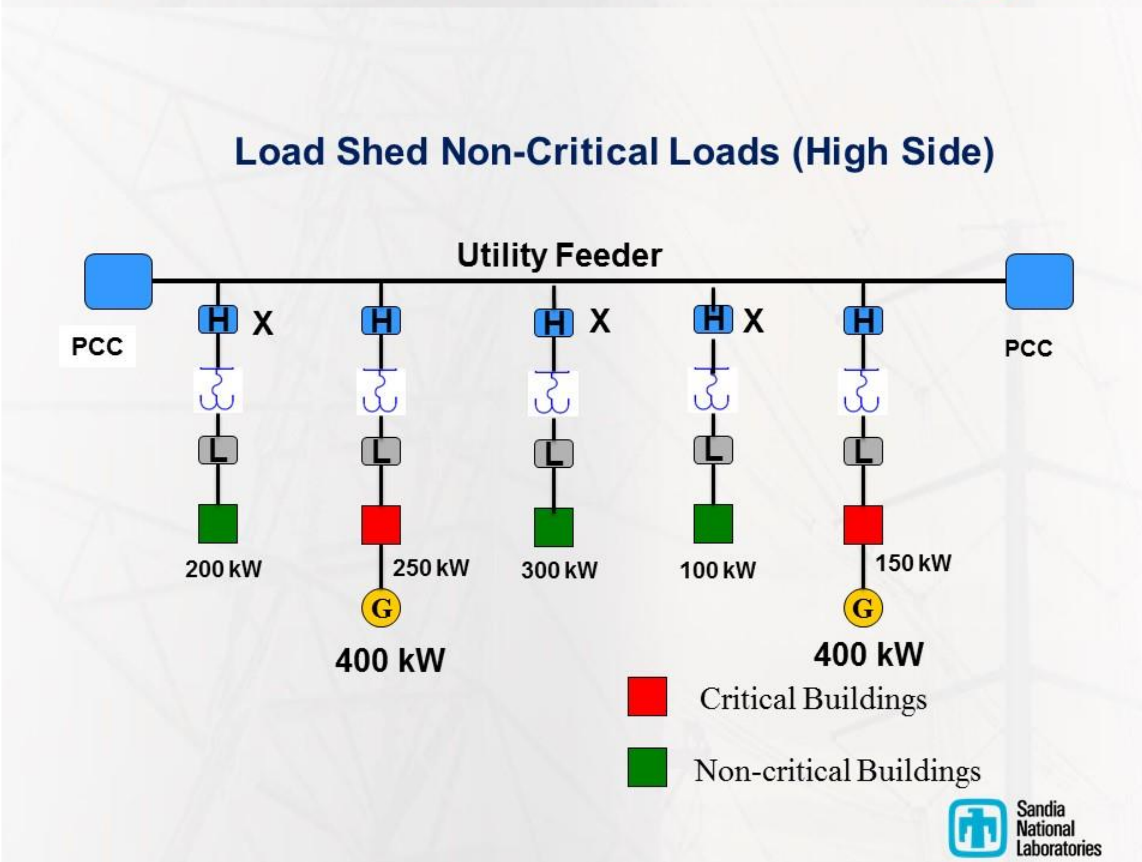

Load Shed Non-Critical Loads (Low Side)
Utility Feeder
PCC
PCC
H
L
X
200 kW
250 kW
300 kW
100 kW
150 kW
G
400 kW
400 kW
Critical Buildings
Non-critical Buildings
Sandia
National
Laboratories


Load Shed Non-Critical Loads (High Side)
Utility Feeder
PCC
PCC
H
L
X
200 kW
250 kW
300 kW
100 kW
150 kW
G
400 kW
400 kW
Critical Buildings
Non-critical Buildings
Sandia
National
Laboratories

Option - Design Microgrid Independent of Utility

- **Requirements:**
  - **May require some ROW of utility lines to form microgrid or can be done UG if ROW can be obtained**
  - **Can be manual or automatic**
- **Pros**
  - **More flexibility in designing which facilities to include**
  - **Microgrid provides more reliability than individual backup generator through redundancy & can serve multiple buildings**
  - **Except utilization of ROW, doesn't interfere with utility**
- **Cons**
  - **More costly than using utility**
  - **May not exist ROW corridors to install system**
- **Issues, Risks and "Show Stoppers"**
  - Who owns, operates microgrid and would it need to interface with utility
  - **Regulatory, permitting, ROW, private business issues**
  - **Could this system be tied to utility & if so how**

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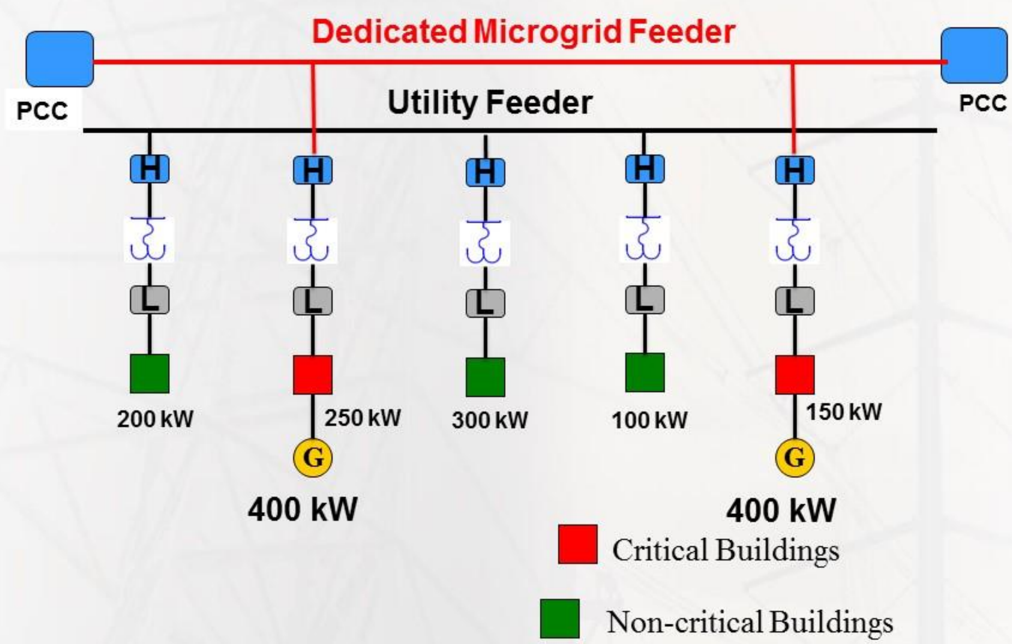
Dedicated Microgrid Feeder



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Option – Design Buildings to Share Backup Generation

- Requirements:
  - Ability to tie backup generators between adjacent buildings
  - Can be manual or automatic
  - Need to find ROW to install system – OH or UG
- Pros
  - Independent of utility so no technical/operational with existing system
  - Can provide additional reliability over individual backup generator through redundancy & can serve additional buildings
- Cons
  - Limited by distance (~1000 ft) and size of generation or cabling sizes become prohibitive
  - May not exist ROW corridors to install system
- Issues, Risks and "Show Stoppers"
  - Are there regulatory, permitting, ROW, private business issues

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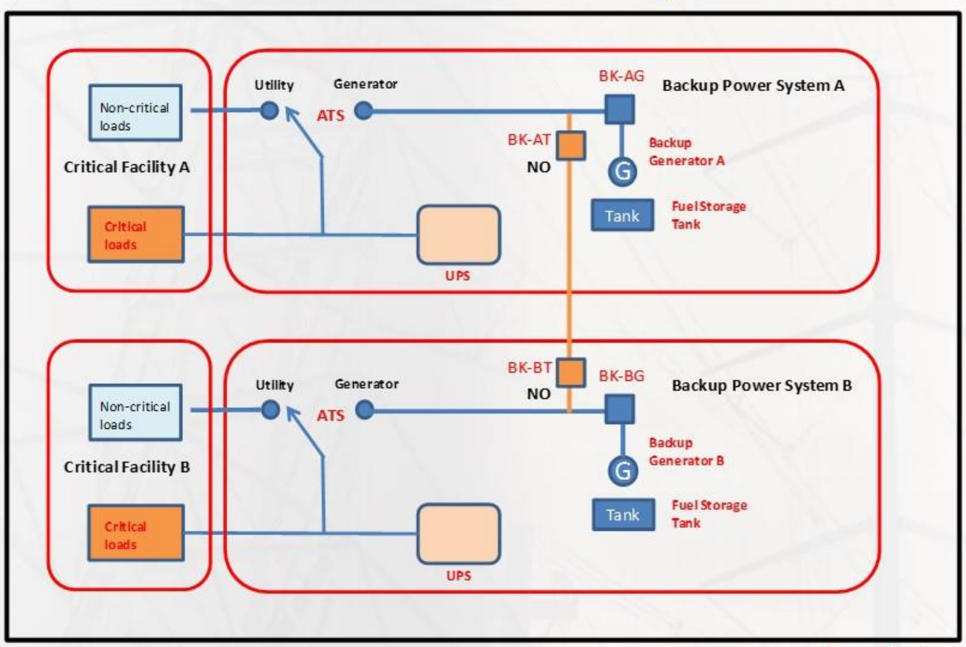
Option - Share Backup Power between Two Buildings



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Option – Add or Enhance Backup Generator System to Building

- Requirements:
  - Sizing and locating Backup generator to entire building load or critical load
  - Adding ATS and necessary rewiring for installation
- Pros
  - Independent of PSEG so no technical/operational with existing system
  - Least expensive option (except pin and sleeve)
- Cons
  - No redundancy so less reliable and efficient than microgrids (MV or 480V)
- Issues, Risks and "Show Stoppers"
  - Must obtain permitting to run as emergency unit, but same requirement for generators in microgrids
  - If required for private business and needed for emergency services, who pays and operates, but same requirement for generators in microgrids

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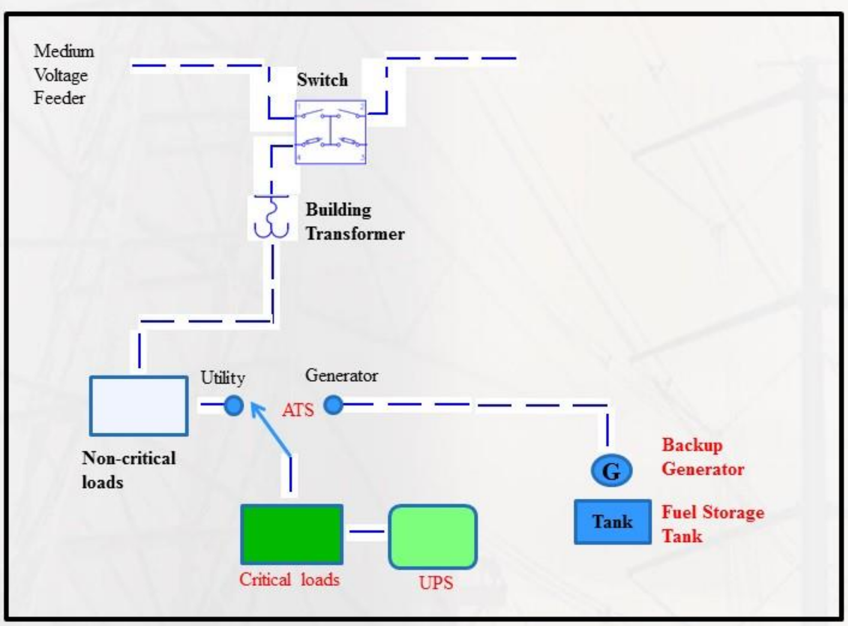
Option - Backup Generators



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Option – Make Additional Provisions for Backup Generators

- Requirements:
  - Refers to provisions to allow backup generator to be hooked up to building during emergencies
  - Sizing to required generator for building load or critical load
  - Adding cabling and/or ATS to be able to connect portable generator
  - Relies on a pool of portable generators to quickly get to building
- Pros
  - Less costly than backup generators
  - Faster and Easier to connect a portable backup generator with system in place
- Cons
  - No power until backup unit installed
  - If there are a lack of generators, buildings with provisions must be prioritized for service
- Issues, Risks and "Show Stoppers"
  - Ability to get to location during emergency and prioritizing
  - If required for private business and needed for emergency services, who pays and operates during emergencies

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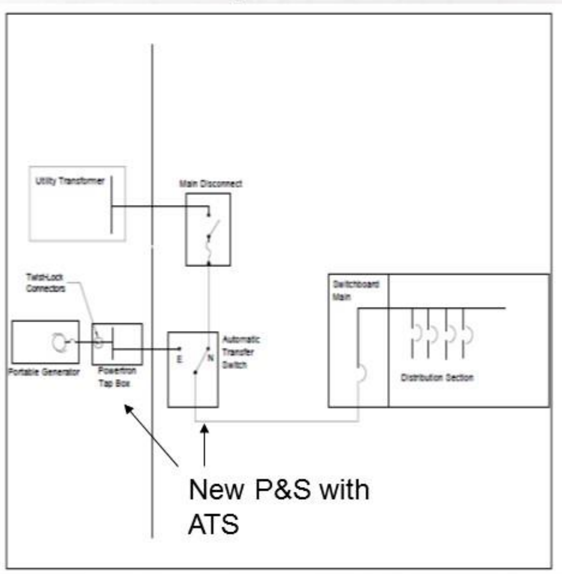
Option – Additional Provisions for Backup Generators

Example Connection



Pin and Sleeve - 50 kW

300 kW

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Example microgrid connection diagrams at both low and medium voltages

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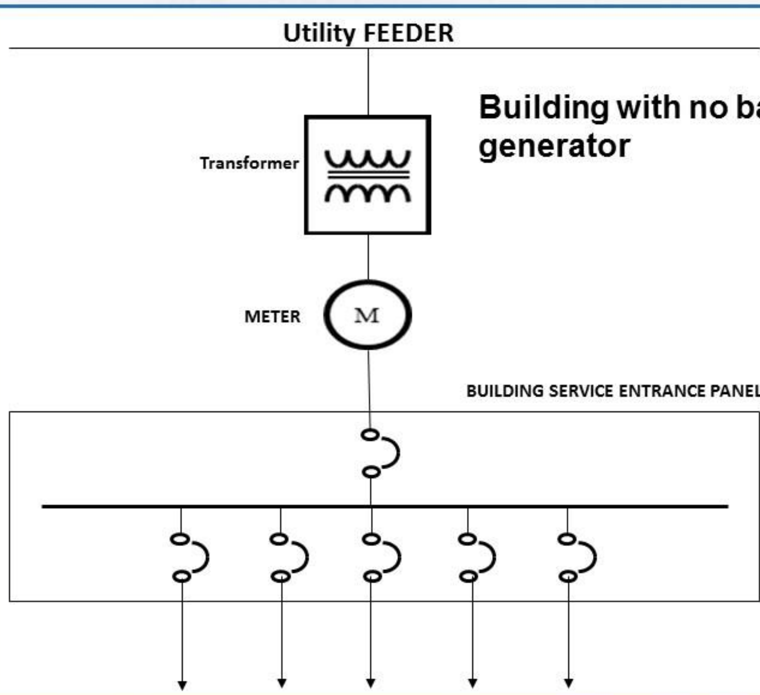
Building with no backup generator



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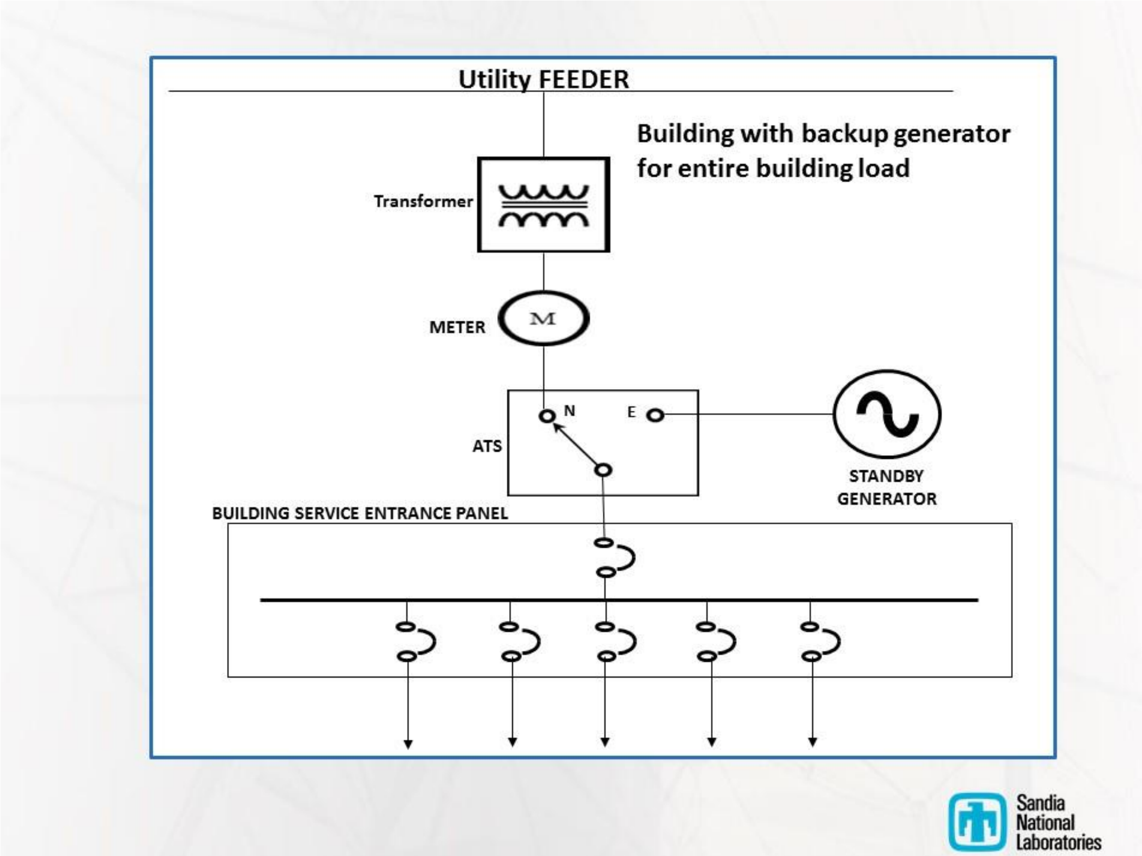
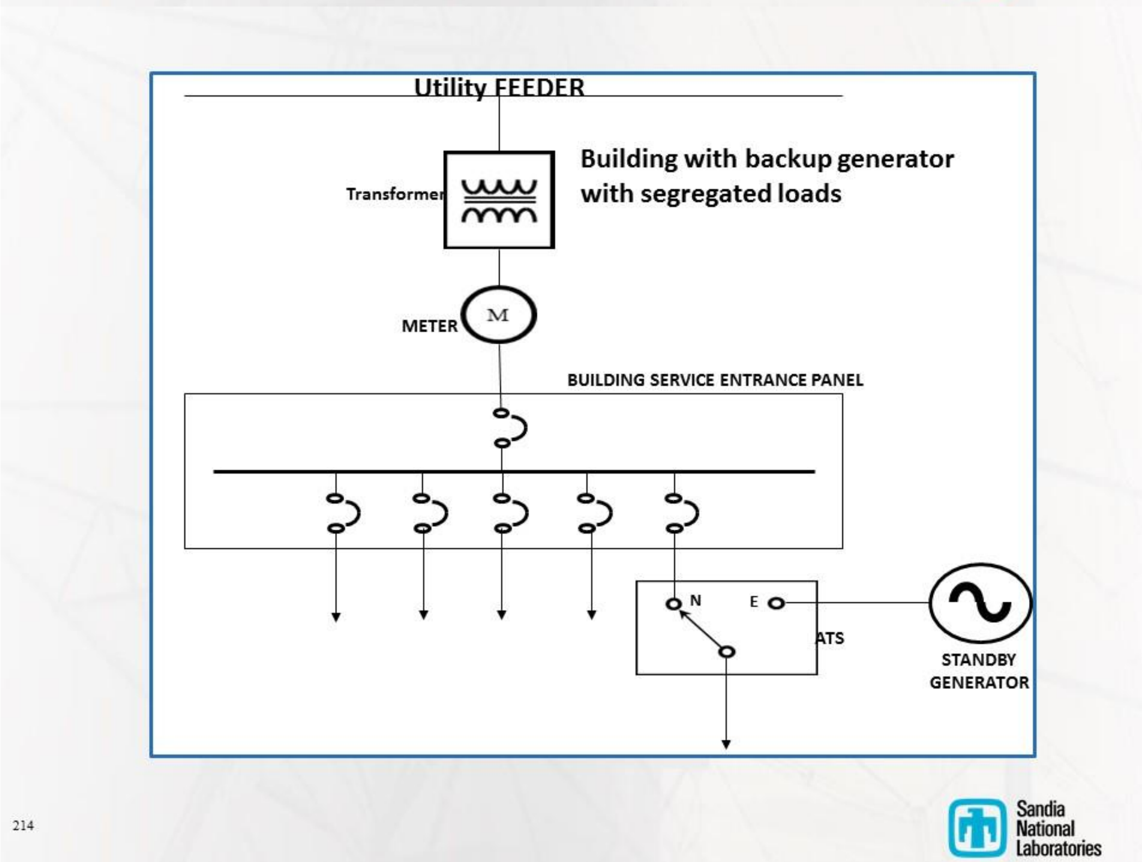
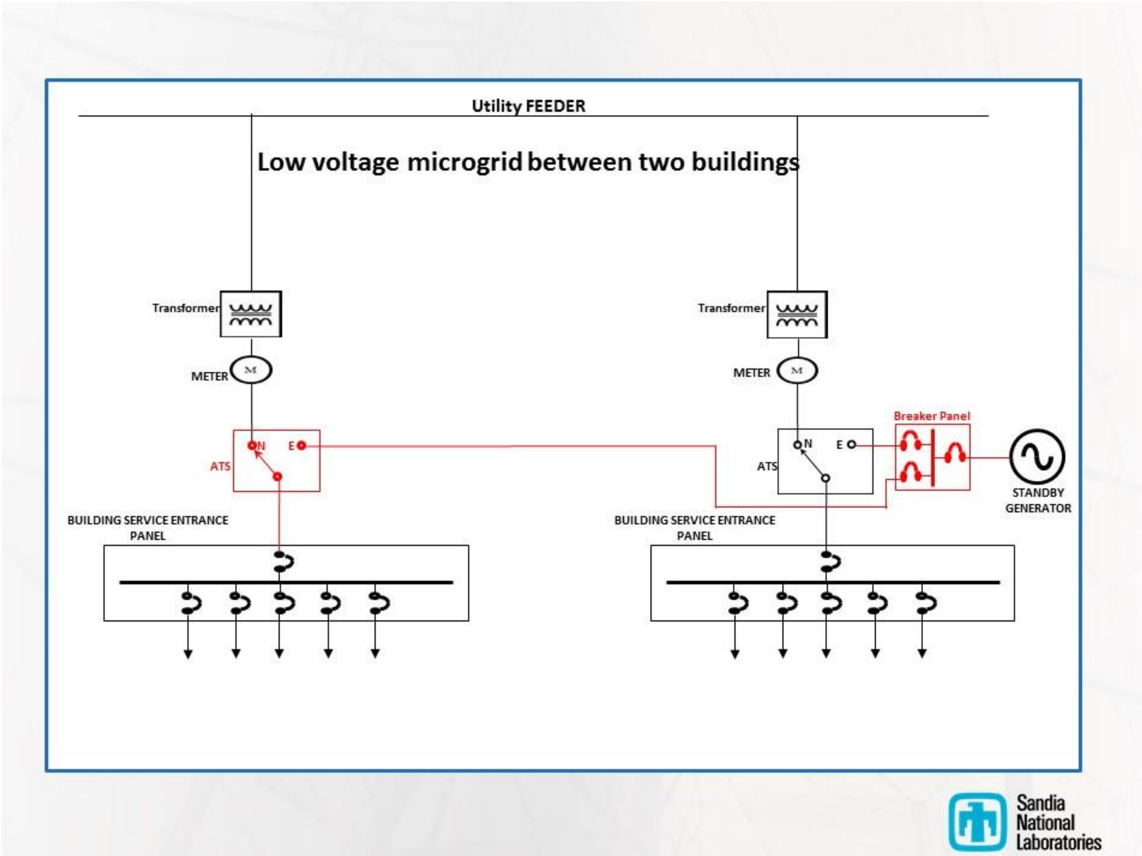
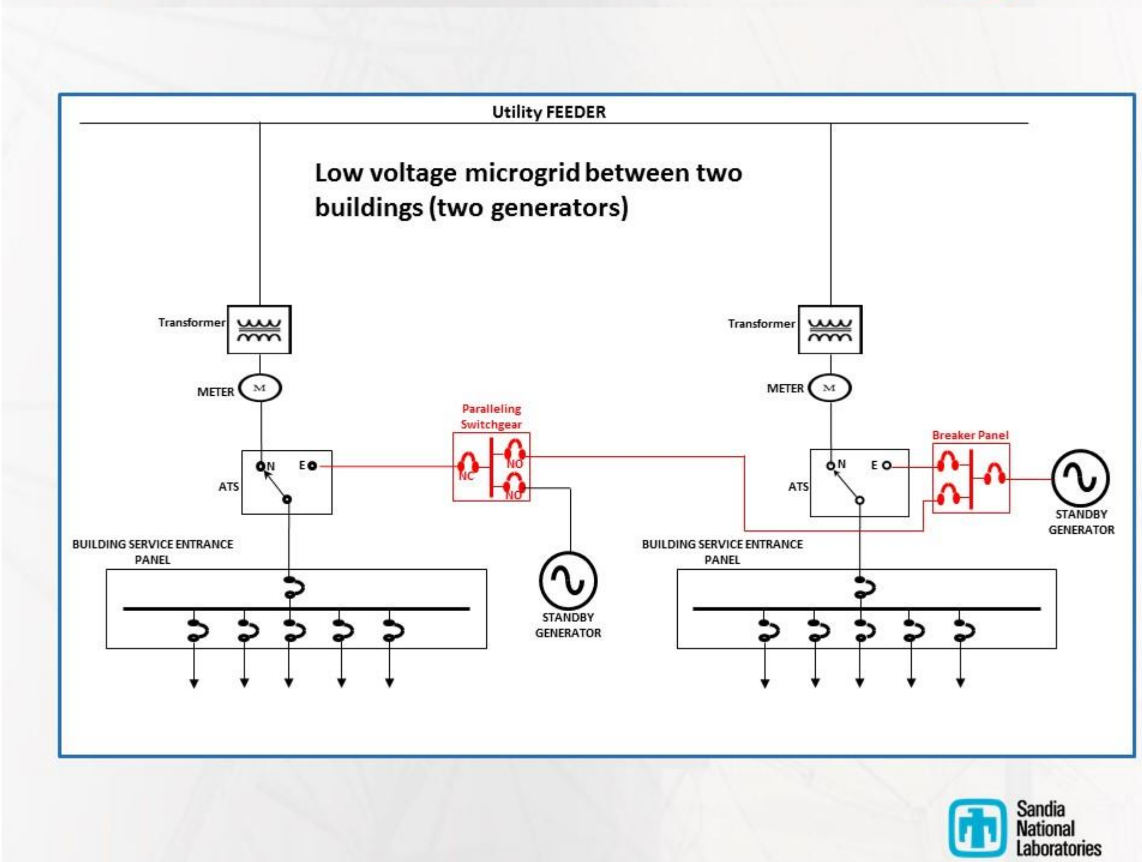
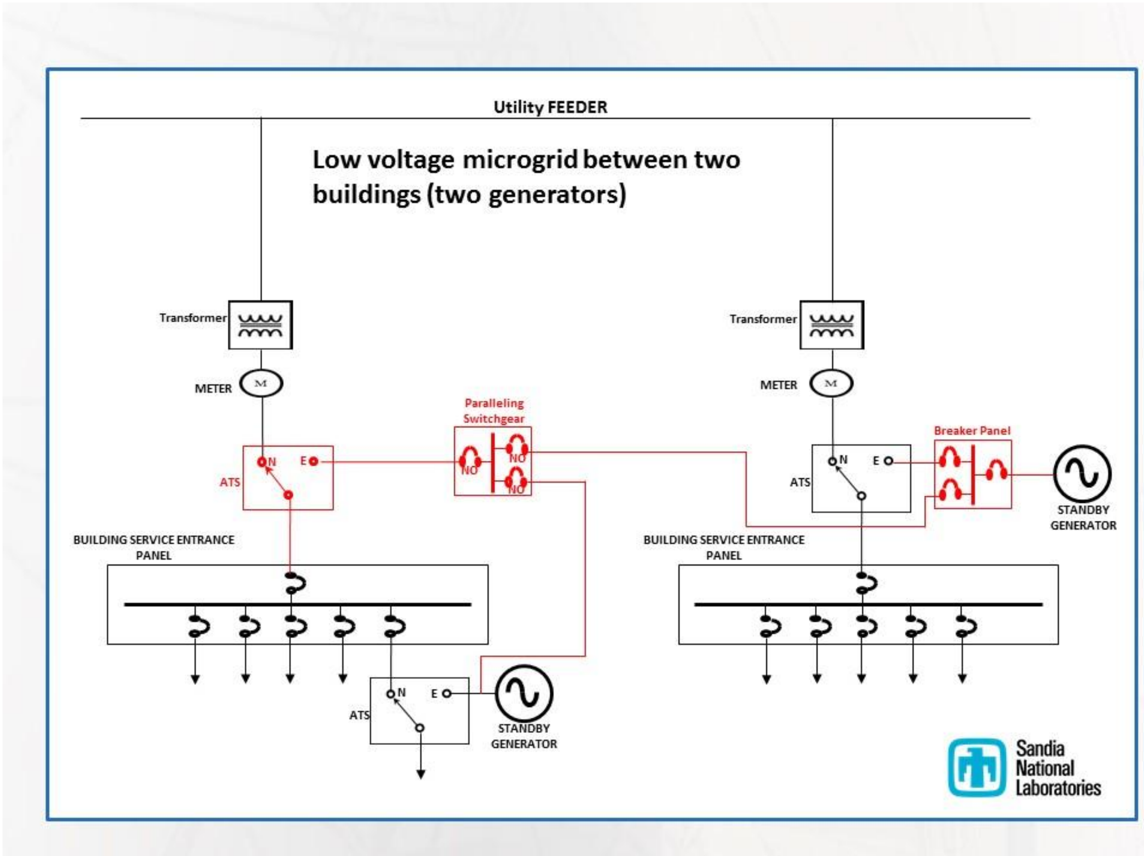
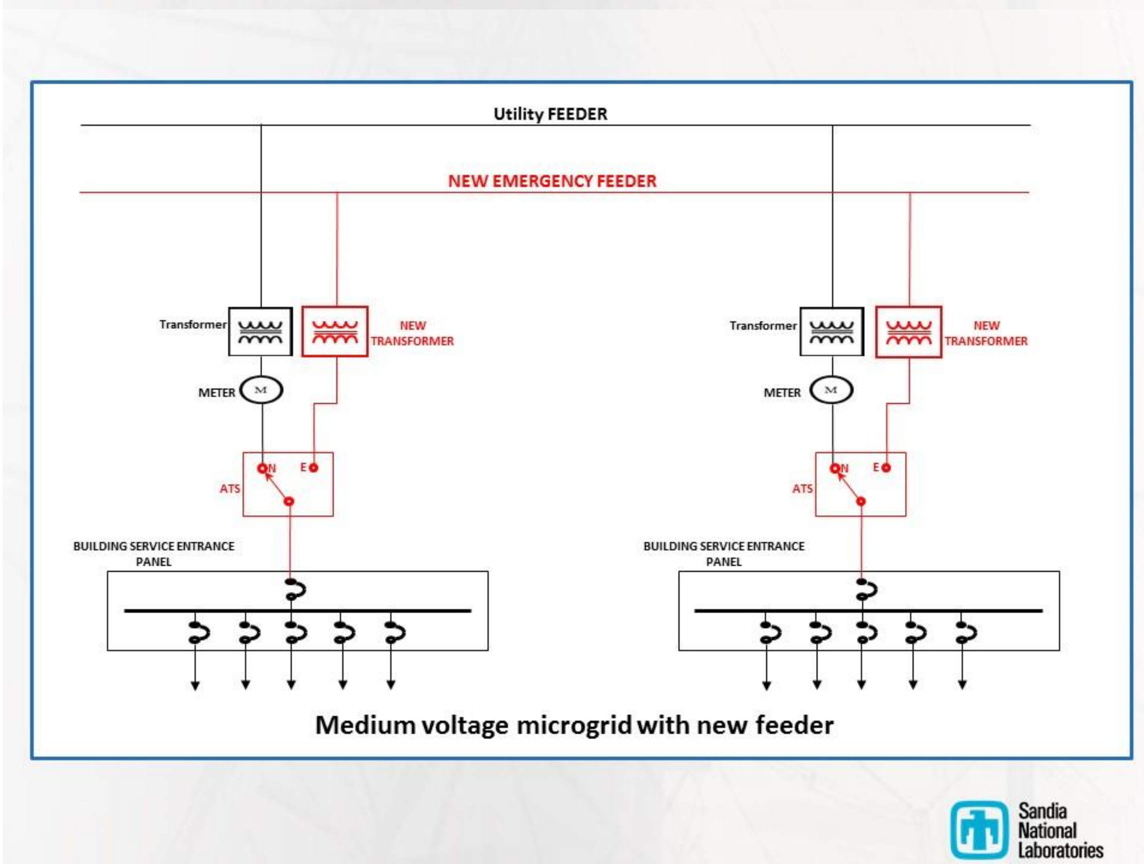

Utility FEEDER
Building with backup generator
for entire building load
Transformer
METER
M
ATS
N
E
STANDBY
GENERATOR
BUILDING SERVICE ENTRANCE PANEL
Sandia
National
Laboratories

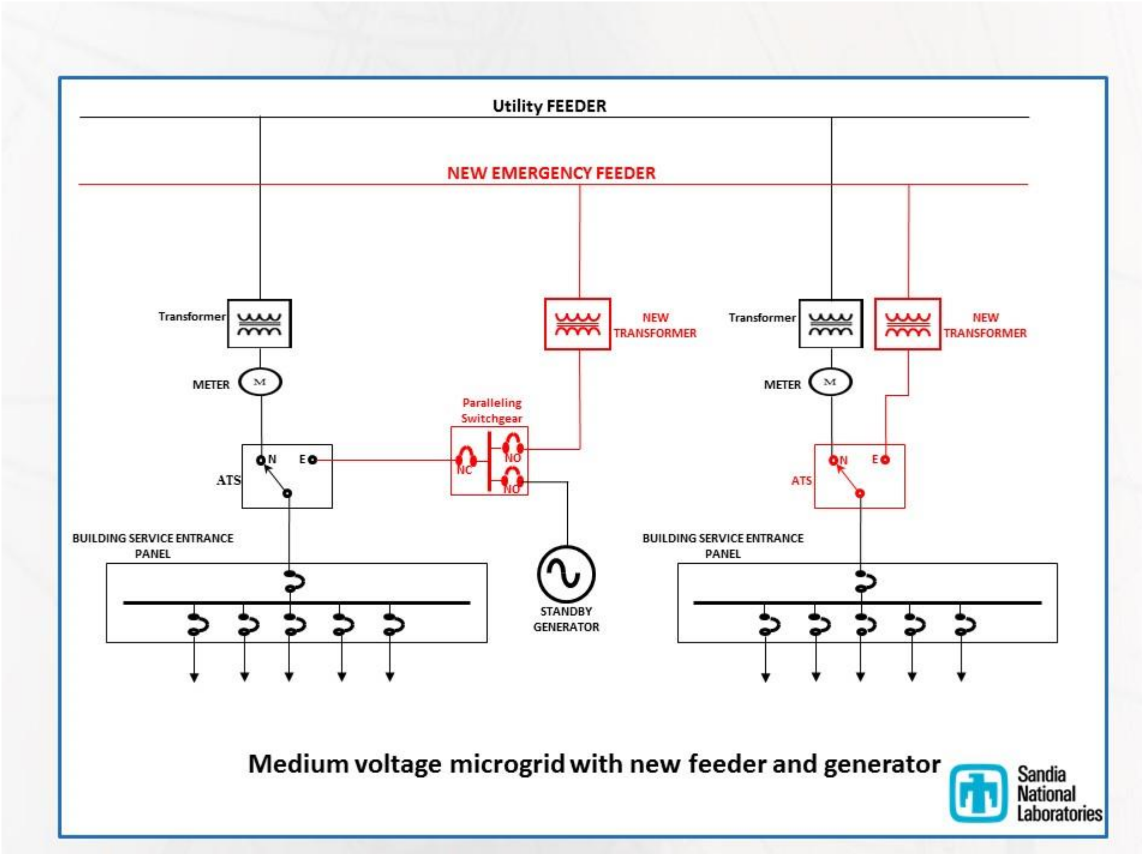

Utility FEEDER
Building with backup generator
with segregated loads
Transformer
METER
M
BUILDING SERVICE ENTRANCE PANEL
N
E
ATS
STANDBY
GENERATOR
Sandia
National
Laboratories
214

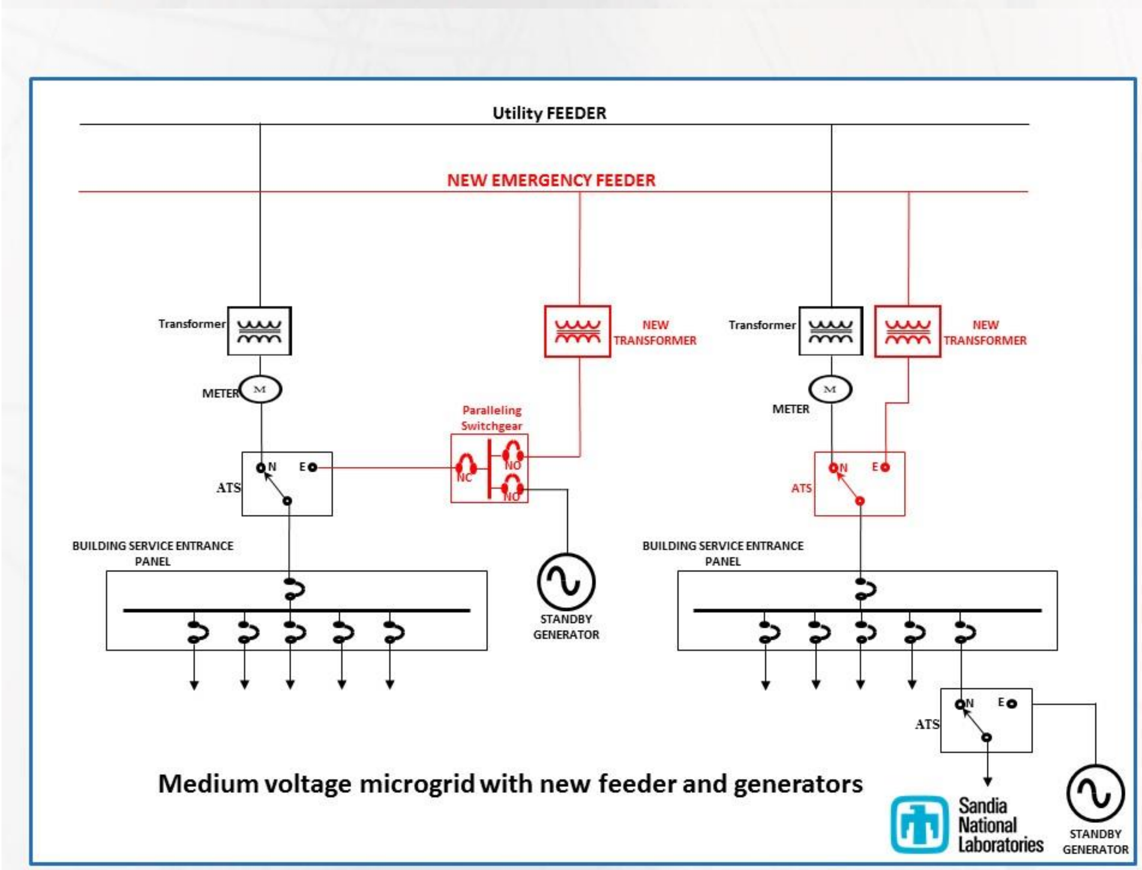

Utility FEEDER
Low voltage microgrid between two buildings
Transformer
Transformer
METER
M
METER
M
ATS
N
E
ATS
N
E
Breaker Panel
STANDBY GENERATOR
BUILDING SERVICE ENTRANCE PANEL
BUILDING SERVICE ENTRANCE PANEL
Sandia National Laboratories


Utility FEEDER
Low voltage microgrid between two buildings (two generators)
Transformer
Transformer
METER
M
METER
M
Paralleling Switchgear
NC
NO
NO
Breaker Panel
ATS
N
E
ATS
N
E
STANDBY GENERATOR
STANDBY GENERATOR
BUILDING SERVICE ENTRANCE PANEL
BUILDING SERVICE ENTRANCE PANEL
Sandia National Laboratories


Utility FEEDER
Low voltage microgrid between two buildings (two generators)
Transformer
METER
Paralleling Switchgear
NO
NO
NO
ATS
N
E
Breaker Panel
STANDBY GENERATOR
BUILDING SERVICE ENTRANCE PANEL
Sandia National Laboratories


Utility FEEDER
NEW EMERGENCY FEEDER
Transformer
NEW TRANSFORMER
METER
ATS
N
E
BUILDING SERVICE ENTRANCE PANEL
Medium voltage microgrid with new feeder
Sandia National Laboratories


Utility FEEDER
NEW EMERGENCY FEEDER
Transformer
NEW TRANSFORMER
Transformer
NEW TRANSFORMER
METER
METER
Paralleling Switchgear
NC
NO
NO
N
E
ATS
N
E
ATS
BUILDING SERVICE ENTRANCE PANEL
BUILDING SERVICE ENTRANCE PANEL
STANDBY GENERATOR
Medium voltage microgrid with new feeder and generator
Sandia National Laboratories


Utility FEEDER
NEW EMERGENCY FEEDER
Transformer
NEW TRANSFORMER
Transformer
NEW TRANSFORMER
METER
METER
Paralleling Switchgear
NC
NO
NO
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ATS
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ATS
BUILDING SERVICE ENTRANCE PANEL
BUILDING SERVICE ENTRANCE PANEL
STANDBY GENERATOR
N
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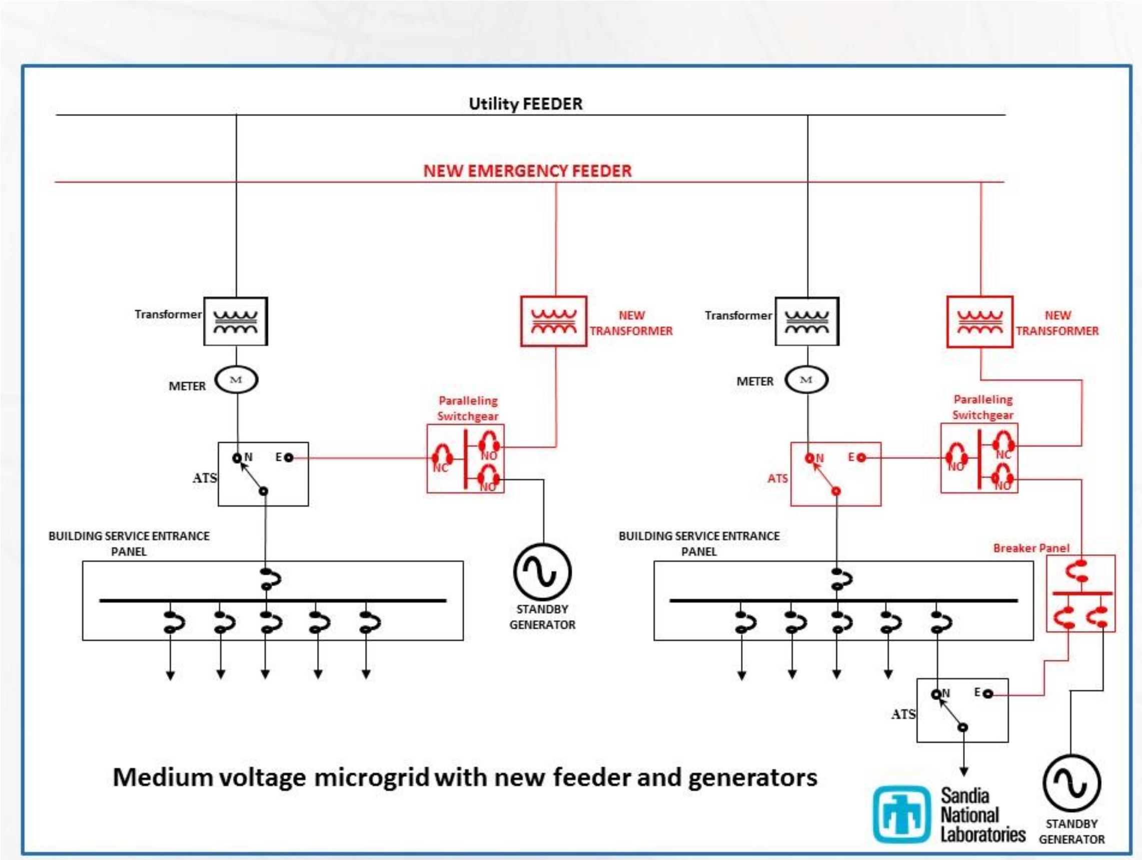
ATS
Medium voltage microgrid with new feeder and generators
Sandia National Laboratories
STANDBY GENERATOR


Utility FEEDER
NEW EMERGENCY FEEDER
Transformer
NEW TRANSFORMER
Transformer
NEW TRANSFORMER
METER
METER
Paralleling Switchgear
Paralleling Switchgear
N
E
ATS
NC
NO
NO
BUILDING SERVICE ENTRANCE PANEL
STANDBY GENERATOR
BUILDING SERVICE ENTRANCE PANEL
Breaker Panel
ATS
STANDBY GENERATOR
Medium voltage microgrid with new feeder and generators
Sandia National Laboratories

APPENDIX E. INFORMATION REQUEST FOR MICROGRID DESIGN

The information and data requested below will allow developers of microgrid conceptual designs to understand the current energy demands and loads, critical loads and demands, available distributed generation resources, operation and control systems, electrical feeder layout and operation, and energy system reliability within the area of consideration (the microgrid). The information will help identify constraints and requirements that must be considered for microgrid hardware, software, control system implementation, and operations.

Personnel – Roles and Responsibilities

Current Personnel Status – please list a name and email address/contact info for each question.

1. Who is currently responsible for the operations and maintenance of the electrical systems (both low voltage and medium voltage) on base?

2. Who is currently responsible for maintenance and operations of the diesel generator backup systems?

3. Who currently manages electrical system control systems (SCADA, EMS, other) at the base? How are the systems monitored and controlled, and what alarms or warning signs are pertinent?

4. Who manages facilities at the base – specifically who manages the buildings that will be considered critical loads for the microgrid? Who manages other control systems (SCADA, EMS, other) that might be connected to these critical loads?

5. Who manages the existing renewable and energy storage systems on the base?

6. Who manages any existing UPS systems? How is this system monitored and maintained?

7. If applicable, who manages any existing vehicle charging stations? How is this system monitored and maintained?

8. Who is the point of contact with the local utility for operating issues? Who on base manages the interconnection agreement negotiations with the utility? Who handles the PPAs?

9. Who is the contact person for microgrid implementation activities?

10. Who will maintain, manage, and monitor any new renewables implemented as part of the microgrid?

11. If applicable, who will maintain, manage, and monitor any new electric vehicle V2G infrastructure implemented as part of the microgrid?

12. Who will be notified if the microgrid is automatically islanded? Who can make the decision to switch to islanded status if necessary?

13. Who will monitor the energy management system when the microgrid is islanded?

Electrical Distribution System

Please provide the following information about the existing electrical system. The description of the operational environment should identify, as applicable, the facilities, equipment, computing hardware, software, personnel, and operational procedures used to operate the existing system.

- ☐ Detailed one-line diagram(s) of the feeder(s) which serve the facility and critical loads, showing all switches (including recloser and sectionalizing/load), normal switch conditions (open/closed), conductor size, transformers and shunt compensation (capacitors) from the substation(s) in which the feeders originate
- ☐ Detailed one-line information for any substations which serve these facility feeders above including bus configuration layouts
- ☐ Describe feeder and bus protection at the substation level for each feeder
- ☐ Feeder(s) voltage (V, kV) and power (KW) for typical heavy and light demand day loads. Include any data on monthly high and low energy use (KWH)
- ☐ Existing distribution model of base electrical system
- ☐ Any planning documents related to distribution system, future maintenance, improvements, etc.
- ☐ Any information pertaining to system feeder historical reliability such as CAIDI, CAIFI, SAIFI, or SAIDI?

- ☐ Metering – please indicate the existing metering at the facilities that serve critical loads and/or on-site generation.
  - Metering – please indicate any planned metering at the facilities that serve critical loads and/or on-site generation and describe any "smart grid" capabilities of these meters.
  - Could meters or measuring devices be installed, if required, for the microgrid project?
  - Is there any historical meter data from any existing on-site generation?
- ☐ Does an integrated utility management plan (or similar document) exist for the base? Could a copy of this be provided?
- ☐ If there is a quest for NETZERO, what renewable energy system changes are envisioned and when. How can we preplan to leverage these installation changes to strengthen the impact of the project?
- ☐ Would the base consider leveraging the micro-grid to lower peak power impact and reduce overall cost of power?

Critical Loads and Buildings for Planned Microgrid

Please provide the following information on buildings and facilities that are critical to the mission of the base. These are the loads that will be supported by the microgrid during an islanded situation.

Critical loads include both entire buildings, and portions of buildings or facilities that are used to support a critical mission. For example, a building might contain a vital operations center on the first floor, but the second floor office spaces are not critical for mission function. Example description: Critical Building X uses ~500KW heavy load, ~300KW light load; during peak ~100KW (20%) is critical & non-interruptible fed by a 100KW UPS with ~1 minute ride through, ~300KW (60%) is critical but interruptible fed by 350 KW diesel generator ~10 second startup (including the 100KW listed for UPS), and remaining ~200KW (40%) load is non-critical. The critical and non-critical loads are segregated by an automatic transfer switch for the backup generator as well as building panel boards which subdivide critical and non-critical loads.

For each critical load (again, either an entire building or a portion thereof) please provide the following:

- ☐ Location of critical load – What is the building name, building number, street address? Please locate the critical loads on one line drawings and geospatial maps.

- ☐ If the critical load is a portion of a building, does the building have any segregation method to separate the loads? Please describe the electrical topology (i.e. building panel segregation, etc.)
- ☐ Provide load profiles for each critical load. If load profiles are not available, estimate critical mission demand (kW) for each critical load over time including significant periods of changing loads. What are the characteristics of the loads (e.g., motors, lighting, communications)
- ☐ Information both on normal feeder(s) switch configurations and alternative configurations to feed loads during maintenance and emergency situations. It is important to clearly demarcate which feeder each critical building is fed from, and how these critical buildings can be switched to be fed during emergency situations. Are there any load shedding schemes in place?
- ☐ Required duration for the mission to be maintained during an outage
- ☐ Percentage or amount (KW) of critical load that requires non-interruptible power
- ☐ Percentage or amount of critical load that requires critical but interruptible power (e.g. critical but can withstand time for backup generator to start)
- ☐ If any of the critical loads are motor-based, are they equipped with variable frequency drives?
- ☐ How much remaining load in the building is non-critical?
- ☐ Will “nice to have” loads be added if there is excess energy being produced during islanded microgrid operations?

Existing Backup/On-site Generation

For each backup generator, please provide the following:

- ☐ Location of generator (or gensets if multiple generators feed building) – note generators can include traditional sources like diesel generators, as well as other sources like micro turbines.
- ☐ Make, model and maintenance agreement for each generator
- ☐ Ratings – voltage (V or kV), and power (kW with power factor, or kVA)
- ☐ Quantity and type of fuel used in each generator and amount of fuel stored for each (e.g. 500 gallon diesel tank)
- ☐ How is diesel delivered? Do you have a contract with one or more diesel fuel providers ? Are you a priority customer ? What could interrupt this delivery?
- ☐ Does the diesel fuel provider have the capability to provide fuel without electricity ? Do they have a backup generator for their facility?
- ☐ Engine governor and exciter information (make, model and available control setting – e.g. isochronous or droop control). Where are the control systems for each generator located, and how are they operated? Is documentation available?
- ☐ Switchgear diagram and controls (auto start, auto transfer switch, breaker etc.) to determine how the generator is tied into the critical building including rating information if a transformer is also used. Do any generators operate in open or closed transition with the utility?
- ☐ Operation/reliability history of generators – how often are generators started? How long do they run? How reliably do they start? Include any information on maintenance (e.g. run 1/wk at 50% load) and during emergency situations (e.g. came on line reliably 80% during 4 of last 5 outages). Are generators operated for peak-shaving, storm- avoidance, maintenance functions, improving power system reliability, etc.?
- ☐ Are there periods when the generators cannot run due to noise, emissions, or other constraints? Is there a limit on the number of hours the generators can run in a year or how much total diesel per year is allowed to be burned at the site annually?
- ☐ Which loads are carried by the generator(s) and which are dropped for the buildings they serve?

- ☐ If the backup generator includes combined heat and power capabilities (CHP) – include information such as exhaust temperature, heat energy available for recovery (BTU/hr), and existing use, etc.

- ☐ Has the base considered using the backup generators to:
  - Reduce installation peak power demands from the utility by shaving power peaks to reduce installation power costs?
  - Support utility power needs for frequency regulation under contract?
  - Support the local utility needs for spinning reserve under a contract?

Data on Natural Gas System (as applicable):

- ☐ Detailed one-line diagram(s) of gas line feeders to facility with pertinent information such as shutoff valves, service locations etc.

- ☐ Information on overall system level gas line capacity and pressure.

- ☐ Natural gas supply reliability and outage data, both offbase and onbase or in the community.

- ☐ Gas line feed and distribution system locations (if not provided by one-line diagrams).

- ☐ Estimated peak and average natural gas use by current buildings or clusters of buildings.

- ☐ Estimated critical mission natural gas demand by building (% of building peak demand) and required duration (e.g. 24/7 for 2 days/5 days etc.)

- ☐ Estimated natural gas demand possible for future developments, both by the total community development or ranges for different sections of development in the community.

Distributed and Renewable Generation

- ☐ Are there any ecological or environmental limitations on the renewable or distributed energy resource utilization? For example, is there any native species habitat, wildlife, noise, land use, or emissions issues that would prevent the placement of PV or wind related hardware including the panels, inverters, fencing, concrete pads, roads, etc.?
- ☐ Are there limits to the distance to a site boundary where PV, wind, or other hardware can be located? I.e. nothing allowed within a certain distance of the perimeter fencing, flight line, etc.
- ☐ Are there cost or schedule constraints regarding obtaining an interconnection agreement with the local utility? Does anyone have experience with this?

Renewables – solar- current systems;

- ☐ Location of PV system, Fixed tilt/single axis tracking/2-axis tracking
- ☐ Size of system in kW; what percentage of peak load could this system supply during an islanded situation during ideal circumstances (full sun, no clouds)?
- ☐ Make and model of inverters; Remote control capabilities?
- ☐ Ratings – voltage (V or KV), and power (KW with power factor, or KVA)
- ☐ Is the PV system designated for supplying a specific load?
- ☐ Is there a Power Purchase Agreement in place with the local utility or third party to purchase power generated from the PV system? What is the agreement with the local utility during islanding? Please provide a copy of any PPA agreements.
- ☐ Who is responsible for operating, maintaining, and managing the current PV system?

Renewables – solar –planned system(s)

- ☐ For areas where a potential distributed or renewable generation resource has been identified, provide as much information on the amount of potential generation (kW). What percentage of peak demand could this supply during an islanded situation?
- ☐ Are there size or height limitations? How much acreage is available for the system? What type of solar - PV, CSP

- ☐ How much funding is available for the planned system, including integration?

- ☐ Location – ground, roof top, parking garage?
- ☐ What feeder, substation, or building would the resource be connected to?
- ☐ Are there architectural or visual impact issues that need to be considered?
- ☐ What permitting is required? How long is the permitting process?
- ☐ Who will be responsible for operating, maintaining, and managing any planned PV system(s)?

Renewables – wind – current system;

- ☐ Location of wind turbines
- ☐ Total energy produced by turbines in kW; what percentage of peak load could this system supply during an islanded situation during ideal wind?
- ☐ Make and model of turbines
- ☐ Is the wind system designated for supplying a specific load?
- ☐ Is there a Power Purchase Agreement in place with the local utility to purchase power generated from the wind turbines? What is the agreement with the local utility during islanding?
- ☐ Who is responsible for operating, maintaining, and managing the current wind system?

Renewables – wind –planned system;

- ☐ For areas where a potential distributed or renewable generation resource has been identified, provide as much information on the amount of potential generation (KW). What percentage of peak demand could this supply during an islanded situation?
- ☐ Proposed turbine manufacturer and model
- ☐ Are there size or height limitations that would affect the placement of planned turbines? How much acreage is available for the system?
- ☐ Location on base – Where are the turbines going to be located and are any locations not available due to radar, bird migration, visual issues, flight line interference etc.?

☐ Grid location - What feeder, substation will the wind turbines be connected to?

☐ How much funding is available for the planned system, including integration?

☐ Are there architectural or visual impact issues that need to be considered?

☐ What permitting is required? How long is the permitting process?

☐ Who will be responsible for operating, maintaining, and managing any planned wind generation system(s)?

Renewables – other including waste-to-energy, wave energy, OTEC, tidal, geothermal, biofuels and bio gas, etc. – current systems;

☐ Please describe other forms of renewable generation located on the site. Include make and model of associated hardware.

☐ Total energy produced in kW; what percent of peak load could this system supply during an islanded situation?

☐ Is the system designated for supplying a specific load?

☐ Is there a Power Purchase Agreement in place with the local utility to purchase power generated from the system? What is the agreement with the local utility during islanding?

☐ Who is responsible for operating, maintaining, and managing the current "other renewable" system?

Renewables – other –planned;

☐ For areas where a potential distributed or renewable generation resource has been identified, provide as much information on the amount of potential generation (kW). What percentage of peak demand could this supply during an islanded situation?

☐ Proposed system model, make, and manufacturer

☐ Are there size or height limitations that would affect the placement of planned turbines? How much acreage is available for the system?

☐ Location on base – Where would the system be located and are any locations not available due to environmental or operational issues?

- ☐ Grid location - What feeder, substation, or building will the generation source be connected to?
- ☐ How much funding is available for the planned system, including integration?
- ☐ Who will be responsible for operating, maintaining, and managing any planned “other renewable” system(s)?

Energy Efficiency Improvement Plans

Are there plans for reducing the energy consumption in buildings such as:

- ☐ Insulation systems for walls, ceilings
- ☐ Green roofing efforts that will reduce air conditioning and heating loads
- ☐ Changes to doors/windows affecting air conditioning and heating loads – replacement, shading, air dams, other
- ☐ Changes to lighting systems or lighting strategies – motion activated, local vs. global activation, other.
- ☐ Changes to power consuming systems (variable speed drives for pumps, motors, fans, other)

Control Systems and Security

- ☐ Describe the existing electrical control system including networking and communications diagrams
- ☐ Available communication links for Microgrid Energy Management System and or protective relaying (wireless, fiber, etc.)
- ☐ What is the existing cyber security policy and can it be provided?
- ☐ What standards (e.g. DoD requirements) are required to be met for control system cyber security? How are these standards currently met? What is the approval process and authority for these requirements?
- ☐ Is there an expectation that the microgrid EMS will be integrated into the existing base control system?
- ☐ Where will the human control interfaces for the microgrid be located? For example, the DPW or EOC?
- ☐ What are the control system characteristics for any planned electrical assets?
- ☐ Control System Visualization - What are the highest priority performance parameters that need to be monitored to show micro grid performance - overall system efficiency, individual generator loading levels and efficiencies, power flows, reserve generation (spinning and supplemental), load use and distribution (critical and non-critical), etc.
- ☐ What is the proposed timing needed for the microgrid to island (UPS requirements)?
- ☐ What is the process for isolating and reconnecting the microgrid to the utility?
    - Has there been coordination with the utility to understand the process and requirements (e.g. will IEEE 1547 standards be followed?) that will ensure stability (frequency and voltage regulation) on both the utility grid and microgrid?
    - What other control requirements with the utility have for the island interconnection device?
    - How will the local utility be notified before microgrid reconnection to the grid?
- ☐ Are there additional physical security requirements that will impact the proposed microgrid?

Electrical Energy Storage Systems

Existing Electrical Energy Storage systems, including UPS

- ☐ Please list any electrical energy storage systems currently operating on the base (including Uninterruptible Power supply (UPS) systems).
  - What is the replacement or maintenance schedule for these systems?
- ☐ Type (battery, UPS, fuel cell, grid connected electrical vehicle)
- ☐ Please provide information on size, power rating, location, and load served (correlate with critical load information), control system and inverters

Proposed Electrical Energy Storage Systems – battery, flywheel, fuel cell

- ☐ What is the proposed purpose for the electrical energy storage system? Peak shifting, ramp soaking for renewables integration, UPS, etc.?
- ☐ How much funding is available for the system, including integration?
- ☐ Can base personnel commit to maintenance and operations procedures necessary for the storage system?
- ☐ What is the proposed location for the storage system?
- ☐ Will the necessary facility upgrades be available to house the storage system, i.e. concrete pad, air conditioning or air circulation, fenced enclosure, secure access, etc.

Proposed Electrical Energy Storage Systems – electrical vehicle to grid

- ☐ Planned vehicle plug in stations - how many are planned, what is the make and model, type, size, proposed location for each? Are they uni- or bi-directional?
- ☐ What is the proposed purpose for the energy produced by the vehicle batteries - peak shifting, UPS function, ramp rate soaking for renewables, etc.?
- ☐ During a microgrid islanding situation, what is the process to get the vehicles to the plug in station to supply backup battery power? How long will this take?
- ☐ How many, and what kinds of vehicles are being considered? For each, what is the battery size and power rating?
- ☐ What loads will be served by the vehicle to grid system?

- ☐ Who will be responsible for operating, maintaining, and managing the vehicle to grid system(s)?

Operations and Maintenance

- ☐ Please describe how the base electrical system is operated and maintained (e.g. metering, doing maintenance, switching during outages, frequency of maintenance activities). How is this work segregated between the power provider and facility operations personnel?
- ☐ Identify the normal day-to-day configuration of the electric system (e.g., key feeder breaker and switch positions).
- ☐ Identify the emergency configuration of the electric system when isolated from the public utility.
- ☐ Identify any operational policies or constraints that apply to the current electrical system. Provide any documentation available. (Operational policies are predetermined management decisions regarding the operations of the current system, normally in the form of general statements or understandings that guide decision making activities.)
- ☐ What displays of each components' status would be required for training when the microgrid is implemented? What roles (operator, referee, system user, data consumer) would potential microgrid personnel fulfill?

Microgrid Demonstration

The microgrid will eventually require a designated test period for installation. This testing will require the microgrid to be operational and supply the critical operation center with power during the outage. Data will be gathered during this demonstration. The rest of the base will not be affected by this microgrid demonstration.

- ☐ Are there times of the year when a demonstration of the microgrid is not an option due to weather, cultural events, or other planned base activities?
- ☐ Are there any specific scenarios that need to be considered as part of the demonstration?
- ☐ Who needs to be notified that a demo is occurring (base personnel? Local utility personnel?) How will they be notified, and who will notify them?

- [ ] What are the conditions under which the demonstration would have to be stopped prior to completion?
- [ ] What is the procedure to get back to the standard (pre-microgrid) configuration?
- [ ] Are there any safety issues that need to be considered for the demonstration?
- [ ] What are the key elements of a process document that the utility and base need to agree on for microgrid islanding and reconnection process?
- [ ] What information needs to be made available during the demonstration? Who needs access to this information?
- [ ] What data (Insolation, temperature, wind speed, direction, precipitation, etc.) would be recorded/visualized/displayed before, during, and after the tests? Where will it be stored?

Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design

WORKBOOK

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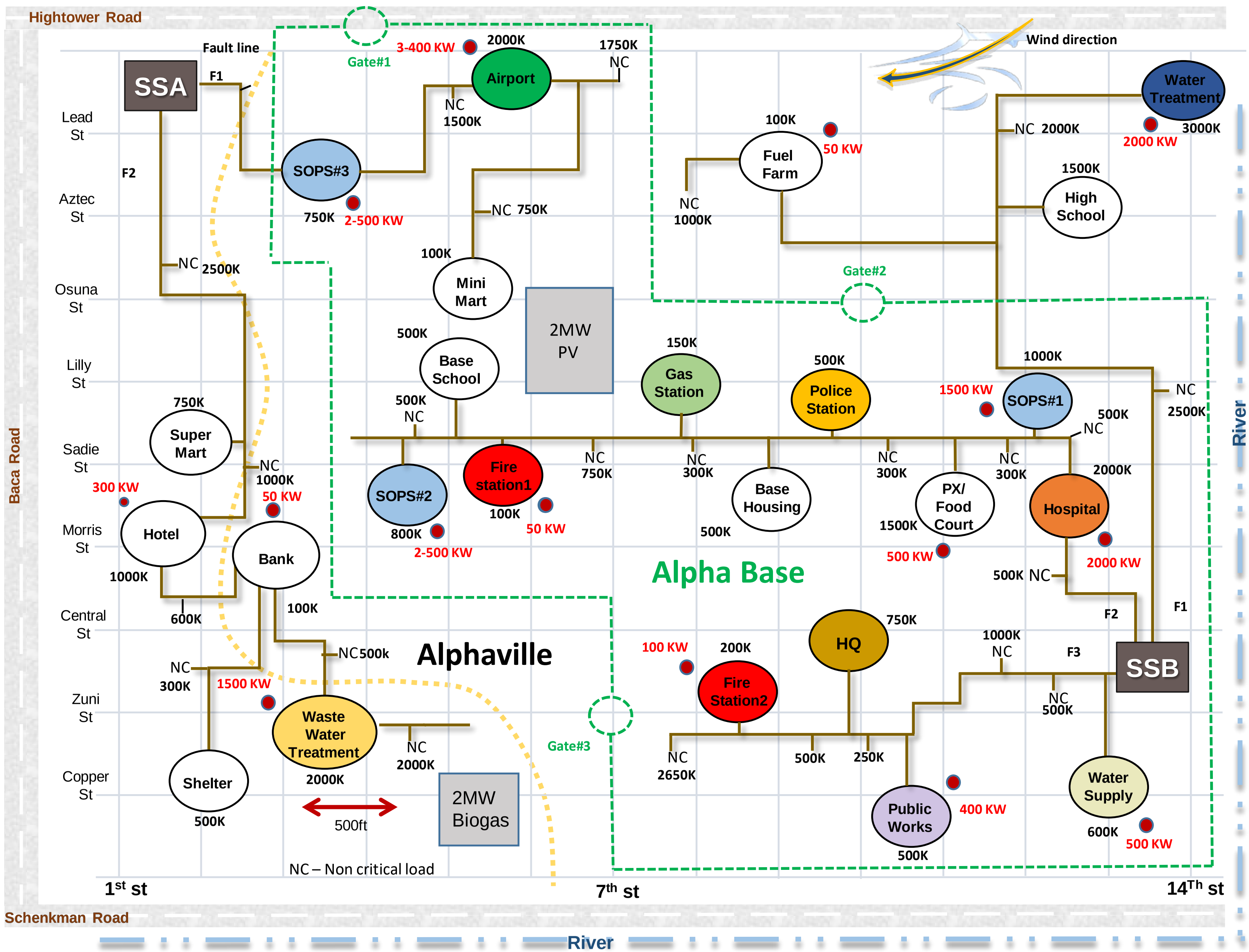
MICROGRID DESIGN COURSE WORKBOOK CONTENT

Alphaville and Alpha Base Feeder Layout



Course Case Study

This section provides background material for the case study to be done at the end of the course. The case study will present basic information on an example area (Alpha Town Center/Base) – located within a city, Alphaville, to allow the class to use the material presented in the microgrid course to develop and evaluate different improvements including advanced microgrids, based on the evaluation of prioritized critical services, buildings, and electrical loads based on selected operational performance goals and objectives for a set of design outage events threats. The performance/risk as well as costs associated with implementing these options will then be evaluated to determine cost effectiveness.

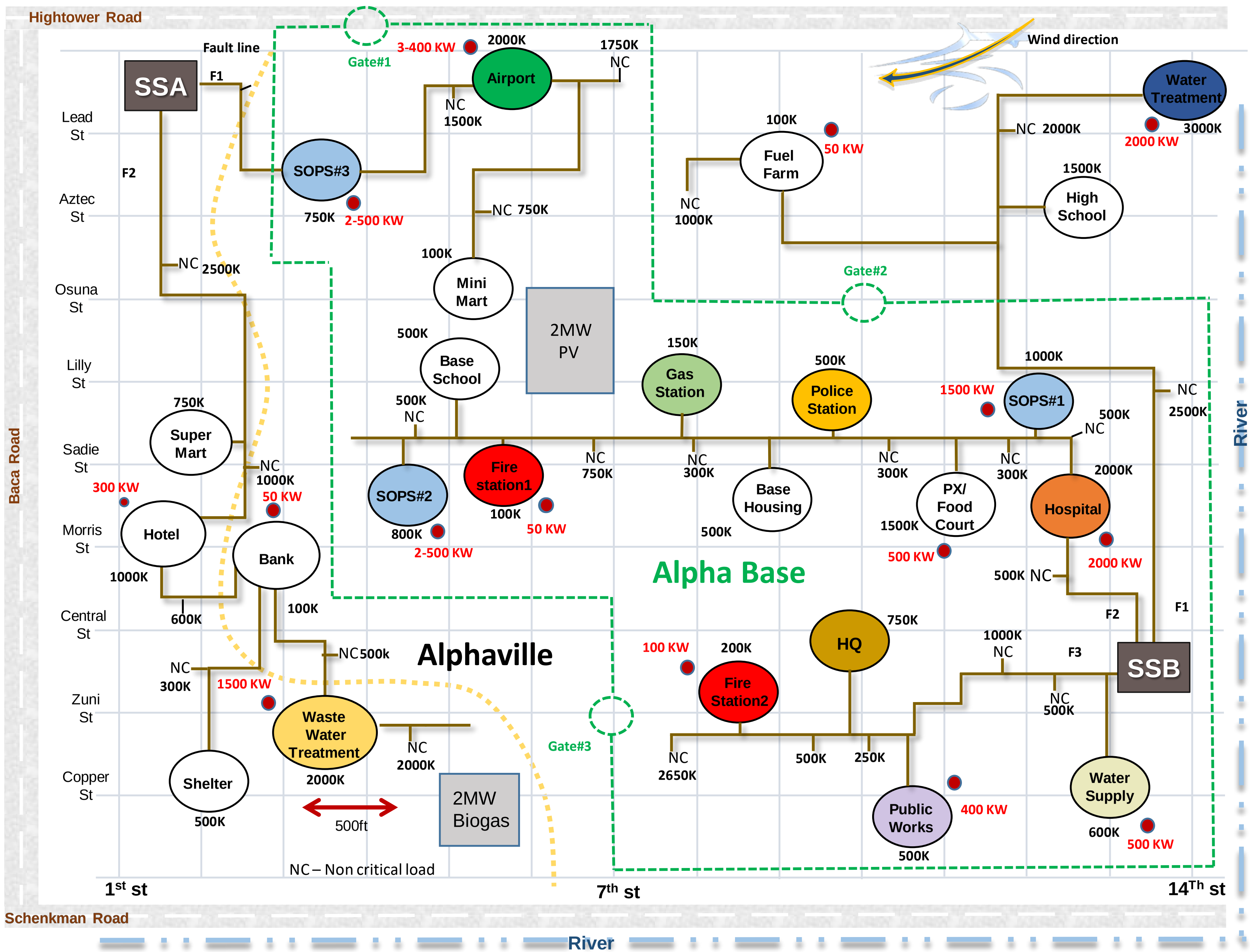
Alphaville

- Alphaville is a small city with a population of 30,000 residents, has its own city government, police, combined fire/ambulance services and a hospital,
- It has a water treatment plant that uses water from a river on the northeast corner of town, a second water supply, and waste water processed at the wastewater treatment plant and discharged in the southwest corner of town, with a 2 MW biogas plant under construction,
- The city is served electrically by a private utility with two substations and five feeders, both overhead (OH) and underground (UG), and that includes a planned 2 MW solar PV plant,
- Most of the northern and central parts of the city has gas service provided by a private utility
- The city has telecommunications (wired and wireless) and a dedicated city telecom network for emergency dispatch centered from a fire/dispatch center
- The city recently flooded from a hurricane, that overwhelmed the city, particularly in the Northeast and Southern parts. Though flood damage from hurricanes is only anticipated every 100 years, city planners want to be better prepared in the future,
- Of particular concern is affordable housing residents who don't have means to evacuate
- There is a fault line running through the city but no major earthquake in 100 years, and
- There are major windstorms from the northeast that in wintertime cause wind damage and falling lines from blizzards and ice storms.

Alpha Town Center/Base

- Supported by Alphaville feeders, with a population of 5,000 civilians
- Has one special manufacturing operations, with high regional and national economic impact if operation is curtailed or lost, and special areas of affordable housing,
- Has a small airport,
- Has a main town center building with emergency management functions,
- Has some important educational functions and missions,
- Has local police, fire and medical services,
- Has a local Public Works Department facility,
- There are some emergency generators that are nominally run for a few minutes each week, but not under load. The generators have day tanks of between 1-2 days of fuel supply.

Alphaville and Alpha Base Feeder Layout



Module 4 – Defining Energy System Functions, and Stakeholders

As the facilities working group of Alphaville, consider broadly what are your major goals and objectives are for an energy surety evaluation for the Town Center.

We want to provide energy surety for what types of services and assets:

What stakeholders need to be included:

What is the criticality of operations: One of a kind or able to be transitioned in given time frame.

In addition to existing backup generation, what types of distribution resources should we consider (e.g. diesel, gas, generators, cogeneration, renewables like PV or wind, etc.):

In addition to providing emergency services, do we want to consider ancillary benefits like cogeneration, providing peak shaving, selling power back to the utility, incorporating a certain set amount of renewables, etc.:

What funding sources are available (federal, city, state, private purchase agreements, etc.):

Module 5 – Prioritizing Critical Services and Facilities

Critical Services and Facilities

	Service ↓	Priorities (H, M, L)	#	Facilities	Priorities of Facilities (H, M, L)	Facility Category Service
1	Special Ops		1	SOP#1		
2	Airport		2	SOP#2		
3	Police		3	SOP#3		
4	Fire/Ambulance		4	Airport		
5	Water		5	Police Station		
6	Waste Water		6	Fire Station1		
7	Fuel		7	Fire Station2		
8	Food		8	Water Treatment		
9	Medical		9	Water Supply		
10	School		10	Wastewater		
11	Other Critical		11	Fuel Farm		
12	Miscellaneous		12	Gas Station		
13			13	PX/Food Court		
14			14	Mini Mart		
15			15	Super Mart		
16			16	Hospital		
17			17	Base School		
			18	High School		
			19	Headquarters		
			20	Public Works		
			21	Hotel		
			22	Bank		
			23	Shelter		

Critical Services and Facilities

	Service	Priorities (H, M, L)	#	Facilities	Priorities of Facilities (H, M, L)	Facility Category Service
1			1			
2			2			
3			3			
4			4			
5			5			
6			6			
7			7			
8			8			
9			9			
10			10			
11			11			
12			12			
13			13			
14			14			
15			15			
16			16			
17			17			
			18			
			19			
			20			
			21			
			22			

Facility Priority List

Facility	Service	Priority (H, M, L)

Module 6 – Selecting Design Basis Threats (DBTs)

Alpha Town Center located within Alphaville is considering options to improve the resiliency that has experienced power outages of 3 to 10 days four times in the past decade due to flooding and heat waves. Additionally, there are rolling brownouts during peak summer seasons in which portions of the city loose power for up to 2 hours a day, but no blackouts though increasing load demand may entail this possibility. There was once an ice storm which took services out to two of the feeders for a couple of days.

Using the following templates, rank design basis threats to determine what you think should be considered at Town Center to develop performance goals to meet these threats.

Design Basis Threat (DBT)

Threats ⬇	Likely hood of event (H 3, M 2, L 1)	Consequence of event (H 3, M 2, L 1)	System resilience to event (H 1, M 2, L 3)	Duration of event (Hrs 1, days 3, weeks 5)	Overall rank scores (Total)

Design Basis Threat (DBT)

Threats	Likely hood of event (H 3, M 2, L 1)	Consequence of event (H 3, M 2, L 1)	System resilience to event (H 1, M 2, L 3)	Duration of event (Hrs 1, days 3, weeks 5)	Overall rank scores (Total)

Module 7 – Defining Initial Performance Goals and Objectives

Based on the critical assets and facilities determined for the city of Alpha Town Center, come up with an initial set of performance goals and objectives to meet energy requirements.

Include:

Critical services, facilities, businesses, industrial areas to have power maintained and how and how much:

Duration of services required to meet DBT, including differences in requirements for longer term outages such as shelter in place, food, water gas, medical supplies, etc.:

Requirements for electric power reliability, redundancy, power quality:

Requirements for backup power sources and fuel supplies, reliability and maintenance:

Additional local or community specific goals and objectives:

Module 8 – Backup Generator Fuel Supply Requirements

Using the data in the following table, estimate the generator fuel use per day and generator tank storage capability in days based upon building peak demand values and generator fuel use table

Building Name	Peak Demand kW	Backup Generator Size (kW)	Generator Use (%)	Fuel Tank Size (Gallons)	Estimated Fuel use (Gal/hr)	Estimated Fuel use (Gal/day)	# Days of Fuel Available
City Hall	75	150		200			
Police Station	15	60		120			
Fire Station A	30	30		60			
Fire Station B	150	200		100			
Warehouse	30	60		80			
Police HQ	100	100		500			
Pump 1	75	300		200			
Example	**100**	**200**	**50**	**300**	**7.7** (from fuel use table – 50% use)	**184.8** (7.7*24)	**1.6** (300/184.8)

Building Name	Peak Demand kW	Backup Generator Size (kW)	Generator Use (%)	Fuel Tank Size (Gallons)	Estimated Fuel use (Gal/hr)	Estimated Fuel use (Gal/day)	# Days of Fuel Available

Equipment Generator Fuel Use Table

	Fuel Used (gal/hr) Based on % Loading			
Gen Rating (kW)	25%	50%	75%	100%
20	0.6	0.9	1.3	1.6
30	1.3	1.8	2.4	2.9
40	1.6	2.3	3.2	4.0
60	1.8	2.9	3.8	4.8
75	2.4	3.4	4.6	6.1
100	2.6	4.1	5.8	7.4
125	3.1	5.0	7.1	9.1
135	3.3	5.4	7.6	9.8
150	3.6	5.9	8.4	10.9
175	4.1	6.8	9.7	12.7
200	4.7	7.7	11.0	14.4
230	5.3	8.8	12.5	16.6
250	5.7	9.5	13.6	18.0
300	6.8	11.3	16.1	21.5
350	7.9	13.1	18.7	25.1
400	8.9	14.9	21.3	28.6
500	11.0	18.5	26.4	35.7
600	13.2	22.0	31.5	42.8
750	16.3	27.4	39.3	53.4
1000	21.6	36.4	52.1	71.1
1250	26.9	45.3	65.0	88.8
1500	32.2	54.3	77.8	106.5
1750	37.5	63.2	90.7	124.2
2000	42.8	72.2	103.5	141.9
2250	48.1	81.1	116.4	159.6

Generator reliability – 60% (0.60), not run weekly (historical)
80% (0.80), run weekly, ~20 min., under no load (IEEE)
95% (0.95), run weekly, under 20 % load, 15 min. (vendor)

Generator types – Emergency – good for 100 hours before major maintenance
Back up – good for 400-500 hours before major maintenance
Prime – good for 8,000-12,000 hours before major maintenance

Module 10 – Baseline Performance/Risk Calculation

**Calculate the performance risk for a three-day outage, based upon the following data table.

Asset	Facility	Critical Building Served (CBS)	Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity (Da/Dn)	Other Notes
1	Special Ops	3/3	100%			
2	Airport	3/5	60%			
3	Hospital	1/1	100%			
4	Fire	2/2	100%			
5	Public Works	1/1	100%			
6	Water Supply	1/1	100%			
7						
8						
9						
10						
11						
12						
	Performance Risk					

Performance/risk defined:

- **PR = 1-(CBS*CLS*RG*(Da/Dn)),** ***where:***
- **PR = Performance Risk**
- **CBS = % Critical Buildings Served**
- **CLS = % Critical Loads Served**
- **RG = Reliability of generation system**
- **Da = Operational availability – up to outage period**
- **Dn = Operational duration needed (outage period)**

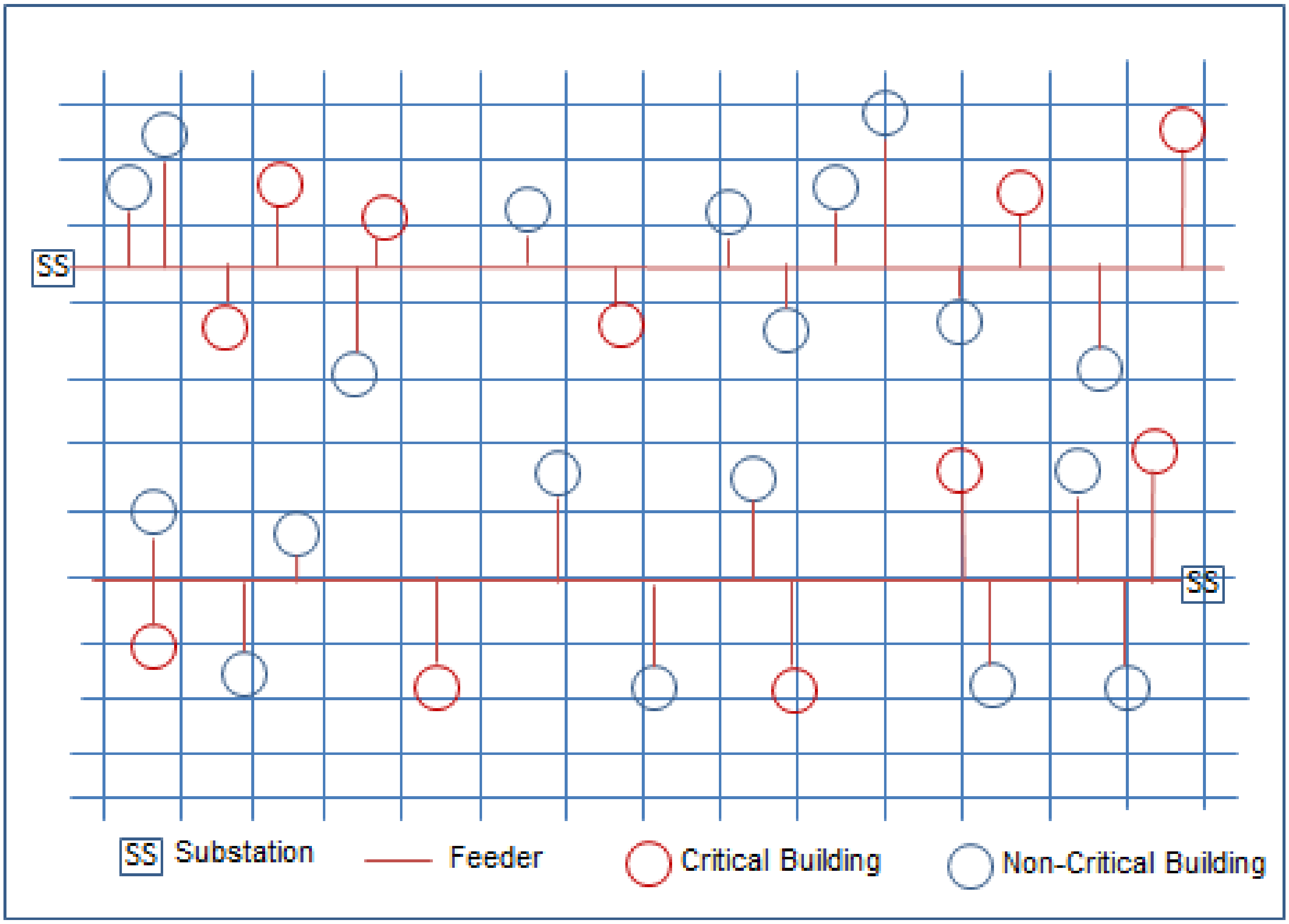
Asset	Facility	Critical Building Served (CBS)	Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity (Da/Dn)	Other Notes
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
	Performance Risk					

Performance/risk defined:

- **PR = 1-(CBS*CLS*RG*(Da/Dn)), *where:***
- **PR = Performance Risk**
- **CBS = % Critical Buildings Served**
- **CLS = % Critical Loads Served**
- **RG = Reliability of generation system**
- **Da = Operational availability – up to outage period**
- **Dn = Operational duration needed (outage period)**

Module 11 – Developing Initial Microgrid Conceptual Designs

Based on the one-line diagram below showing two independent feeders with critical and non-critical loads, cluster buildings together to come up with some initial sets of microgrid conceptual designs.



Module 11 – Improved System Performance/Risk Calculation

Use the previous calculations from Module 8 for performance risk for the baseline system. Add or improve facility generators, fuel capacity and reliability to increase the performance risk of the system.

Calculate the new performance risk for a three day outage, based upon the following data table for the existing system. Calculate and insert information on the table in order to do the performance risk calculation. Consult Performance Risk Analysis Methodology to help with the calculation.
**Calculate the performance risk for a three day outage, based upon the following data table.

Asset	Facility	Critical Building Served (CBS)	Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity (Da/Dn)	Other Notes
1	Special Ops	3/3	100%			
2	Airport	3/5	60%			
3	Hospital	1/1	100%			
4	Fire	2/2	100%			
5	Public Works	1/1	100%			
6	Water Supply	1/1	100%			
7						
8						
9						
10						
11						
12						
	Performance Risk					

Performance/risk defined:

- **PR = 1-(CBS*CLS*RG*(Da/Dn)),** ***where:***
- **PR = Performance Risk**
- **CBS = % Critical Buildings Served**
- **CLS = % Critical Loads Served**
- **RG = Reliability of generation system**
- **Da = Operational availability – up to outage period**
- **Dn = Operational duration needed (outage period)**

Module 11 – Performance Risk Calculation for Improved System – Worksheet Area

Improve system in exercise 1 for the set of critical facilities considered with a combination of Energy Resiliency improvements for the facilities considered.

Considerations can include:

- Advanced Microgrids
- Additional Backup Generation or portable generation ties where microgrids not feasible
- Other resiliency improvements, efficiency, combined heating and cooling, energy management systems, etc.
- Load Shedding of non-critical loads
- Increasing overall fuel storage capabilities
- Improving backup generation maintenance procedures
- Others

Generation resources can include:

- Distributed generation (diesel, gas)
- Renewables, such as PV, wind, geothermal, biogas, etc. to offset costs
- Energy Storage
- Others

Module 11 Additional Worksheets

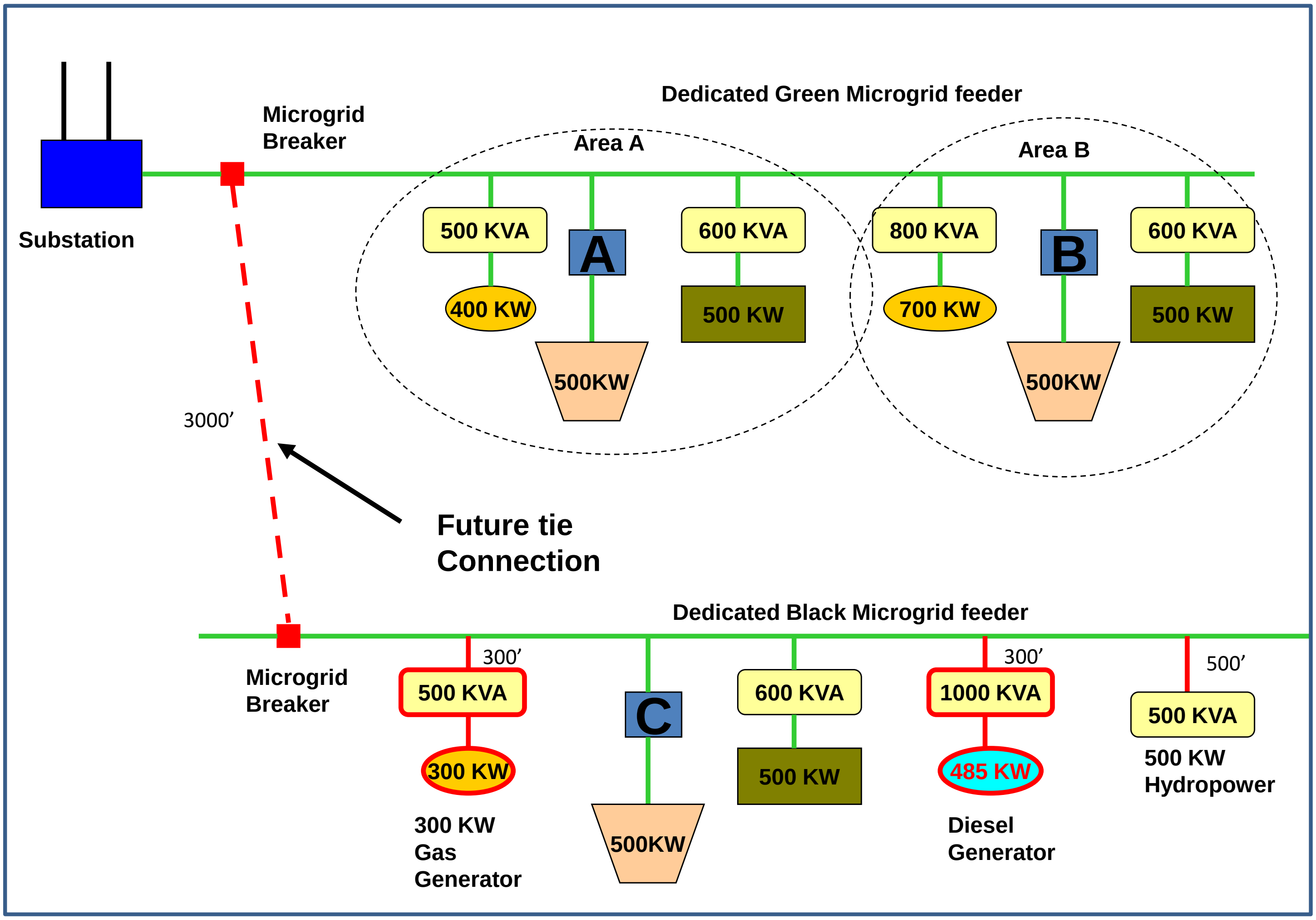
Asset	Facility	Critical Building Served (CBS)	Critical Load Served (CLS)	Generator Reliability (RG)	Existing Fuel Capacity (Da/Dn)	PR (1-(CBS*CLS*RG*(Da/Dn))
1						
2						
3						
4						
5						
6						
7						
8						

Performance/risk defined:

- **PR = 1-(CBS*CLS*RG*(Da/Dn)),** ***where:***
- **PR = Performance Risk**
- **CBS = % Critical Buildings Served**
- **CLS = % Critical Loads Served**
- **RG = Reliability of generation system**
- **Da = Operational availability – up to outage period**
- **Dn = Operational duration needed (outage period)**

Module 12 – Cost Estimation

Below is a proposed microgrid conceptual design. In red are new equipment elements which will work with existing elements to form the microgrid. All lines are underground and lengths are shown in feet. Calculate costs for this microgrid conceptual design using the cost table and worksheet below. Consult Generic Cost Analysis Methodology and cost table to help with the calculation.



Equipment Cost Table

Equipment	Cost $
OH Cable	$150/ft
UG Cable	$300/ft
Transformers	$40/KVA
HV Breakers	$100k/Unit
Reclosers	$30k/Unit
HV Switches	$20k/Unit
LV Breaker	$50K/Unit
Manhole	$15k/Unit
Pin & Sleeve	$100k/Unit
Controls	$100k/generator
Diesel Generator	$500/kW
Natural Gas Generator	$1000/kW
PV	$2300/kW
Wind	$1000/kW
CHP (Combined Heat & Power)	$2500/kW
Batteries	$2000/kWh
Fuel Tank	$1.5/gallon
Retro fit Buildings	$750/kW
Natural Gas Fuel	$10/MMBTU

Conceptual Design Cost Evaluation

	Quantity	Cost ($K/unit)	Total ($K)
Cable			
Transformers			
Switches			
Misc. Cost			
Generators			
Renewables			
Energy Storage			
Controls			
Cost Savings			
Subtotal			
25% Design & Eng. Cost			
25% Contingency Cost			
Total Cost ($k)			

Step by Step Process for Developing Conceptual Designs

Equipment generator fuel use table and backup generator reliability information is provided for generator related calculations. The equipment cost table is provided for cost calculations.

Separate building, feeder distribution and gas distribution layout maps exist along with a legend to develop microgrid conceptual designs

1. Prioritize critical services and buildings

Use Critical Services and Facilities and Facility Priority List worksheets to perform this exercise

2. Evaluate and Select design basis threat to be used in the conceptual design

Use Design Basis Threat (DBT) worksheet to perform this exercise

3. Calculate the critical loads

Use Facility Load Data as well as Feeder Data & Load Factor Calculation worksheets to determine the system as well as building load factors. Take the average of these load factors to calculate building loads to fill out the Facility Calculated Loads worksheet. The facility calculated loads will be the loads which microgrids will be designed for.

4. Calculate the storage capability and reliability of existing backup generators

Use the Facility Backup Power Data worksheet to fill out the Generator Calculations worksheet.

5. Evaluate the Performance/Risk of the Baseline System

Based on previous worksheets in particular which existing buildings are served by backup generators at what reliability, fill out Performance Risk Analysis for Baseline System to determine the baseline Performance/Risk

6. Determine performance objectives (including time duration required to meet DBT)

Consider the baseline performance/risk and use Performance Objectives worksheet to come up with performance objectives for microgrid conceptual designs to be developed.

7. Develop conceptual design microgrids to improve system performance risk

Consider all of the data calculations for the baseline system and layout maps to develop microgrid conceptual designs to improve the baseline system Performance/Risk. Use Conceptual Design Selection worksheet to evaluate ways to use existing as well as new generation, renewables, energy storage and fuel storage to improve the performance/risk of the baseline system. Use this data to fill out Performance Risk Analysis for Conceptual Design worksheet to determine the conceptual design Performance/Risk compared to the baseline.

8. Determine the costs associated with the conceptual design microgrid

Use Conceptual Design Cost worksheet to itemize costs for new generators and microgrid equipment necessary for the microgrid. Use this information to fill out the Conceptual Design Selection Evaluation and Conceptual Design Cost Evaluation worksheets. The selection evaluation worksheet is intended to check to see if conceptual have sufficient generation to meet critical loads with N-1 redundancy, the ability to lose any single generator and still remain in service. The cost evaluation worksheet is for summing the total costs for the microgrid conceptual designs along with the Conceptual Design Cost worksheet.

9. Time permitting, repeat steps 6-9 with extra provided worksheets with a slightly less costly set of conceptual designs and see how much the Performance/Risk changes.