



Making microgrids work:

Practical and technical considerations to advance power resiliency

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I. Introduction

According to **Eaton's Blackout Tracker Annual Report**, electric outages cost our economy \$150 billion annually and impact approximately 14.2 million people.

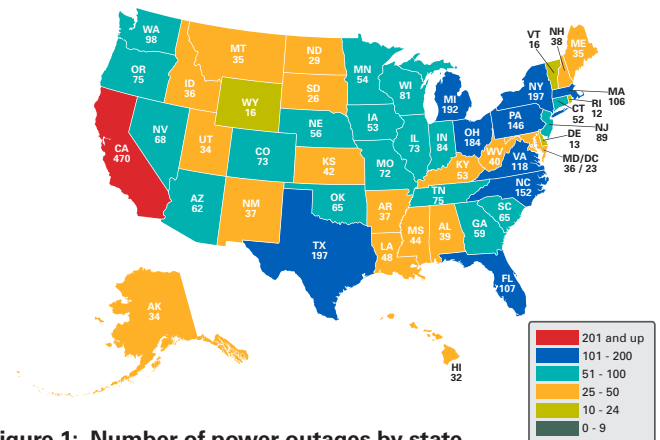


Figure 1: Number of power outages by state

Factors such as increasing occurrences of natural disasters, the ongoing threat of cyber attacks and growing awareness of inadequate, outdated or failing grid infrastructure all compel future development in technology to provide power continuity. Traditional standby generation is no longer adequate. Microgrids provide a platform to keep the power on and operate critical assets over long periods of time while isolated from a damaged or failed grid. Microgrids can generally better manage distributed power generation by providing optimal control, dynamic stability and balancing the demand and generation on a small but critical scale.

Early microgrids for the military focused on providing intelligent mobile power distribution to support power reliability and fuel savings on military Forward Operating Bases (FOBs). The high cost of safe and reliable access to fuel in combat situations led the U.S. Army to consider energy alternatives and resource management strategies. The reliability of continuous power for force support is paramount to troop safety and keeping FOBs operating around the clock. A reliable, energy-efficient system was needed to help

manage small distributed generators. In response, systems like the **Eaton Intelligent Mobile Power Distribution System** provided power surety. The system was able to become self-sufficient through a demand-managed microgrid that not only transformed independently operating generators, but also reduced fuel consumption at FOBs by more than 30 percent.



Figure 2: Eaton Intelligent Mobile Power Distribution System

A more resilient, responsive infrastructure is critical beyond military requirements. Power resiliency—the ability to sustain power and recover from adverse events—is critical across a host of industries and businesses, including utility, healthcare, industrial and governmental applications.

In other geopolitical areas, basic electrification remains a critical driver for microgrid innovations and their applications. Globally, over one billion people still lack access to electricity. For these communities, microgrids provide a viable platform for bringing electricity to the developing world. **Africa's largest microgrid project in Equatorial Guinea's Annobon Province**, for example, provides stable, reliable and consistent power supply to the island, thereby advancing regional economic development.

This white paper provides a basic survey of current microgrid technology, including its barriers, benefits and application areas. The microgrid feasibility study is considered a recommended means for developing more site-specific requirements and result in a positive return on investment (ROI). The paper also discusses a pre-engineered option for semi-automated, modular control microgrid architecture along with tips for identifying qualified vendors and providers of turnkey solutions.

II. Basic microgrid definitions

The Department of Energy (DOE) microgrid exchange group defines a microgrid as “a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid.” In essence, microgrids are standalone electrical power systems that consist of multiple generating assets and often storage sources supplying loads that can be powered independent of the primary utility transmission and distribution grid.

Two of the greatest benefits of microgrid technology are increased reliability and power quality to large critical loads like mega scale data centers and hospital districts. Onsite generation already exists in these loads and microgrid technology enhances the reliability by sourcing the loads in addition to transmission and distribution systems. Peak loads can be reduced through microgrids, while lowering demand charges associated with peak energy costs and providing an economic structure to install microgrids to use the existing onsite generation.

Microgrids can also be successfully leveraged to either defer capital investments in the grid or enable participation in new ancillary services. Increasingly, microgrids are further leveraged to effectively accelerate the adoption of distributed renewable energy sources that are intermittent, which reduces global dependence on fossil fuels while lowering climate-damaging carbon emissions.

Despite these many benefits, some technical and regulatory issues must still be addressed to realize the full potential of microgrid systems. Current barriers span economic and technical aspects.

Economic barriers include the high cost of building microgrids from scratch, the cost of upgrading legacy equipment and infrastructure to operate microgrids, net metering issues, regulatory and market issues, the high cost of components, difficulty in quantifying the benefits, funding and maintenance.

Technical challenges include technology immaturity, upgrading legacy generator controls, addressing complex energy imbalances to ensure optimal control, islanded microgrid protection and ensuring cybersecurity needs. Lastly, as communications become faster and more data intense, microgrid systems must also adapt to current real-time network demands and interfaces.

In most current microgrid designs, a few key components can be outlined. The microgrid is tied to the upstream grid via a point of interconnection (POC) and is managed by different controller architectures. Of greatest importance are the microgrid's local controllers, different from the device controllers, which are typically configured for energy storage, photovoltaics, engine-generator control, load connection, or general system coordination and communication. Local control of assets enables faster, semi-autonomous or autonomous control of the microgrid devices to better maintain operation within connected equipment limits.

Local controllers scale, normalize and manage control, operational and monitoring data flow to an upstream system controller. This controller and a human machine interface (HMI) then oversee connections to the upstream grid, including system configuration, POC monitoring and application selection and control functionality.

According to the DOE exchange group definition, “a microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island modes.” The technology available today allows microgrids to function with distributed generation assets during times when the grid is healthy and operating properly, while also having the capability to physically disconnect from the grid and operate in an islanded mode for extended periods of time, powering critical infrastructure.

Three basic operating modes are typical of microgrids:

- **Normal grid connected operation:** During normal operation, the microgrid is connected to the grid and the loads are powered by a power mix of grid and DER power. Local DER assets may be running behind the meter on the customer site.
- **Islanded operation:** During islanded operation, the microgrid system is not connected to the grid and the load is powered by the DER independently, off the grid.
- **Outage mode (or Black-start mode):** When generation type and size are not adequate for seamless islanding, normal connection to the grid is suspended, resulting in a blackout and island mode operation being started with proper sequencing of generators and loads. This could occur for a variety of reasons. For example, due to DER size or lack of load shedding, the DER may not be able to handle the load.

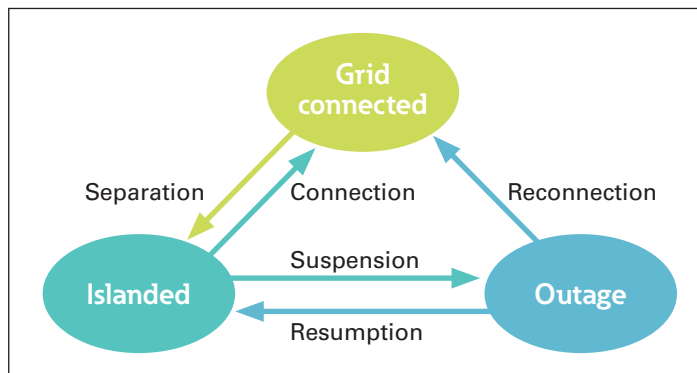


Figure 3: Microgrid system operating mode

III. When to consider microgrid applications

In the U.S., microgrids are ideal solutions for several common installation scenarios:

1. Community microgrids that serve as refuges during hurricanes or other weather issues in disaster-prone areas
2. High-resiliency areas for military and mission-critical areas
3. Rural and remote areas that currently operate on a weak grid
4. Areas where electricity is prohibitively expensive, like Puerto Rico and Hawaii
5. Upgrading the utility transmission and distribution system—microgrids can provide functionality on the grid that enables the deferment of more involved upgrades of transmission and distribution system assets

As related standards are currently in the works, the philosophy and approach to islanding are evolving. Also, with the increased penetration of DER, utilities are increasingly looking to keep renewable assets online (not islanded) and able to ride through events that may impact the grid.

It is also important to note that healthcare institutions already have backup systems to support reliable power, in line with the requirements of the **Joint Commission** (including EC.02.05.03 and EC.02.05.07); typically, these address short-term emergency power situations and incorporate a variety of assets—from diesel generators to other DERs. As events like Superstorm Sandy demonstrated, it is imperative to have systems in place that are able to do more than support short-term outages, but rather are able to support critical community functions in the face of potential longer-term grid outages. Powering only the critical loads is not enough during extended outages—powering the community around critical loads is needed. This is achieved through microgrids, not by typical standby power.

IV. How to develop a site-specific microgrid plan

Many questions can arise while exploring microgrid sizing and design options. No one-size solution can fit all circumstances; rather, to understand each specific context, many factors must be explored, among them the existing electrical infrastructure (if any), load profile and growth, utility rates, existing generation assets, generator control capabilities, etc.

A “feasibility study” is used to identify and define the microgrid project for optimal technical features (use cases) and economic return. Qualified vendors have evolved routine methods to assess the full breadth and depth of standard microgrid concerns while defining the unique and specific details appropriate for each potential implementation case.

A **feasibility study** should attempt to answer in very simple terms whether or not a microgrid makes good sense to employ in a specific circumstance and if so, what configuration and components are optimal to meet the specific power needs of the given scenario. The feasibility study process walks customers through these concerns step-by-step: first determining critical needs and requirements, then developing a microgrid plan and finally outlining more specific technical aspects and recommendations.

Initial screening questions might touch upon functionality requirements; existing load and generation information; automation infrastructure availability; utility requirements; generation preferences; and other security, legal and commercial aspects.

For example, the screening might attempt to uncover functional specifications by exploring critical load requirements as well as any load shedding, demand response or black start (outage mode operation) needs. Peak electrical and thermal load profiles, load types and profiles must be identified prior to the design. During the screening, further assessment of existing generation and automation systems, including their scope, functionality and interfaces, should be pursued in-depth to determine more specific microgrid assets and system topology.

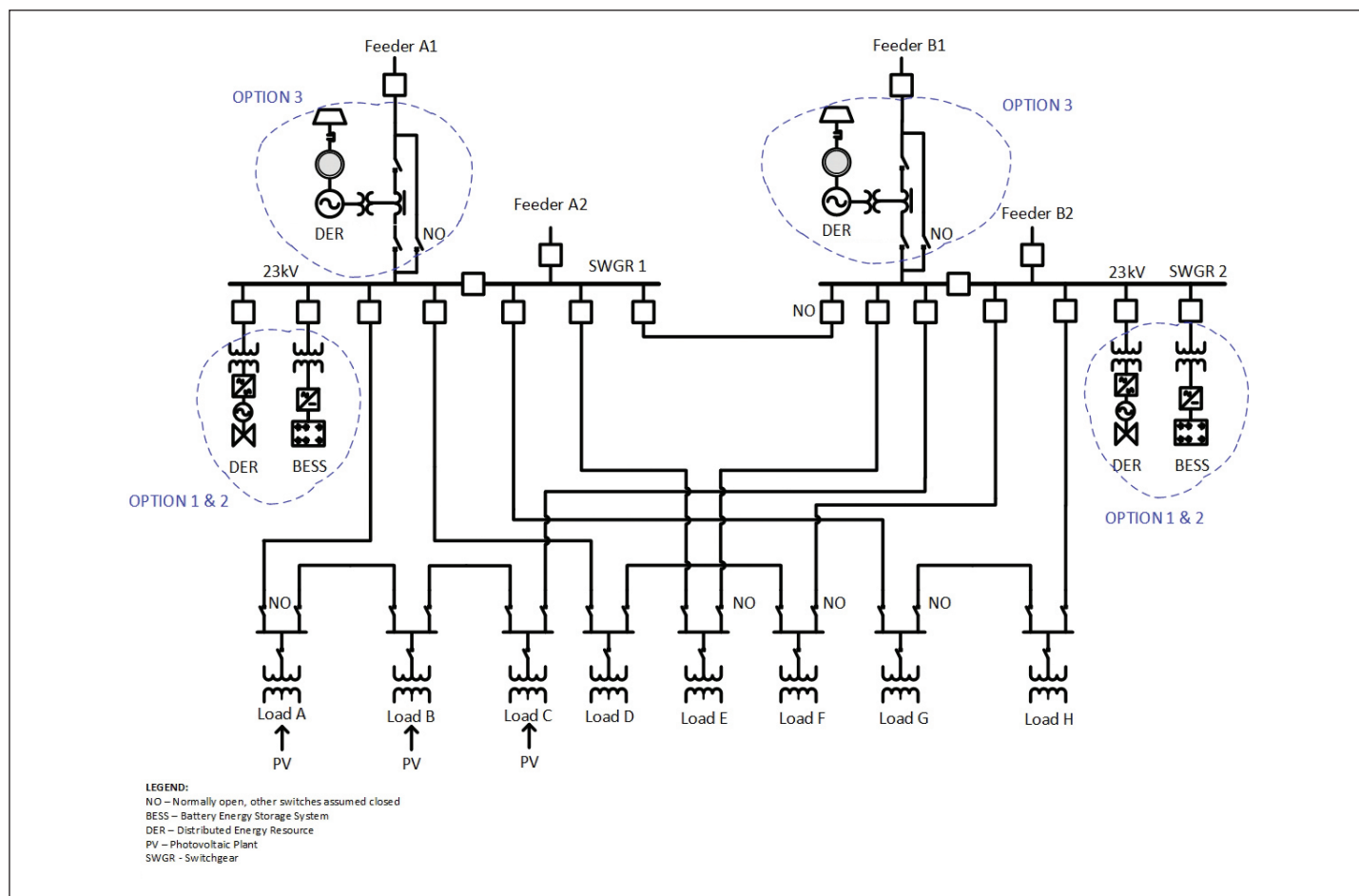


Figure 4: Sample of proposed microgrid configuration options

Each critical asset (facilities and present applications) must be identified and addressed in the study in terms of their energy needs and the criticality of each asset. Based on these identified power-critical assets, load sizes and profiles, the location of supply and storage infrastructure necessary to adequately support critical assets will be identified and designed into the proposed system.

These technical considerations help define the microgrid's functions and control system. Constraints are considered in detail to help fine-tune chosen microgrid components and sizes. Commercial tools to model microgrids include CYME™ power engineering analysis, software, PSCAD and others.

Another aspect of the feasibility study should cover economic analysis. It is important to explore whether or not a microgrid solution will be economically feasible. The feasibility study can help to define the type of appropriate microgrid components and their sizes to more effectively control cost. Optimal component sizes minimize the levelized cost of energy (LCOE) for shorter payback duration. Available tools range from custom spreadsheets provided by the vendor to commercial evaluation tools like DER-CAM, Homer or NREL Blast.

The feasibility study supports documentation of utility requirements inclusive of billing, interconnection and application requirements, SCADA communications, ownership agreements, metering contracts, permits, incentives and other environmental concerns.

With all analysis complete, a comprehensive and tailored energy reliability plan can be developed for the microgrid implementation. The resulting feasibility report comprehensively details the intended functionality of the proposed microgrid and its scope, existing system assets to serve the load profile, a proposed design, details on distributed energy resources including renewable energy sources, recommendations for suitable energy storage technologies and their sizing based on the microgrid requirements, an overview of operational modes and control strategies within the design and detailed cost estimates for ascertaining benefits.

Renewable energy assets, if desired, can also be incorporated into the microgrid design. The DER (renewable or not) should be selected based on what is most appropriate for the system's goals, be it generators, energy storage, solar, or other renewables. Existing and future distributed energy resources such as solar, wind, combined heat and power (CHP), fuel cells and energy storage are evaluated. Additionally, the type and availability of the fuel to power other distributed generation assets is evaluated under the foreseeable contingencies and environmental rules.

Additional studies addressing more specific topics may also be attached to the feasibility report. Examples include short-term reliability improvement recommendations; site-specific studies of load flow scenarios, short circuit and dynamic simulations to address transients; review summaries of environmental or noise issues; and microgrid protection recommendations tailored to operational modes.

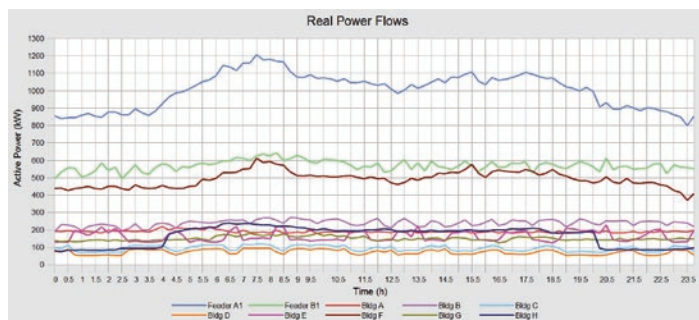


Figure 5: Sample microgrid simulation result

If economic feasibility is a focus of the study, additional details may address cost-benefit analysis of various DERs and energy storage options, including optimal sizing for minimized levelized cost of electricity, in view of available incentives; or, financial pay-back options for peak-shaving, load shifting and/or shedding; net metering (power export); or ancillary services solutions.

V. The virtual microgrid advantage

How can you be sure the microgrid will perform as intended before you cut the ribbon on the project? Even if performance and functionality can be verified in advance, what if you could go a step further and analyze the data needed to improve performance before the system is installed?

Just because a microgrid seems like it should work does not mean that it will. Making something real is the ultimate challenge, especially when the system is complex and involves many interworking components including evolving generating assets, the electrical grid and resiliency requirements to satisfy the needs of a certain application.

Developing a microgrid requires power system, automation and control knowledge well beyond the specific energy resources and equipment involved. Seeing the big picture and understanding how to optimize the overall system is a critical aspect to microgrid success.

In other words, even a simulation of individual microgrid components does not provide the fundamental assurance of system performance or provide data beyond a small part of a complex system. For this reason, it is useful to leverage simulation software and experience. For example, in utility applications, distribution system modeling with CYME software and other technologies has provided industry-tested critical modeling capabilities to better show the interdependency among system components, while providing more precise simulation of distribution systems and distributed energy generation resources.

Feasibility studies can do more than provide the sizing of equipment and assess the functionality and likely future performance characteristics. The last compelling aspect of a feasibility study is the ability to see how the system functions before ground is broken on the project. This virtual microgrid provides insights on the feasibility, design and application in a virtual environment.

Virtual microgrids, or hardware-in-the-loop simulations of complex microgrid systems, enable owners and project designers to understand the system as if the assets and devices were already connected. This demonstration informs how the system is configured and optimized during the design phase. The ability to play with the microgrid system before it is in place helps drive a better understanding of the system dynamics and feasibility—all based on data from the simulation. The virtual microgrid also gives owners confidence that the system will perform as expected, as well as data-driven insights to modify the design to optimize performance.

Often, the specific use cases and application requirements for a microgrid are somewhat fluid and depend on a multitude of factors, including grid conditions, user energy demand, renewable generation, etc. Virtual microgrid simulation enables specific use cases to be demonstrated and gather the data from the results.

Additionally, customers' data can be imported into the virtual microgrid to help develop the system's load profile and utility rate structures. From there, data can be exported from the virtual environment for further evaluation and measurement of performance metrics agreed upon in advance of the project breaking ground.

Accurate simulation results lead to more precise planning and management of the microgrid system, including its distributed generation and distributed energy resources. This allows projects to move more quickly and successfully, with confidence they are optimized out of the gate.

Insights from a virtual microgrid can be configured to specific requirements and application considerations, enable pre-engineering and system configuration and optimization to save time (and money). Today, the microgrid controller can be pre-configured and mapped based on the feasibility study and virtual microgrid simulation to help avoid project delays and save time during the installation and commissioning phase. The next critical part of the system to examine is the controller and how its design can impact the microgrid and support evolving system requirements.



Figure 6: Eaton's virtual microgrid managed by the physical Power Xpert Energy Optimizer™ controller

VI. Using a microgrid system controller

An **integrated, modular, distributed control architecture** can enable adaptable, scalable control for microgrid applications. Because this kind of solution focuses on configured rather than custom programming, the controller can ultimately reduce onsite and other engineering costs, especially when a virtual microgrid is tapped to provide system insights.

A pre-engineered, factory-designed and tested controller should be based on a replicable model that is designed for further customization to site-specific requirements. This approach can simplify microgrid control system configuration—easing device and system testing while assuring adaptable control over changing microgrid assets. Easy configuration ensures maximum flexibility and scalability for the microgrid and its stand-alone energy storage applications.

The controller functionality should coordinate automated system sequencing in response to user commands, system status, limits or faults. Additional control functions could also include active control, data logging, alarm management and processing, as well as security.

VII. Finding a qualified microgrid supplier

Three factors should be considered when seeking a qualified microgrid supplier: expertise, experience and demonstrated success with prior projects.

Proven power engineering, automation and control experience is essential in any microgrid partner. Suppliers should also be able to provide rapid, dedicated, local support to help expedite projects and on-the-ground expertise to address unforeseen challenges.

Vendors should be able to provide more than the right controller. Because every project carries unique circumstances, the best vendors will work with you to fully understand and plan for your individual project's needs. Customized solutions help optimize, build and maintain an automated, secure and cost-effective microgrid.

The best-case scenario is utilizing a virtual microgrid that provides data-driven insights and understanding of device communication interfaces and performance characteristics that can be verified before installation and commissioning.

Vendors who offer the capability to provide turnkey solutions often afford greater experience and flexibility. A vendor's project portfolio can be indicative of the breadth and depth of its solutions experience.

When **Portland General Electric (PGE)** needed to develop a working smart grid for its new Salem Smart Power Center, a 5-megawatt demonstration facility in Portland, Oregon, Eaton provided power systems engineering expertise and industry-leading solutions to test new smart grid technologies with its business and residential customers. The project advanced PGE's electrical infrastructure by demonstrating a highly reliable medium voltage feeder that today serves as a replicable energy storage model for reliably powering commercial and residential customers.

In another example, Eaton assisted the Department of Defense (DoD) in the design and development of **microgrids designed for seamless transition between grid-connected and islanded operation at Fort Sill**. The project provided valuable experiences working with a high concentration of dynamic and nonlinear loads. Many real-world microgrid installations are likely to be retrofit applications that require similarly high penetration of dynamic loads. The resulting microgrid improved energy security for the DoD by providing operation during grid outages and leveraging renewable energy sources as well as integrating a battery energy storage inverter into a commercial isochronous control system with monitoring features and advanced optimization methods.

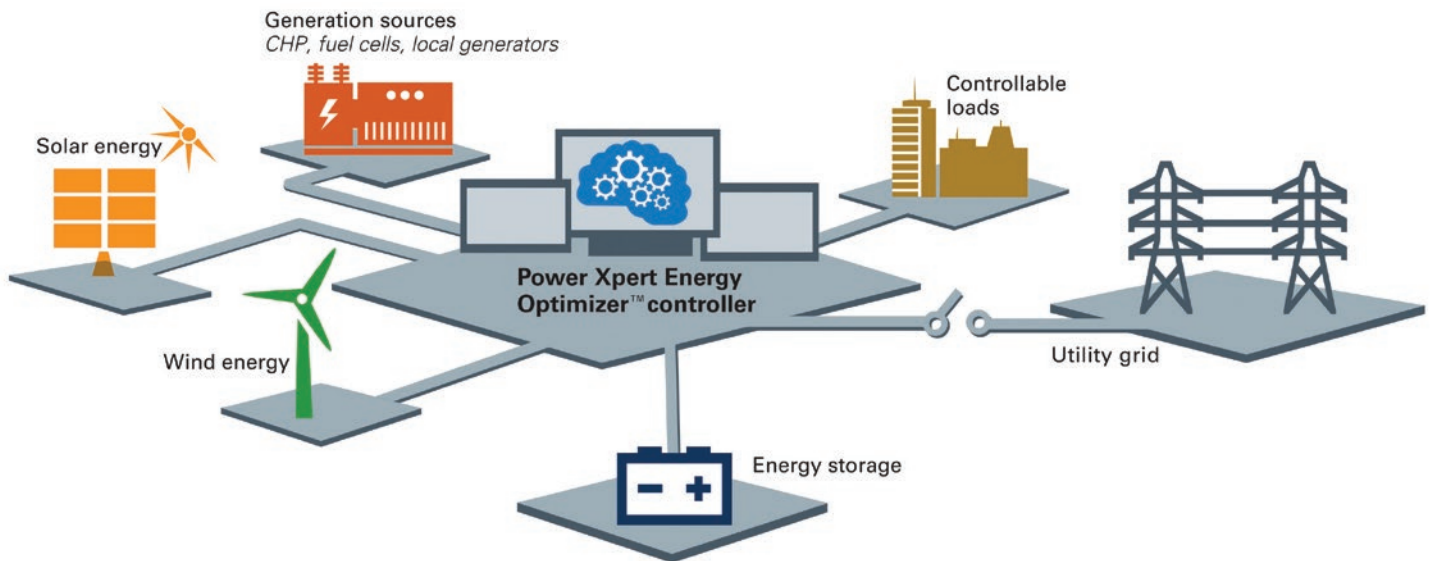


Figure 7: Eaton microgrid energy system

Eaton's Electrical Engineering Services & Systems team is one of the largest and dispersed group of experienced engineers and technicians. We offer extensive experience in electrical power distribution systems design, feasibility studies, installation, startup, commissioning, maintenance, troubleshooting, life-extension and ongoing monitoring of operating parameters as well as failure indicators.

When it comes to selecting DER for microgrid applications, Eaton is DER agnostic and selects the appropriate energy solutions. Given the system goals and existing assets, Eaton works to identify the optimum DER.

Over the decades, Eaton has performed thousands of complex power system, automation and control studies—with scores of successful projects ranging from designing and installing new power systems to servicing, maintaining and modernizing to extend the useful life of aging systems. Understanding the entire system and how all the microgrid components work together delivers a powerful advantage, especially when coupled with data-driven insights. With a proven history of power system excellence, Eaton understands the microgrid evaluation and design process needs to precisely match and meet the goals of a specific project.

Eaton has also has invested in a full-scale operational microgrid at its Power Systems Experience Center in Pittsburgh. Visitors to the Experience Center can see an operational microgrid system and its testing laboratory, with access to a controlled environment that allows direct observation of microgrid performance, testing, demonstrations and training. Through this laboratory and other research and testing facilities, Eaton continues to invest time and resources to experiment with the operations of microgrids, with the goal of better understanding the unique feasibility, dynamics and requirements of each customer. Through this commitment to project success, Eaton provides an experienced partner that is dedicated to making microgrids work, with successful deployment of systems that meet and go beyond your specific needs.

For more information, please visit: Eaton.com/microgrid.

Resources

Forbes: Why reality is the best innovation challenge, by Jonathan Salem Baskin with Eaton's John Stampfel

Design of the Fort Sill Microgrid, by Andrew Paquette, Ronald Harley School of Electrical and Computer Engineering Georgia Institute of Technology; Vijay Bhavaraju, Slobodan Krstic, Peter Theisen at Eaton

Eaton's Intelligent Mobile Power Distribution System for military applications

Portland General Electric: **a working smart grid that's a model in energy intelligence**

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About the authors

Martin Baier is an engineering manager at Eaton. Baier was part of the team that started Eaton's engineering services organization nearly twenty years ago and recently was the engineering manager of electrical solutions and services in the Europe, Middle East and Asia (EMEA) region for Eaton. Over a career that spans three decades, Baier has also managed Eaton's power systems engineering and automation services teams. He holds professional engineering status in Pennsylvania and is a senior member of IEEE and writing group member of the SCC21, P1547 Standard series that deals with the interconnection of renewable and dispersed generation in utility systems.

Dr. Vijay Bhavaraju is a principal engineer in Eaton's corporate research and technology team. He has over 35 years of industrial and academic experience. His current responsibilities include the design of microgrids and investigation and design of new topologies and architectures for distributed energy resources. At Eaton, Dr. Bhavaraju was a principal investigator for an Army funded microgrid project and was technical lead for other microgrid projects.

William Murch is the director of services for Eaton's microgrid energy systems business. Murch leads Eaton's microgrid energy system solutions and has more than thirty years of experience in electrical systems. He has worked with customers across commercial, industrial and utility applications to solve complex power management challenges.

Dr. Sercan Teleke is an expert in energy storage, solar photovoltaic (PV) systems, microgrids, renewable energy integration, power electronic applications to power systems and power system design and analysis. His professional career includes consulting experience and interacting with various electric utility companies and renewable energy developers across North America, as well as manufacturing experience. He is a senior member of IEEE and IEEE Power and Energy Society.

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