



Microgrid evolution fuels smarter energy management

Smarter energy management delivers reliability, efficiency and cost savings

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Introduction

Electrical power is essential. From the time when our alarm goes off in the morning to when we turn the lights off at night, we use electrical power. In terms of magnitude, each person in the U.S. spends around \$3,052 on electricity (2012 figures). With a population of about 314 million people at the time, our energy habits equate to spending something in the order of \$958 billion per year.¹

Our homes, businesses, healthcare, community infrastructure and educational institutions all rely on power. Yet, due to an aging infrastructure and increasing demand, our electrical grid is not as reliable or resilient as we need. In the face of major storms, grid outages, grid instabilities, cyber threats and other events, we need to be smarter and more cost-efficient about how we generate, manage, distribute and strengthen our power grids.

With increased capacity of solar, wind, energy storage, combined heat and power (CHP) and other distributed energy resources, there is an opportunity to optimize energy to support resiliency to critical areas. In addition, as technology and material costs for solar PV and energy storage have improved, it is now possible to generate reliable energy to improve grid resiliency at competitive market pricing levels.

Over the last decade, microgrids have become an increasingly compelling means to not only keep the power on, but to manage distributed energy resources and energy costs. According to GTM Research², the trends driving microgrid growth include:

- Energy resiliency requirements stemming from extreme weather/power outage events
- New business models for microgrid ownership that involve multiple stakeholders
- Technology innovations enabling strategic energy management
- Opportunity for microgrids that support commercial and industrial customers



Microgrids must be able to operate in parallel with the grid and as standalone electrical power systems that consist of multiple generating assets and often storage sources supplying loads, which can be powered independent of the primary utility transmission and distribution grid.



Powering Business Worldwide

In the beginning: Department of Energy, utility project is the first of its kind

In October of 2012, a 5 MW / 1.25 MWh energy storage system, part of a broader U.S. Department of Energy Smart Grid Demonstration project, was commissioned for Portland General Electric (PGE) in Salem, Oregon. This early energy storage system was integrated with an existing distribution feeder and utility-dispatched distributed generation to form a high-reliability zone. The system was an industry-first; it used lithium-ion battery technology in a large, utility-scale application that could operate connected to the traditional utility supply or as an island in voltage forming mode, allowing the generation on the feeder to connect to it.

When connected to the substation, through intelligent power management, the energy storage system can store or release energy depending on energy market conditions to optimize lower cost generation resources. The system can also prioritize renewable generation over fossil fuel plants, ensuring that the utility makes the best use of renewable energy that is already available.

The integrated control system operates the energy storage system in a variety of modes interfacing with inverters, power meters, the battery management system and the utility's upstream system controls. This closed loop control system coordinates the operation of the inverters and balances states of charge among the 40 battery blocks. In the event of an upstream outage, the control system, combined with custom inverter programming, provides seamless support for loads—keeping the power on for commercial and residential customers served by the feeder. The system also allows the operator to request that the batteries be equalized in charge and enables the storage system to respond to real and reactive power commands from the utility, helping the utility test its smart-grid control algorithms.

The intelligent energy storage system along with the dispatchable generators create a high-reliability feeder that can detect faults and island the medium-voltage feeder—helping to improve service reliability. Inside of the high-reliability zone, a 2.5-mile smart feeder system provides reliable power for residential, commercial and light industrial customers. Additionally, the energy storage system has sufficient capacity to support the microgrid for several minutes, creating a backup power supply in case of an interruption.

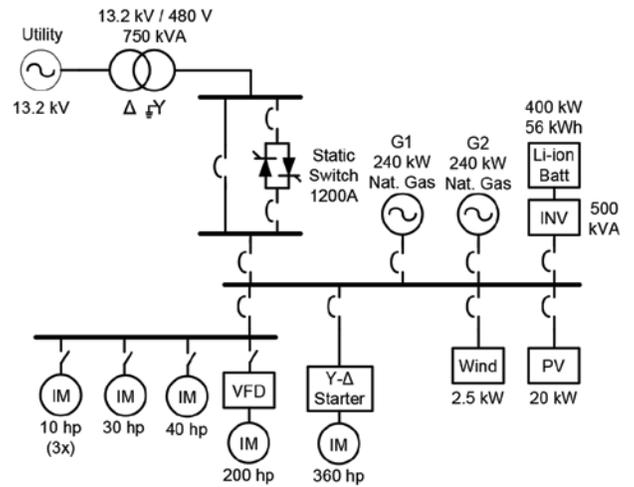
Five years ago, the system was at the forefront of smart grid technologies—helping to build the intelligent distributed energy resources of today while continuing to deliver value for the utility's customers. PGE continues to add more features to the energy storage system.

Early microgrids: Defense initiatives advance technology and demonstrate capability

Energy resiliency and security is a critical concern for the Department of Defense (DoD), which needs to operate regardless of electric grid outages from cyber-attack, natural disaster, aging or lacking infrastructure, or equipment failure. The DoD is also responsible for most of the U.S. government fuel consumption and is one of the largest single consumers of energy in the world. As such, it has a vested interest in ensuring energy resiliency, reducing consumption and controlling costs, and has pursued a variety of initiatives to reduce fuel needs and change the mix of resources that it uses.

Military security relies on energy surety

The DoD recognized a shortage of demonstrated large-scale microgrids that would support its interests in energy surety, reducing fuel cost, resupplying convoy casualties and increasing renewable energy capacity. In 2013, a full-scale demonstration project at Fort Sill in Oklahoma showed that such a system could work off grid and balance the use of solar, wind and natural gas backup power and store energy for later use.



The Fort Sill microgrid one-line diagram

The project was part of the DoD's effort to better reduce costs and increase reliability. The microgrid extended the smart grid to integrate renewable resources and optimize fuel mix, energy storage and system operations to reduce cost, carbon footprint and the system architecture—maximizing reliability and uptime.

The key innovation in this project involved adapting a conventional control system for monitoring and control of a microgrid with generators and inverters, instead of developing a system controller and monitoring from scratch. The project built on microgrid control technology to improve the level of maturity and demonstrate a full-scale DoD microgrid.

The Fort Sill microgrid provides valuable experience for seamless transitions between grid-connected and islanded operation and experience with a high concentration of dynamic and nonlinear loads. As microgrids are retrofitted into existing systems with a high penetration of dynamic loads, the Fort Sill microgrid demonstrated the ability to provide energy resiliency by operating during grid outages, seamlessly transitioning between grid-connected and islanded operation, and integrated renewables and energy storage.

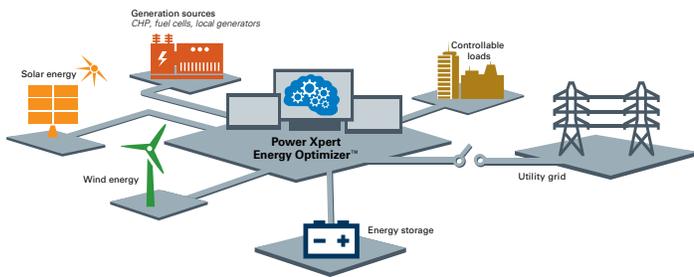
Microgrids on the move

Military success and security in combat situations depends, in part, on safe and reliable access to fuel, which can come with a high price tag. Considering the price of fuel for forward operating bases, or the actual cost of buying, moving and protecting a gallon of petroleum, the costs of supplying battlefield generators with fuel has increased dramatically. This dependence and the threat it faces in forward operating bases led the U.S. Army to seek both energy alternatives and resource management strategies.

Eaton developed the [Intelligent Mobile Power Distribution System](#), a reliable, energy-efficient system to help manage generator output in 2014. By transforming an independently operating system of generators into a demand managed microgrid, the Intelligent Mobile Power Distribution System provides power only where and when it is needed. This technology indirectly limits the risk that our troops face to use, transport and store petroleum due to the decrease in fuel consumption.

The system supports resiliency by providing adequate power to meet current energy demands, instead of inefficiently engaging all the generators continuously, which can reduce energy waste. Further, the system also uses intelligent load management technology to prevent grid collapse in the event of a generator fault. If one generator were to fail, the Intelligent Mobile Power Distribution System prevents a stoppage of energy flow by shifting demand onto the supporting generators, thereby providing a constant, safe supply of power.

The U.S. Army's military installation at Fort Devens, Massachusetts demonstrated that the demand-managed microgrid significantly outperformed the traditional approach that relies on multiple independent generators. This system reduced fuel consumption more than 30 percent at the forward operating military base.



Eaton's microgrid energy system

Enabling technology

These and other successful early deployments helped advance and innovate on technology that is enabling new applications and driving value from microgrid systems. The control architecture is one of the most important elements of a microgrid system—it provides the brains behind the operation. In most current designs, the microgrid is tied to the upstream grid via a point of interconnection (POI) and is managed by local control of assets, which enables faster, semi-autonomous or autonomous control of the microgrid devices to better maintain operation within connected equipment limits.

Nearly five years ago, early U.S. Department of Energy Smart Grid Demonstration projects showed the technology was feasible to manage the utility-scale storage system and integration of renewables. However, at that time, the controller was a customized solution. Today, an integrated, modular, distributed control architecture is becoming a reality.

Using lessons learned from early projects, new technology that is pre-engineered, factory-designed and tested provides a replicable model that is designed for further customization to site-specific requirements. This approach can simplify microgrid projects that use a variety of renewable or distributed energy resources plus storage, making it easier to test the system and support forward compatibility as the system evolves. The easy configuration of the controller helps maximize the flexibility and scalability of the system while reducing engineering cost.

When looking for a 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 built-in security measures.

Industry trends: The move to a more distributed energy model

The costs to generate and store energy are decreasing, which is changing the nature of the utility grid from a centralized generation model to a distributed system of sources and loads. The electric system architecture is a system that allows consumers, especially consumers of large amounts of energy, to generate, store and manage energy usage. In effect, power generation is moving closer to the user due to the availability of microgrid system technology that can be leveraged with multiple types of renewable or distributed generation as well as the lower cost of energy storage.

Solar capacity dramatically increases, while costs decline

As the installed costs for solar PV projects have rapidly declined in recent years, more solar PV has been installed in the U.S. 2016 was another record-breaking year; the U.S. market added 14,762 MWdc of solar PV, just about doubling the capacity installed in 2015 and adding (on average) a new megawatt of solar PV capacity every 36 minutes. 2016 was also the first year that solar was the top source of new electric generating capacity brought online, making up 39 percent of added capacity.

In the first quarter of 2017, the U.S. installed 2,044 MW of solar PV, reaching 44.7 GW of total installed capacity. Much of this new capacity was driven by growth in the utility-scale sector, which has added more than a gigawatt in the last year.

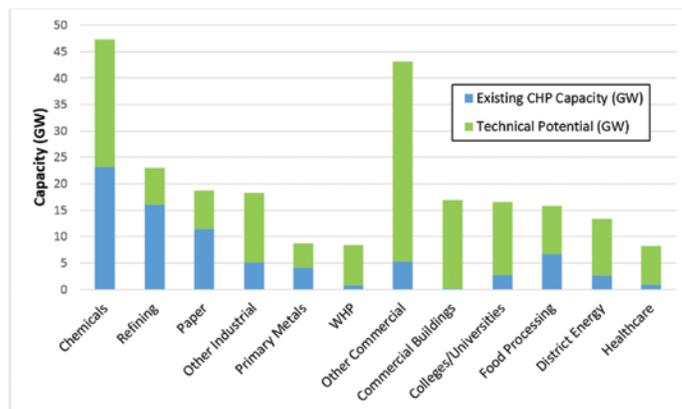
As the number of installations increase, equipment prices have decreased; utility-scale system prices have fallen below \$1 per watt for the first time according to GTM Research and the Solar Energy Industries Association (SEIA) reports. Today, enough solar energy is generated to power 8.7 million homes. And, analysts anticipate the industry will more than double installed solar capacity in the U.S. over the next five years, surpassing 100 GW.

Transformation: Combined heat and power (CHP) systems

CHP is an efficient approach to generating electrical power—capturing heat that would be wasted to provide thermal energy that can be used for heating, cooling, hot water and industrial processes. CHP helps reduce energy costs, increase efficiency, reduce greenhouse gas emissions and support energy resiliency. And while this clean energy solution has been around for a century, it is underutilized and poised for growth according to a 2016 Department of Energy (DOE) report.³

CHP can scale and be used in large industrial complexes, commercial building, institutions, municipal facilities and residential applications. In the 1970s, the industrial sector was largely responsible for CHP technology growth. However, this growth began to slow in 2000. Today, commercial applications are installing more CHP systems than any other sector, especially multifamily residences (according to GTM Research).

DOE reports estimate that there is more than 240 GW of technical potential for CHP, largely in commercial facilities. The technical potential reflects an “estimation of market size constrained only by technological limits” and it cites multiple trends driving growth, including lower costs and ability to support resiliency, utility interest and project replicability.

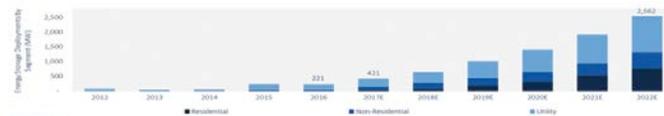


U.S. DOE CHP Deployment Program, 2016.

Existing CHP compared to on-site technical potential by sector

Energy storage predicted to experience explosive growth

Nearly five years ago, a mere 0.34 GW of energy storage could be found globally. Fast forward to today, and the market is expecting 6 GW to be installed in 2017 alone. Analysts expect the energy storage market to grow 47 percent this year over 2016 installations globally. Most of these deployments will be as utility-scale projects, while residential and non-residential projects are also showing significant growth. It is important to note that with the increased penetration of renewable energy resources, utilities are seeking to optimize these renewable assets to reduce grid impact and enhance stability—the sweet spot for energy storage.



GTM Research, U.S. annual energy storage deployment forecast, 2012-2022E (MW)

Already, more than 60 million people in the U.S. mid-Atlantic states and Washington D.C. are saving on their energy costs and receiving reliable power because of storage systems in the region. The regional transmission organization, PJM Interconnection, has projected a 10 to 20 percent reduction in its frequency regulation capacity due to additional storage projects, which could save customers millions of dollars.

On the other side of the country, the California Public Utilities Commission (CPUC) approved a target that requires the state's three largest utilities and other energy service providers to procure 1.3 GW of energy storage by 2020. Just late last year, energy storage systems built in the southern part of the state added about 40 MW on a fast-tracked timeline to provide critical grid support and capacity, deferring more expensive, involved electrical grid updates.

Microgrid drivers today

The drivers for microgrid systems have evolved and the technology is being used by a broader mix of industries and applications. Installing a microgrid is no longer limited to science projects and forward operating military bases. Microgrids can now be easily applied to facilities that already have solar, storage or other on-site generation sources.

For example, Eaton's full-scale operational microgrid at its Power Systems Experience Center in Warrendale, Pennsylvania provides power continuity for utility grid interruptions and peak demand management, as well as a live platform for demonstrations and testing. The system, installed in 2017, takes advantage of solar PV and a natural gas generator, as well as recently added energy storage to power the lighting, HVAC and house loads for a large part of the Experience Center. The system intelligently manages on-site energy resources and the utility supply to provide peak shaving, PV smoothing and shifting, demand management, seamless islanding and reconnecting to grid power and grid-connected power factor.



Eaton microgrid system at the Power Systems Experience Center in Warrendale, Pennsylvania

With the increasing penetration of distributed resources, microgrid growth surpassed estimates in 2016 and have moved well beyond utility and military applications. Specific incentives to install microgrid systems varies according to industry.

| | Primary Incentives | | | Ownership |
|-----------------------|---------------------------------------|---------------------------------|-----------------------------------|-----------|
| University, R&D | Cost Reduction | High Reliability (Labs, Campus) | R&D, Emissions Reduction | |
| Military Installation | High Reliability (Mission-Critical) | Cost Reduction | Less Risk (Supply, Security), R&D | |
| City, Community | Reliability (Critical Infrastructure) | Energy Policy Targets | Defer Investment | |
| Public Institution | Reliability (Public Safety) | Cost Reduction | Emissions Reduction | |
| Commercial | Cost Reduction | Emissions Reduction | Environmental Stewardship | |
| Remote Community | Renewables Integration | Investment Deferral | Reduce Supply-Chain Risk | |
| Island | Cost Reduction | Reduce Supply-Chain Risk | Renewables Integration | |

Ownership Model: End-User → Utility/Muni

Source: Greentech Media, U.S. microgrid growth beats estimates, June 2016

As our electric grid becomes more complex, it is increasingly important that it is smarter, more reliable, allows for bi- and multi-directional transmission, and is responsive to the fluctuating consumption habits of businesses, residents and emerging community needs. This smarter grid will enable better control of energy costs, reductions in energy requirements, more effective support of sustainability initiatives and improved power reliability.

Optimization through the lens of experience and technological innovation

If microgrid projects continue to meet analyst estimates, we will be relying more on stored and renewable energy. As projects increase, it is important to consider supplier expertise, experience, business stability and success with prior projects.

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

Vendors should also be able to provide more than the right controller. Because every project carries unique circumstances, look for a vendor who understands the challenges, and can plan for individual project's needs today and in the future.

Every application for a community, business or military base is unique and customized solutions can help optimize, build and maintain an automated, secure and cost-effective renewable energy and storage project. A vendor's past projects can be indicative of the depth of solutions experience. Often, those who offer an "end-to-end" solution, including design, procurement and installation, can help you achieve your renewable energy and storage goals in less time and at a lower installed cost.

About the authors

Bruce G. Campbell currently leads Eaton's Microgrid Control development team. His experience includes performing power quality investigations, electrical system analysis and design for utility, industrial and commercial power systems, and leading various engineering teams. Campbell has also served as manager of Eaton's High Power Test Laboratory, conducting high-current testing for product development and third-party certification.

Jim Dankowski is in charge of the strategic planning and customer engagement for the government segment. With 35 years of experience in the electrical power distribution and control industry, Dankowski's knowledge has delivered unique and creative solutions that support Eaton's clients with their energy initiatives and facility/systems optimization efforts.

Nathan Justice is a microgrid application engineer at Eaton with two decades of experience with electrical power systems. Justice has managed microgrid projects from feasibility to operation, including: project development, procurement, construction, commissioning, operation and maintenance, and stakeholder satisfaction.

Robert Kirslis has more than 20 years of experience in the planning and implementation of renewable and microgrid technologies to optimize and build resiliency for utility, industrial and DoD facilities. Serving as the senior microgrid application engineer at Eaton for the Electrical Engineering Services & Systems division, Kirslis helps customers advance their businesses by delivering highly reliable power management solutions. Across the Americas, Kirslis uses his expertise to help complex electrical engineering and construction projects achieve new levels of energy efficiency, power reliability and safety—and optimize the potential of renewable energy integration.

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 30 years of experience in electrical systems. He has worked with customers across commercial, industrial and utility applications to solve complex power management challenges.

Endnotes

¹ Energy spending according to U.S. Department of Energy 2012 figures (latest available): <https://energy.gov/maps/how-much-do-you-spend-energy>; Population data from U.S. Census Bureau: https://www.google.com/publicdata/explore?ds=kf7tgg1uo9ude_&met_y=population&dim=country:US&hl=en&dl=en

² GTM Research, U.S. Microgrid Growth Beats Estimates: 2020 Capacity Forecast Now Exceeds 3.7 Gi gawatts, June 2016, <https://www.greentechmedia.com/articles/read/u-s-microgrid-growth-beats-analyst-estimates-revised-2020-capacity-project>

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