ELECTRIC POWER
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Microgrids: A Primer

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Microgrids: A Primer

Introduction

A number of distributed energy trends add up to increased interest in microgrids. The objectives and value propositions include access to renewable resources for energy and environment, a more resilient electricity supply amidst storms, optimized energy use by local generation and by local control. Individually these objectives are already being served in various applications and with available distributed energy technologies. A prominent example is roof-top photovoltaic (PV) systems. Widely deployed and custom fit to end-user's sites these systems rely on the grid for balancing differences in output and demand. Also common, battery energy storage and standby generators protect critical processes in applications like hospitals and computer centers. Commercial combined heat and power (CHP) systems usually serve local heat requirements with power to the public grid as a byproduct. Nothing new here, but put them together with a grid connection and a control, and you have the makings of a microgrid.

In concept microgrids employ an integrated approach that captures the benefits of several distributed resources. They may provide value to both producers and end users. It's a good concept, but still, the extent of adoption will depend on many factors such as renewable policies, the weather and the price of natural gas. Also future advancements in distributed energy technology and product options are expected to bring improved economics. Ease of grid integration will also be a critical factor in deployment. The challenge, and opportunity, is to create a safe and effective operational collaboration. Utilities can play an important role here. Considered from the broader system viewpoint, harnessing distributed resources can add both flexibility and resiliency to the electric power grid.

This primer reviews the drivers for distributed resources and their extension into a microgrid configuration. It explores barriers and challenges for adoption including technical, economic and regulatory. Technologies expected to improve performance or support integration are identified. The primer touches on ownership and business models as well as the likely end-user candidates where a microgrid may contribute to uptime and overall energy efficiency. Finally, it discusses the future for microgrids and points out ways utilities can strategically incorporate them into the larger grid operations.

Background

Even though today's electric grid is highly reliable, in the United States, it is vulnerable to disruptions caused by natural disasters, particularly severe weather. As shown in Figure 1, 2012 was a particularly bad year for extreme weather in the US. Aging of the grid infrastructure only exacerbates this problem, creating new concerns over energy reliability and grid resiliency. A single storm can cost billions of dollars in terms of direct damage to the grid as well as causing significant power outage-related costs, including lost productivity [1], see side bar.

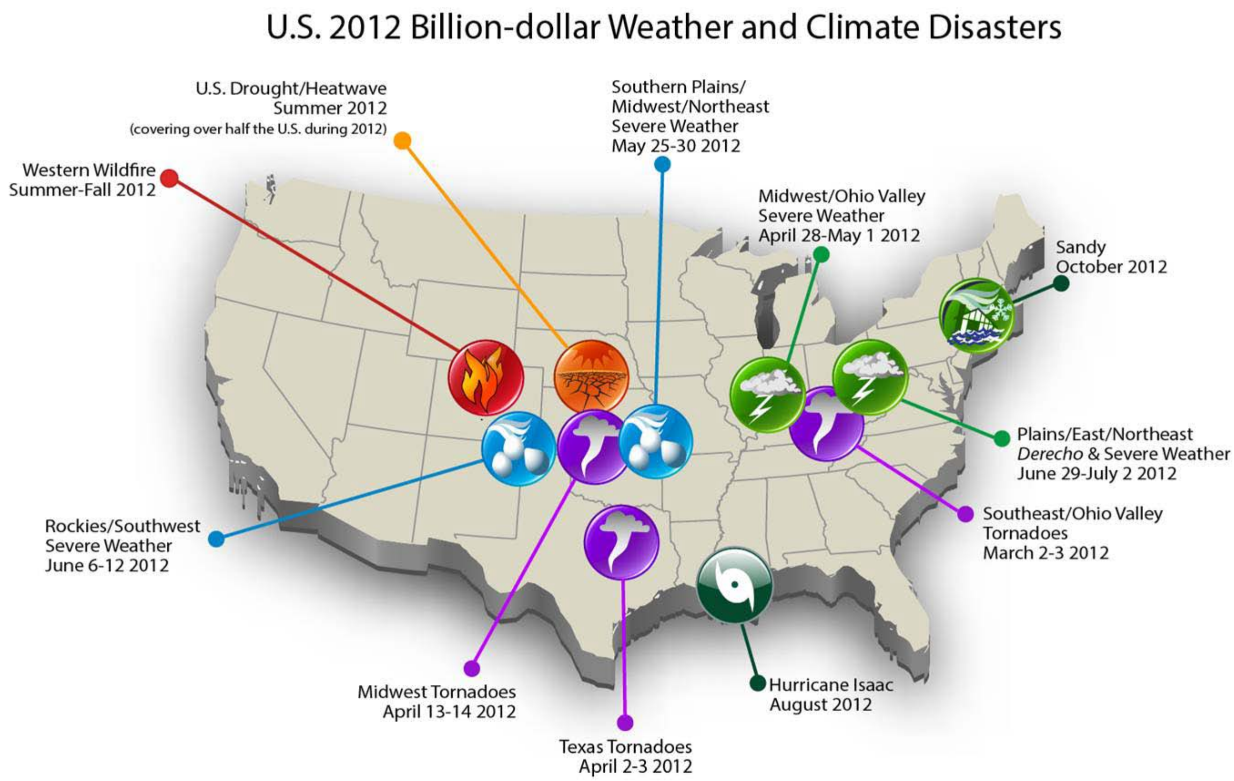

Figure 1: Extreme Weather and Climate Disasters in U.S.
Source: National Oceanic and Atmospheric Administration (*http://www.ncdc.noaa.gov/news/ncdc-releases-2012-billion-dollar-weather-and-climate-disasters-information*)

Side Bar on Sandy

One such storm, Superstorm Sandy, hit the Atlantic Seaboard in late 2012. Sandy is estimated to be the second costliest storm on record, behind only Hurricane Katrina. Over 8.5 million customers from Delaware to Massachusetts lost power [2]. New Jersey and New York were hit particularly hard. In some regions, it took weeks or even months—especially in the coastal areas—to restore power, despite the work of 65,000 workers deployed from around the country. The long downtimes, while not unusual by historical standards [3], were considered unacceptable by the public for a modern society and economy.

A few bright spots were evident amidst the catastrophe. At Princeton University, power went out only briefly before being restored [4]. Power remained on for the New York University campus in the middle of Manhattan [5], even as the grid went down around it. At Co-op City, a large housing development in the Bronx, 60,000 residents continued to have access to power throughout the storm [6].

What kept the lights on in these locations, even as more robustly protected areas such as data centers, airports, and hospitals experienced power and fuel outages? These sites had installed *microgrids*—coordinated systems comprising distributed generation, storage, and controllable loads—to augment normal power from the grid. In all of these instances, microgrids had been designed to provide efficiency advantages through cogeneration of heat and power (CHP), but after Sandy it became clear that load management with CHP also provided precious additional reliability and resiliency.

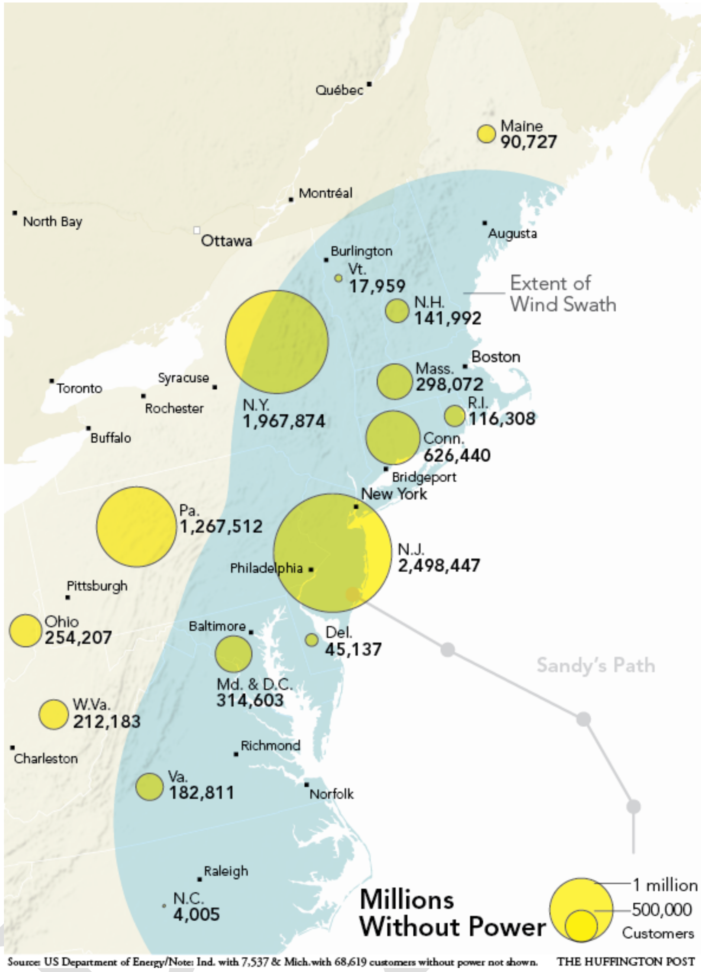

Figure 2: Hurricane Sandy Power Outage Map
Source: Huffingtonpost.com (http://www.huffingtonpost.com/2012/10/30/hurricane-sandy-power-outage-map-infographic_n_2044411.html**)**

End Side Bar on Sandy

A more resilient grid is one that is better able to sustain and recover from adverse events like severe weather—a more reliable grid is one with fewer and shorter power interruptions felt by the customer. The benefits from microgrids during Sandy were unique to those few customers within the microgrid.   For the remaining and majority of customers, a number of beneficial improvements to distribution resiliency are being considered in storm-prone areas.

EPRI members have identified several specific approaches [7] [8] to enhance grid resiliency, including hardening of overhead distribution structures, undergrounding of feeders, enhanced vegetation management, advanced reconfiguring methods, and better planning and communications to shorten repair and recovery times. Recent weather events have put the spotlight on all of these approaches for improving system resiliency.

Resiliency strategies can also consider options like microgrids that provide electric service capacity when the grid is not available. As an illustration, in Connecticut, the state developed a

Microgrid Grant and Loan Pilot Program [9] [10] to develop microgrid solutions that can provide power to critical facilities. The state will invest $1.5 million upfront to fund preliminary design and engineering costs for selected finalists. The state will invest an additional $13.5 million for microgrid projects selected in the final round.

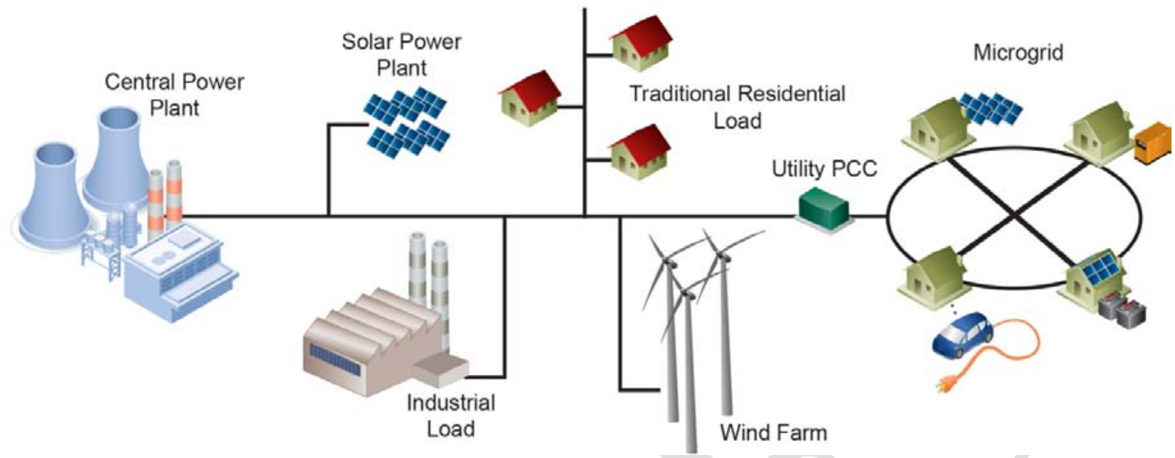

Figure 3: Microgrid as Part of a Traditional Utility System

Cases where a local microgrid survives a bad storm are not unusual. And, they are receiving a lot of press coverage. Recent publications cite benefits, challenges and investments in microgrid powering options. IEEE Power Energy Magazine devoted its July/August 2013 issue to the topic opening with the marquee "Microgrids – Coming to a Neighborhood Near You." There has also been favorable legislation for distributed generation technologies, such as in California and Connecticut. Combined heat and power (CHP) is the subject of a 2012 Obama Executive Order to double US capacity by 2020. All of these signs persuade a closer look at the microgrid concept on our road to a more resilient, and flexible, electric grid in the future.

Whether or not these distributed resources become a large part of the future grid, the idea of an integrated approach and of capturing the value of many resources, has merit. This concept is inherent to the operation of the existing power grid, which offers interconnectivity as an intrinsic attribute. Microgrids follow along many of the same technical arguments. Properly integrated, with operational collaboration and utility knowhow, they will likely contribute to flexibility and resiliency needed to meet the demand for continuous supply of electric power in the future.

What Are Microgrids?

Although the idea has received a great deal of attention of late, the concept of the microgrid is not a new idea. The microgrid is simply a modern reformulation of power systems as they were originally designed by Edison and other electrical pioneers. Like the traditional centralized electric grid, microgrids generate, distribute, and regulate the supply of electricity to consumers but do so locally and on a much smaller scale.

The term "microgrid" is sometimes used loosely to describe a number of concepts involving distributed generation. However, there is a specific definition of microgrids that has achieved broad acceptance: **A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or "island" mode** [11] [12]**.**

This definition of microgrids has been adopted by the U.S. Department of Energy (DOE) as well as EPRI. Two salient features distinguish microgrids from other grid-modernization efforts:

1) A microgrid is a collection of generation and load centers with fixed limits.
2) As a unit, a microgrid can operate in both *grid-connected* and *isolated* ("island") modes.

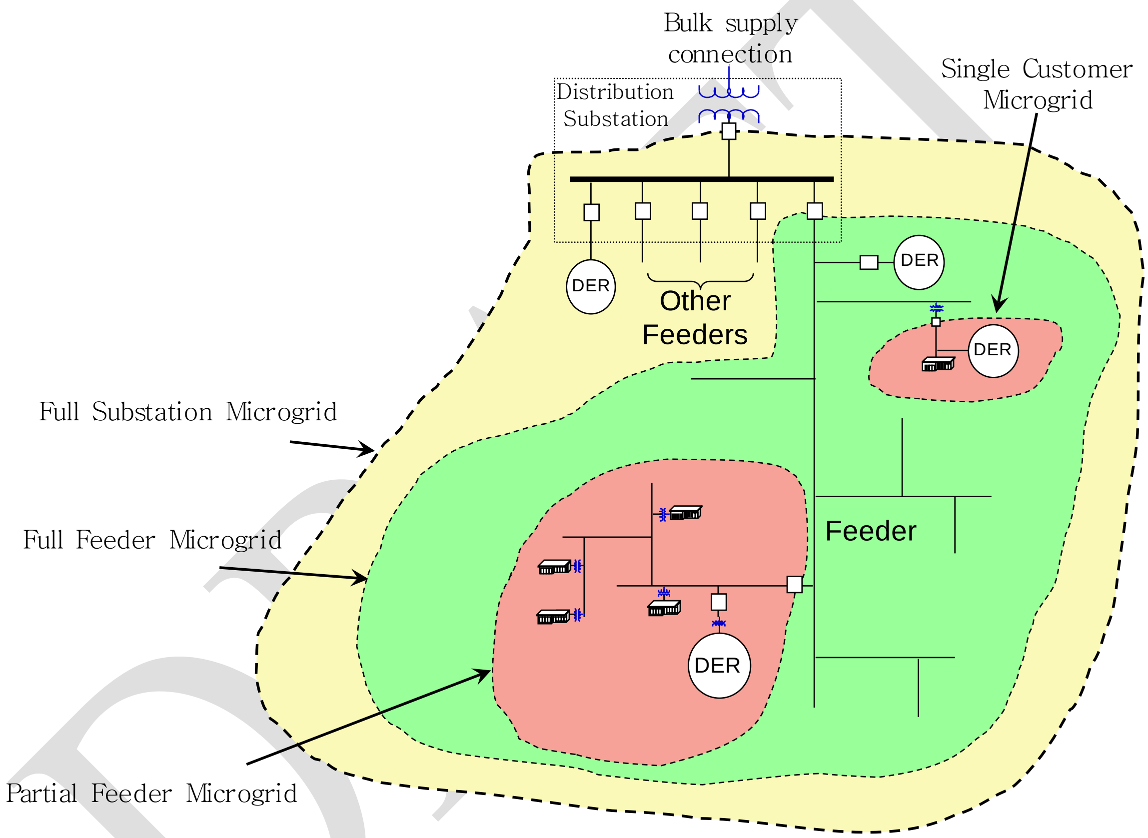

Figure 4: Examples of Microgrid Architecture on a Radial Distribution System – From Single Customer upto the Entire Substation

Note that microgrids are not a replacement for traditional utility infrastructure, but instead form a self-contained organization of distributed generation and demand management that is capable of self-balancing when necessary. Individual microgrids may in fact spend most of the time operating in a grid-tied mode, with power flowing both ways between the microgrid and the surrounding system. A parallel bidirectional connection can achieve particular operational goals, such as improved reliability, cost reduction, and diversification of energy sources. The option to separate from the grid provides a backup or emergency operation mode.

It is not the type of generation, load, or its associated intelligence that defines a microgrid, but rather ***the ability of the local power-generating system to alter its association with the larger grid.*** Microgrids may contain elements of other grid-modernization technologies such as renewable generation, demand response, energy storage, and electric vehicle-to-grid (V2G), but these are not required for the existence of a microgrid. In fact, in most cases in which full-time distributed generation has been installed, the solution is based on conventional generators which use local waste fuels, or which operate as cogeneration facilities (providing both heat and power). Legally required backup and emergency systems, such as diesel generators in hospitals, may operate in parallel with the grid for the purpose of routine testing. Including reliability and economic applications some of the basic "building blocks" of microgrids may already reside in many networks.

What related grid ideas are not considered to be microgrids? The "virtual power plant (VPP)," or other shared metering arrangements for economic purposes, may contain elements of a microgrid but are not, by themselves, considered to be an example. VPPs often provide the automation and control features required to remotely and automatically dispatch and optimize generation, demand response and storage but they do not operate within fixed boundaries. Similarly, a utility may have a unique ability to reconfigure its distribution feeders in response to outages and during contingencies and to change the power delivery grid configuration. This is also not considered to be a microgrid, in this case due to the absence of local generation and ability to balance generation and load within the area. Also, local generation that only operates for interruptible load agreement, for emergency or standby, is not a micro grid.

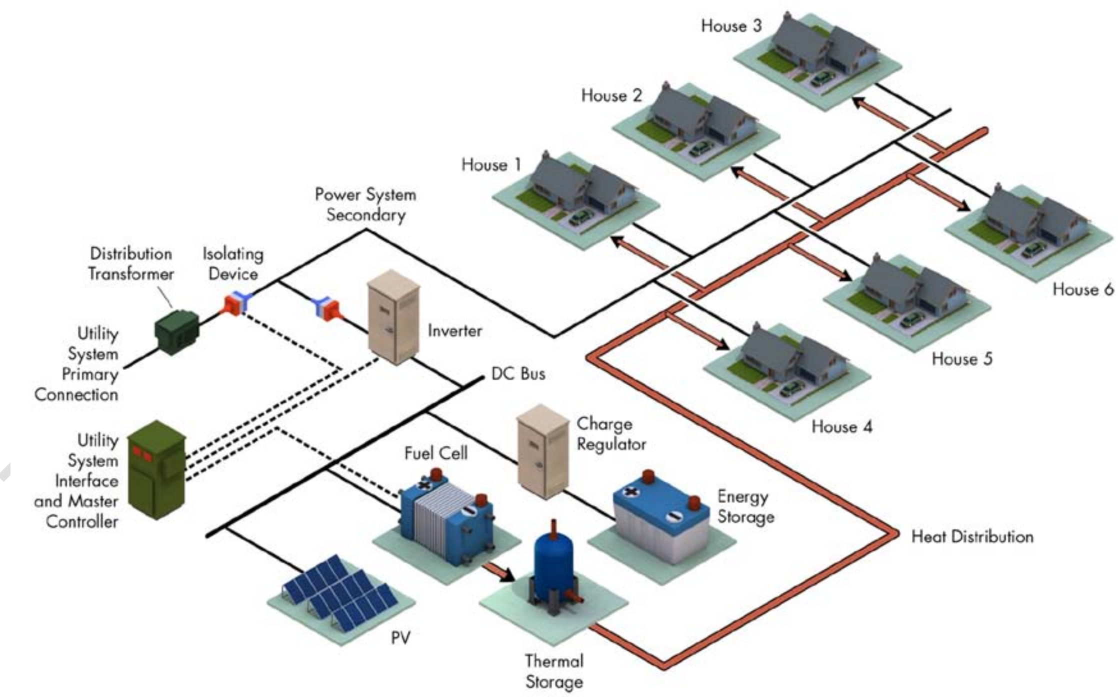

Figure 5: A Community-Level Grid-Connected Microgrid System

The Value of Microgrids

More than ever before, we rely on continuous, disturbance-free, and economic electricity in our businesses and our daily lives. To the extent microgrids can contribute to meeting these electricity needs, they will have value. A number of related factors may increase the future value of microgrids. These factors include emerging lower-cost distributed energy technologies, environmental concerns, and a growing reliance on uninterrupted electric service.

Evolution of the Existing Grid Infrastructure

If today's microgrids can bring economic and reliability value, why did the history of the electrical infrastructure migrate from mainly small and distributed grids to a large grid with centralized generation? At the beginning of the 20th century, most major cities operated their own grids that were islanded from each other. As late as 1918, half of electricity customers in the United States were still receiving their power from small-scale isolated power systems with generation plants sized well under 10 MW in capacity [13]. The areas served were less than a few square miles, and the power systems in individual towns were not interconnected with each other.

Many of these early power systems were not particularly reliable because all the energy for each small grid was supplied from a single power plant or two. It became clear to power system engineers of the time that interconnecting small systems and pooling resources would improve reliability. Generator redundancy, coupled with benefits in load diversity and load factor, sowed the seeds of change for interconnecting the many isolated systems in a larger electrical grid. Between 1910 and 1920, various technological innovations set the grid on a path moving away from distributed generation and towards a system based upon increasingly larger-scale central plants interconnected via transmission lines. As the electric power system has evolved, the economies of scale and the advantages of interconnectivity in a centralized electric grid approach have proven to be both reliable and economical. Some of the more significant technical and economic benefits are:

From a technical operations viewpoint:

- Balancing the load and generation is easier with aggregation of many users.
- Large system inertia provides better response to unplanned events and extends time to react.
- Load imbalances, inrush, and distortions are more likely handled by large, robust systems.
- The variability of wind and solar generation collected over large areas will be smoothed.

From an overall system economics viewpoint:

- Increasing the size of generation plants provides significant economies of scale.
- A broad range of generation options allows for fuel flexibility and more economic dispatch.

- Natural resources such as hydro, coal, nuclear and wind can be harnessed to meet electricity demand, even when they are far from population centers.

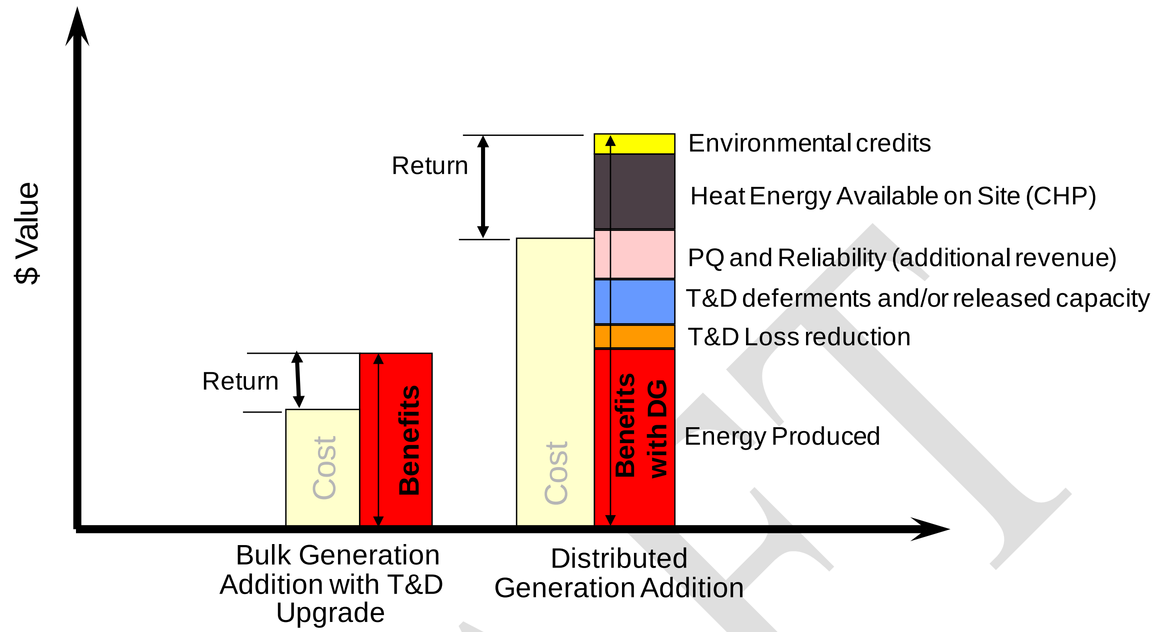

Figure 6: Scenario Comparing DG Value in T&D Support to That of a Bulk Plant

Changing Technology and Need Are Drivers for Microgrid Adoption

While the centralized grid has shown many advantages, particularly through high-growth years of the electric industry, future grid expansion faces challenges. The cost of building a new transmission and substation infrastructure has significantly increased in most areas with delays for approvals and permitting access to rights of away in highly populated urban areas and general public resistance to the construction of new lines. Long distribution lines and service drops for the more remote customers add service cost and increase losses. There are also challenges to recover from large area damage to lines in areas with a lot of exposure to trees, wind, and flooding.

A microgrid approach can complement a traditional grid by helping to overcome power delivery situations with high grid exposure and limited access and serve critical loads. Advancements in distributed generation technology and storage enable more practical systems. Application of energy management—including heat recovery, efficient appliances, and demand control—can help to overcome the challenges of operating a small power system. The following are considered to be drivers that determine the business case for microgrid applications:

- *Improvements in distributed energy resource (DER) Technology* — The cost of renewable forms of distributed generation such as wind turbines and photovoltaic sources has dropped significantly, while performance has improved significantly during the past decade. Products such as fuel cells and flywheels offer new opportunities for distributed energy generation and utilization. Furthermore, the cost of more traditional forms of distributed generation, such as internal combustion engines and small combustion turbines, has declined due to technology improvements and increased scale of production.

- *Opportunities Arising from Combined Heat and Power* ─ Energy conversion to electricity close to end users creates increased opportunities for waste heat capture in combined heat and power systems. As natural gas prices continue to fall, CHP[1] becomes a more reasonable alternative for commercial buildings and campuses that can use the waste heat for building heating.
- *Ancillary Services* ─ The power grid sometimes requires additional real or reactive power, especially at times of high load. These reserves are typically supplied by generators today. In the future, system operators will likely be able to use distributed generation, storage, and controllable loads in concert to supply these services.
- *Advanced Power Electronics* ─ New power-conditioning and control technologies brought about by power electronics are making possible improved inverters (needed for DC sources) and better means of integrating and controlling a DER that is operated on a distribution system.
- *Public Policy* ─ Public policy today favors distributed generation that offers improved efficiency, lower emissions, enhanced power-system security, and other benefits of national interest. These polices include tax credits for renewable energy, standards for power generation portfolios, emissions restrictions, net metering, and various other incentives.
- *More Knowledgeable Energy Users* ─ Energy users are becoming more aware of alternative power approaches and are more willing to consider onsite generation options than just a few years ago.
- *Demand Response* – Demand response investments and capacity have increased sharply since 2010. A microgrid is now a prime candidate to participate in variable rate and demand response programs, providing a potential resource to distribution or transmission system operators.
- *Energy Arbitrage* – Even when the microgrid is operating with a grid-connection, local generation sources can be used to reduce energy imports from the main grid during peak hours, taking advantage of time-of-use pricing to reduce cost to the consumer. Local generation can also be used to reduce demand charges.

When the above drivers are all positive, a *well-designed and applied* grid-connected microgrid may offer lower cost, higher reliability, and lower emissions than some conventional-source scenarios [14]. The microgrid advantage comes from enabling a self-reliant customer (or group of customers) to operate during grid contingencies, but also to utilize the larger grid as a resource for energy balance, reliability, and access to external energy markets.

Extended Applications

Grid-connected microgrids can utilize a wide range of technologies, including power generation and storage, communication and control, and advanced metering and end-user interfaces. Microgrids are often customized to the purpose and place they are built and incorporate the latest

[1] An Executive Order issued by President Obama in 2012 established a new national goal of 40 GW of new CHP capacity by 2020—a 50-percent increase from today.

technology developments. These factors have created a great deal of variability in modern microgrid design and construction, and therefore no two microgrids are exactly alike.

Although massive and very public grid events, such as Sandy, will likely provide much of the political capital for microgrid development, other applications also stand out. Microgrid technologies are being deployed to provide rural electrification in areas with otherwise poor reliability [15]- [16], in military installations with energy security concerns [17], and at datacenters, hospitals, and other industries with critical up-time requirements [18].

Several university microgrids have served as critical disaster recovery in the aftermath of natural disasters [19], including a 13.4 MW system at New York University-Washington Square Park, a 3.6-MW system at Utica College in New York, a 1-MW system at Tohoku Fukushi University in Japan, and a 37-MW microgrid at Cornell University in Ithaca, New York.

Utility-Owned Applications

Customer-owned microgrids, however, are not the only embodiment of this concept. Nothing about microgrids precludes utilities from becoming involved in research, development, and demonstration projects for the public, as well as a stakeholder benefit. Two major utility-owned developments have moved into the demonstration phase and are worth mentioning as examples:

San Diego Gas & Electric ("Borrego Springs") – Borrego Springs is a desert community with a rather high concentration of photovoltaics and a lengthy transmission connection. Although SDG&E owns the vast majority of the microgrid equipment, a significant portion of the system's energy comes from customer generation. In order to leverage customer assets and improve the reliability of Borrego Spring's distribution network, SDG&E combines dispatchable generation (diesel), energy storage, and renewable sources with extensive demand response systems for a coordinated microgrid prototype. Even when the microgrid remains connected to the larger network, internal assets may be leveraged to obtain a significant reduction in peak load [15].

Sacramento Municipal Utility District ("CERTS Concept") – At its headquarters in Sacramento, SMUD demonstrates the power of CHP systems as a backbone of a utility-owned microgrid. Combining heat and power enhances the efficiency, cost effectiveness, and ultimately the value of distributed generation equipment. Once again, this dispatchable generation source is combined with PV and battery storage, which are controlled in concert, whether the microgrid is islanded or not [14].

As described before, some utilities across the country are beginning to investigate these issues and are beginning to implement microgrids where their use makes sense immediately. These conditions include:

- *The presence of critical loads.* Critical load areas such as hospitals and financial institutions are a natural early-deployment opportunity for microgrids. Many of these areas are campuses that can be easily decoupled from the main grid, and many already have substantial on-site generation, although often in the form of underutilized backup systems such as reciprocating diesel engine generators. These generators can be replaced with small gas turbines and solar photovoltaic generation, along with control apparatus to produce a true microgrid. By creating and managing such a microgrid that normally operates in concert with the main grid, but which can operate independently when needed, the utility can ensure both higher reliability and more efficient operation in normal modes.

- *Areas with existing distributed generation.* Some locales have a large existing base of solar PV or natural gas-fueled distributed generation. These locations may further benefit from the installation of local storage and control systems that can help balance the system locally, reducing the strain on the main distribution grid and reducing costs to the utility while increasing reliability and providing a valuable service to end consumers.

- *Customers with potential to use combined heat and power.* Many industrial customers have a need for high-temperature process heat. Others simply need heat for buildings in the winter. Combined heat and power technologies can significantly increase the energy efficiency of customer facilities, reducing emission levels and reducing costs. With the use of absorption chillers, waste heat can even be used to cool buildings in the summertime.

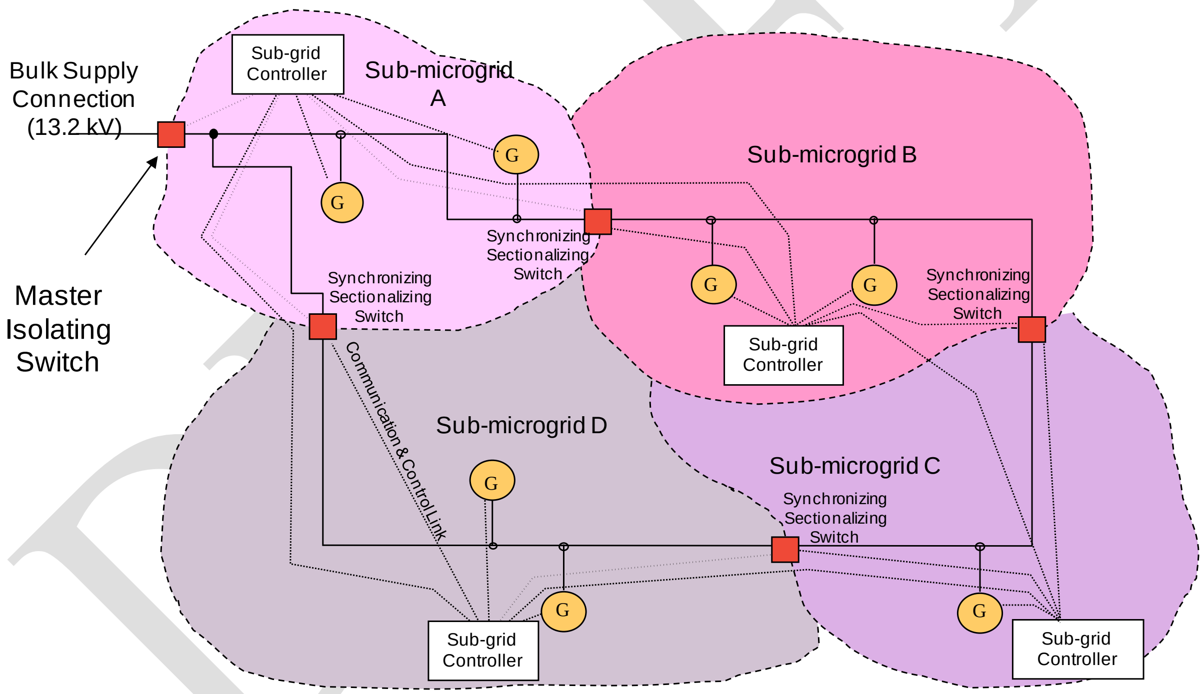

Figure 7: Opportunity for Grid-Connected Microgrid

Barriers and Challenges to Microgrid Adoption

The technology and equipment necessary for creating microgrids are already available, as is evident from several very successful microgrid demonstration projects in recent years. New and better performing products continue to come to market, while cost continues to decrease. With these factors in mind, it would be logical to indicate that there are no major technical barriers to microgrid adoption. However, in order to design a truly grid-integrated microgrid that seamlessly integrates local DG and controls with the larger grid, several technical issues will need to be addressed [20].

Technical Challenges

Establishing a Generation Portfolio – In order to avoid over-investment in any one technology, a balanced energy portfolio is a requirement for microgrids. While this would not impact a permanently grid-parallel DER installation, balance is paramount to managing the cost of a microgrid while it is islanded. For the majority of microgrids, this involves combining a bulk energy source (such as a PV array), energy storage, and dispatchable generation (such as diesel or CHP).

Connection and Protection – Once the energy sources are in place, the interconnection and protection technology must be likewise evaluated. Transfer switches and reclosers must be installed such that the system may be safely islanded at the point of common coupling with the utility. Breakers and reclosers designed to operate with fault currents commensurate with the larger system connection may need to be redesigned for compatibility with island mode, where fault currents might be sufficiently lower. Once breakers are opened, insulation coordination may need to be revisited in the surrounding areas.

Seamless Transitioning – Once the connection at the point of common coupling (PCC) is severed, the DER and load on the microgrid side are left to run isolated. Even if the units transition seamlessly, in such a small system, the likelihood of phase and frequency drift is quite high. When operating conditions on the rest of the system are normalized and ready for reconnection, the microgrid must either smoothly transition to match the utility conditions or black out the system prior to closing the connection point. Without some synchronization process, a reconnection could damage the generation and load inside the microgrid, as well as the surrounding systems [21] [22].

System Stability and Control – Controlling the energy balance in the microgrid system is likely the most difficult challenge for prospective microgrids. Unlike the traditional utility system, which is based on the vast majority of generation occurring through rotating machines, microgrids have orders of magnitude less inertia, especially microgrids with high percentages of renewable generation. Thus, control algorithms and demand response may need to operate much more quickly in order to preserve energy balance and system stability, with an eye on architecture and interaction. Alternatively, energy storage located on the system can provide additional balance and stability, but often at a substantial cost.

Power Quality – Because microgrids may result in higher short-circuit impedance as compared to a larger system, total voltage harmonic distortion in microgrids could be significant. Similarly, capacitor-switching and other transients must be managed in order to avoid equipment damage. Large, aggregated sources of reactive power are often not present, making motor starting and other VAR-intensive operations a concern.

Economic and Regulatory Challenges

Ownership & Business Models

The economic challenges for microgrids are substantial, because the generation equipment can be quite expensive, and setting up control systems can take a great deal of time and effort. Owners of the equipment will require a well-defined return to justify the upfront purchase of this equipment, and this may be difficult when the benefits of the microgrid accrue to a number of users. At present, microgrids are likely to be cost-effective only in conditions where strong economic motivations can justify an appropriate financing approach for the owners of the microgrid's assets.

Ownership of the generation equipment and wires can be one of the thorniest issues regarding microgrids. Of course, ownership is relatively straightforward if the generating entity is providing power only to its own buildings and facilities (in the case of a university, or an industrial complex, for instance). However, if the microgrid is created cooperatively by multiple entities, with electricity being generated by some and delivered to others, the economic framework for how costs and ownership rights are shared can be incredibly complex.

In addition, independently owned microgrids will still have to establish their business relationships, with the utility providing their connections to the bulk grid. Under the Public Utility Regulatory Policies Act (PURPA), some customer-owned microgrids can be categorized as Qualifying Facilities (QF). To be a Qualifying Facility, a microgrid must consist of renewable generation of less than 80 MW or be a cogeneration facility that generates both electricity and useful thermal energy. Qualifying Facilities are entitled to buy and sell power to the local utility at competitive rates, which can simplify many of the economic issues around operation of the microgrid.

However, many microgrids will involve multiple entities in generation and use, which will complicate the relationship to the local utility. Utilities will be expected to provide a certain level of energy as well as reliability service to the microgrid, but because of local generation, utilities will not recover the full value of this service through conventional kWh charges alone. While some utilities have experimented with fixed service charges, customers and regulators have been reluctant to accept such approaches. It is undeniable that the grid provides substantial value to self-generating customers, in the form of reliability and balancing. Finding fair and equitable approaches to providing this value will be important.

Utility ownership of the microgrid addresses some of these issues. In the *unbundled utility business model*, the utility owns and maintains the electric distribution facilities serving the microgrid, while the participating customers or third parties own generation and storage assets. The utility will likely operate or direct the microgrid control system, and possibly use a control scheme that can accommodate the interests of multiple DER asset owners. In addition, the utility may own its own generation and storage assets on the microgrid. An example of an unbundled utility microgrid is San Diego Gas and Electric's microgrid in Borrego Springs, California, as described earlier. The unbundled approach simplifies payment between generators and consumers on the grid and may allow a mechanism for recovery of system connection costs through a kWh fee collected on energy transfers within the microgrid.

It is possible to consider a *vertically integrated utility business model*, in which the electric utility owns all of the microgrid distribution infrastructure as well as the generation and storage assets, operating the microgrid as a small grid and selling power to consumers. While there are no utility-owned vertically-integrated microgrids known to operate presently, this model has been used in the past (particularly in the early days of the grid), and some aspects of this model are represented by the distributed generation reliability project carried out by Central Hudson Gas & Electric and NYSERDA in New York State [23]. However, with self-generation becoming an increasingly popular notion among both residential and business customers, it is unlikely that any microgrid would remain purely vertically integrated for long.

An Uncertain Regulatory Landscape

As with ownership issues, regulatory issues concerning microgrids can be complex and difficult to identify, let alone solve. Microgrids are not a defined legal entity under most utility regulatory bodies. As of 2012, no national government has developed an integrated or comprehensive policy creating a viable market for utility distribution microgrids. There are complex rules in place across the U.S. that govern electric power generation and distribution, and the specific terms of regulation are key in determining the role of microgrids. Who has the authority to operate a microgrid? Should a microgrid be considered a public utility?

As described above, some customer-owned microgrids may be exempt from federal and state regulations applying to public utilities, if they meet the standards for a FERC-jurisdictional Qualifying Facility. However, regulatory pitfalls abound for a prospective local generator trying to sell power to local users. The local utility with franchise rights in a service territory typically has exclusive rights to build wires and infrastructure over public land (such as roads), which can complicate the ability for even a single customer to build a microgrid unless the local utility is involved and cooperative. Small generators that are not Qualifying Facilities will have to meet the interconnection regulations and standards established by FERC and by the local balancing authority. Microgrid operators may be subject to the same laws applying to property easements, environmental compliance, consumers' rights, and technical performance as a distribution utility. It is difficult to see how microgrids could make economic sense under such conditions.

To date, regulators and legislators have paid little attention to policy addressing these issues. Aggregators, independent power producers, and other entities have noticed the rapid expansion in deployment, as well as the reduction in cost, of distributed generation (particularly solar). The potential benefits of microgrids in improving reliability, resiliency, and efficiency, have begun to highlight the value of regulatory change.

Until such regulatory action takes place, existing utilities have a strong opportunity to establish microgrids themselves. Utility-owned microgrids would not face any additional regulatory burdens (beyond those already present for existing grids), and existing utilities are already skilled in the distribution and sale of energy. Their franchise rights would enable them to establish relationships with local generators and customers as well as build and maintain required distribution assets with relative ease. In deregulated states, the relationships between utility-owned microgrids and local generation assets will require careful consideration, but most utilities are already well-aware of the legal avenues that such relationships require.

These conditions give existing distribution utilities a formidable advantage over new entities in establishing microgrid projects with multiple generation assets and multiple users. So far, utilities have not capitalized on this advantage. It is likely that this advantage will fade or disappear, if the regulatory environment shifts to become more favorable to microgrids.

The Future of Microgrids

The need for grid resiliency is undeniably important, and the approach to resiliency is worthy of consideration by provider and customer alike. Grid resiliency efforts include hardening of the grid against initial failure, shortening recovery times in the event of failure, and enhancing survivability during failure. While much attention has been placed on grid hardening, solutions that also address recovery and survivability can be very important. If the same technologies can also accomplish other goals, such as enhancing grid flexibility to allow the accommodation of more renewable generation, or increased system efficiency, then those solutions can be even more valuable. Microgrids have the potential to address all of these goals.

Beyond these indirect benefits, there are also direct benefits that serve as practical reasons to consider microgrids as a means to improve reliability and resiliency:

- *Microgrids have a successful track record, making them a practical deployment option.* Microgrids are not a theoretical technology; they have been installed by many entities for various reasons, and in some cases they have been operated successfully for decades. Navigant Research records 405 microgrid projects that are being planned, proposed, under development, or fully operating, as of April 2013, with 219 of those projects in the U.S. [17]. The revenue from microgrid construction is projected to rise from $10 billion in 2013 to over $40 billion annually by 2020 [18].

- *Microgrid core technologies are getting better and more cost-effective.* Low-cost solar photovoltaic installations, cogeneration turbines running on lower-cost natural gas, more cost-effective energy storage options, and highly efficient energy-management systems and control algorithms have each reduced the cost and thereby increased the value of microgrid deployments [19].

- *Microgrids have proven value.* While microgrids may be expensive to set up, they may have relatively short payback times for those who can afford them. Most microgrid installations have been motivated by a desire to save money through operational efficiency, rather than by a requirement to provide reliability or resiliency. Nevertheless, both sets of benefits have proven valuable. The FDA's White Oak microgrid project cost $71 million but is expected to save $11 million a year in electricity, setting aside any benefit from resiliency advantages [19].

- *Microgrids may be enabled by future regulation.* As customer-sited generation continues to become more attractive, regulators are already investigating how to leverage distributed energy resources to improve the reliability and resiliency of the grid and may continue to issue rulings that favor the deployment of such technologies in the future.

This is not to say that the existence of microgrids is a *fait accompli*. There are still many technical challenges to be overcome for microgrids to achieve their full potential, and economic difficulties may make multi-user microgrids uneconomic to achieve, at least without utility intervention. It is still an open question whether existing utilities will build on their natural advantages to implement microgrids where they make sense today. An alternative may be slower deployment of microgrids in the future, through purchase and installation by well-financed customers themselves, or through companies pursuing a power-purchase agreement (PPA) business model directly with consumers. The result of these approaches may be a gradual decline in kWh demand for utilities, similar to that presently being seen as a result of distributed generation in some parts of the country.

However, applying the microgrid concept in some situations may allow a utility to enhance the reliability, resiliency, and efficiency of electric power directly to consumers. While there continue to be technical, economic, and regulatory challenges to such implementation, utilities are possibly the best poised at the moment to overcome these challenges and leverage grid-connected microgrids as one technology option in its portfolio to increase flexibility, connectivity and resilience.

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