Microgrids for Energy Reliability

By Dave Robinson

Emergency or standby generators have been the traditional go-to source of backup power for hospitals, military bases, municipal centers, colleges and universities, data centers and other critical facilities when facility managers needed to ensure continued building operations during a utility outage.

These diesel-fueled generators were built and rated for standby operation, as opposed to prime power generators used for continuous operation, and automatically connected critical loads to the generator via a transfer switch if the primary utility feed was disrupted. Over time, these emergency generators have become more reliable, efficient and durable.

However, as reliable as back-up generation has become, one promising alternative that has recently gained attention is a "microgrid." Microgrids go beyond simple backup generation to combine distributed generation, load management and dynamic interaction with the utility to help organizations fortify energy infrastructure, improve reliability and protect against broader disruptions on the main grid.

A microgrid embodies the intelligent management of local electric power generation supplying local electric loads. Microgrids make sense for organizations that have a high demand for electrical and thermal energy in their facilities, and where loss of critical operations poses a significant risk of revenue loss, data loss, or impact to safety and security. This includes military sites, federal, state and local government facilities, hospitals, data centers and research-driven universities.

What's the Need?

A variety of external drivers have made a microgrid approach more appealing. The foremost has been the weather. Severe weather events, often named "Hundred Year Storms," have been occurring with much more regularity. Recently, 8 million customers across the Eastern seaboard lost power during Hurricane Sandy, and nearly half a million were still without power several weeks later.

These mega storms, including Hurricanes Irene, Sandy and Katrina, are on the rise as weather patterns and climates shift, creating a more urgent need for localized and standalone power. In fact, the average annual number of victims from natural disasters worldwide was 232 million from 2001 to 2010, with $109.3 billion in estimated annual economic losses over the same period.[1]

The second critical change is the nature of the electric grid. While there has been much talk about the build-out of the

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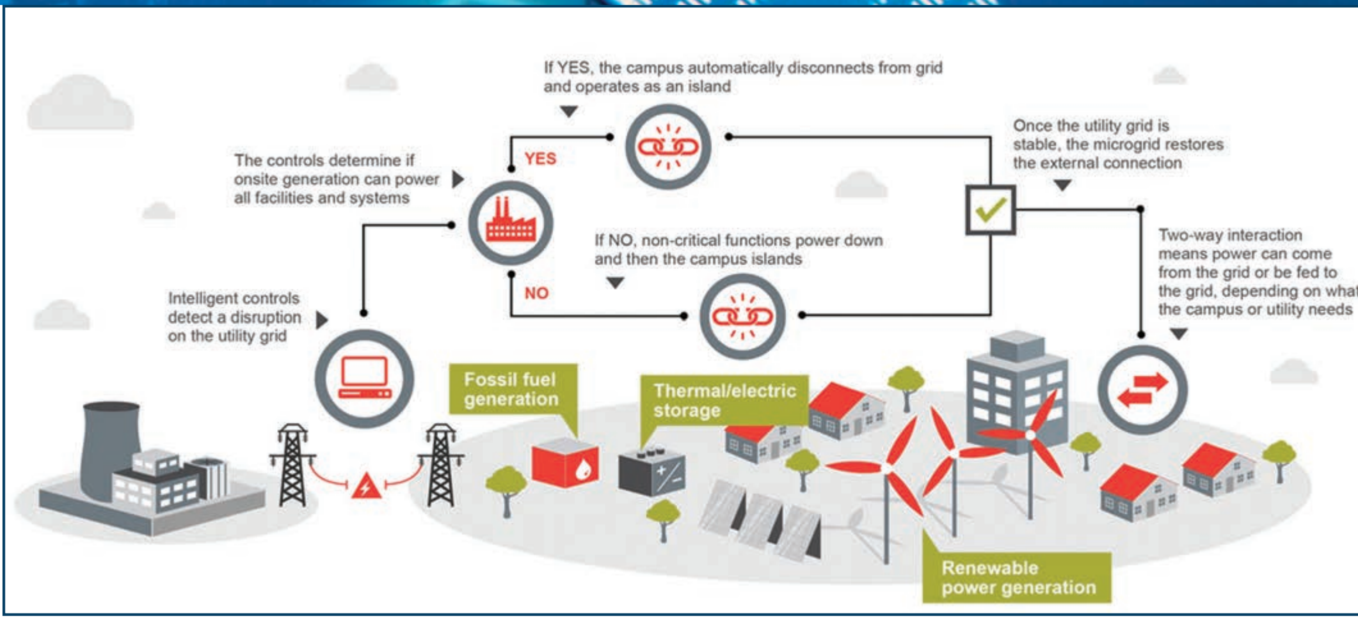

Figure 1: Illustrative construction and operation of a microgrid.

new smart grid, the majority of our current, physical infrastructure is very old, most of it put in place during the 1950s with some pockets dating even as far back as the late 1800s. Much of it, especially in urban centers on the East Coast, is above ground, and was not intended to withstand the impact of increasingly severe weather or accommodate the dynamic energy landscape taking shape today. In fact, the American Society of Civil Engineers recently graded the U.S. electrical infrastructure with a "D+" thanks to rising network congestion and inability to adequately meet population and demand growth.[2]

This ever-aging infrastructure is being burdened as never before. Electricity demand has increased by about 25% since 1990 while construction of transmission facilities decreased by about 30%.[3] Today's society has grown increasingly reliant on devices that require this electricity to function. Whether it's personal devices such as cell phones to office equipment such as PCs, laptops, and printers, to medical diagnostic and university research equipment, it is hard to find any facet of residential, commercial or industrial life that is not "electrified." Substantial investment in generation, transmission, and distribution equipment will be required over the next two decades to keep pace with this demand, as much as $1.5 trillion to $2 trillion by 2030 according to the Edison Foundation.[4]

The net result of an old, overburdened, and ever-threatened electricity grid is power outages. Today, the average outage duration in the United States is 120 minutes and climbing. Compared to outage durations for the rest of the industrialized world (less than 10 minutes[5]), the U.S. clearly has major room for improvement.

The annual costs from power outages are staggering, significantly impacting key parts of our economy including manufacturing, transportation, and service industries that rely on powered networks for communication, transaction, and data storage. The Congressional Research Service in 2012 reported that data from various studies indicated the economic cost of storm-related power outages in the U.S. was between $20 billion and $55 billion per year.[6] What's more, "costs" aren't necessarily measured by economic criteria alone. Consider that U.S. military bases rely on the civilian grid to power 99% of their war fighting capabilities, homeland security missions, and rescue and relief operations, according to the Defense Science Board Task Force on DoD Energy Strategy,[7] with only limited standby generation capabilities.

The character of power outages, however, is also changing. In addition to an increased frequency and extended duration, the geography or footprint of outages is much larger, often impacting entire communities and large portions of states. When power is out for days and weeks at a time, many core services are unavailable. Grocery stores, gas stations, and community centers are closed, forcing residents to travel great lengths to gain access to basic goods and services.

Further, the growing prevalence of both physical and cybersecurity threats also poses a significant challenge to energy delivery. According to the U.S. Industrial Control System Cyber Emergency Response Team (ICS-CERT), in fiscal year 2012 the organization responded to 198 cyber incidents across all critical infrastructure sectors, with 41% coming from the energy sector.[8]

When electricity goes out, either suddenly or with notice, and either for short- or long-term duration, there is a tremendous negative impact. How many times has a military installation's mission been jeopardized? How many times has a long-term research experiment been put at risk? How many times has a hospital needed to evacuate its patients? How many times has a water supply been compromised, with lower pressure and lack of supply? Such critical facilities abound, and their susceptibility to these outages has never been greater.

In the context of our changing energy landscape, standby generation systems are severely limited. They rely on a transfer switch, which means they cannot operate and be fully tested when the grid is operational. The generator itself is usually significantly oversized (sometimes driven by building codes), and unable to use its full output potential. Onsite fuel storage is based on short-term operating expectations, and storing more fuel is often not an option. Most importantly, reliable operation of a standby generator presumes limited hours, with the chance of a failure dramatically higher with each operating hour.

Given these limitations, many might question the decision to continue with this approach. The fact is that standby generation equipment is fairly ubiquitous and well known, satisfies the mandate for onsite generation for critical facilities, and is reasonably inexpensive to install. What is not factored into the financial equation is that the solution includes unused (or excess) capacity that is available only in emergencies, and not in times when the electric grid is stressed, and there might be financial benefit to operate the system.

How Does a Microgrid Really Work?

A microgrid provides a variety of benefits that make it superior to traditional approaches. Microgrids serve multiple buildings or loads, removing the need for duplicative standby power sources as well as improving the host facility's electrical infrastructure resiliency.

Microgrids use multiple generation sources, likely including renewables such as solar PV and wind that greatly lower the host facility's environmental impact. Microgrids allow for extended runtimes, exceeding several weeks of operation and ensuring the host facility's mission is not compromised by a utility outage.

Consider a large medical, military, research or university campus environment that has a requirement for ultra-reliable power reliability and quality. The campus has a single point of electrical connection to the grid, likely a set of medium voltage (15 kV class) switchgear where one or more feeders enters the campus. From this switchgear, power is distributed to the campus buildings and operating facilities, with transformers that step down or lower the voltage to something suitable for use (such as 277/480V or 120/208V).

Many of these campus environments also use district energy systems where the majority of thermal energy (chilled water, hot water, steam) is generated with large chillers and boilers in a central plant and then distributed to the buildings. To be a microgrid, the campus will include on-site power generation equipment, potentially including both traditional, fossil-fueled generation and renewable generation such as solar photovoltaic (PV) or wind power. There is likely a financially attractive opportunity to simultaneously generate electricity and thermal energy (cogeneration, or combined heat and power). Depending on the specifics of the campus, the amount of power generation (typically either combustion turbines or reciprocating engines) may or may not be able to completely supply the electrical loads in the absence of utility grid power.

In normal operation, the campus operations team decides how much power to generate and how much power to purchase (typically based on a financial analysis of the options). Having the utility grid connection allows for planned and unplanned maintenance of the power generation equipment without disruption to any of the buildings and facilities. When the grid experiences a blackout or power reliability/quality event, however, the campus control system has to be able to make quick, nearly instantaneous actions to ensure the microgrid remains operational with as little impact on the campus as possible.

If there is enough onsite generation capacity to completely serve the campus, including all of the central plant equipment, the microgrid controls open the breakers and electrically isolate from the external grid. At this point the campus is in island mode and the power generation controls match the output to the campus electrical demand.

If there is not enough onsite generation capacity, the microgrid control system takes quick action to reduce the campus load to the point where it can be completely served by the onsite generation. This will likely include shedding some of the large loads in the central plant (such as the chillers) as well as load within the campus buildings and facilities. This is a highly choreographed, predefined sequence of sensing and control, where the campus operations team has established the protocols and processes for which electrical loads are the most critical, and which ones can be impacted based on the amount of load that must be shed. Once the campus load and generation supply are in balance, the microgrid controls can open the breakers to island.

Once in island mode, the generation control system is expected to maintain the balance between generation output (supply) and campus load (demand). During this time, the microgrid control system monitors the utility grid to see if the power quality and reliability conditions are back to normal. Based again on predefined standards and protocols, the microgrid control system closes the breakers re-connecting the microgrid to the utility grid.

The microgrid control system is designed to continuously monitor the utility grid and take action automatically, seamlessly, with extremely quick response time such that campus occupants and operations are likely not even aware of the switch, especially when there is ample generation to carry the campus load. The control system can also initiate a similar sequence of events to go into island mode when the campus operations team identifies potentially impactful problems in the area, whether weather- or security-related.

Design Considerations

While microgrids can be a vast improvement over traditional standby generation systems, they must be designed, constructed and operated with care. Similar to other complex technical energy solutions, there are a number of key considerations, including security, energy efficiency of the host facility, generation system efficiency, and system contingencies.

Table 1 provides comparison of microgrids and standby generation systems.

System security is a growing area of concern not just for microgrids but for all types of electric generation solutions. The more an organization relies on its electrical system for a critical

Microgrid Component	Purpose	Standby Equivalent [Differences]
Local Generation	Provide electricity for on-site needs both when the utility grid is operational as well as when it is not.	Backup generator [can only serve load that is connected to the transfer switch].
Local Load Management	Delivers electricity to equipment and manages the equipment's demand to ensure proper balance, shedding loads if they are greater than the output of the local generation.	None [backup generator has built-in generator output (supply) controls but it does not control loads and cannot shed loads if they are greater than output of the local generation].
Parallel Operation With Market Interaction	Allows local generation to seamlessly start and provide full nameplate electricity output to the facility with excess output going to the grid and financial compensation going to the facility manager.	None [Standby systems do not operate in parallel with the grid but they can be used to remove that connected (less than nameplate) load from the utility grid, with financial compensation going to the facility manager].
Island Mode	Ensures system is able to both "black start" (come online when the utility grid is not operational) and deliver electricity to the facility over an extended period of time.	Backup generator [can black start and operate in island mode but only serve load that is connected to the transfer switch].

Table 1: Primary components of a microgrid with standby generation comparison.

mission, the greater care must be taken to make sure it is not compromised by an outside agent. This includes physical threats such as weather (hurricanes, floods, tornados) or more subversive attacks that can also compromise cyber security. Microgrid designers need to make sure that the physical location of electricity generation and distribution equipment is kept secure including fences, buildings, and locks (for exposed equipment). They also need to incorporate as many cyber security standards as possible.

Microgrid experts agree that the cheapest megawatt to install is the one that is not used. As such, it is wise to perform a facility energy audit and implement energy conservation measures (ECMs) before sizing the microgrid generation equipment. It may be possible to substantially reduce the amount of generation required to meet the facility load, reaping a secondary benefit of the ECMs. Concurrent with ECM installation is the potential to upgrade building controls to both make them more efficient and make them easier to control during load control situations.

If the host facility has a substantial requirement for thermal energy (chilled water, hot water and steam), a combined heat and power (CHP, or cogeneration) system should be part of the solution. CHP uses the often-wasted thermal energy that results from onsite generation, in the form of jacket water (for reciprocating engines) and exhaust heat. The majority of standby generation systems do not use this thermal energy, as there are not enough operating hours to justify the added expense.

As the primary goal of the microgrid is to maximize electrical system resiliency and avoid any impact from utility grid outages, care should be taken to consider failure modes and plan on contingencies in critical equipment this includes the following items:

• Water supply. Onsite generation and associated central plant equipment have a requirement for make-up and cooling water that must be maintained. An off-site utility power outage could compromise the availability of this water. Having an on-site source (such as a water tank) will minimize this vulnerability.

• Generation redundancy. Whether planned or unplanned, generation system outages are inevitable. Microgrids should be designed with suitable redundancy in the generation system, including the appropriate response from the load control systems.

• Electrical distribution system redundancy. A single-line, radial electric feeder from the generation equipment to the building or similar load center is potentially a single-point-of-failure. Where possible, microgrids should include loop-fed electrical distribution systems that allow for electricity to flow to a load in several directions, thus allowing the load to be quickly restored if there is a cable fault or similar, unplanned disturbance.

• Controls response. There are many scenarios whereby the microgrid needs to use its load control system, including island mode (utility outage) operation and trying to minimize the use of utility generation if it is costly to do so. In each of these cases, it is important that the load control system be robust, well-planned, and fast-acting.

One final best practice for microgrid system professionals is that they should always be considering ways to make their systems better. This continuous improvement practice can take many forms. Equipment settings and tolerances should be regularly reviewed and improved. Operating procedures should be constantly refined. Site communications protocols should be tested. In short, when a microgrid is providing mission critical electricity, a failure to plan is a plan for failure!

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