MOVING AWAY FROM CENTRAL POWER

Asset management evolves as microgrids play various roles

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Microgrids, as many readers are aware, are small power systems of several megawatts (MW) or less in scale that possess three primary characteristics: distributed generation with optional storage, autonomous load centers and the capability to operate interconnected with or islanded from a larger grid. These small-scale systems offer a variety of benefits in the Smart Grid era.

Microgrids that localities build to serve campuses, communities, and cities can contribute to Smart Grid's sustainable benefits. They are wonderful examples of the "think globally, act locally" principle. They draw their energy from locally available, preferably renewable, resources. They use Smart Grid technologies to continually monitor customer demand and they can enable innovative pricing and other programs to manage the load and encourage customers to conserve energy. Moreover, microgrids can export and sell excess capacity back to the grid, in support of high-voltage (100kV-800kV) bulk power systems.

Depending on local demand and available, local power resources, microgrids can be almost entirely self-sustaining. In fact, in most applications they can produce as much energy as they consume and generate "zero net" carbon emissions. We're building a microgrid at the University of Minnesota Morris (UMM) campus that uses biomass from nearby farms, as well as solar and wind resources.

Thus, microgrids are akin to and supportive of Smart Grids with regard to the potential to substantially reduce energy consumption and CO2 emissions. In fact, CO2 emissions alone could be reduced by 58 percent by 2030, compared to 2005 emissions, if Smart Grids, aided by microgrids, were to become the norm.

Certainly, the 450,000-mile-long, high-voltage North American power grid backbone, which is 97 percent efficient, needs to be strengthened with HVDC lines that can integrate wind, solar and other domestic energy resources—including microgrids—into the centralized grid. The upgraded backbone, combined with microgrids, will help us meet our goals for an efficient and eco-friendly electric power system that relies less on fossil fuels.

To achieve these goals, microgrids will need to be managed for optimal performance, security and resilience, whether by a utility or a third party seeking energy self-sufficiency for financial or reliability reasons. Furthermore, it is possible to connect multiple microgrids in a cellular architecture to increase reliability, redundancy, and resiliency, which can serve utilities, end-users and society as extreme weather and other anomalous events stress the high-voltage grid.

In a "cellular power network", each microgrid possesses numerous independent, intelligent, decision-making agents in a multi-agent architecture. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

Asset management in this context requires more than just the sensors that enable condition-based maintenance, as is the case elsewhere on the grid. Asset management means understanding how a cellular power network behaves and how it can be managed and maintained for optimal performance.

Thus, asset management, when applied to microgrids, will become a more flexible concept as microgrid sensors and controls reach beyond each individual microgrid to communicate with other, similarly equipped microgrids. In fact, asset management in the microgrid context will depend greatly on how the microgrid is configured and the role it plays. The success of asset management for microgrids also depends on economies of scale; as microgrids proliferate, their components presumably will drop in price. We will further explore market drivers in a moment.

So keep asset management in your mind, as an underlying theme as we explore the likely configurations and roles microgrids will play in the mid-term future and how the market likely will grow.

CENTRAL OR DISTRIBUTED GENERATION?

The question is often posed, should we maintain a high-voltage power grid or pursue a paradigm of completely distributed generation—for example, with microgrids? The simplest answer: From an overall energy system perspective—with its goals of efficiency, reliability, security, resilience and sustainability—both models are needed, and they should work in tandem. We need a stronger and smarter high-voltage power grid as a backbone to efficiently integrate intermittent and geographically distributed renewable sources into the overall system. In addition, we need microgrids as efficient and self-sufficient as possible, which can island rapidly in emergencies.

At this point in the history of electric power service, most of us are familiar with the advantages of a centralized power system, and recent events such as Hurricane Sandy have brought home the vulnerabilities and disadvantages of such a design. The ability of the high-voltage power grid to withstand physical assault needs hardening. In addition, the reliability and resiliency of the grid needs improving. Improving these capabilities on the grid will require leadership, significant investments, and time to implement.

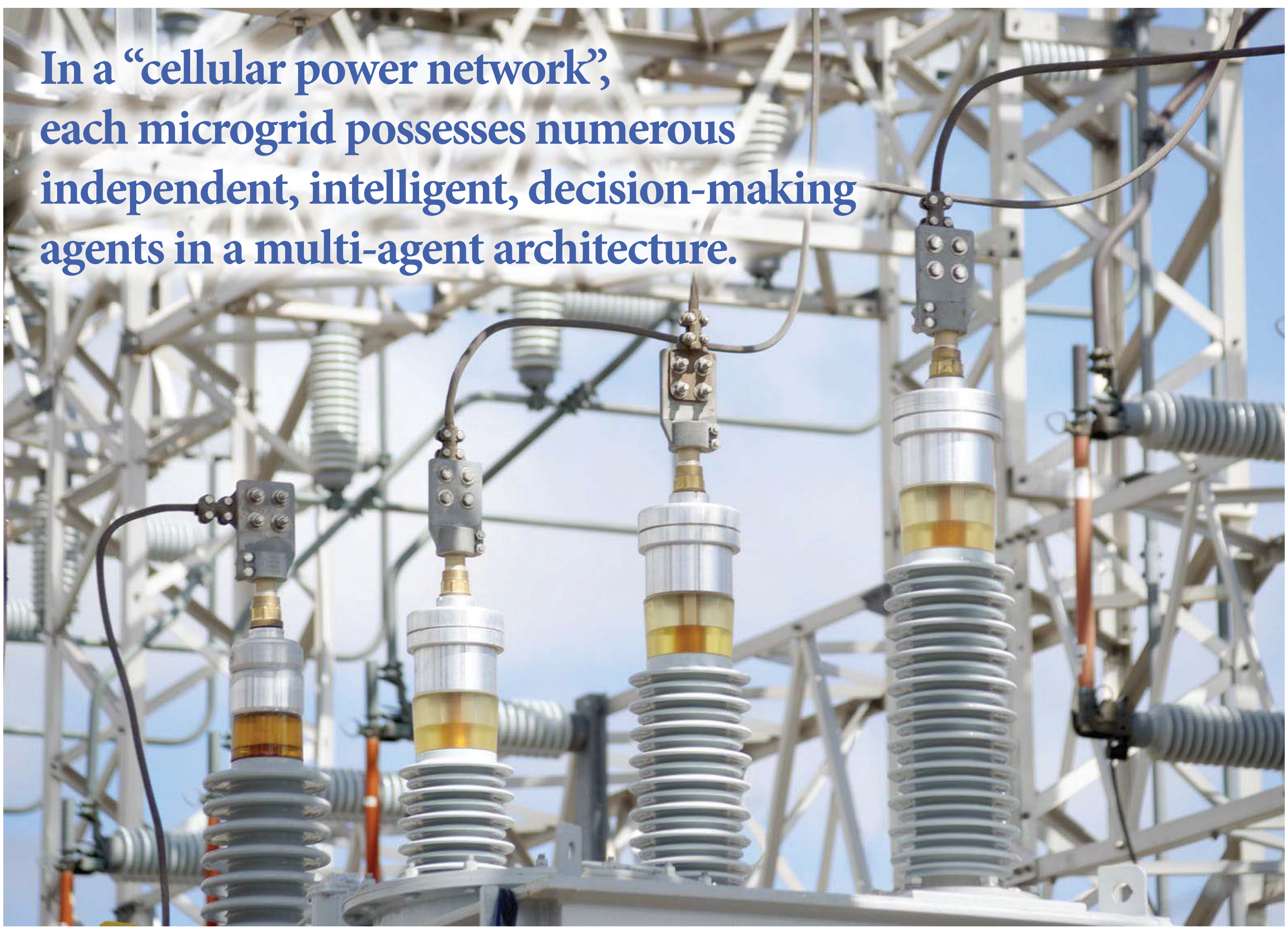
Meanwhile, recent extreme weather events and other natural disasters have inspired end-users and customers who bore the brunt of outages to ask themselves how they can make themselves less vulnerable to such widespread unreliability in their electricity supply.

For some utilities, microgrids will be part of the answer. Today and in the immediate future, microgrids represent only a tiny fraction of operational power systems. Navigant Research (formerly Pike Research) expects the total installed capacity of the world's microgrids to grow to just 4.7 gigawatts (GW) in 2017 from 1.1 GW today. However, because evidence is emerging that microgrids can play a role in supporting loads during crises affecting high-voltage grids, the market for microgrids inevitably will grow significantly. Specifically, the microgrid located at Tohoku Fukushi University in Sendai, Japan, performed remarkably well in keeping local loads supplied when the rest of the grid was compromised.

Microgrids' contributions to reliability and resiliency can be boosted by linking several together in a cellular architecture, which can continue to provide electric service even if one or more constituent microgrids is compromised by a disastrous system event. A cluster of microgrids avoids vulnerability to single points-of-failure, thus increasing the reliability and security of the electricity supply to end-users. Wide-area integration of physically disparate microgrids can be achieved by means of evolving control and communication systems.

Besides providing greater reliability of supply, microgrids will have other advantages, including the integration of "greener" but smaller-capacity electricity sources, such as solar photovoltaics. Microgrids also provide the basis for new operating approaches such as virtual power plants, in which many small consumers of electricity can be aggregated to reduce consumption and sell excess electricity into the grid at times of peak demand.

This vision presents challenges. One is socio-economic in nature. History suggests that fundamentally redesigning any critical infrastructure requires subsidies and government involvement. Active participation of the for-profit private business sector is also required. According to a 2012 Navigant Research study, the worldwide market opportunity in microgrids is expected to reach $17.3 billion by 2017. Heavy initial investments will be needed in information technology, updated or novel sensing and protection technologies and in personnel training.



TOP DOWN OR GRASSROOTS?

I've mentioned the top-down role of government and the private sector in financing and propelling the proliferation of microgrids. Conversely, perhaps initially, growth may well come from grassroots demand. Localities will find microgrids attractive because they can meet community energy demands in an eco-friendly way with reliability and cost advantages. Cities, communities, and universities are great candidates for microgrids because their projects are manageable in size and local participants are passionate about the opportunity. As microgrids succeed in that environment, showcase projects can be emulated.

Should utilities find that building, owning and operating microgrids benefits their business model, they will seek cost recovery from consumers, who will benefit from increased reliability and resiliency. Conversely, if end users such as cities, communities, and/or universities decide that, a microgrid would benefit them; stakeholders in those communities will bear the direct cost. (Still, interconnections with the utility-operated grid are governed by utility requirements that must be met.) In either case, it is imperative to educate all stakeholders on the costs and benefits of microgrids and related Smart Grid technologies in order to gain public support for such projects.

MELDING CENTRAL AND DISTRIBUTED GENERATION

To date, microgrids have been applied at the distribution voltage level. However, they may be applied at higher voltage levels too, where they have the potential to become a significant element in the grid. With enhanced information technology to improve sensing, control and monitoring, it is possible that the larger grid could be sectionalized into self-sustaining microgrids whose electrical boundaries may be defined by expected levels of reliability. Such a transformation would require a series of pilot projects to study and overcome technical, economic, and social challenges.

The United States Department of Defense, through the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program, is investigating the feasibility of microgrids supplying various U.S. bases. Europe is also investing significantly in a modernized grid, for example, in the context of the European Union's More MicroGrids project. Besides illuminating technical issues, such projects will shed light on social benefits and challenges, including the receptiveness of large corporate and individual residential consumers to new technologies.

In a brief article on managing microgrids, a few other topics are worthy of mention, including security, storage, standards and autonomous operations

and system behavior. Readers will note along the way that Smart Grids and microgrids share many of the same challenges, yet dissimilarities exist as well.

SECURITY

"Security" covers both privacy and cyber security and it is fundamentally necessary for reliable grid operations and for customer acceptance of Smart Grids and microgrids. Work on security standards and technology is ongoing. It is critical that security is incorporated into the architectures and designs at the outset, not as an afterthought. For the microgrids I am involved with, we employ security technologies for each component and for every customer application in a manner that cannot be reverse engineered. If any part of the system is compromised, the system reconfigures to protect itself and fend off attacks.

STORAGE

Without an "inventory" to access, utilities have little flexibility in managing electricity production and delivery. Likewise, intermittent renewable resources such as solar and wind cannot be relied upon for hourly electricity supply.

Although some commercially-proven technologies can store electricity by converting and storing it in another form—think of flywheels, pumped hydro and batteries—only 2.5 percent of North American generation capacity, for example, uses such plants. This is because most storage options (except pumped hydro and compressed air) are relatively unproven. Their value proposition is complex and poorly understood. Moreover, the uncertainties of changing regulatory rules make storage options too risky for most investors.

These hurdles to cost-effective energy storage must be addressed for Smart Grid as well as microgrids and even nanogrids that might serve an individual household or business.

STANDARDS

Development of operating standards is crucial, if utilities are to be convinced that intentional islanding of the larger grid into microgrids during system crises is useful and non-detrimental. IEEE 1547.4 is one such forward-looking standard now recognized by the National Institute of Standards and Technology.

AUTONOMOUS OPERATIONS

An autonomous microgrid is operated and coordinated by intelligent controls without significant reliance on human intervention. The principle of

“locality” for an autonomous microgrid implies that it operates with maximum independence from other microgrids and minimal interdependencies. To place this notion of autonomy in context: a cellular power network is a large-scale dynamic-topology power network composed of autonomous microgrids that each exhibit self-similar properties to enable scale-up, but which can default to locality to continue functioning if and when other microgrids in the network fail.

The architecture for the autonomous microgrids and microgrid assemblies being modeled in my research is based on a multi-agent architecture for operating cellular power networks. In the architecture, each autonomous microgrid, and resulting cellular power network, is composed of numerous independent, intelligent, decision-making agents. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

We have tested microgrids that incorporate a dynamical systems perspective of threat and uncertainty to investigate the performance of the multi-agent architecture for autonomous microgrids and microgrid assemblies as part of cellular power networks. As opposed to the computer science perspective that focuses on securing information, the focus of this work is on analyzing the actions or dynamics of network components and their overall management. The goal of such assessments is to determine the expected performance of such systems, including the effects of failure, repair, contention for resources, attacks and other uncertainties. Again, asset management in this fluid, network environment must remain a flexible concept.

Simulation models capture detailed system behavior, but they require a great deal of time to run. Analytical models, in contrast, create an abstraction of the system, but once set up, they make it easier and faster to carry out trade-off studies, perform sensitivity analyses, and compare design alternatives.

CURRENT RESEARCH

Research that serves the Smart Grid will also benefit microgrids. During the past two decades, my research efforts have focused on a better understanding of the true dynamics of complex and interdependent energy and communications networks and their economics in order to enable stronger, greener, more secure and smarter power grids—whether they’re large and centralized or small and local in nature, such as microgrids.

Our on-going R&D projects include work on distribution system automation, security and resilience, smart power delivery and utilization systems and cyber-physical security. Of particular relevance to microgrids, we also have a project focused on security analyses of autonomous microgrids which includes analysis, modeling, and simulation of failure scenarios and development of attack-resistant architectures.

The objective of this cluster of projects is to model, design, and develop reconfigurable and distributed smart energy systems supported by secure sensing/wireless communication network overlay and fault-resilient, real-time controls. The results will aid in the development of Smart Grids and microgrids.

In fact, university microgrid projects offer very practical environments for testing Smart Grid systems. Our Smart Grid Assessments for communities at the UMM campus and UMore Park is a case in point. Building and managing our own microgrid provides direct experience on microgrid management and it serves as a test bed for consumer- and community-scale Smart Grid-related innovations. These projects engage faculty, postdoctoral students, researchers, undergraduates, and consumers from across the local community, as well as utilities from a wider Smart Grid coalition in Minnesota.

FAMOUS LAST WORDS

Recent disruptions of high-voltage grids and traditional distribution systems—Hurricane Sandy’s first anniversary just passed—illustrates that if electricity supplies were not so dependent purely on centralized power plants and assets, and on the one-way flow of electrons and information, then customers would experience greater electrical reliability. That, in a nutshell, is the promise of microgrids. ET

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