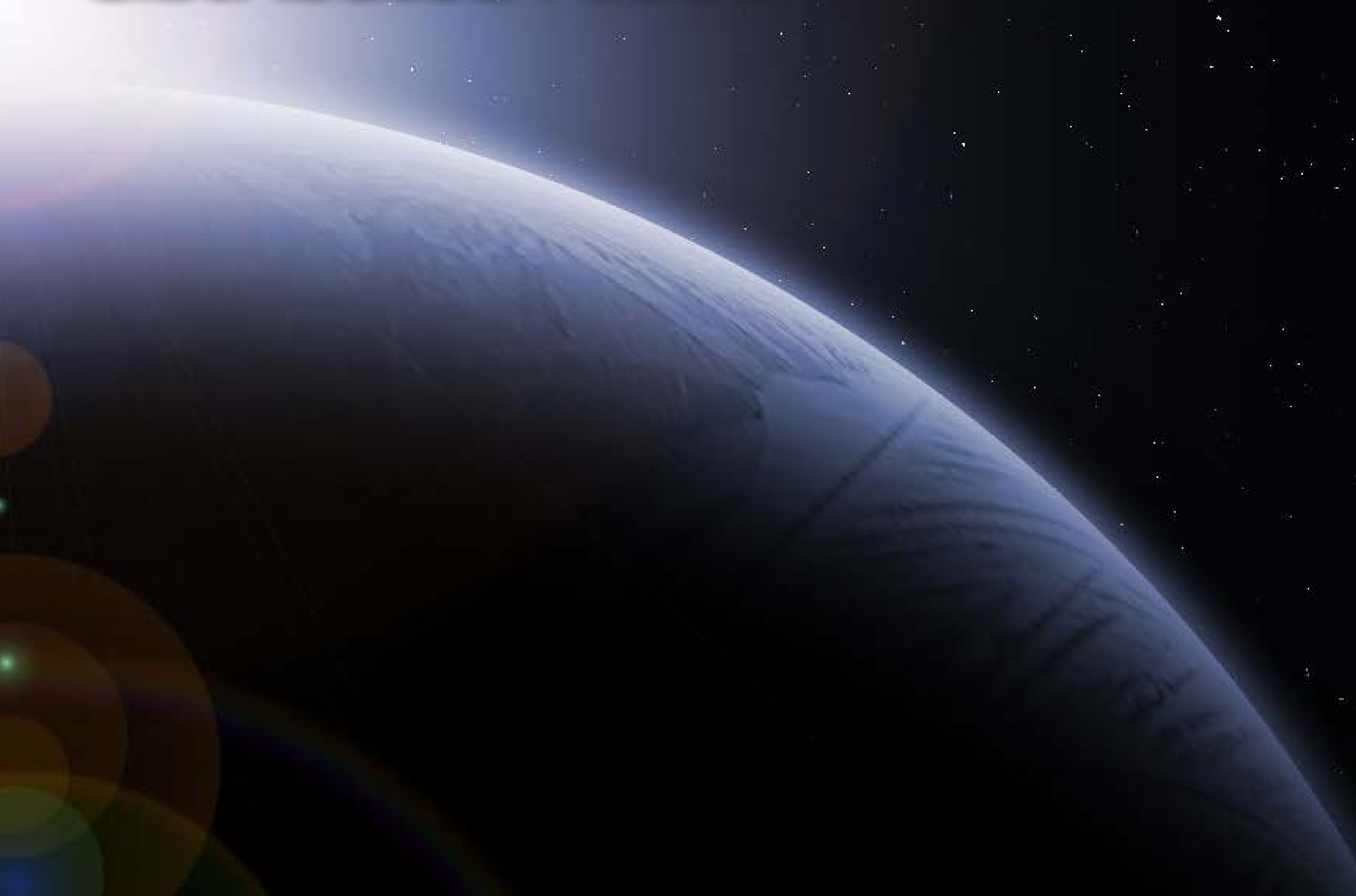
THE POWER OF MICROGRIDS

Photo credit (planet): LoganArt, Pixabay

BY MASSOUD AMIN, IEEE Smart Grid, University of Minnesota

Navigant Research forecasts that the worldwide microgrid market will grow to more than 4,000 megawatts in capacity by 2020. However, policymakers must emphasize standards and create a regulatory environment that supports this growth.

Harmonizing centralized and distributed resources



Over a year ago in *Electricity Today Magazine,* I articulated how the North American power sector might move from centralized power to a national network of microgrids. Since then, the vision and its practical details have come into sharper focus.

Modernizing the distribution grid is not only a job-producing super-project, but also a protocol for innovation, organizing the creation and distribution of electricity-enabled high-quality services through thousands of smart microgrids. Such microgrids include office and industrial parks, military bases, college campuses, large buildings, and entire communities—each microgrid and nearly every node serve both as suppliers as well as users of electricity. In effect, the microgrid is a local electricity refinery, raising the reliability, resilience, security, efficiency and quality of the electricity services and supply.

This modus operandi is within reach now in niche applications, as demonstrated by the U.S. Department of Energy (DOE) Smart Grid Investment Grant (SGIG) projects, and the U.S. Department of Defense (DoD) bases' modernization projects. Currently, at least 23 ongoing microgrid implementations are occurring across the United States as well as many projects in China, Japan, South Korea, India, Austria, and the European Union.

However, beyond niche deployments, a major blocker to worldwide microgrid adoption is uncertainty among end users on returns on investment, which vendors and manufacturers can effectively manage by tailoring the solution architecture and project implementation schedule to meet the end user's requirements.

Energy and water conservation measures are the quickest pathway to realize microgrid project payback. Moreover, electric utilities can combine the aforementioned measures with simple demand response programs. Microgrids are not a do-it-yourself project—even for organizations with deep electrical and mechanical engineering expertise.

Commercial and industrial facilities can provide a positive business case for microgrid adoption, cutting energy costs while potentially providing a demand response opportunity for the local utility.

Photo credit (local microgrid in Sendai, Japan): NTT Facilities, Tokyo

Clear policy and associate regulatory instruments are necessary to capture the full benefits of smart microgrids and to integrate them into existing electricity distribution networks. Utilities must actively support policy participants to assure the success of this highly beneficial transition.

Navigant Research reports that the microgrid market is "heating up quickly" around the world with North America at the forefront, expecting worldwide microgrid capacity to grow to more than 4,000 megawatts by 2020.

Canadian Solar, one of the world's largest solar power companies, has opened a microgrid test center in Ontario that will share information and services with utilities, community colleges, and companies that want to develop smart microgrids. These factors are also driving microgrid innovations in underdeveloped parts of Africa, Asia, and Latin America.

Looking ahead, I envision a hybrid system with a central power backbone, sectionalized for reliability and resilience, with a cellular power network of microgrids overlaying it. Each individual microgrid, whether for a building, campus, or "smart" city, would rely on local energy resources as much as possible to serve local citizens. Each individual microgrid would coordinate with others and with the entire system.

This ambitious view of the power industry's mid-term future offers benefits, and it will encounter challenges. Technological progress, including the IEEE Standards Association's work on industry standards, may help push the wide adoption of microgrids forward in the near future.

However, stakeholders must imperatively cooperate in order to make global microgrid adoption a reality. Furthermore, stakeholders must unite to overcome the challenges of creating a sustainable, reliable, and resilient power system for the 21st century. Strictly speaking, stakeholders can prepare for the future or allow it to unfold haphazardly. In this issue of *Electricity Today Magazine*, my main objective is to provide the necessary information that can help readers prepare for the future through a systematic framework. I'll discuss the likely attributes and benefits of a hybrid system, the technology challenges, and the likely drivers and outcomes.

A CELLULAR POWER NETWORK

Microgrids' key attributes in the present context include integration of local power generation (for example, renewables), managed loads, and balancing the two while islanding from the central grid when necessary. However, integrating multiple microgrids—each with its own collection of intelligent, decision-making agents—into connected "cellular" networks of localized microgrids is another matter entirely.

The complexity and scale of such an endeavor will require an advanced, multi-agent architecture and new sensing, automated control and protection technologies, as well as public/private investment with assessment of return-on-investment and policies.

The result might be described as a large-scale, dynamic-topology power network created by a honeycomb of

Solar panels on office buildings may enable a single building to become a microgrid or serve as just one element in an office park-based microgrid.

Photo credit (solar power building): Christiane M, Pixabay

interdependent microgrids. Each microgrid would possess similar characteristics that enable a large-scale network and each would default to its specific locality if others fail.

An ideal hybrid system experiencing a natural or intentional extreme event would coordinate the transmission backbone and individual microgrids in tens of milliseconds to protect the entire system. With a natural event, electric utilities will have the ability to look ahead for seconds—even days—and take measures to limit system damage.

The coordination and interdependency of a cellular power network gives new meaning to the concept of asset management, which must optimize each element—and the system as a whole—in the most cost-effective and timely manner.

Although many microgrid demonstrations currently exist, providing a solid foundation to actualize global microgrid adoption, such a smart and self-healing system has never been built. However, at the University of Minnesota, myself, and other researchers are using simulation and analytical models to test the behavior of such systems for optimizing performance, protection, and failure scenarios.

RECENT RESEARCH

In my work, investigating cellular power systems, we use both simulation models and analytical models. Simulation modeling involves a digital prototype of a physical, real-world system and the use of physics and first-principle science to predict real-world performance.

Analytical modeling helps us understand system behaviors under a wide range of scenarios and gives us a deeper level of abstraction and clearer insights into physical characteristics as well as market, policy, and environmental outcomes. Furthermore, analytical modeling helps us test the system architecture and its ability to become secure, reconfigurable, and resilient.

In the past year, computational speeds have increased nearly fifteen-fold, which attain faster, more high-fidelity simulations. Specifically, we simulate the behavior of multi-agent (autonomous or semi-autonomous) distributed systems used in microgrids. The microgrids can be "cellular" or modular power systems that select to connect to or disconnect from neighboring microgrids, based on desired performance objectives (including reliability, security and resilience, metrics/indices or on price and ownership).

We allow the models themselves to introduce failure modes that we have not anticipated, such as "black swan" events, very rare but high-impact events. This experiment produces greater confidence in our findings, particularly in identifying precursors that presage trouble.

Additionally, we use modeling to administrate trade-off analyses for component costs, carbon outputs, and market considerations. A cellular power network's interdependencies are based on market economics and policy mandates as well as technology.

TECHNOLOGY & OTHER CHALLENGES

Sensors, controllers, and control logic require technological improvements and price reductions in order for a cellular power system to become feasible (which, I believe, is possible).

Microgrid implementations are increasing globally, with current major projects taking root in North America, Europe, Asia, and India. Global standards are facilitating adoption and creating economies of scale.

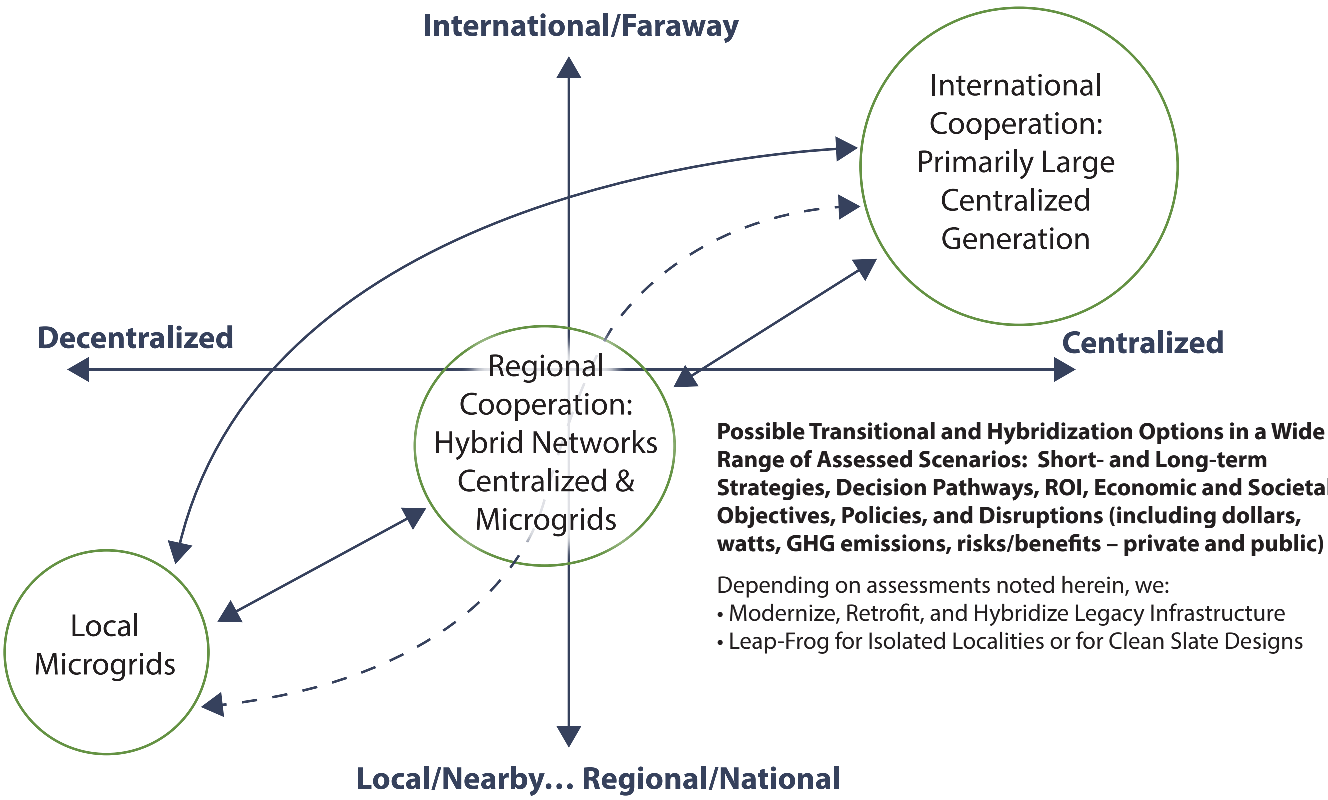


Photo credit (global network): Gerd Altmann, Pixabay

This diagram illustrates the relative necessity for cooperation in scenarios driven by centralized or decentralized power on a scale ranging from local to international. In the lower left, a local, decentralized microgrid, for instance, requires only local cooperation. At center, a hybrid grid composed of a legacy backbone/transmission system overlaid by microgrids, for instance, requires regional and/or national cooperation. At upper right, international cooperation is required to coordinate the operations of a centralized grid.

Asset management in such a vast network is terra incognita (unknown territory). Economic modeling will help illuminate the practical, market-based behaviors and challenges of a cellular system.

The power industry will overcome certain challenges as utilities, companies, and other investors implement discrete microgrids (which is currently underway). Homes and offices that adopt DC-to-DC systems in which solar panels directly feed electronics and lighting will achieve efficiencies that aid the supply-load balancing act. High-voltage direct current (HVDC) transmission lines and power electronics will improve the backbone of a hybrid network.

In Beijing, China, some electronics-heavy facilities are now

Widespread uptake of residential solar power may challenge utility business models and could become a significant generation source for single home, community and/or municipal microgrids

Photo credit (residential solar): moerschy, Pixabay

developing all-DC distribution microgrids to feed power to consumers. In Japan, instead of having AC to DC power converters on each computer, some companies are installing centralized converters and distributing DC power across their server farms.

Security, storage, and standards will develop apace and will help support a hybrid power network. In the multi-agent distributed architecture that the University of Minnesota researchers are currently testing, each agent has layers of defense built in from the chip level upward. We use secure standards and protocols for communications as well.

BUSINESS DRIVERS

Historically, public/private partnerships have facilitated large shifts in critical infrastructure. However, in the near term, simple economic drivers will shift the current, centralized power paradigm.

Utilities will use a top-down approach to adopt microgrids, integrate renewables, improve problematic distribution circuits, and enhance customer service with reliability and resiliency. Buildings, campuses and communities will adopt microgrids from the ground up, driven by the economics, improved power quality and/or the desire for a sustainable energy destiny. In both instances, the business case must work for the sponsor.

Melding the top-down and bottom-up approaches into a nationwide cellular power network, backed by a sectionalized transmission system, may present new challenges. With proper adherence to global standards, however, this shouldn't present insurmountable technical hurdles.

FAMOUS LAST WORDS

Microgrids in a cellular power network, aligned with a modernized transmission backbone, are technically feasible. The remaining technical challenges will likely be resolved, thanks to the economics of the resulting power market influencing the outcome. Meanwhile, business, environmental, and aspirational drivers will push top-down and bottom-up microgrid implementations. These factors will have major implications for all stakeholders and energy provisioning in the 21st century. ET

Massoud Amin is the chair of the IEEE Smart Grid as well as a fellow of the IEEE for leadership in Smart Grids and security of critical infrastructures. Additionally, he is a professor of electrical and computer engineering, director, and endowed chair of the University of Minnesota's Technological Leadership Institute.