Scalable Microgrids for Enhancing System Resiliency and Efficiency

The two severe blackouts caused by the August and October 2011 storms affected nearly 880,000 customers and led to enormous economic and social upheaval in the State of Connecticut. Improving the resilience of the electric power infrastructure has been an urgent need not only to reduce the vulnerability of the power grid to extreme weather events but also to enhance power supply reliability on a day-to-day basis. Among different options, the microgrid, which integrates local distributed generators (DGs), customer load, energy storage, intelligent protection and control devices, is an emerging paradigm for power system reliability enhancement and for effective use of renewable energy resources. Microgrid is believed to be a potent option to prevent, mitigate, and recover power outages because of its compatibility to the grid, flexibility in accommodating diverse sources, substantially immune to tree damages, and inherent stability when operating autonomously. Our recent report entitled 'Reliability Evaluation of Selective Hardening Options' has summarized the reliability benefits of microgrids for critical infrastructures within selected CT towns under different weather conditions (normal weather, major storm, tropical storm, Category 1, Category 2 and Category 3 storms). Besides the improved grid resilience, a microgrid can provide a wide variety of technical, economic, environmental and social benefits to stakeholders and electricity users. Below is a summary of microgrid benefits in different aspects and the additional R&D efforts that are needed to achieve the benefits.

Reliable Integration of Renewable Energy. Direct interconnection of renewable energy resources (RES) on a distribution feeder can compromise power quality and system reliability because of the intermittency and unreliability of RES. Microgrid, on the other hand, can offset RES fluctuation by using storage units (during islanded operation) or utility generation reserves (during grid-connected mode). Furthermore, smooth transition from grid-connected to islanded mode largely eliminates the sustained loss of load and therefore significantly improves the power supply reliability.

Stabilization of Distribution and Transmission Grids. The progressive integration of RES and electric vehicles (EVs) has led to uncertainties in both generation and load, creating widespread system security issues. The challenge mainly arises from coping with the natural cycles of renewable resources because all RES ultimately derive energy from natural sources that vary in their availability over different timescales and geographical locations. Accommodating the impacts of RES and EVs only at transmission level would be inefficient, if not prohibitive, because this requires substantial reserves from conventional generators and expensive emergency power curtailments. As RES and EV penetration rises, transmission operators will soon find themselves closer to the technical limits of their system, and under pressure to find ways to cost-effectively increase those limits. Accommodating high levels of RES and EV penetration at the distribution level is of importance for reducing stresses in both the distribution and transmission systems. Microgrids are mostly interconnected to the distribution grid and therefore can effectively satisfy load demands. The booming of microgrids and the deployment of coordinated control in multi-microgrids would significantly improve the security and adequacy in power grids.

*Peak Load Reduction***.** Obviously, a grid-connected microgrid can reduce peak load in the neighboring distribution circuits if it comprises adequate amount of dispatchable DGs. Moreover, appropriately located microgrids can contribute to the *Reduction of Network Losses and Voltage Regulation*. If the majority of load demand can be met locally by microgrids, the energy losses in the process of delivering energy from remote power sources to local loads will be significantly reduced. It should be noted that high R/X ratio of distribution circuits results in a weak coupling of reactive power with voltage magnitude. For a microgrid with lots of non-disptachable DGs, therefore, its capability of voltage regulation might be quite limited.

Demand Response. Microgrid provides a flexible platform for shifting or interrupting local loads in response to load shifting or reduction signals from utility side. A requirement for the successful application of demand response schemes is the adoption of smart metering and smart control of residential, commercial and industrial loads within the microgrid. Further, time-of-use price, dynamic pricing, or critical peak prices could offer customers powerful incentives to participate in demand responses.

Ancillary Services. The participation in local ancillary service market can open up new opportunities for microgrid to meet system obligations and achieve business proliferation. When grid-connected, microgrids can provide different services such as frequency control support, voltage control support, congestion management, reduction of grid losses, and power quality improvement to help maintain the integrity, stability and power quality of transmission and distribution system. If the main grid has emergencies, microgrid can offer black start capabilities to pick up local load as well as frequency and voltage control to accelerate the restoration of utility grid.

Currently, a few microgrid pilot programs are being developed to test and validate the benefits, efficiency, performance, and operation under community and critical infrastructure conditions. Among them are CT's first-in-the-nation statewide microgrid program and DOE-supported New Jersey Transit System Microgrid. That being said, it should be emphasized that the *market environment and regulatory settings* has a significant impact over wheter or not a commercial microgrid would be able to survive and thrive. *Public policy support*, therefore, will be one of the key enabler that helps create local markets for ancillary services, recognize the locational value of microgrids, popularize demand repsonses through microgrid, and encourage technological innovations leading to further cost reduction.

Last but not least, it is always important to continue the *research and development* of novel technologies that unlock the potentials of microgrids as building blocks of smart grid. At UCONN, our power engineering team is partnering with power industry to push the technological frontiers and practicality of microgrids. Our research themes include (1) Seamless power flow and power management, (2) Optimization of microgrid subsystems for efficiency and reliability, (3) Micro/macro grid resilience & sustainability, (4) System-level optimized planning/operation, and (5) Commercial viability studies and policy/regulatory research (in collaboration with CCAT. Besides the low-level power electronic architecture and control, our research has been focused on differentiating technologies including distributed control, coordination and multiple time scale optimization towards ultra-low outage time, emission reduction and optimized energy efficiency, for instances:

Ultra-fast Programmable Communication Networks. We aim at building reconfigurable, ultra-fast networking for highly resilient communication that provides inexpensive, ultra-reliable means for high speed distributed, coordination control and unified online condition monitoring for performance and reliability.

Optimal Power Flow in Microgrid. New approximate dynamic programming algorithms are being developed to minimize the operational cost, unreliability cost and environmental cost of the microgrid by optimally dispatching distributed generators, reactive power resources as well as demand responses.

Robust Integration of Intermittent Renewables. New technologies are being established to better use intermittent resources, including: Markovian modeling as opposed to scenario-based descriptions of intermittent renewables for modeling efficiency; Advanced optimization of mixed-integer commitment and dispatch problems for effective integration of renewables with less reserve or regulation requirements; Integrated operation with microgrid-level storage devices for improved load-following capabilities and higher efficiency.

Distributed Optimization of Microgrids Considering Demand Response. The novelty lies in the distributed optimization of microgrid operation consideration demand response on the part of microgrid residents with shadow price as coordination signals for near-optimal solutions. The core solution is analysis, characterization and Markovian modeling of demand response in microgrids.

Load/Generation Shedding for Microgrid Resilience. The goal is to mitigate highly disastrous events that cannot be covered by other microgrid protection and controls. The key is to find ultra fast load/gen shedding to maintain system stability and reliability with minimum amount of load/gen shed. UCONN's technologies of Surrogate Lagrangian relaxation and branch-and-cut are adopted for solving the problem.

Reliability Characterization of Microgrids. Microgrid reliability under various extreme conditions is assessed using UCONN's active distribution and microgrid software packages which provide probabilistic metrics suited for quantitative economic evaluation. This provides a tool for the load serving entity and the community to optimize the microgrid design to achieve the DOE-specified reliability goals.