A Smarter Grid enables Communal MicroGrids

Terry Mohn
President, General MicroGrids
San Diego, CA USA, Terry.Mohn@GeneralMicroGrids.com

ABSTRACT

Adding renewable energy resources into the existing bulk generation power system can be accomplished through a smarter power grid when the integration includes complex, end-to-end control strategies and consumer participation. An interesting consideration is that integrating distributed energy resources (DER) will likely become the normal state, as siting transmission becomes more challenging. Microgrids will evolve from both utilities and consumers. They will produce DER, which will require addressing facets of both the electrical power system and the new smart grid control infrastructure. As smart grid develops, integration and optimization of grid control logic are areas that stand as key enablers to a rapid growth of renewable generation.

This paper presents the impact significant renewable energy generation can wage against the existing power system and how sophisticated smart grid control elements can address its integration into communities of distributed energy microgrid systems.

Keywords: smart grid, microgrid, distributed generation, renewable energy, communal microgrids

1 MOTIVATING CONTEXT

The energy market in the United States is going through an evolution. For example, California Governor Arnold Schwarzenegger issued Executive Order S-14-08 on November 17, 2008 which requires that 33 percent of the electricity sold in California come from renewable energy resources by 2020. New large wind farms throughout the state and solar farms in the desert areas have been contracted by major utilities to address their increased energy requirements as well as regulatory obligations. Many of these new sources require construction of large-scale long distance transmission power lines to move power. Transmission is expensive to build, environmentally sensitive and politically unpalatable to the local communities and regulatory bodies.

With budget pressures as well as a desire for higher reliability, consider also that consumers are taking direct control over their energy portfolio. Prior to the recent recession, electric energy prices rose over 10% per year for five years across most of the US while outages were becoming more common place. Adding a more costly generation mix into the utility portfolio will once again result in both concerns. Consumers are therefore building generation onsite using various incentives to lower their capital costs. Alternatively, power producers will develop and build the capacity and sell DER through power purchase agreements; thus achieving a flat energy budget for decades, while achieving higher reliability and a carbon-friendly outcome.

The technical difficulty becomes one of how to reduce aggregate demand, or conversely, increase distributed generation in real time as bulk wind or solar drops or peaks. For consumers who build their own onsite generation, balancing supply with demand becomes critical. Similarly, these same consumers who build their own localized DER will start to consider how they might take advantage of neighboring resources. Microgrids can protect and service the larger utility-operated grid and cooperate with adjacent microgrids. They can work independently as well as aggregate their capabilities. They become integrated communities.

Through the introduction of a central control system, placed between the bulk power grid and the distributed energy resources, customer owned assets will collectively stabilize the frequency and voltage swings witnessed on the bulk transmission system and in adjacent microgrid communities. It is entirely feasible to incorporate large end-use energy participants as additional resources of renewable energy and potentially offer them revenue.

2 DER BENEFITS AND RISKS

Benefits

- Ability to improve grid reliability by controlled distributed generation at the large energy consumer level
- Align with Go Green initiatives in states
- Ability to better manage consumer energy and fuel costs
- Ability to achieve energy efficiency guidelines
- Enable smaller customers to bid their reserve distributed generation resources into the wholesale energy market
- Provide a potential new revenue stream for each customer

Risks

- Consumer buy-in to the DER concept
- Absence of large scale control systems
- Scheduling the introduction of DR, DG, and storage at each customer site to develop an effective aggregate

- Availability of incentives and necessary capital markets
- Investors for customer-owned resources and their buy-in
- Ability of regulatory bodies to create policies for managed DR and DG
- Requires significant time to educate and coordinate the regulatory agencies

3 MICROGRID BASED POWER SYSTEMS

Research and federally funded pilot projects have demonstrated that distributed resources operating within a microgrid are a viable energy efficiency option and have the potential to greatly improve our energy generation and reliability issues.

A Microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources. Microgrid components include; distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management. When renewable energy resources are included, they usually are of the form of small wind or solar plants, waste-to-energy, and combined heat and power systems.

Microgrids perform dynamic control over energy resources enabling autonomous and automatic self healing operations. During normal operations, peak load, or grid failure the Microgrid can operate independently from the larger grid and isolate its internal assets and associated loads without affecting the larger grid's integrity.

The Microgrid operations described are quite dynamic and require sophisticated control of many attached components. New and legacy components will comprise the Microgrid and the grid enterprise will operate as a distributed and collaborative suite of control, generation, distribution and load nodes. Advanced demand management and price aggregation operations will require enterprise-wide information exchange as well as distributed and cooperative control methods. Control operations such as dynamic decisions to island the grid or apply power from distributed generation units will require real-time monitoring and complex power analytics.

4 MICROGRID CELLS

Multiple classes of Microgrid deployments will evolve to support different purposes and size of power generation capability. The different classes of Microgrids can scale to be economically efficient, as well as environmentally supportive, and produce varied levels of self-sustainable power. Many Microgrid networks will cooperate using smart grid technologies. Legacy utility grids will expand by connecting dispersed Microgrids that each contains distributed renewable generation to the existing bulk power system. Campuses will add and manage their own cost-effective and environmentally clean power generation along with establishing academic research centers. Industrial parks will build Microgrids, flattening rising energy costs and provide self sustainable, reliable power to their factories.

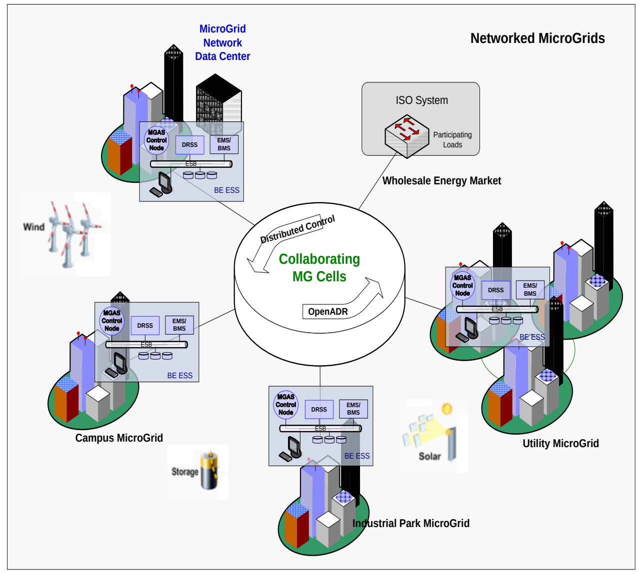

Figure 1 Networked Microgrid Cells.

The different classes, and sub-segments, of individual Microgrids can be viewed as cells that are networked to form a collaborative and distributed power system (see figure 1). Each cell addresses a local focus, yet is available to support adjacent cells with power generation for the purpose of demand response or failure recovery. Adjacent cells can be leveraged to provide sustaining power when a neighboring cell can't support its demand or scheduled as a planned fail-over recovery mechanism. The adjacent cell concept presents an opportunity for each class of Microgrid operator to generate revenue by bidding excess generation capability into the wholesale energy market or potentially to negotiate collaboration directly with a neighboring cell. This collaboration is, in essence, communal microgrids.

5 MICROGRID CONTROL TAXONOMY

Operating a Microgrid and its attached distributed energy resources requires sophisticated control mechanisms. The independent role of specific Microgrids and the varying specific control needs of the attached resources require deployment of a control system that considers a hierarchy of control objectives.

At the grid level, optimization and overall grid stability goals are paramount. At the device level, efficient energy production and device optimization are key. At the load level, efficient energy consumption, cost and reliability are the critical elements. This broad set of requirements creates an implicit Microgrid control hierarchy. It indicates that a single controller cannot effectively make decisions for all attached elements and draws the conclusion that a distributed control system supporting multiple and cooperative goals must be provided. A system of individual control nodes that collaborate and cooperate to optimize across the full hierarchy of goals for the power system is desired and fundamentally required.

Two critical areas arise as primary control logic requirements for orchestrating a Microgrid; 1) Control logic managing power stability of the grid and 2) Control logic managing the digital information and automation layer of the grid. Tables 1 and 2 present a summary of the two separate, yet holistic, control areas existing within a Microgrid.

TABLE 1 ANALOG-CENTRIC CONTROL GOALS

Analog-Centric Control Goal (Power Stability)	**Constraints**
Voltage Stability	Monitor voltage state variables. Dynamically balance electrical load and generation levels to maintain voltage level within a nominal operating range.
Frequency Stability	Monitor frequency state variables. Dynamically balance electrical load and generation levels to maintain voltage frequency within a nominal operating range.
Rotor Angle Stability	Monitor generator state parameters and switching circuits. Control power distribution such that generators connected to the grid rotate in synchronicity and produce alternating current at the same nominal frequency.
Transient Stability	Monitor and balance the power distribution and congestion to maintain transient disturbances within a nominal level.

TABLE 2 DIGITAL-CENTRIC CONTROL GOALS

Digital-Centric Control Goal (System Automation)	**Constraints**
Demand Response	Dynamically orchestrate the shedding and adding of load and generation. Dynamically orchestrate the connection of power generation and storage devices.
Distributed Generation	Control and optimize the generation of power based on cost of energy, reliability and environmental constraints.
Energy Storage	Control and optimize the storage of energy based on cost of energy, reliability and environmental constraints.
Energy Metering	Measure, aggregate, analyze and publish energy usage.
Energy Forecasting	Analyze and predict consumption, price, generation and failure risk. Generate system and power profile optimization programs.
Energy Market Trading	Perform price monitoring, negotiation and settlement.
System Monitoring	Analyze cyber security, information flow, information quality, business processes and topology. Generate reports and programs to optimize system performance and provide control center visualization.

The analog-centric, power distribution and transmission infrastructure monitors and balances the stability of power. The digital-centric information infrastructure computes the need for power and where to procure it based on price, reliability and grid situational awareness. Integration of the two control perspectives is required to mediate the constraints of dynamically generating and consuming power against the risk of possible grid instability.

Providing control to manage power stability includes analyzing and orchestrating voltage level consistency, voltage frequency stability and the underlying power signal phase relationships. Avoiding catastrophic system failure and keeping the grid at operating equilibrium requires monitoring and performing changes to these power state variables at the granularity of seconds or minutes.

Of course, all of this is compared against situational considerations, such as outage detection, planned maintenance, and meteorological conditions.

Providing control to manage the Microgrid digital infrastructure, and its associated distributed energy generation, storage and loads requires analyzing a broad set of operational parameters and system-wide state variables. These parameters include dynamic price and performance attributes of the distributed energy generation as well as information reflecting the energy consumption, cost, environmental and reliability desires of the distributed loads.

In the legacy power grid, system control came from the perspective of the utility organization and its captive audience of customers. Load shedding and “peaker generation” were the primary means of managing peak demand. Base-load power generation came from the utility’s bulk systems and therefore, the core intent of the control system was managing the power stability of the grid.

The Microgrid’s digital domain brings in additional non-power specific infrastructure with associated control functions that orchestrate critical IT elements, “the smarter

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grid". Cyber Security, Distributed Information Management, Process Automation, Workflow Orchestration and Advanced Resource Forecasting stand as new control areas that must be addressed in the pursuit of building out the modern power grid.

The Microgrid also adds the notion of dynamic cost and carries control complexities arising from the automation of distributed energy generation and storage. This new set of "digital goals" needs to be considered holistically and combined with the existing and traditional set of power balancing goals. Additionally, with the introduction of distributed energy resources, the power system control logic must now consider a distributed and cooperative set of decision logic versus the legacy logic which was primarily focused on local and "bulk energy" driven criteria.

6 CONTROL DRIVERS

Legacy power grid issues have evolved over many decades and have become well known. Power engineers have a myriad of commodity components to choose from when designing traditional bulk power systems and cogeneration. However, incorporating renewable energy generation, networking microgrids, and integrating distributed energy resources is in the evolutionary stages. Consequently, commodity product or technology does not yet exist. As presented in this paper, it's apparent that a new paradigm of control is required to address the holistic, combined analog/digital centric perspective power engineers must now consider.

Many control idiosyncrasies exist and must be accounted for when developing Microgrids and integrating renewable and variable energy resources. The characteristics of renewable energy systems, particularly electronically-coupled units, are different from those of legacy turbine generator units. Microgrids are subject to a significant degree of local imbalance caused by the presence of variable energy resources. A large portion of the energy supply within a Microgrid can be delivered from highly variable wind and solar based generation units. As such, new modes of control as well as short and long term energy storage must now play roles in attempting to stabilize and manage the volatile energy distribution. New topological constraints are also in play, such as the ability to island sections of Microgrid loops from the ubiquitous power grid without affecting macro level load balancing and synchronization.

Economics will also add new control constraints. A Microgrid may be required to provide pre-specified power quality levels or preferential services to critical industrial loads such as factories, data centers or health care institutions. In addition to supporting regular scheduled loads, Microgrids will participate in wholesale markets, and as such, be required to control generation and distribution to support energy trading in an effort to financially sustain them. Energy market trading will also convey additional security, measurement and accounting traceability aspects not previously addressed in the legacy power grid.

7 SUMMARY

The demand response, distributed generation and energy storage subsystems applied in Microgrids are creating new smart grid technology requirements in the areas of automation, management and control of alternative energy sources. The call for dynamic and distributed control methodologies, not only within Microgrids but also across multiple networked Microgrids, presents new technical challenges along with expanding economic opportunities. Energy production by distributed resources can provide stabilizing effects for the national power system. However, integrating the management and control of distributed resources into the bulk renewable energy market suggests that end-to-end control systems are needed to manage the assets in real-time. Achieving the modern power system goal requires incentives, either through new market mechanisms, funding for development, or regulatory change to authorize utility participation to achieve a networked environment across the distribution systems nationwide; particularly, if customers own many of the assets.

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