Smart Grid creates an Over-the-Counter Market for Energy Sales

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***Abstract*— As policy makers seek to integrate a serious sociological and environmental issue into energy production, the typical utility is faced with not only technology upgrades, but also dealing with new systemic events that occur far beyond its franchise borders. 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 incentives to participate.**

Application of renewable resources will provide environmentally clean, and eventually, cost effective energy alternatives to the existing mix of electric generation assets. An even more interesting consideration is that integrating distributed energy resources (DER) will likely become the normal state, as siting transmission becomes more challenging. DER requires addressing facets of both the underlying analog-centric electrical power system and the nascent digital-centric information 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 a serious discussion of 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 distributed energy systems. Technology addressing these concepts is under development now by General MicroGrids' Microgrid research and development program in San Diego California.

Keywords- smart grid, microgrid, distributed generation, renewable energy, control, integration, information technology

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. In the last few years, emphasis has focused on renewable energy resources as a potential solution. 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. A further anticipated proliferation of these large scale wind and solar power generation farms has the potential to substantially improve the achievement of both state and upcoming national climate legislation. However, these renewable power types create variable generation determined by prevailing meteorological conditions. Whereas large scale, bulk storage of electrical energy is problematic and expensive, application of novel distributed control mechanisms has the potential to address the volatility issues associated with wind and solar power generation in a cost effective manner.

A secondary, yet equally important concern is that construction of large-scale long distance transmission power lines to move power from remote bulk renewable resources into the urban areas that comprise the load centers has also proven to be problematic. Transmission is expensive to build, environmentally sensitive and politically unpalatable to the local communities and regulatory bodies.

Addressing the sociological and environmental movement towards clean energy has brought new power quality concerns to the current electric power system. Regional policies that mandate high levels of renewable energy standards (RES), such as California and the Northeast, are struggling to find technical solutions to manage power system control. Power quality distribution problems have been caused by the fact that areas with rich renewable potential are very distant from their major load centers. Often, they are hundreds of miles apart, either in other states or regulatory regions. As of December 2009, 35 states required utilities achieve between 5% (AZ) and 38% (MA) renewable generation mix by 2015. These states and regions are in danger of creating significant power instability on large transmission systems. Through rapid adoption of bulk renewable generation, these instabilities could soon become a national issue. President Obama has made the national RES a cornerstone of his energy strategy – advocating that 25 percent of our electricity be generated from renewable sources by 2025.

The technical difficulty becomes one of how to quickly reduce aggregate demand, or conversely, increase distributed generation in real time as bulk wind or solar drops or peaks. Through the introduction of an enterprise-wide control system, placed between the bulk power grid and the distributed energy resources, customer owned assets could collectively stabilize the frequency and voltage swings witnessed on the bulk transmission system. Customer energy management is not a new concept. It is already used by network operators in a number of situations such as load shedding in emergencies, frequency control in autonomous grids containing renewable energy units, and it has been investigated as a means of providing voltage control in distribution networks with high level of distributed generation. In addition, the California Independent System Operator (CAISO) has developed a Proxy Demand Response and Participating Load concept that allows integration of utility renewable resources into the California wholesale energy market. 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

Energy policies are motivating a nationwide desire to increase the application of renewable energy resources, distributed generation and energy storage devices. Successful application of distributed generation requires an enterprise-level system perspective which views generation and associated loads as an integrated and autonomous subsystem or a "Microgrid". Research and federally funded pilot projects have demonstrated that distributed generation operating within a Microgrid is a viable energy efficiency option and has 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.

A technical complexity for Microgrids is the sensing, monitoring and resultant control of distributed energy resources. Microgrids will need to perform complex system control functions such as; dynamically adding or removing new energy resources without modification of existing components, automating demand response, autonomous and self healing operations connect to or isolate from the transmission grid in a seamless fashion and manage reactive and active power according to the changing need of the loads.

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. The most fundamental Microgrid operations will require a common data exchange vocabulary to enable the distributed components to share control and status as well as provide a mechanism for new sources to publish source, load and power capabilities. 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.

Microgrids will fundamentally need to interoperate with legacy bulk power systems and their associated data and network infrastructure. Microgrid deployments can take several forms and sizes, such as a utility run metropolitan area grid, industrial park, college campus or a small energy efficient community. Once Microgrid controls are operational at a local level on the distribution grid, they become resources for the larger bulk renewable generators. What's so great about the smart grid is its flexibility to serve many purposes.

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 collaborate 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.

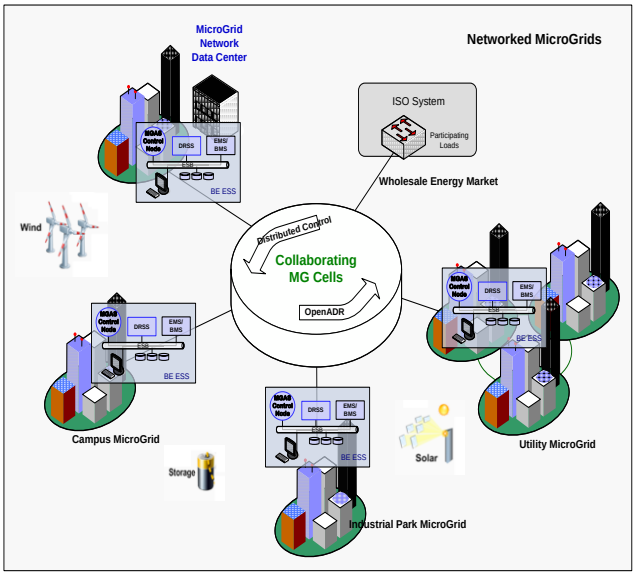

Figure 1. Networked Microgrid Cells.

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, a new energy market.

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 I and II present a summary of the two separate, yet holistic, control areas existing within a Microgrid.

TABLE I. 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 II. 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 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. MGAS MICROGRID CONTROL FRAMEWORK

General MicroGrids' Microgrid research program addresses system architecture design, simulation, prototyping and fundamentally a goal of product development to enable build out of Microgrids. Of particular interest is the integration of distributed renewable energy generation. As discussed in this paper, integrating renewable and variable resources will require new and novel control systems technology. Integration of DER will require control logic that addresses both the unique characteristics of the DER units as well as provide capability to orchestrate control in a highly distributed environment. To address this need, one of the specific areas General MicroGrids' Microgrid design has been developing is an agent based, cooperative control system. In this capacity, we have been developing the Microgrid Agent Control System (MGAS), shown in figure 2. MGAS is a modular platform for performing distributed Microgrid control. It is specifically architected to support a variety of Microgrid classes via its service oriented design and hierarchy of agent families.

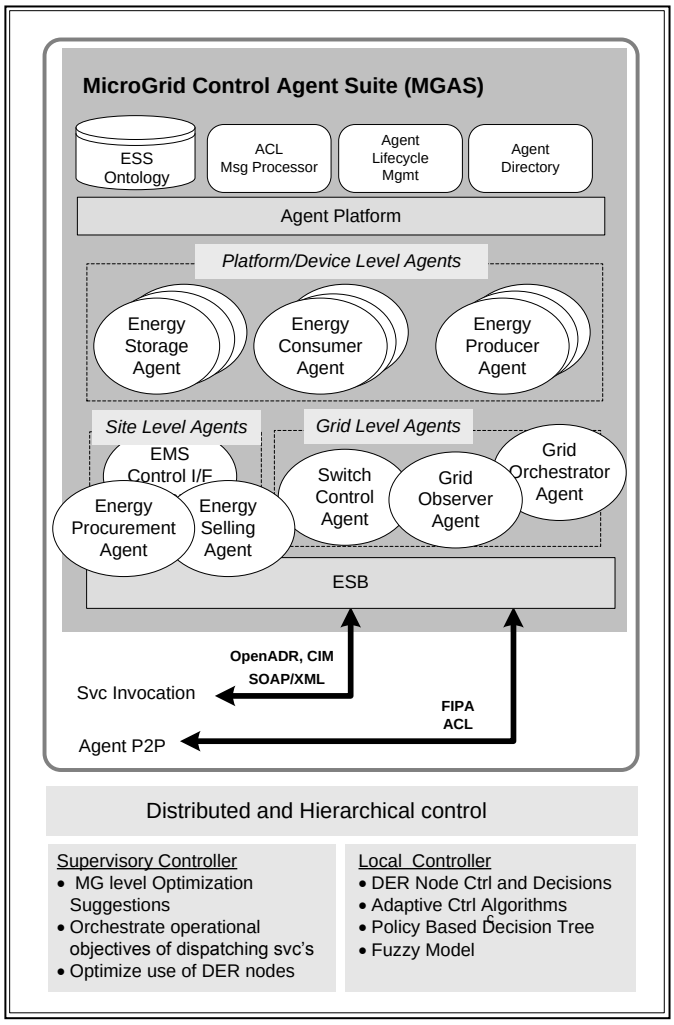

Figure 2. Microgrid Agent Control System

MGAS is a multi-agent framework for distributed and cooperative Microgrid control. The notion of an agent implies that MGAS services include functionality to collaborate with other services across the grid while acting locally to perform their specific and unique control functions (i.e. agent node behaviors). MGAS services consist of cooperative agents that orchestrate distributed energy resource control and automation as well as Microgrid switching and self-healing operations. MGAS agents collaborate as a cooperative control system to execute distributed control protocols and services for automated demand management, energy storage and energy generation. MGAS applies the OpenADR standard for DR control signals, IEEE 1547 for interconnect and the IEC Common Information Model (CIM) standard to exchange information metadata. FIPA compliant agent communication protocols and lifecycle management technology are also applied to facilitate standards based agent interoperability. This collaborative and semi-autonomous agent architecture enables true distributed control and mitigates single point of failure risk.

The MGAS framework incorporates several architectural features that enable scaling and fail-over mechanisms to address the reliability and performance needs of large enterprise systems. High transaction processing rates and real time data access are supported through an enterprise data fabric that performs node-level data caching, replication and distribution functions across multiple networks and sites. The MGAS is deployed on Java-based application servers using service load-balancing and clustering configurations to manage and scale the system performance. Agent behaviors and decision actions are implemented using policy-based workflow orchestration to facilitate adaptability and extensibility and serve as a key mechanism to tune agent operations for site specific needs.

The primary system goal of MGAS is to create an adaptive and intelligent control system enabling collaboration and cooperation between DER nodes. MGAS is built as a collection of reusable agents that will interoperate within the many interfaces and devices on the distribution level of the power delivery infrastructure. Figure 2 shows the hierarchy of agent behaviors implemented in the MGAS framework. Three core families of agent behaviors are established: Grid-Level Agents, Site-Level Agents and Device-Level Agents. From these three primary sets of behaviors a variety of agent types are sub-cast and implemented. The three core behaviors are inherited by all sub-cast agents and serve to promote common mechanisms of decision behavior and functionality.

Core MGAS behaviors inherited by all sub-cast agents include;

- Built in support for policy based workflow orchestration which allows for configuring multiple operational criteria.
- Decision logic that incorporates analysis and response criteria based on electrical grid parametric models and rule based contingencies.
- Embedded behaviors for coordination with power analytics modules and grid protection schemes that manage grid reliability.
- Agent behaviors can be configured to operate autonomously (decisions are specific and local to the agent) or semi-autonomously (decision are collaborative towards achieving joint objectives with other agents).
- Agent control behavior implementations are based on real-time, deterministic domains (i.e. all actions have defined, bounded response times).
- Agent deployment and communications are performed using Smart Grid and Web Service standards (XML, SOAP, WSDL, UDDI, OpenADR, CIM).

8. 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.

Biography

Terry Mohn is the Chief Strategy Officer of General MicroGrids located in San Diego. He is responsible for ensuring clean and renewable electric generation can reliably meet the demands of utilities, municipalities and communities. This includes advancing General MicroGrids technology portfolio and capabilities towards emerging integrated microgrids and sustainable community solutions. Mr Mohn was previously chief technology strategist for the Sempra Energy utilities, with emphasis on smart grid. He specializes in clean energy and the improvement of the electric grid by using modern technology.

Mr. Mohn has 30 years experience in large-scale system architecture, business strategy, and technology investment strategy. Terry specializes in the business integration of technologies, primarily supporting smart grid, home automation systems, communication systems, distribution automation, smart metering, demand response, and sense and control.

Mr Mohn is Vice Chairman of the GridWise Alliance, appointed to the National Institute of Standards and Technology Smart Grid Advisory Committee, an advisor to the DOE for smart grid and advisor to the California Energy Commission for demand response and emerging technologies. Mr. Mohn worked closely with LBNL developing the OpenADR standard and was also co-founder of OpenAMI and UtilityAMI, now part of OpenSG, and charted to develop requirements and standards for AMI and HAN systems. Following these efforts, he worked on the early ZigBee HAN standards as well as Utility Standards Board's meter data standards. Mr. Mohn was very involved writing and editing the GWAC Framework for Interoperability, EPRI's Intelligrid and Galvin's Electricity Initiative.

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