Microgrids, Distributed Energy Resources & Smart Grids Changing Planning, Design and Operations of the Power System

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The electric industry is at a major crossroad and traditional approaches to problem solving are being replaced by new technologies including distributed resources, microgrids, storage and demand response. The traditional grid was originally designed for one job: to deliver electricity one direction to customers from a handful of power plants. It didn't have to be flexible or adaptable or transparent – it just had to be strong and reliable. The steady, one-way flow of electricity that has been around for more than a century is transforming into an active, multidirectional stream of power that shifts back and forth between customers across the utility grid. Additionally, the penetration of wind, solar, storage and load response are contributing to reshaping power system analysis.

Decisions affecting the T&D networks made today will affect how power is supplied for decades to follow. Software developers, planners and designers must recognize the need to update T&D technologies along with models driving the grid now. Both power suppliers and consumers are responding to the rapidly changing environment and market.

Increasing distributed renewable sources requires a fundamental review and continuous evaluation of the existing infrastructure that transmits and distributes electricity to accommodate these new sources of energy. T&D system planning, the way we know it today, must change and adapt to the dynamics of this new energy market to allow full technology integration. Capital projects along with communication systems must be planned and executed today with consideration of future growth of distributed sources.

Big changes are also fueled by Internet of Things, smart grid, block chain, big data and data analytics. Modern network devices will be triggering actions with no human interaction that will contribute to mitigating adverse impacts or avoiding power outages. At the same time, generation systems will be optimizing cost across a diverse portfolio of sources including renewables, microgrids, storage and load all on top of traditional resources.

Tomorrow's modern power system will be a mix of generation sources including microgrids, working together, and delivering energy in multiple directions. Technology is reshaping operations providing capabilities for energy providers to tap into new sources and collect more data for a new era of power systems analysis and design. Application of advanced methodologies will provide us even more information including predictive and prescriptive analytics, forecasting and optimization of operations. The prospects for analytics are expanding because of the increasing availability to develop better models and software.

The number of reasonable variations in our planning and operating studies is growing exponentially and swelling the number of scenarios directing actions. Planners and operators of the electric grid can no longer exercise their experience to make quick or "gut" decisions in response to these changes. Instead, power system engineers must resort to building new sophisticated and powerful optimization tools. Along with smart, advanced control and communication, these innovative resource pools with varying types along with diverse locations and ancillary services must be configured to provide enhanced grid resiliency for extreme events.

In modern power systems, microgrids will be providing enhanced resiliency for some consumers. They will be owned by utility customers, third parties and/or agencies providing life safety services and will be an expanding part of capacity on the grid. Though relatively small in scale so far, many commercial and industrial customers are evaluating the feasibility of microgrids, and this trend is only expected to grow. Power cost, reliability, and environmental sustainability are growing concerns that are the primary drivers for microgrids. Adverse weather events and increased cyber security threats only strengthen the need for a better solution to today's power grid.

The two primary drivers for microgrids are power cost and power reliability, with a third consideration being environmental sustainability. Knowing that economics is the most important factor to a business' success overall, we can identify the most important characteristics of a microgrid to be successful, namely size (capacity) to achieve scale for power cost reduction, and criticality of power in terms of business impact cost. Put another way, customers with large loads and expensive consequences from power supply problems are the best candidates for microgrids. As noted above, environmental sustainability will always be a secondary consideration to a business enterprise, though to a greater or lesser extent from customer to customer.

A completely unique class of customers is civil agencies providing life safety services. In these applications, costs and consequences related to power supply are not evaluated the same as they would be for a business. Life safety services by civil agencies are normally mandated by the government and the extent of flexibility in system cost considerations are determined with the Secure Microgrid® process presented as the second part of this microgrid section.

A decision to be made is who will be the provider of last resort; i.e., should a micro-grid fail, will the utility be responsible for providing power to that micro-grid? This issue leads to questions regarding regulatory requirements for microgrid design, fees and basis for fees for back-up power, penalties for utility performance failure, etc. These regulatory issues are noted here as a factor related to microgrids for completeness of this section.

For the purposes of developing a plan, microgrids are addressed in two ways. The first consideration is with respect to estimating the potential capacity that microgrids may contribute to the grid. Secondly, we want to assure that microgrids that are eventually installed will meet the needs of the customer, which is accomplished by applying the **Secure Microgrid®** process. Meeting the needs of both parties is critical to assuring a mutually beneficial and sustained relationship.

MICROGRID POTENTIAL

Determining the potential capacity from microgrids on the grid is a major component. Identifying this potential is based primarily on identifying business customers with large loads and expensive consequences from power supply problems. A subset of microgrid customers outside of these business-based customers are government agencies providing life safety services. These governmental agency facilities are first addressed below and business customer types follow after.

Identifying and quantifying electric loads related to government agencies providing life safety services can be accomplished by mapping these critical facilities and overlaying on that map information from a multiple hazards map. Integrating this composite map with the electric loads of the facilities provides a data base of loads and locations of potential microgrid candidate facilities. The load data from these potential government agency microgrid applications is added to that of the business customers to compile a total estimated potential of microgrid capacity that might be viable. Use of maps provides input ranging from prioritizing location decisions for microgrids to criteria for developing construction standards. Government agency life safety facilities to consider include the following:

- Public Safety and Security
  - Hospitals and other medical facilities
  - Mass emergency shelters
  - Civil Defense and Emergency Management centers
  - Fire and Police stations
- Utilities
  - Potable water treatment facilities
  - Waste water treatment facilities

Identifying and quantifying significant electric loads related to potential microgrids for business customers is accomplished by simply first identifying customers with large loads from PREPA's existing customer base; these customers want to reduce their power purchase costs. For example, as an initial screening criterion a minimum average daily peak load for inclusion in this category may be 2 MW loads and above. The economics of any particular microgrid must be evaluated on a case by case basis, and the minimum capacity level will need to be set according to sample economic evaluations performed during the term of this IRP project.

A slightly more complicated addition to these are the customers who experience expensive consequences from power supply problems; these may include both large and smaller load customers as these customers want to reduce the impact from power problems, which may or may not be related to how much power they use. This second set of business customers can be identified by their type of industry and/or operations they perform. For example, commercial businesses that have revenue based on an uninterrupted stream of transactions, such as a chain of grocery stores or gas stations, may not have relatively large electric loads, but could have large financial consequences to power supply anomalies. Industries such as pharmaceutical or others employing process plants operating on a batch production basis may lose not only the product being manufactured at the time of the power supply anomaly but may also require a great deal of time and labor to clean out spoiled or solidified product from plant equipment. Petrochemical plants with complex continuous process production methods may lose product due to both downtime during the time of a power anomaly and also an extensive amount of time necessary to re-heat and bring the continuous process back online.

Identifying these types of customers requires a greater amount of investigation but enhancing the process of investigation can be achieved by engaging with manufacturing and industry association leadership. These industry representatives have a broad base of knowledge of their membership and associated manufacturing processes to assist in more efficiently creating a data base of potential microgrid candidates interested in reducing impact to their facilities from power supply anomalies. The load data from these potential business customer microgrid applications is added to that of government agencies to compile a total estimated potential of microgrid capacity that might be viable. Industrial, commercial and institutional type customers to consider for potential microgrid application in this category include the following:

- Industrial
  - Petrochemical
  - Pharmaceutical
  - Radioactive and other toxins
- Transportation
  - Airports
  - Ship harbors
  - Bus depots
- High-Density Occupancy
  - Educational and Institutional facilities
  - Hotels
  - Office buildings
  - Penal institutions
  - Auditoriums, theatres, stadiums
- Agricultural
  - Food-storage, processing, transfer
  - Irrigation systems
  - Water containment - dams, other impoundments

MICROGRID DEVELOPMENT

The basic concept of the Secure Microgrid® is to use a standardized development process where no standardized solutions exist. This is because almost all microgrid projects will each be unique for the specific application being looked at. Characteristics of successful microgrid projects include:

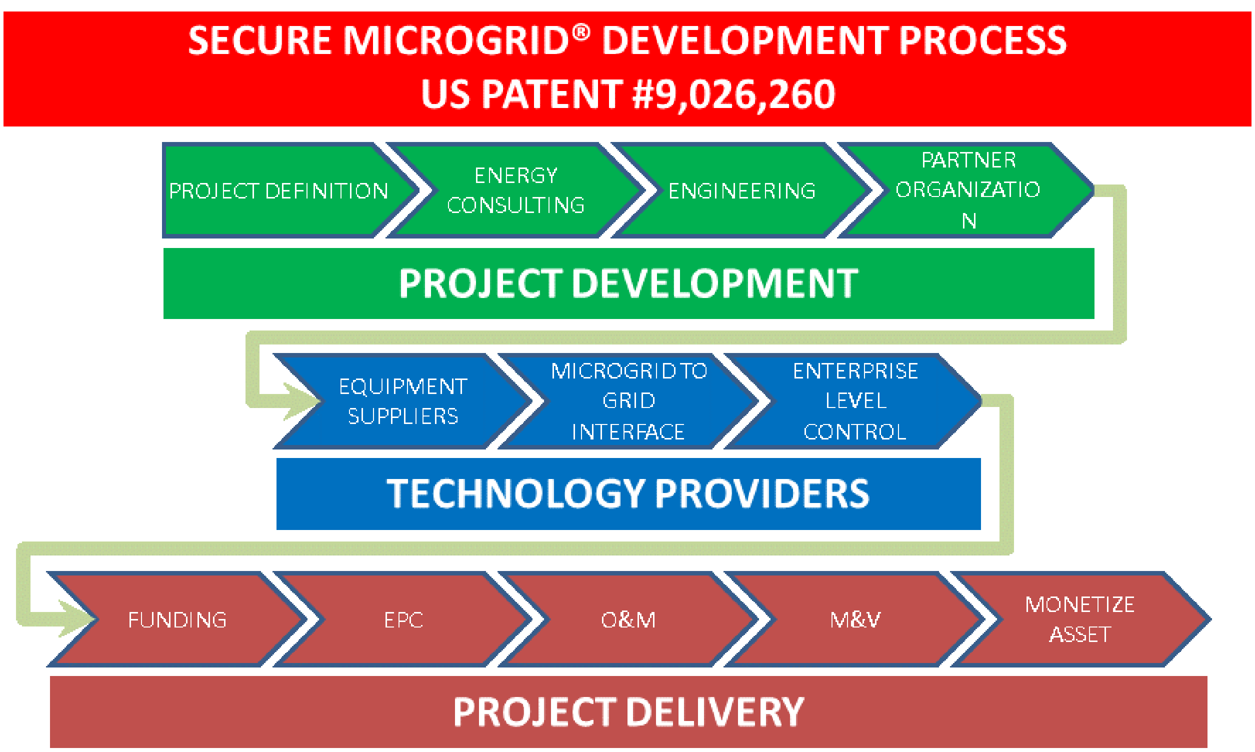
- **Controlled process**: Use a standardized, replicated process to create unique, yet optimized designs
- **Robust stakeholder engagement**: Customer loads dictate system design instead of utility agency dictating power supply
- **Iterative design optimization**: Optimization requires tenacious teamwork to create the "best" power system
- **Get it right the first time**: Economics+Performance must meet the customer's needs to avoid costly revisions
- **Project delivery**: Fully planned prior to site mobilization to assure schedules are maintained
- **Long-term verification of performance**: Pro forma validation is critical to meeting financiers' requirements for continued investment in future projects

Cost-effectively providing reliable and resilient power to mission critical loads requires a hardening of power generation and distribution systems to withstand natural and manmade assaults. Microgrids facilitate integration of distributed energy sources to provide seamless power supply in both grid-connected and island mode operation. This seamless functionality includes communication and coordination with existing customer equipment and systems, utility grids, the power market, additional enterprise-level facilities, selected loads and sources within the microgrid, severe weather and security notifications, and myriad other components and subsystems within the smart microgrid. The data exchange and strategic processing of information both within and external to the microgrid allows optimization of power supply costs, power security and environmental sustainability.

The patented **Secure Microgrid®** engineering process (US patent #9,026,260) employs a standardized approach to create a road map for upgrading power distribution systems. The Secure Microgrid® process is prioritized based on both project-specific performance criteria and funding constraints. The result is a highly reliable and secure microgrid that is technically cost optimized. The Secure Microgrid®

process can be used at a customer's facility to evaluate the existing power system(s), perform facilities assessments for energy efficiency and load reduction opportunities, create design upgrades for power security and economic performance improvements, explore funding methods and sources, collaboratively determine with a facility's team the improvements to be implemented, execute the project, and perform long-term monitoring and verification (M&V) of system performance, both functional and financial. These improvements can include renewable energy capacity, as well as natural gas or diesel fueled Combined Heat and Power (CHP) integrated with a district energy system, to provide long term power security enhancement. Use of battery energy storage systems (BESS), particularly in conjunction with solar PV generation, can provide enhanced power security, power quality and economic dispatch capability. Existing emergency diesel generator "fuel-constrained" operation can be extended for additional running-time when integrated with these local power sources. Strategically coordinating operation of any or all of these systems is the type of functionality readily accomplished by the Secure Microgrid® engineering process. In many cases, these improvements can be financially enhanced with grants, tax credits, and other financial instruments available to 3rd party financiers.
The comprehensive approach employed by the Secure Microgrid® to designing smart microgrids begins with a baseline facility assessment. This establishes conditions used to evaluate microgrid performance and economic benefits achievable from specific improvements of a distributed energy system. The initial site assessments also provide the launch point for design of the system configuration ultimately desired to achieve the specific economic and reliability objectives being targeted. The result will be reduced demand for purchased power when the utility grid is operating and increased mission-critical emergency power during an extended utility outage. With use of the Secure Microgrid's® standardized process, a project team can hit the ground running to cost-effectively implement an optimized power supply system in the least amount of time.

THE SECURE MICROGRID®



The graphic above depicts the three phases of a standard Secure Microgrid® project:

a. **Project Development**, including Energy Master Plan development and associated engineering activities
b. **Technology Providers**, selection and procurement
c. **Project Delivery**, including installation of the system, operations and maintenance, and long-term Monitoring & Verification of performance

Depending on the amount of energy efficiency engineering and energy planning already performed at the customer's facility, varying levels of work will be required in each of these phases. An initial assessment must be performed on-site to establish the baseline existing conditions. In general, the following describes the work that can be performed in each of the phases.

Project Definition: The power supply requirements are established in reverse of the traditional approach for utility supply – in other words, starting at the customer's loads. An **Energy Master Plan** is created to identify current and planned mission critical and facility non-critical loads, various systems that could meet the unique requirements of the various load types, and customer criteria for the business operation, including environmental sustainability. Loads are evaluated in detail to define both quantity and quality required. Depending on the functions of equipment on individual circuits at the facility, the robustness (and cost) of the distribution system can be optimized on a per-circuit basis. Or, if the microgrid is for a campus or municipality application, this power supply optimization would be performed on a higher-level basis, perhaps at the individual building basis versus at the equipment load basis.

For example, a pharmaceutical or petrochemical process plant may need very reliable power supply to prevent equipment damage and/or destruction of expensive products due to material hardening and clogging equipment and piping or being ruined chemically from interruption of the manufacturing process when a power outage of just a few minutes occurs. A robust back-up power supply system, possibly to the level of an uninterruptable power supply (UPS) may need to be incorporated into the microgrid to meet the customer's needs.

However, a waste water treatment plant which may have many large electric motors driving pumps and other equipment, may be able to tolerate a 10-minute outage and simply resume operation when the utility power is restored with little or no impact. A back-up power supply system may not be necessary in the microgrid in this facility to meet the customer's needs.

These different types of operations require detailed evaluation to assure the correct level of reliability (i.e., cost) is applied to the power distribution system for the different load types in each product process application. There are also different supporting load types at each facility, such as non-critical HVAC for office cooling versus HVAC for large warehouses used for storing chemical products sensitive to ambient room temperatures. Each of these load types demand different types of power supply designs which requires an in-depth understanding of the customer's business to be able to develop a cost AND performance optimized power system. In other words, an understanding of each customer's unique application is needed to simply define the criteria for identifying mission critical and non-critical loads.

In the same way, power quality requirements must also be addressed based on the type of equipment and processes being run at the customer's facility. Voltage and frequency fluctuation can have immediate impact on sensitive electronics or long-term life-cycle degradation on motors. Knowing the details of the customers load, not just kW and kWhr numbers, is the key to optimizing a distributed energy system.

The Energy Master plan includes analysis of power surety, economic and environmental optimization methods, an initial set of funding options, including potentially planning for third party ownership of the system. This analysis is used to create the **Secure Microgrid® Design Criteria**.

Energy Consulting: An energy usage and efficiency improvement assessment is performed to determine the potential for efficiency gains, load balancing, momentary/continuous load reduction, procurement options, environmental impact reductions, as well as special customer-specific desires to energy use that may exist. This assessment includes potential enhancements to existing renewable energy systems and new renewable energy recommendations. Tasks typically associated with energy efficiency programs are primarily evaluated from an economics point of view. For example, an air conditioning system may be rather old and below modern efficiency level but may have been well maintained and in good operating conditioning. Replacing this air conditioning system may have been prudent with an acceptable simple payback period when power was just purchased from the grid. However, the new microgrid delivered power incorporating higher efficiency combined heat and power with an energy storage system, possibly solar PV, may supply power at a lower cost resulting in the simple payback period for replacing the air conditioning equipment being extended to unacceptable lengths. One can see that once all of the various equipment and load types at a facility are identified, the process of developing the "best" microgrid power system requires iterating, on capital costs versus operating payback. Depending on the size and complexity of the facility the microgrid is powering (e.g., a single water treatment plant versus a college campus), the extent of iteration required for system design optimization can be rather extensive. On a case by case basis, a project cost-benefit decision has to be made as to whether to take a higher level, more macro view of the degree of optimization to be undertaken.

Engineering: Upon completion of optimization of the existing facility loads. The initial microgrid system design and integration engineering is performed for the specific facility being addressed. A failure modes effect analysis (FMEA) is used to specify a **Design Basis** to meet the project Design Criteria. The output from tasks up to this point is a 35% design package. A final design package results from iterations of the above listed tasks and is completed in the EPC tasks section.

Partner Organizations: A Department of Energy and/or Department of Defense branch lab partner brings specific knowledge and capability to support the team. For this project, long range vision supports as well as confirmation of strategic optimization of project objectives, is afforded by AFRL's participation.

Equipment Suppliers: The desired supplier team is comprised exclusively of best-of-breed equipment and software suppliers. However, diligent and continuous vetting of partners is critical in the emerging technology field the Secure Microgrid® is navigating in. The primary equipment components includes a Master Controller, and, potentially, an Enterprise Level Controller depending on the scale of the microgrid. The Master Controller coordinates equipment functions (both loads and power distribution) according to normal or emergency mode of operation. It also provides intelligence for power supply routing and grid versus island mode mission critical load powering (note: a general assumption is that the majority of microgrids will normally operate in grid parallel mode, continually importing some amount of grid power for both technical and economic reasons). An overlaying communications backbone provides for the load and power source control capability to optimize system operations. This communications backbone for the entire point-to-point (loads-to-substation) power distribution system includes equipment comms language, data management, display dashboards and notification systems for ongoing O&M of this specialized equipment, as well as a robust and dynamic cyber security functionality. Software updates will assure continued optimization as well as impenetrability of mission critical systems.

Funding: Projects developed with the Secure Microgrid® process can be implemented in a phased approach to match annual budgeting strategies, approval criteria, or may be 3rd party funded.

Construction (EPC): Proper project execution of this new and critical system must be performed by a well-qualified organization. These services can be provided on a direct, fully outsourced basis or oversight indirect basis with the owner acting as the General Contractor (e.g., owner contracts all design work, directly purchases capital equipment and spare parts, hires construction and commissioning contractors, provides all financing and project management services, etc.).

Operations and Maintenance (O&M): Ongoing O&M of both the standard and specialized equipment in a microgrid, including software updates, are critical to assure continued functionality at performance levels required to support the initial Design Criteria.

Monitoring and Verification (M&V): A key aspect of a successful installation is effective use of data that is able to be recorded and analyzed. Proper use of data allows for verification of supplier billings, smart power procurement, feedback to personnel for power usage culture change, tracking of equipment performance & identification of poor performing equipment, etc.

Monetize Asset: In order to execute a potential future ownership transfer, planning this point should be considered in the initial evaluations of Project Development for physical boundary definitions to assure ease of title transfer and/or performance guarantee boundaries.

CONCLUSION

Overall, our planning, design, and operation of the modern power system should be guided by the following principles:

- Maintain and enhance the safety, security, reliability, and resiliency of the electric grid, at fair and reasonable costs, consistent with customer goals
- Facilitate comprehensive, **coordinated**, transparent, and integrated grid planning across distribution, transmission, and resources
- Ensure optimized utilization of resources and electricity grid assets to minimize total system costs for the benefit of all customers

Our software, models, planning, design and operations must transform now to reflect modern power systems. Individual power system components can no longer operate and plan independently of one another. With these integrated resources and intelligent, dynamic system operations software, secure cross communication throughout the industry (transmission, distribution, resources and load) will be a necessity to ensure the guiding principles can be maintained.

The power industries approach needs to recognize T&D grids as a much more complex combined power system with no clear separation of functions. This change is a catalyst for the future and we must become a champion for creating projects and programs that deploy advanced analytics, communications and controls. Each of us has a duty to encourage talks allowing new innovative ways of planning, design and operation to move forward swiftly and positively. Our challenge is to define practical implementable steps supporting our goals along with being cost effective; **the longer we wait the harder it gets.**