Technical Report

Achieving Operational Optimization in Microgrid Implementations

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With the increasing penetration of distributed generation sources, such as solar PV, as well as energy storage technologies, microgrids—small-scale versions of centralized electric grid functionality—are gaining popularity. Microgrids can generate, distribute, and manage power and energy locally within a customer's defined area—downstream of the utility connection. When properly designed, built, optimized, and operated, microgrids can achieve important goals for their owners, including cost control, reliable energy delivery, resilience, and carbon emission reduction.

This paper will review:

- The characteristics of microgrids and their various operational objectives
- The feasibility analysis required to plan a successful microgrid implementation
- Technological solutions to achieving microgrid objectives
- Strategies for optimizing microgrids to achieve these objectives

1. Microgrid Characteristics

"No matter the complexity, a microgrid controller and associated devices are needed to provide an optimized system."

Microgrids are developed by property owners and investors (on behalf of the owners) who wish to achieve levels of improved energy performance for the property. Here in the United States, microgrids can range in size from single buildings to large seaports. In developing countries, they can be designed for villages and urban areas that are not covered by a local utility. All installations are intended to be self-sufficient and operate independently from the larger grid. In most cases, however, the electric grid remains connected, if available, and the microgrid can even be designed to export services to the grid.

Microgrid complexity is driven by a number of factors: the number of buildings or loads, the types and number of generation sources, critical and optional load management, the owner's objectives, and any regulatory constraints. Single-building microgrids tend to have fewer generation sources than multi-building and large campus installations. A simple example is a single building utilizing demand response, one solar photovoltaic (PV) panel, one battery, and the associated control systems. On the other extreme, a complex microgrid could encompass a 20-building business campus with light manufacturing, offices, and condominiums serviced by demand response, electric PV, electric vehicle charging stations, electrical and thermal storage, a combined heat and power (CHP) system, and biogas fuel cells, all made optionally available as Virtual Power Plants (VPPs) to the wholesale market. No matter the complexity, a microgrid controller and associated devices are needed to provide an optimized system.

Depending on the complexity, the microgrid will require a variety of hardware, including building management systems, generators, batteries, and the gateway controllers to each. It will also require a system protection scheme to protect from inadvertent conditions, using components such as switches, relays, sensors, and metering, as well as programmable logic controllers to automate some processes, such as synchronizing frequency and ramping effects, while maintaining constant voltage.

Likewise, to achieve their owners' operational objectives, microgrids need to have a microgrid controller that monitors the system operation, optimizes and controls all resources in real-time, schedules resources in near real-time through forecasting load and DER generation, and provides operational score-cards and system health data.

Microgrid Operation Objectives

Most property owners consider one or more of the following objectives to determine the merits of building a microgrid:

- **Reliability:** The property requires higher energy availability than can be provided by the local utility. This is primarily for stable voltage and frequency requirements.
- **Resiliency:** The owner has suffered or cannot afford too many storm or other frequent outages with "longer than acceptable" restoration times.
- **Efficiency/Economics:** Utility electric prices (both energy and demand) have either become unpredictable or are escalating too high.
- **Environmental Impact:** The utility does not share the owner's standards for levels of carbon emissions.

2. Feasibility Analysis of a Microgrid

Before building a new microgrid—a so-called "greenfield" project—or retrofitting a building to be a microgrid—a "brownfield" project—the property owner will conduct a thorough feasibility analysis to determine the practicality of the effort and what it will take to achieve the owner's operational objectives. This analysis must identify the scope of the project, the microgrid objectives—technical, economic, and environmental—and the budget estimate. The project begins with the site survey, including the load inventory, an inventory of the existing on-site technology, energy efficiency programs, metering, distribution system, and utility interconnection. The analysis will also investigate the opportunity for energy efficiency retrofits for any existing buildings, with the goal of reducing the energy consumption before investing in more detailed engineering studies.

"Simulations and optimization will show the most optimal combination, size, and number of each of these equipment types."

The next step is to model the system based on the information and data gathered during the site survey. Many feasibility studies use energy modeling software tools to find the most optimal microgrid design that will satisfy the owner's objectives at the least cost. The feasibility study will model electrical critical and interruptible AC and DC loads, based on the metered data and/or billing information, thermal loads, hydrogen loads, and on-site Distributed Energy Resources (DERs), including PV systems, wind turbines, energy storage (batteries, fuel cells, super capacitors, flywheels, hydrogen, etc.), and mini hydro plants. Consultants must also model existing on-site generation (diesel generators, CHP plant, gas turbines), based on the equipment characteristics, the fuel flow, and the fuel efficiency curve. In this phase, engineers must determine if a CHP or combined cooling, heat, and power (CCHP) system is a technically feasible solution for the proposed site. The utility rate structure with energy consumption rates, demand charges, and fuel cost will also be modeled. Simulations and optimization will show the most optimal combination, size, and number of each of these equipment types.

The feasibility analysis will identify the key stakeholders in the microgrid project and determine if net metering, state and federal incentives, grants, and payments for reduction in emissions are available for the proposed system and microgrid ownership structure. It also needs to address the costs of the project, including capital costs, replacement costs, fixed and variable operation and maintenance costs, and fuel costs, as well as various miscellaneous costs such as permitting, land-use approvals, administration and government approvals, required licenses, engineering services, civil construction costs, logistics, labor wages, and the cost of system upgrades. Finally, the analysis team will perform sensitivity analyses of the final microgrid design to verify the robustness of the optimized system and determine the sensitivity of the output results, if any of the input data and assumptions are modified. The effect of uncertainties of input variables such as the future fuel prices, load growth, wind speed average data, and solar irradiation average data will be evaluated at this time.

Scope	Objectives	Stakeholders	Technical
	Economics	Environmental	Regulation
Site Survey	Electric & Thermal Load	Geospatial	
	Energy Efficiency / Utility Rates	Existing Resource Energy Supply	
Technical Analysis	Modeling	DER / Heating & Cooling System	
	Analysis	Optimization	
Design	Final Technology	Costs / Revenue	Return on Investment
Operation	Operating Practice		

Figure 1:
Key Elements of a Microgrid Feasibility Study

If the proposed microgrid will participate in a local ancillary, demand response, or capacity services market, the feasibility study will also determine the potential revenues from these services. The calculation of the cost-benefit ratio and internal rate of return will include savings from avoided grid outages (both scheduled and unplanned), net metering, revenue from providing ancillary services, avoided emission allowances, avoided emission damages, fuel savings, and improvements of overall system reliability, power quality, resiliency, and efficiency.

3. Technology Solutions to Achieving Microgrid Objectives

As noted above, microgrids come in different sizes and shapes, with different operational objectives. While one microgrid may place a lot of emphasis on the quality of electricity it produces and how frequently that electricity gets interrupted, another may focus on the cost and accept a less stringent power quality and lower levels of electricity availability. Because of the difference in the operational philosophy, the design and the technology requirements for these two microgrids will be fundamentally different.

"The microgrid will act as a Virtual Power Plant and respond to a control signal for changing its generation, within the maximum and minimum limits."

Mindful of the diverse technology requirements, the following detailed architectural framework can be adapted to any microgrid for its technology design. This framework follows the same fundamental concepts illustrated in EPRI's work,[1] however it has been greatly advanced to provide a very detailed technology solution framework.

Microgrid Technology Framework

As illustrated in *Figure 2*, the Microgrid Technology Framework consists of five broad different layers of technology:

Layer 0: Equipment

This most basic layer deals with equipment and load. It includes resources such as micro-turbines, diesel generators, wind generators, solar PV panels, storage systems, and the point of coupling to the utility grid. It would also include loads — both critical loads and non-critical, dispatchable loads, which can be controlled, if needed. Other devices such as reclosers, switches, and circuit breakers also fall within this category.

Layer 1: Protection and Control

This layer deals with protection and control systems, which are designed and deployed to deal with abnormal system conditions to disconnect the faulted system. Examples of system disturbances which need protection include faults on the system or equipment. Protection and control systems include generator control, circuit over-current protection, other frequency and voltage protection devices, and more.

Layer 2: Automation and Control

This layer deals with process automation and control in executing the processes that need to happen to facilitate system operations. Processes such as islanding, synchronization, and load following need to be programmed for automated execution. These layers normally use Programmable Logic Controllers (PLC) or other similar solutions which are programmed to execute the automated processes.

[1] *Grid Interactive Microgrid Controllers and the Management of Aggregated Distributed Energy Resources (DER)*, EPRI Final Report, November 2015

Layer 3: Monitoring, Scheduling, Optimization, and Control

This layer provides monitoring, scheduling, optimization, and control of all microgrid resources, including purchases from the utility to minimize the total cost of running the microgrid. The layer considers the characteristics of all resources, including solar, wind, and storage systems.

Layer 4: Grid Interactions, Analytics, and Market Solutions

This layer provides solutions for interaction with the grid, as well as grid applications such as demand response, outage management, and asset management. It also provides solutions for data analytics and reporting, as well as solutions for interfacing with electricity markets.

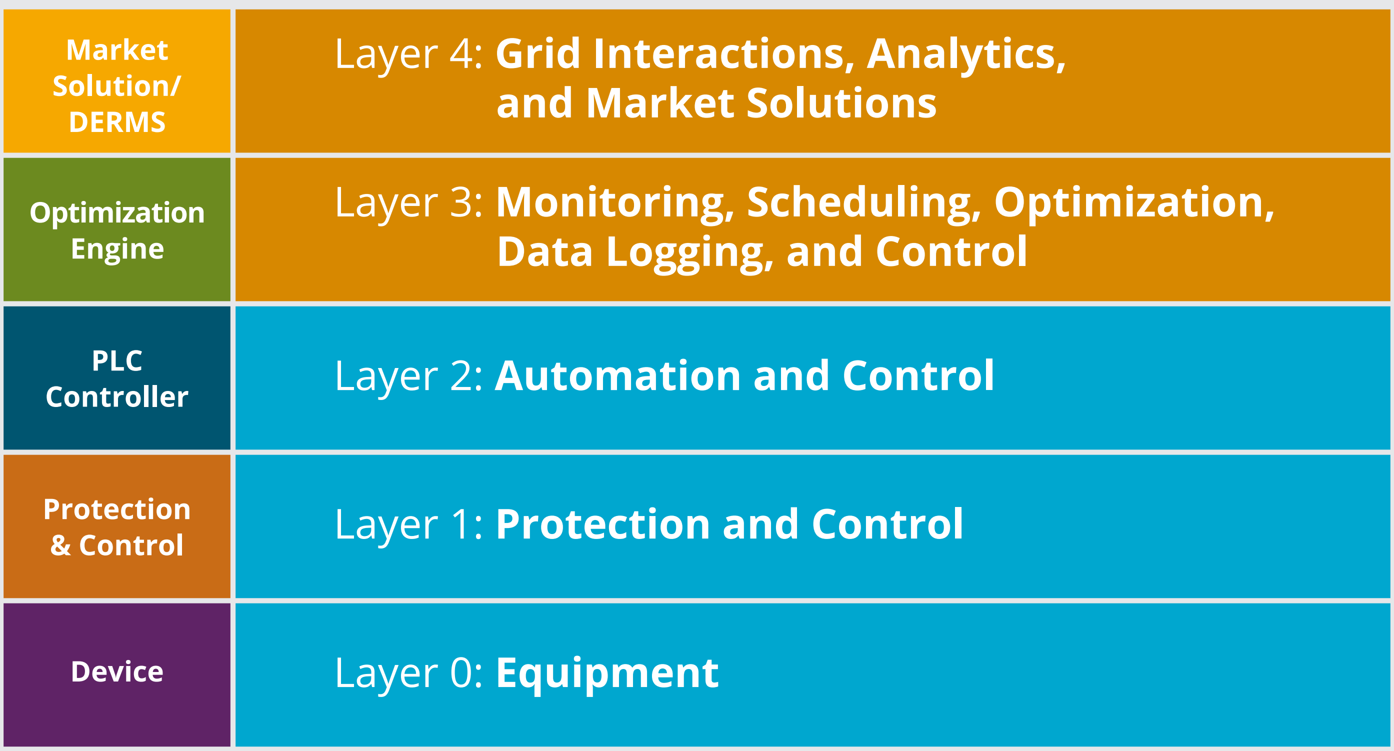

Figure 2: Broad Layers of Microgrid Technology Framework

Cyber and Physical Security

At each of these layers, the microgrid is furnished with a number of control systems. To ensure that the resiliency and reliability objectives of microgrids are fulfilled, the cyber and physical security vulnerabilities of a given microgrid must be properly addressed.

Within the microgrid, encryption and authentication should be used wherever possible. For mission critical systems, it is important to use devices which support secure protocols. For microgrids that either inherit or use devices that do not support any secure protocols, the site's physical and network security must be designed to address the internal security requirement.

Each external communication must be evaluated to determine its nature. If the data are private or proprietary in nature, they must be transmitted in a secure fashion. Digital certificates are an important component of Transport Layer Security (TLS, sometimes called by its older name, SSL), a protocol designed to provide communication security over the Internet. When used with the TLS protocol, properly signed digital certificates prevent an attacker from impersonating a secure website or other server.

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If the data are important but not private or proprietary, methods should be deployed to prevent false data from impacting the microgrid's operation.

4. Modes of Operation

Microgrids operate similarly to the utility grid, where all the circuits are energized as required to supply power to each of the connected loads. A key difference in operation from most distribution utility grids is that those tend to operate as radial, centrally supplied, and distributed into smaller and smaller circuits in a single-directional flow, always ensuring there is an over-supply of power margin to the load. In contrast, most microgrids are designed to support bi-directional power flow.

Microgrids embrace another significant difference in operation compared to the utility grid. The microgrid is intended to connect and disconnect seamlessly from the utility, with the ability to operate in three distinct modes: Grid Connected, Disconnected, and Isolated.

When the grid is connected and the utility is fully functional, the microgrid can be seen to operate as an extension of the utility grid. Power flows from the utility and is optionally consumed by the property. If, however, the utility experiences energy interruptions for whatever reason, the microgrid seamlessly disconnects from the grid and self-supplies all of its needs according to the performance objectives that were established. Once the microgrid senses the utility grid is stable again, it can seamlessly reconnect to the utility and continue on. Finally, some microgrids are in remote locations and not connected to the utility grid. These microgrids operate in an Isolated mode.

5. Optimization Strategies

There are a number of optimization strategies a microgrid can take to achieve the operational objectives of the microgrid owner:

Resource Optimization

In this optimization strategy, resources are scheduled and dispatched to minimize the operation cost of a microgrid. The resources optimized include micro-turbines, solar, wind, and storage systems, as well as purchases from the utility and dispatchable loads.

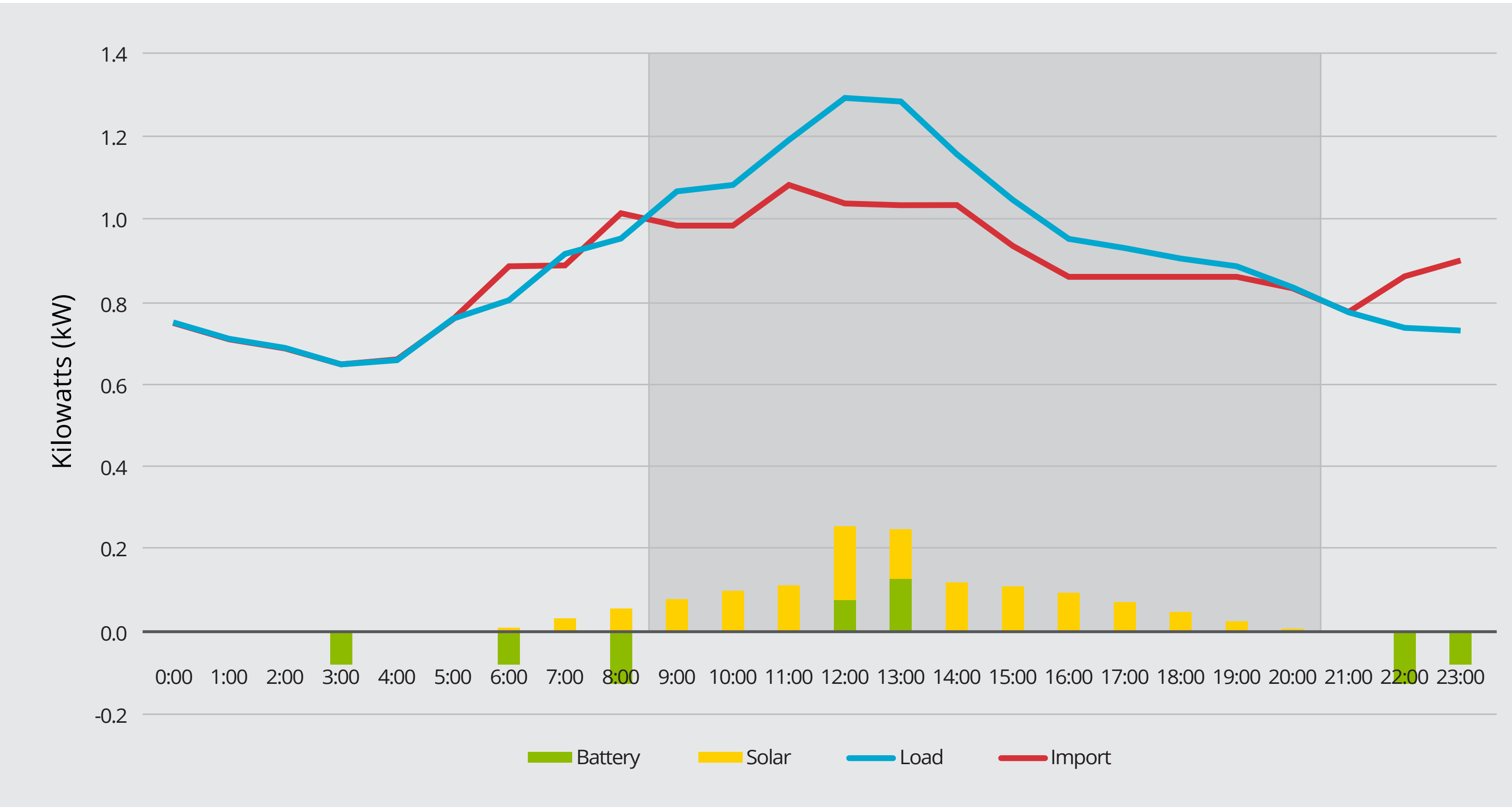

Figure 3: Peak Shaving with Only Battery and Solar

Resource and CHP Optimization

Some microgrids have CHP or CCHP facilities, which use the thermal energy of the exhaust gas for heating and/or cooling purposes. It is important that the resource optimization considers the constraints imposed by the CHP/CCHP, which puts limits on the gas turbine to respect the heat requirements for the CHP/CCHP system. Another approach is to optimize the CHP/CCHP operation along with the rest of the resources, to maximize system operation efficiency.

Utility Program Participation

In this strategy, a microgrid can expose itself as a resource to participate in a utility program such as Demand Response. The microgrid will act as a VPP and respond to a control signal for changing its generation, within the maximum and minimum limits. Once the program is called by the utility, the microgrid needs to fulfill the required amount of generation change.

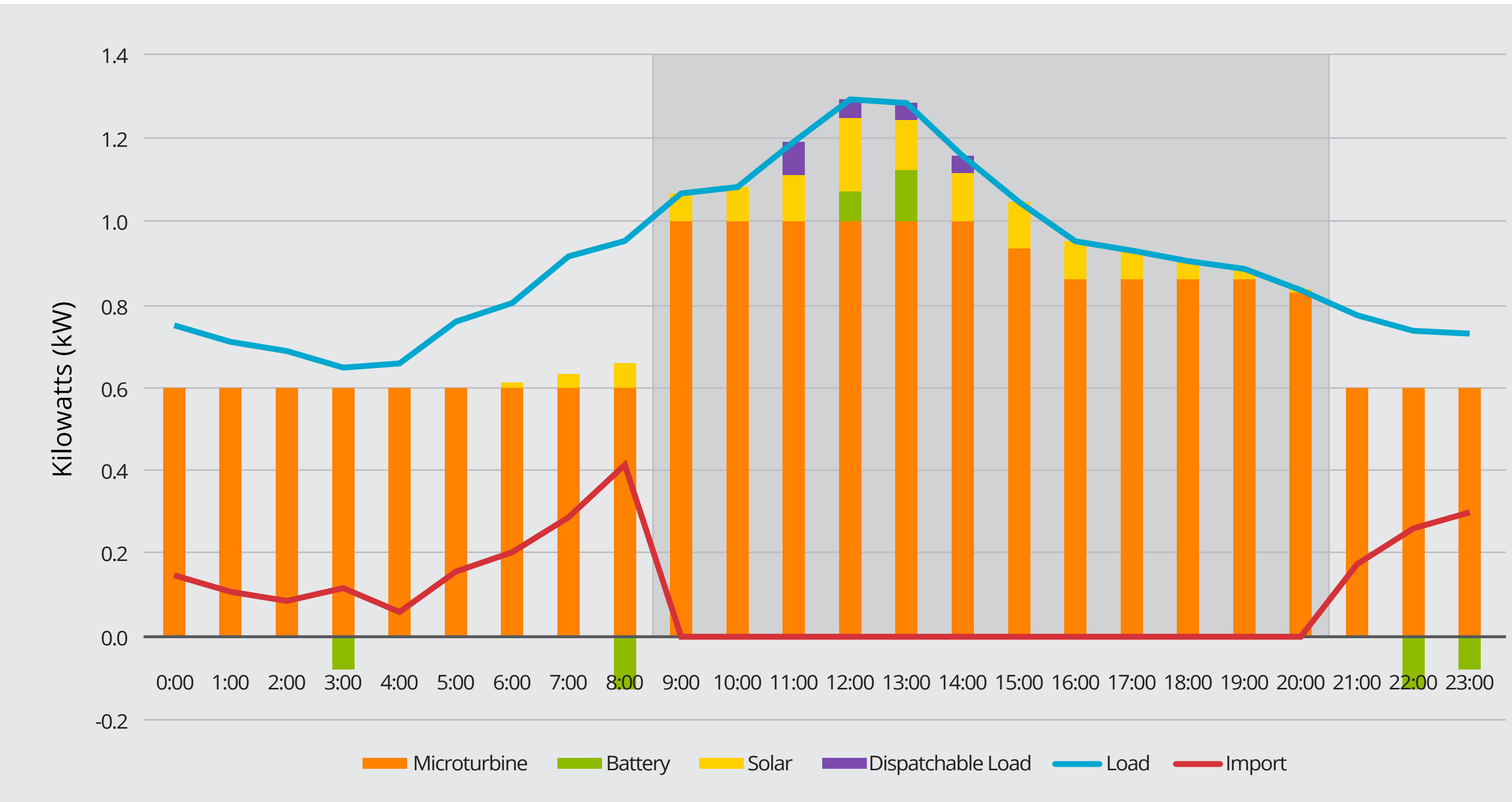

Figure 4: Optimization Solution for Microgrid with Dispatchable Load

Electricity Market Participation

In this optimization strategy, the microgrid exposes itself as a VPP participating in an electricity market by offering energy or ancillary services, again within the maximum and minimum limits. The external entity will call on the energy and ancillary services required, and the microgrid will need to respond by changing its resource dispatch set-points.

6. Conclusion

To successfully implement these optimization strategies and achieve the microgrid owner's business objectives, a microgrid must be able to efficiently and effectively schedule available energy resources and orchestrate the operation of prioritized loads. Microgrid optimization software, such as OATI GridMind,™ can be targeted to maximize economic value, improve reliability and resiliency, or minimize environmental impacts:

- **Improved Economics:** The optimization algorithms minimize the overall cost of meeting microgrid load, including the cost of purchases and sales to and from the utility or adjacent microgrids.
- **Higher Reliability:** In islanded mode, the microgrid optimally balances generation and load, ensuring critical infrastructure, which minimizes loss of productivity. At all times, the optimization and control system manages generation and load balance to meet voltage and frequency requirements.
- **Increased Resiliency:** If the microgrid is shut down for any reason, it can restore very quickly. In the event of a blackout, the microgrid can be used to help restore the grid.
- **Reduced Carbon Emissions:** By targeting higher uses of renewable generation sources, like solar PV and wind turbines, as well as reducing non-critical loads, the microgrid can help reduce carbon emissions in line with the owner's goals for environmental stewardship.
- **Utility and Market Integration:** The optimization software can expose the microgrid to the utility and relevant energy markets as a VPP participating in demand response programs and ISO/RTO capacity, energy, and ancillary service markets, as detailed in the November 2016 FERC Notice of Proposed Rulemaking (NOPR).

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Ultimately, a microgrid has many resources at its disposal. When an advanced optimization system is used to manage these resources, it can create value unavailable to simple, generation-only projects. Without this advanced optimization and control, the microgrid will have less flexibility and fewer pathways to maximum efficiency and positive ROI.

OATI GridMind is a microgrid controller that continuously monitors the status, generation, and load resources of a microgrid. GridMind is a self-contained controller software that runs locally on the microgrid and orchestrates the dispatch and scheduling of the microgrid resources through industry-standard interfaces. When connecting to the utility grid and energy markets, GridMind treats the microgrid as a single resource and exposes grid services, such as ancillary services, to a Distributed Energy Resource Management System (DERMS).

Together with the OATI webSmartEnergy DERMS solution, OATI GridMind optimizes microgrid functionality to meet the business objectives of microgrid owners and can help integrate microgrids into utility operations.

Learn more at **oati.com/microgrids** or contact **sales@oati.net** for a consultation.

About the Contributors

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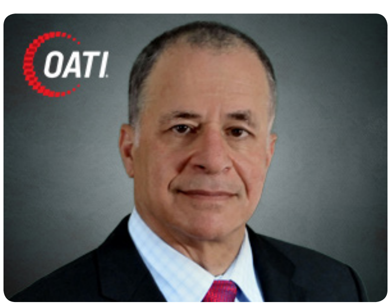
Dr. Ebrahim Vaahedi is Associate Vice President Microgrid Software Development for OATI, with more than 30 years of experience in different segments of the energy industry. He specializes in the development and execution of technology strategies for utilities. Dr. Vaahedi joined OATI following his position with a major Canadian utility as Chief Technology Officer, where he was accountable for developing and executing a consolidated technology plan for the delivery of a $140 million Control Center project. Dr. Vaahedi is the author of "Practical Power System Operation," a recent book in modern power system operation.

Terry Mohn

Mr. Mohn is the OATI Executive Consultant, Microgrids, IOU, and RTO Business Development. A well-known Smart Grid and Microgrid industry expert, Mr. Mohn has 30 years of experience in large-scale system strategy and design. Previous to his position with OATI, he was CEO of General MicroGrids, VP Innovation of BAE Systems energy business, and Chief Technology Strategist for the Sempra Energy utilities. He served two terms as Vice Chairman of the GridWise Alliance and a three-year term on the Department of Commerce's Smart Grid Federal Advisory Committee. In addition, Mr. Mohn was previously an advisor to the DOE and California Energy Commission for research and emerging technologies. He also served as United Nations Foundation Microgrid Work Group Chairman.

Kevin Burns

Mr. Kevin Burns has more than 30 years of experience in electric utility operations, information systems development and support, and software sales. Mr. Burns serves as President of TranServ International, Inc., an independent provider of transmission management and power system study services. He participates in the management and deployment of all tariff, scheduling, transmission planning, and study related activities. His experience includes regional tariff services deployment, various software support positions, OASIS project management, business development, and strategic business planning.



Kash Nodehi, Ph.D.

Dr. Kash Nodehi has more than 30 years of experience in the energy industry and currently serves as Executive Vice President at OATI. Dr. Nodehi has designed and developed system architectures on numerous OATI products, including the OATI GridMind microgrid control system, OATI GridControl, the OATI tagging system and Energy Trading System, webScheduler, webTrans, webOASIS, and webAccounting, as well as settlement system solutions. He also lead the technical team in various OATI product deliveries, such as Midwest ISO ICCS, Midwest ISO Physical Scheduling System, Southwest Power Pool Scheduling System, TVA Transmission, Energy Scheduling, Southern Company Transmission Scheduling, and a number of other OATI webTrans product deliveries and service offerings.

About OATI

Founded in 1995, OATI is an end-to-end provider of software solutions, infrastructure, hardware, and security for the energy industry. The OATI portfolio includes more than 95 software and hardware product offerings that span Smart Grid, Energy Trading & Risk Management, and Transmission Solutions.

OATI has more than 1,000 staff members and 1,600 customers. Supporting all of these are OATI's state-of-the-art NERC Critical Infrastructure Protections (CIP)-compliant Data Centers.

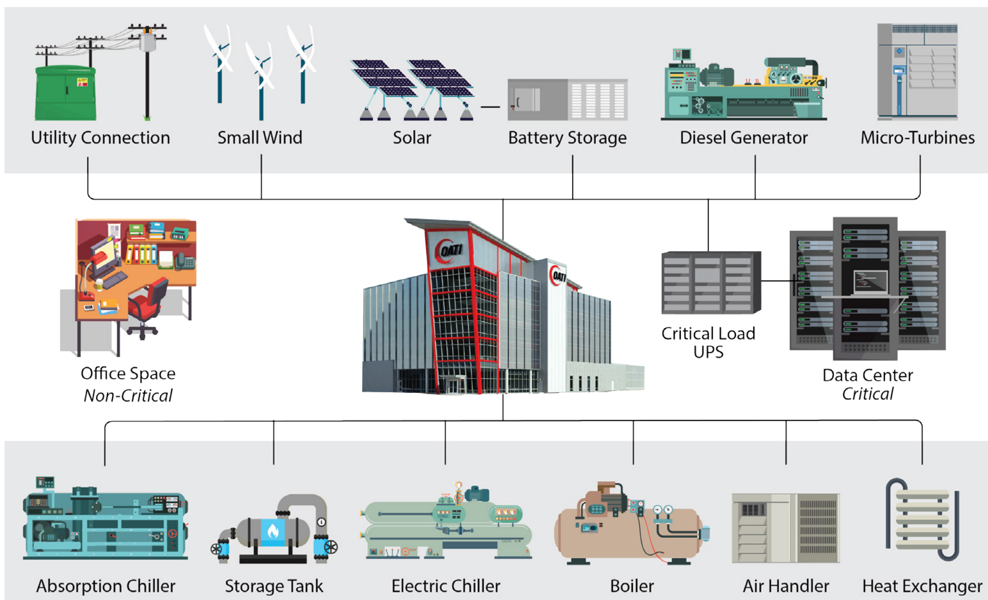


Figure 5: OATI Microgrid Technology Center, Bloomington, MN

From cutting-edge software to highly specialized infrastructure, over the past 20 years, OATI has placed priority on investing resources into the most innovative and creative technological advancements. Besides being a world-class facility full of the newest and latest technology, the OATI Microgrid Technology Center in Bloomington, Minnesota, is a state-of-the-art microgrid. By investing time and resources into a microgrid, OATI is able to fully harness and contribute to the benefits of advanced microgrid technology and pave the way for others to follow by establishing best practices. ***USA Microgrids***, an OATI company, focuses on full-service microgrid development, including consultation, design, build, operations, and maintenance services to help organizations achieve their power reliability, energy price stability, and environmental stewardship objectives.

To learn more about OATI products and services, visit **oati.com**.