Office of Electricity Delivery
and Energy Reliability
Smart Grid R&D Program

DOE Microgrid Workshop Report

August 30-31, 2011

San Diego, California

Acknowledgment

The U.S. Department of Energy (DOE) would like to acknowledge the support provided by the organizations represented on the workshop planning committee in developing the workshop process and sessions. The preparation of this workshop report was coordinated by Energy & Environmental Resources Group, LLC (E2RG). The report content is based on the workshop session discussions, with session summary descriptions taken from the report-out presentations by individual teams during the closing plenary. Contributions to this report by all workshop participants, via expressed viewpoints during the workshop and review comments of the draft report, are duly acknowledged.

The Microgrid Workshop was sponsored by the DOE Office of Electricity Delivery and Energy Reliability. The workshop was hosted by the University of California, San Diego.

Executive Summary

The U.S. Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability (OE) held the Microgrid Workshop on August 30-31, 2011, in San Diego, California. The purpose of the workshop was to convene experts and practitioners to assist the DOE in identifying and prioritizing research and development (R&D) areas in the field of microgrids. The targets of the OE microgrid initiative are to develop commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020.

A workshop planning committee with representatives from the national laboratories involved in microgrid initiatives was assembled to develop the workshop process and sessions. Additionally, the committee members provided nominations of experts and practitioners to the DOE for invitation to the workshop. The workshop had a total of 73 registrants, representing vendors, utilities, national laboratories, universities, research institutes, and end users. The technical topic sessions were jointly conducted by some of the committee members as well as industry co-leads.

The first day of the workshop consisted of an opening plenary session followed by two breakout sessions run in parallel. Breakout Group 1 (blue) focused on microgrid components under the following subtopics: switch technologies, control and protection technologies, and inverters/converters. Breakout Group 2 (red) focused on microgrid systems under the following subtopics: standards and protocols, system design and economic analysis tools, and system integration. The second day of the workshop consisted of a combined session in which the selected industry representatives reported the summary of their sub-sessions to the entire group. The report-out presentations consisted of priority R&D areas and their performance baselines, targets, and actionable plans.

Conclusions from the breakout session discussions and the report-out presentations are summarized below. Sections 3 and 4 of this report summarize key points from each of the breakout sessions, while Section 5 summarizes key points during the closing plenary.

Major Findings

The following are the key R&D areas identified for the six sub-sessions to achieve the above-stated DOE 2020 targets for microgrids:

Switch Technologies

- **Legacy grid-connection technologies to enable connect/disconnect from grid:** Achieve functionality without designating any specific technologies. Focus on integration of functions and generation sources, long-term maintainability, and reliability.
- **Requirements based on customer and utility needs**: Collect information on end-user needs and determine functions for a myriad of applications.

Control and Protection Technologies

- **Best practices and specifications for protection and controls; information models:** Conduct pilots with the DOE/U.S. Department of Defense (DoD) to develop use cases and provide guidelines for multiple approaches. Leverage what works at the transmission level to the distribution level.

- **Reliable, low-cost protection:** Use a layered approach with the first level being protection of components for fast and local decisions, the second level being control for system stability (load reconfiguration), and the third level being optimization.
- **Switches to handle full fault:** Develop fault current limiting devices at the point of connection to the grid.

Inverters/Converters

- **Topologies and control algorithms for multiple inverters to operate in a microgrid:** Define functionalities needed for combining multiple power sources. Develop control and methods for coordinated operation of multiple, smaller distributed inverters (<100 kW).
- **Advanced power electronics technologies:** Design topologies for reduction in volume, cost, and weight of passive components using switch and magnetic technologies for higher efficiency. Develop multi-functional power conditioning systems including transformer function, DC circuits, and multiple types of generators.

Standards and Protocols

- **Universal microgrid communications and control standards:** Define an end-to-end communications and control standard that links distributed generation, loads, and utility connections with standardized component capabilities that are consistent with applicable cyber security standards.
- **Microgrid protection, coordination, and safety:** Modify existing anti-islanding distributed energy resources (DER) techniques to operate correctly in microgrid operations, and develop new unintentional islanding techniques to handle more DER in the microgrid. Define acceptable anti-islanding requirements for microgrids that export power. Develop new protection and coordination methods to handle faults and abnormal conditions when grid-connected and inside microgrids. Coordinate disturbance response with utility.

System Design and Economic Analysis Tools

- **Microgrid multi-objective optimization framework:** Develop a multi-objective (based on quantitative metrics) optimization framework over time (dynamic programming). Develop microgrid-specific design tools and build a library of solutions and tools by 2020.
- **Design an operations optimization methodology with uncertainty:** Uncertainty includes financial risk and return; design should be risk-resilient. Perform a “stress test” of preliminary operational design against a variety of external factors that threaten system operation.

System Integration

- **Common integration framework:** Develop a common framework for cyber security/control/physical architectures. Vertically integrate information management systems.

Path-Forward Discussions

During the closing plenary, workshop participants suggested the following next steps:

- Effective reporting and sharing of lessons learned and best practices on existing microgrid initiatives and projects, including those at the military sites.
- Integration of the R&D areas identified across all technical sessions in this workshop for pursuit to better address some common, crosscutting elements (standards, control, protection coordination, security, etc.).
- Follow-up on and increased collaboration among existing microgrid projects for knowledge sharing.

As presented, the findings of this workshop will be used by the DOE to formulate a potential microgrid Funding Opportunity Announcement in FY 2012 or FY 2013. The input provided during this workshop is valuable guidance to the DOE to accelerate widespread adoption of microgrid technologies and achieve its stated 2020 targets.

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1. Introduction

Microgrids have been identified as a key component of the smart grid in order to improve system energy efficiency and reliability and to provide the possibility of grid-independence to individual end-user sites. As defined by the Microgrid Exchange Group (MEG), “A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.”

The long-term goal for the DOE Office of Electricity Delivery and Energy Reliability (OE) microgrid initiative is: “To develop commercial scale microgrid systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply [UPS] plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020.”

According to the MEG, the benefits of microgrids include:

- Enabling grid modernization and integration of multiple smart grid technologies.
- Enhancing the integration of distributed and renewable energy sources that help to reduce peak load and reduce losses by locating generation near demand.
- Meeting end-user needs by ensuring energy supply for critical loads, controlling power quality and reliability at the local level, and promoting customer participation through demand-side management and community involvement in electricity supply.
- Supporting the macrogrid by handling sensitive loads and the variability of renewables locally and supplying ancillary services to the bulk power system.

Smart Grid R&D Program

There are several ongoing projects supported by the Smart Grid R&D Program, established within the OE and tasked with accelerating the deployment and integration of advanced communication, control, and information technologies that are needed to modernize the nation’s electric delivery network. The goal of the Program is two-fold: (1) to dynamically optimize grid operations and resources for a robust, flexible, and secure “plug-and-play” electric grid, and (2) to fully integrate demand response and consumer participation into grid resource planning and operations. Ongoing projects in the areas of dynamic optimization of distribution grid operations through integration of advanced sensing, communication, and control technologies in microgrids are summarized below.[1]

Nine Renewable and Distributed Systems Integration (RDSI) projects were selected in 2008 via a competitive DOE solicitation. The primary goals of these projects are to (1) demonstrate at least 15% peak demand reduction on the distribution feeder or substation level through integrating distributed energy resources (DER), and (2) demonstrate microgrids that can operate in both grid parallel and islanded modes. The application of technologies in an integrated fashion has the potential to allow more power to be delivered through existing infrastructure, thereby deferring transmission and distribution investment, and to increase the reliability of the grid by adding elements that make it more stable and reconfigurable. Other potential benefits include addressing vulnerabilities in critical infrastructure, managing peak loads, lowering emissions, using fuel resources more efficiently, and helping customers

[1] D. T. Ton, W. M. Wang, W-T. P. Wang, “Smart Grid R&D by the U.S. Department of Energy to Optimize Distribution Grid Operations,” Proceedings of the 2011 IEEE Power & Energy Society General Meeting at Michigan, Detroit, MI, July 24-28, 2011.

manage energy costs. The total value of the RDSI program will exceed $100M, with approximately $55M from the DOE over five years and the rest through participant cost share.

There is also a significant effort by national laboratories on microgrid designs, analysis, and demonstrations at test facilities and military bases. Lawrence Berkeley National Laboratory (LBNL) is teaming with American Electric Power (AEP), the University of Wisconsin, and Sandia National Laboratories (SNL) to apply Consortium for Electric Reliability Technology Solutions (CERTS) microgrid concepts in AEP's Dolan Technology Center-Walnut Station Test Facility in Groveport, Ohio. CERTS microgrid concepts are also being applied in field demonstrations by the Sacramento Municipal Utility District, Chevron Energy Solutions (RDSI project), and the U.S. Department of Defense (DoD) at Fort Sill and Fort Maxwell. LBNL has also developed the Distributed Energy Resources Customer Adoption Model (DER-CAM), which is an economic model to predict and optimize the capacity and minimize the cost of operating distributed generation in microgrids.

SNL is working on the Energy Surety Microgrid (ESM) methodology, which uses cost/performance data and lessons learned from military bases to develop approaches for implementing high reliability microgrids and assist in planning and analysis of potential risks in future commercial projects. So far, 13 military bases have been evaluated using the Sandia ESM methodology. Furthermore, the DOE is supporting SNL, Oak Ridge National Laboratory (ORNL), Idaho National Laboratory, National Renewable Energy Laboratory (NREL), and Pacific Northwest National Laboratory (PNNL) to work with the DoD to conduct the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) at Pearl Harbor-Hickam Air Force Base, Hawaii; Fort Carson, Colorado; and Camp Smith, Hawaii. A key part of SPIDERS is standardization of the design approach, contracting, installation, security, and operation of these microgrids to support future applications. At ORNL, the Distributed Energy Communications & Controls Laboratory is developing controls for inverter-based DER to provide local voltage, power, and power quality support for the campus distribution system. On the simulation side, PNNL has been developing GridLAB-D™ as a distribution system simulation tool that integrates grid operations at several levels, including microgrids.

Five new projects are being awarded through the FY 2010 Smart Grid Research, Development, and Demonstration (RD&D) Funding Opportunity Announcement (FOA) to support dynamic optimization of grid operations. These projects are in the areas of integrated modeling and analysis tools to automate distribution; advanced sensing, monitoring, and control technologies to enhance asset use and grid reliability; and voltage regulation for high penetration of renewable generation.

As a continuing effort to broaden and deepen stakeholder engagement in jointly planning and implementing RD&D activities, the Smart Grid R&D Program convened the Microgrid Workshop to seek industry input on identifying key R&D areas and their performance baselines, targets, and actionable plans. This input will be used to guide the development of technical topic areas for a potential FOA in FY 2012 or FY 2013.

Workshop Organization

The DOE began the workshop effort by assembling a Workshop Planning Committee that included Dan Ton (lead), Merrill Smith (DOE); Jason Stamp, Abbas Akhil, Mike Hightower (SNL); Tom King (ORNL); Joe Eto, Chris Marnay (LBNL); Ben Kroposki, Greg Martin (NREL); and Paul Wang (E2RG). The committee identified the major cost components (percentages in parentheses are estimates of costs) for the microgrid as follows:

Energy Resources (30-40%)	Switchgear Protection and Transformers (20%)	Smart Grid Communications and Controls (10-20%)	Site Engineering (30%)	Operations and Markets
Energy storage; controllable loads; distributed generation; renewable generation; combined heat and power	*Switchgear utility interconnection* (including low-cost switches, interconnection study, protection schemes [programmable relays], and protection studies)	*Standards and protocols; control algorithms and software* (integration with energy management system [EMS], prime movers, utilities); real-time signals (openADR); local SCADA access; power electronics (*smart inverters,* DC bus [typically on the battery])	A&E *(modeling and analysis); system integration, testing, and validation*	O&M; market (utility) acceptance

The italicized subtopics were identified as areas having potential for significant cost reduction by the Smart Grid R&D Program efforts. Two parallel breakout groups were then organized to address these subtopics. The two breakout groups, subtopics, and technical leads were finalized as shown in the following table.

Breakout Group #1 (blue) Lead: Tom King, ORNL Facilitator: Lee Krevat, San Diego Gas & Electric Note-taker: W. Maria Wang, E2RG	Breakout Group #2 (red) Lead: Jason Stamp, SNL Facilitator: Byron Washom, University of California – San Diego Note-taker: Mustafa Biviji, E2RG
▪ **Switch technologies** Technical leads: Greg Martin, NREL; Scott Kolek, Encorp ▪ **Control and protection technologies** Technical leads: Aleks Dimitrovski, ORNL; Le Tang, ABB Inc. ▪ **Inverters/converters** Technical leads: Burak Ozpineci, ORNL; Leo Casey, Satcon[2]	▪ **Standards and protocols** Technical leads: Ben Kroposki, NREL; Charlie Vartanian, A123 Systems ▪ **System design and economic analysis tools** Technical leads: Jason Stamp, SNL; Mike Clark, Encorp ▪ **System integration** Technical leads: Juan Torres, SNL; Phil Smith, Honeywell Building Solutions

The planning committee members prepared lead-off presentations on baselines, projections, and technology pathways for these subtopics. These presentations (available via links in the Agenda provided in Appendix A) were used as seeds for discussion of priority R&D areas for each breakout group based on the following checklist:

[2] Leo Casey did not attend due to weather-related travel restrictions.

1. Determine a list of R&D topic areas where R&D would impact achieving the DOE microgrid technical performance/cost targets by:
    - Seeking feedback on those areas identified in the lead-off presentation
    - Asking attendees to identify any missing areas
    - Building consensus on a priority list of impactful R&D topic areas:
        - High (must discuss): limited to 1 or 2 areas
        - Medium (good to discuss): limited to 1 or 2 areas
        - Low (only if there's time)
2. Define an R&D activity for each agreed-to R&D area, in priority order, until the allotted session time is reached:
    - Baseline performance with specifics on the following:
        - Technical functions or capabilities for current applications
        - Costs for current applications
        - Limitations for target applications (current and future)
    - Performance targets with specifics on the following:
        - Technical functions or capabilities for target applications
        - Costs for target applications
        - Why the performance targets are needed
        - Significance and impact of the performance targets with respect to achieving the DOE microgrid targets
    - Actionable plan for R&D with specifics on the following:
        - R&D scope
        - R&D milestones, cost/performance targets, and their schedules
        - Transformational R&D components (a strong role for the DOE)
        - DOE and non-DOE (other federal agencies, state/local governments, industry, universities, national labs) roles in the activity
        - Uniqueness of this project and/or synergy to other ongoing projects
3. Elect spokesperson(s) for report-out the next day (using provided presentation template)
    - One or two spokespersons per technical session

Timeline

The workshop planning committee convened weekly or bi-weekly via teleconference to plan details of the workshop. The timeline items leading to the workshop event on August 30-31, 2011, at University of California at San Diego (UCSD) are summarized below:

- March 16: Planning Committee kickoff meeting.
- May 27: Preliminary breakout session topics with session leads suggested.

- June 16: Breakout session subtopics finalized.
- June 22: Invitations sent by the DOE to all invitees, along with the preliminary agenda. Workshop registration opened.
- July 21: Two facilitators confirmed.
- August 15: Agenda finalized (Appendix A) and registration closed.
- August 23: Session subtopic presentations finalized and leads confirmed. Plenary speakers confirmed.
- August 30-31: Workshop held at the Meeting Rooms at Fifteen, UCSD.

Participants

Potential invitees were nominated by the committee members. The accumulated list was reviewed and shortlisted, following which invitations were issued. The 73 registrants represented vendors, electric utilities, national laboratories, universities, research institutes, end users (including military bases, municipalities, and data centers), and consultants. The participants chose their breakout groups during registration. The list of registrants can be found in Appendix B.

Products

- Report-out presentations by nominated representatives at the closing plenary to summarize priority R&D areas, baselines, performance targets, and actionable plans for each breakout session subtopic.
- Detailed workshop report to guide the DOE in identifying priority R&D areas that the DOE can impact for microgrid development.

2. Opening Plenary

Dan Ton and Merrill Smith, DOE Smart Grid R&D Program Managers, kicked off the workshop by welcoming and acknowledging the host, UCSD. Dan mentioned that the mission of the OE is to modernize our nation's electric grid and highlighted the importance of microgrids as part of this mission. He then introduced Gary Matthews, Vice Chancellor for Resource Management & Planning at UCSD. Gary welcomed the participants of the workshop by giving an overview of the various sustainability efforts on campus. These efforts include solar technologies, electric vehicles, improved building efficiency, and microgrids for emergency response. Dan Ton continued the proceedings by highlighting the goal of the workshop as identifying priority R&D areas for a potential microgrid FOA in FY 2012 or FY 2013, while Merrill Smith highlighted the various ongoing microgrid initiatives such as the RDSI projects, DER-CAM for renewable systems integration, ESM methodology, SPIDERS demonstrations, and groups such as CERTS and the MEG that are working on microgrid advancement. Even though these microgrid demonstrations exist, this workshop strives to focus on and identify R&D areas that could help achieve the Smart Grid R&D Program's long-term goals:

- 20% reduction in distribution outages (as measured by the System Average Interruption Duration Index [SAIDI]) for improved reliability
- >98% reduction in outage time of required loads for improved reliability
- 20% load-factor improvement for improved system efficiency via integration of DER, demand response (DR), and plug-in electric vehicles (PEVs)

3. Breakout Session 1

Tom King, ORNL, was the lead, and Lee Krevat, San Diego Gas & Electric (SDG&E), was the facilitator for breakout session 1, which consisted of 34 registrants. Each of the three subtopics began with an overview presentation to set the stage for subsequent discussions. These discussions are summarized below according to notes from W. Maria Wang (E2RG). Refer to the report-out presentations linked to in the Agenda provided in Appendix A for the entire list of non-prioritized R&D areas suggested during the discussions.

Switch Technologies

Subtopic leads/presenters: Greg Martin, NREL, and Scott Kolek, Encorp

The ‘disconnect’ functionality is key for switches to address the issue of utility back-feed from DER and comply with IEEE 1547 standards. There are three common types of switch configurations: single point of common coupling (PCC), transfer switch to DER, and UPS backup (no interruption to other DER). Common switch technologies include the static switch (non mechanical, fast; high cost), contactor (transfer switch; very reliable), and circuit breaker (over-current protection included). The transfer switch is more expensive than the circuit breaker because often the circuit breaker is included in the contactor solution.

While most participants were not comfortable selecting the right switch for their application, they agreed that industry should focus on engineering while the DOE needs to invest in advancement of the technology. The group also indicated the following system-level issues:

- AEP found that coordination between inverter and switch design is important to deal with high current and switching speed.
- Standard breaker curve protection is inadequate.
- Are we dealing with reactive or non-reactive loads? Should there be separate grids with different switches?
- DOE demonstrations are meant to address system issues.

The shortlisted priority R&D areas for switch technologies were as follows, with the top areas bolded:

- **Legacy grid-connection technologies to enable connect/disconnect from grid**
    - Need to drive down costs for switch engineering and equipment (hardware) because they are bottlenecks for application. Move from custom switches to standardized switches to drive cost down; increased volume creates market.
    - Integration of functions and generation sources – synchronization, harmonization. Fort Bragg did not have a technology that could solve the harmonics problem with gensets that were not synchronized.
    - Achieve functionality without designating specific technologies. Need to define basic microgrid connect/disconnect functionality, e.g., number of cycles, seamless transition, etc.
    - Focus on long-term maintainability and reliability. Needs to work for 20 years?
    - Converter interface in lieu of a switch may be a research area.

- **Requirements based on customer and utility needs**
    - Collect information on end-user needs and determine functions for myriad of applications.
    - Transition time depends on customer requirements.
    - Define different topologies.
- DC microgrid/switch
    - Operation and control schemes for DC microgrid without and with energy storage.
    - Adaptive integrated control/protection schemes for DC microgrid.
    - Power control of DC microgrid using bus signaling and load shedding.

It was also agreed that switch technology is mature, so the DOE should focus on collecting and sharing information on operational issues and lessons learned. R&D should focus on adding/improving functionality and lowering cost. R&D targets include the following criteria: not limited by visual disconnect, seamless (¼ cycle or ½ cycle to 3 cycles, depending on customer requirements), transient-free re-syncing, meeting utility requirements at the switch (instead of generators), and interoperability.

Control and Protection Technologies

Subtopic leads/presenters: Aleks Dimitrovski, ORNL, and Le Tang, ABB Inc.

Robust, layered control architecture is needed with different response times for devices with fast internal/local control and central microgrid control, which in addition to static optimization provides dynamic optimal control, communications between subsystems, and demand management. Control and protection systems provide the ultimate emergency control, and the current issue with protection is mostly related to latency. To address these needs, a prioritized list of R&D areas that the DOE could impact was discussed as follows, with the top areas bolded:

- **Best practices and specifications for protection and controls; information models**
    - Conduct pilots with the DOE/DoD to develop use cases.
    - Provide guidelines for multiple approaches.
    - Leverage what works at the transmission level to the distribution level.
    - Phased approach – "pre-standard research best practices."
    - Basic classification of protection approaches.
    - Mitigate "re-engineering" microgrid protection.
- **Reliable, low-cost protection**
    - Use a layered approach with the first level being protection of components for fast and local decisions, the second level being control for system stability (load reconfiguration), and the third level being optimization. DOE can invest in developing components to protect against high fault current, or a quick decision tool for a fault or disturbance. Data and latency depend on the level.
    - Efficiency and renewable integration requires rethinking architecture and power flow analysis.

- **Switches to handle full fault**
    - Fault current limiting systems at PCC – truly transformational and may have significant benefits.
    - Design around the fault.
- Truly distributed system level control
    - Develop distributed supervisory system level control architecture and integrate it with local controls of particular energy resources.
    - Interconnections: solve for robust communications between particular distributed supervisory controller modules.
    - Stability and interactions - develop supervisory and local controls to guarantee stable operation on a system level regardless of architecture and type of energy resources.
    - Demonstrate feasibility through modeling and laboratory testing or real system operation.
- Make components that can handle fault current flow or detection, then system level control.
- Protection using new technologies (adaptive and integrated protection/control system - intelligent system interruption, fault isolation, and rapid recovery).

In summary, the DOE should focus on collecting information on specifications and best practices, developing robust, reliable, and low-cost protection using a layered approach, and dealing with faults (for which there is no baseline data).

Inverters/Converters

Subtopic lead/presenter: Burak Ozpineci, ORNL

A major cost challenge with inverters is the use of SiC and GaN devices. Inverter cost is currently being addressed by the DOE Sunshot program, and cost plateaus for high power systems. To address remaining issues, a prioritized list of R&D areas that DOE could impact was discussed as follows, with the top areas bolded:

- **Topologies and control algorithms for multiple inverters to operate in a microgrid**
    - Define functionality that is needed, avoid specifying approach.
    - Currently, there is limited capability for multiple sources, and a custom system requires too much engineering. The target is to integrate multiple power sources – rotating machinery, inverter based, multiple (balanced) utility feeds.
    - Control of multiple, smaller distributed inverters to address microgrid functionalities such as islanding, synchronization, voltage and frequency regulation, and load sharing (vs. Solar Energy Grid Integration Systems [SEGIS] efforts).
    - Switching between voltage sources, master/slave (unique to microgrids?).
    - Operating mode – autonomous vs. grid connected vs. islanding.
    - The current baseline is IEEE 1547 while the R&D target should be IEEE 1547.8 that has provisions for ride through, volt/VAR regulation, frequency control, and no user disturbance for on/off grid.
    - Other R&D targets include a standardized control environment and open architecture.

- **Advanced power electronics technologies**
    - Develop topologies for reduction in volume, weight, and cost of passive components.
    - The current baseline has a dedicated power converter for each device; alternative approaches are being developed. The target is to develop a single, multi-functional power conditioning system with multiple devices (unique to microgrid application), including transformer function, DC circuits, and various generators (e.g., small modular reactors).
    - Develop switch and magnetic technologies for high voltage and higher efficiency. The baseline for switches is 1.7 kV, 5-10 kHz. The target is 10-15 kV at the same frequency and higher efficiency with 0.1% loss per switching level; or 1.7 kV at >50KHz.
    - A caveat on this R&D area is that similar technologies are already being developed through the DOE, DoD, and the Advanced Research Projects Agency-Energy (ARPA-E) Agile Delivery of Electrical Power Technology (ADEPT) program.
- Develop validated dynamic models of system interactions at the converter-grid interface.
    - Currently lack good models of synchronous generators and for renewable energy sources.
    - ARPA-E Green Electricity Network Integration (GENI) program has similar awards.
- Advance lifetime of converter technology for microgrids
    - The DOE can take lead to understand failure modes. Control degradation and improve life so that industry will invest in inverters.
    - There is currently a solicitation on solar inverters for longer life and lower cost.

4. Breakout Session 2

Jason Stamp (SNL) was the lead and Byron Washom (UCSD) was the facilitator for breakout session 2, which consisted of 39 registrants. The three subtopics each began with an overview presentation to set the stage for subsequent discussions. These discussions are summarized below according to notes from Mustafa Biviji (E2RG) and the report-out presentations (linked to in the Agenda provided in Appendix A).

Standards and Protocols

Subtopic leads/presenters: Ben Kroposki, NREL, and Charlie Vartanian, A123 Systems

IEEE 1547.4 was acknowledged as the baseline standard for microgrids, while P1547.8 will help broaden and support the IEEE 1547 standard in the future. P2030 was also cited as an important standard with respect to interoperability in microgrids. There were 18 R&D areas identified for standards and protocols, some of which were then eliminated, followed by voting on the remaining areas for priority and finally consolidation into two key areas that are described below:

- Universal microgrid communications and control standards
  - *Description of the R&D scope:* Clearly define an end-to-end communications and control standard (schema or data structures) that links distributed generation, loads, and utility connections (link EMS, building automation systems [BAS], utility, microgrid controller, industrial metering, and market participation) with standardized component capabilities (DR, BAS, diesels, loads, etc.), consistent with applicable cyber security standards.
  - *Technical performance baselines and R&D target:* Current microgrid communications and control are custom built, and are thus costly and risky to scale up. There are not consistent capabilities from DER and BAS. The R&D target should focus on interoperability, easier BAS integration, response to ancillary signals and optimized system operations with low integration and design costs, as well as standardization for easy and affordable scaling.
  - *Cost baselines and R&D target:* The current costs are about $100K to integrate each DER/BAS, while the targeted costs should be probably as low as $10K per DER/BAS.
  - The milestones include developing a plan to address interoperability of legacy equipment, BAS integration, DER fleet, and external signals with microgrids in year 1, followed by deployment in years 2 and 3.
  - The synergistic developments for this activity are being carried out by IEEE SCC21 Projects (1547 and 2030) and NIST Smart Grid Interoperability Panel.
  - A caveat is that Standards Development Organizations (SDOs) take considerable time to reach consensus for the final standards approval, so it may be best to publish best practices based on real-world examples in the interim.
- Microgrid protection, coordination, and safety
  - *Description of the R&D scope:*
    - Modify existing anti-islanding DER techniques to operate correctly in microgrid operations. Develop new unintentional islanding techniques to handle larger numbers of DER in microgrid. Define acceptable anti-islanding requirements for microgrids that export power.

        - Develop new protection and coordination methods to handle faults and abnormal conditions when grid-connected and inside microgrids.
        - Coordinate disturbance response with utility.
        - Develop protection and coordination practice in microgrids with high levels of inverter-based DER.
    - *Technical performance baselines and R&D target:* The currently used standards are limited to IEEE 1547, with a lack of standard for protection of microgrids with multiple DER units. There is a need for a standard that addresses protection, reverse power flow, and anti-islanding with multiple DER and to also have a standard way to implement protection with inverter-based DER for various microgrid markets (commercial, DoD, etc.).
    - *Cost baselines and R&D target:* As the current costs are in the range of hundreds of thousands of dollars (that is 100% of microgrid costs for under 4 MW) to perform interconnection studies, the targeted costs should be less than 5% of microgrid costs to make their implementation feasible.
    - The milestones include developing a plan to address protection, coordination, and safety with microgrids in year 1, followed by deployment in years 2 and 3, and publishing best practices at the end of year 3.
    - In terms of synergistic developments, R&D work has been done in the field of microgrid protection by the CERTS and RDSI projects.

System Design and Economic Analysis Tools

Subtopic leads/presenters: Jason Stamp, SNL, and Mike Clark, Encorp

The session presenters discussed various tools for microgrid conceptualization, economic and performance analysis, and electrical network analysis. Discussion then went into controls use cases (automated grid management and control, supervisory control, protective relaying, microgrid configuration management, and connections to other systems) and test cases for cyber security use cases (usability, functionality, and transparency). The group suggested five R&D areas (detailed in the report-out presentation linked to in Appendix A), which were narrowed into the following top two based on a majority vote:

- Microgrid multi-objective optimization framework
    - *Description of the R&D scope:* Multi-objective (based on quantitative metrics, e.g., reliability optimization, carbon minimization, ramp-rate limiting, demand charge reduction, lifecycle costs, etc.) over time (dynamic programming); application of microgrid(s) must be considered during optimization of conceptual design and all other operational aspects of the system; microgrid-specific design tools needed (as opposed to re-purposed existing products); grid-constrained production simulation models/tools.
    - *Technical performance baselines and R&D target:* The currently used tools are generally a mixture of proprietary tools used as a force fit. There is a need for: comprehensive methodology for multi-objective microgrid design, gap analysis with respect to current tools suitable to the lifecycle of microgrid, and support of open model framework for

collaboration, maintenance, and reuse to address the more than 140 microgrid projects totaling over 1.1 gigawatts (GW) of capacity worldwide.[3]

    - *Cost baselines and R&D target:* The current costs range from $250K to $1M (for small microgrids, costs go down dramatically but are still proportionally high). The targeted costs should be 5% of project costs for <1 MW, 1 to 2.5% of project costs for <10 MW, and 1% of project costs for >10 MW.
    - A tested framework should become available by 2015, and it should be institutionalized by 2020.
    - This will lead to a library of documents/software and lower costs, and will support the DOE targets on SAIDI reduction and load outage.

- Design and operations optimization methodology with uncertainty
    - *Description of the R&D scope:* Design and operations optimization methodology under uncertainty (including financial risk and return) for key architecture and variables (e.g., user behavior, cyber security, fuel price, equipment failure, renewable portfolio standards, climate, load characterization change); "stress test" of preliminary operational design against external factors that threaten system operation; risk-resilient design.
    - *Technical performance baselines and R&D target:* The currently used technique is to conduct a sensitivity analysis and go with engineering judgments. There is a need to develop a framework that allows comprehensive design and a suite of complementary offerings, supports open model framework for collaboration, maintenance, and reuse, and must have validation and verification cachet.
    - *Cost baselines and R&D target:* The current costs make this activity not investment-worthy by commercial lenders. The targeted costs should be 5% of project costs for <1 MW, 1 to 2.5% of project costs for <10 MW, and 1% of project costs for >10 MW.
    - The tested optimization methodologies should be available by 2015 and should be institutionalized by 2020.
    - This will lead to a methodology reference library and reduced costs, and will support DOE emissions and system efficiency targets.

System Integration

Subtopic leads/presenters: Juan Torres, SNL, and Phil Smith, Honeywell Building Solutions

The cost-prohibitive system integration process (including microgrid electrical, control, and security subsystems assembly, implementation, and operations) was defined and system integration-related challenges were discussed in the context of the U.S. Food and Drug Administration (FDA) White Oak Campus case study. Five R&D areas were suggested (detailed in the report-out presentation linked to in Appendix A), which were then voted on and eventually consolidated into the following single high-priority area for DOE to possibly support:

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[3] Pike Research report, "Microgrids," December 2010, http://www.pikeresearch.com/research/microgrids

- Common integration framework
  - *Description of the R&D scope:*
    - Common framework cyber/control/physical architectures.
    - Vertically integrated information management systems (including all devices in a system: storage, generation, renewable energy, EMS, etc.) and communications protocols suitable for microgrid applications (e.g., need more bandwidth upstream and less bandwidth downstream, need real-time mode).
    - Microgrid common integration bus (similar to enterprise integration bus).
    - Power integration bus like common DC or AC sources and loads and other components.
  - *Technical performance baselines and R&D targets:* System integration is currently done by brute force, tailored and proprietary for each project. The R&D targets are to develop an open, scalable architecture for cyber/control/physical security, reflect the maturity of microgrids with their own standardized set of practices, have a common language to promote compatibility, and develop a framework of physical and communication adapters.
  - *Cost baselines and R&D target:* System integration currently costs one-third of the project cost. The targeted cost should be 10% of the total project cost.
  - Implementation should be done with the help of DOE microgrid workshops for various markets to gather existing microgrid best practices/lessons learned, analyze for common denominators, and baseline integration costs by 2013. A white paper on common integration framework guidelines should be published by 2014, and a comparative analysis between baseline and common integration framework microgrid projects should be performed by 2015.
  - A relevant project is the ESM focusing on a common integration framework, while certain military microgrid projects could also provide lessons learned and their project template used to cover other microgrids.

5. Closing Plenary

The closing plenary session included report-out presentations for each of the six subtopics across both breakout sessions by industry representatives chosen from each group. Discussions then ensued on the R&D areas as well as microgrid research in general. Key points and participant comments from these discussions for each individual subtopic are provided as follows:

Breakout Session 2 Report-out Presentations

Standards and Protocols

Presenter: Sunil Cherian, Spirae Inc.

Dr. Cherian presented the two high priority R&D areas for the Standards and Protocols session: (1) Universal microgrid communications and control standards, and (2) Microgrid protection, coordination, and safety. More information on each of the areas (including description of R&D scope, technical and cost baselines, and R&D targets as well as milestones) is provided in the previous section. Key discussion points on this subtopic include the following:

- Standards for protection are necessary, hence the 'microgrid protection, coordination, and safety' R&D area is important for the DOE to consider.
- The 61850 communications and control standard does not completely address microgrid issues. There are existing standards for coordination or extension to microgrids; this is an important R&D activity.
- P2030 interoperability standard is device-specific and needs to be extended to apply to microgrid fleets.
- The lack of standards for a microgrid isolated from the main grid by an inverter system has not been addressed.

System Design and Economic Analysis Tools

Presenter: Steve Pullins, Horizon Energy Group

Mr. Pullins presented the two R&D areas that received the highest votes in the System Design and Economic Analysis Tools session: (1) Microgrid multi-objective optimization framework, and (2) Design and operations optimization methodology with uncertainty. More information on each of the areas (including description of R&D scope, technical and cost baselines, and R&D targets as well as milestones) is provided in the previous section. Key discussion points on this subtopic include the following:

- R&D area – 'Multi-objective optimization framework': library of solutions and tools by 2020. This framework will drive down microgrid costs. R&D cost target refers to preliminary design to specification stages.
    - The framework could be institutionalized state by state or as a series of standards. The plan is to use standards in the SDOs. The International Electrotechnical Commission (IEC) is the legal entity for standards.

- R&D area – ‘Optimization methodology with uncertainty’: the design would account for financial risks.
    - The optimization will be done for multiple variables, and the decisions are going to be dynamic (accounting for factors such as weather).
- The two R&D areas address all four DOE targets. The second R&D area is an extension of the first but with uncertainty.
- Making buildings ready for load shedding is included as a cost in the model.
- It is assumed that physics-based processes in components are well-modeled; however, this might not be the case, e.g., inverter models are not shared. There should be an emphasis on modeling activities. Library should include state estimation models.

System Integration

Presenter: Joe Heinzmann, Altairnano

Mr. Heinzmann presented the R&D area that received the highest votes in the System Integration session: Common integration framework. More information on the area (including description of R&D scope, technical and cost baselines, and R&D targets as well as milestones) is provided in the previous section. Key discussion points on this subtopic include the following:

- Developing common integration framework, e.g., for hotel and supermarket microgrids, will be useful.
- DOE should use third-party vendors to verify and validate projects that have already been implemented. This could help in documenting long-term savings, which will help accelerate the adoption rate of microgrids.
- The currently used microgrid definition has been provided by the Microgrid Exchange Group (an *ad hoc* group of experts). The definition does not have to be restrictive on what a microgrid can be. Microgrids are an element of smart grid, which itself has different definitions, so it is more important to define the attributes. IEEE standards have some definitions on microgrid components and functions. Microgrid definition only matters for financial incentives.

Breakout Session 1 Report-out Presentations

Switch Technologies

Presenter: Robert Lasseter, University of Wisconsin

Dr. Lasseter presented the two priority R&D areas in the Switch Technologies session: (1) Legacy grid-connection technologies to enable connect/disconnect from grid, and (2) Requirements based on customer and utility needs. More information on each of the areas (including description of R&D scope, technical baselines, and R&D targets) is provided in the previous section. Key discussion points on this subtopic include the following:

- Need to consider coordination of switches with loads as a system issue.
- Need to deal with existing infrastructure.
- Re-syncing is relatively easy compared to other functionalities.

- Currently there exists no baseline or white paper; the DOE can help determine best practices for putting switch in, coordinating load shedding, etc.
- Hardware and technology for components are there; mainly need best practices.
- Not tripping due to power quality issues shows the value in spinning reserves. Determine customer requirements; have customer focus groups to determine how fast switch needs to be and what they are willing to pay.
- Definition of seamless depends on coordination with loads.
- IEEE 1366: 5-minute interruption.
- Microgrid can shake up the UPS market.
- Can be applied to distribution feeder (utility needs).
- Having power quality as differentiated service may be interesting R&D topic.
- DOE role: facilitation and documentation of best practices.

Control and Protection Technologies

Presenter: Mark Zeller, Schweitzer Engineering Laboratories

Mr. Zeller presented the three priority R&D areas in the Control and Protection Technologies session: (1) Best practices and specifications for protection and controls; information models, (2) Reliable, low-cost protection, and (3) Switches to handle full fault. More information on each of the areas is provided in the previous section. Key discussion points on this subtopic include the following:

- What does the information look like for a control and protection package? Packaged solution will drive costs down.
- In AEP's experience, negative and zero-sequence at inverter end were used to trip. They have not looked at short circuit causing trip.
- No performance baselines are available for protection on a DC microgrid, though some standard procedures exist for an AC microgrid. We know what does not work, but still do not know what is going to work.
- Baselines should come out of Santa Rita Jail RDSI project. The DOE can help in collecting information from case studies to determine a baseline.
- Borrego Springs microgrid did not have use cases on protection schemes for islanding.
- Utility-owned generation is a paradigm shift. But these generators are limited to 200 hrs/yr operation, so they are a limitation and are only useful for occasional islanding.

Inverters/Converters

Presenter: Shalom Flank, Pareto Energy

Dr. Flank presented the two R&D areas that received the highest votes in the Inverters/Converters session: (1) Topologies and control algorithms for multiple inverters to operate in a microgrid, and (2) Advanced power electronics technologies. More information on each of the areas (including description of R&D scope, technical baselines, and R&D targets) is provided in the previous section. Key discussion points on this subtopic include the following:

- Pareto is connected to the grid using inverters, so they are always connected but still islanded.
- Nine companies at this workshop are part of the EMerge Alliance, a non-profit organization promoting DC power standards.
- Need to resolve the synchronization issue with distributed micro-inverters.
- Perhaps faster switching can reduce the amount of capacitance required, eliminating a key failure mode. There may be a cost tradeoff, though.
- Big issue is how to get power electronics to last 20 years; this is an industry problem.
- Need graceful degradation so that the component will still be a part of a working system.
- Coordinated operation of multiple inverters is a new topology that is required.
- Discussion on controls focused on a higher system level than just a component level.

Closing Remarks

Dan Ton adjourned the workshop by acknowledging all the organizers, UCSD, and all the attendees at the workshop. Following, additional comments were made by participants:

- The Santa Rita Jail project is a well-acknowledged microgrid project, with intermediate reports on batteries and other capabilities at the site available online at DER.lbl.gov, which also contains past presentations on the microgrid symposia. The timeline for final project reports is unknown. Perhaps there can be links to other sources such as this on the workshop website.
- It might be good to have a meeting for discussions on key technical issues for RDSI projects. What are the attributes of the information that needs to be collected from these projects?
- The DoD has tasked MIT Lincoln Laboratory to look at what microgrid projects are out there. It will be useful if the DoD could share lessons learned with a broader audience.
- The Smart Grid Information Clearinghouse hosted by Virginia Tech has lessons learned published online for some projects (http://www.sgiclearinghouse.org/).
- New domain expert working group under the smart grid interoperability group has an effort on distributed renewables, generators, and storage that will identify gaps in microgrid standards and develop use cases for information exchange requirements.

Appendix A: Workshop Agenda

AGENDA

DOE Microgrid Workshop

August 30-31, 2011

The Meeting Rooms at Fifteen
UC San Diego, San Diego, CA

http://hdh.ucsd.edu/fifteen/photos.asp

Transportation services between the meeting location and Sheraton La Jolla Hotel will be provided. Daily shuttle schedules are listed at the end of the agenda.

Day 1, Tuesday, August 30

7:30 **Continental Breakfast at the Meeting Rooms at Fifteen**

8:30 **Opening Plenary Session**

- **Welcoming Remarks**
  Gary Matthews, Vice Chancellor for Resource Management & Planning, UC San Diego
- **DOE Goal of Microgrid Development and "Setting the Stage" for the Workshop**
  Dan Ton and Merrill Smith, Program Managers, DOE Smart Grid R&D Program
- **Breakout Group Assignments & Technical Session Ground Rules**

Breakout Group #1 Lead: Tom King, ORNL Facilitator: Lee Krevat, SDG&E Note-taker: W. Maria Wang, E2RG	**Breakout Group #2** Lead: Jason Stamp, SNL Facilitator: Byron Washom, UCSD Note-taker: Mustafa Biviji, E2RG
– Switch technologies (Technical leads: Greg Martin, NREL / Scott Kolek, Encorp) – Control and protection technologies (Technical leads: Aleks Dimitrovski, ORNL / Le Tang, ABB Inc.) – Inverters (Technical leads: Burak Ozpineci, ORNL / Leo Casey, Satcon)	– Standards and protocols (Technical leads: Ben Kroposki, NREL / Charlie Vartanian, A123 Systems) – System design and economic analysis tools (Technical leads: Jason Stamp, SNL / Mike Clark, Encorp) – System integration (Technical leads: Juan Torres, SNL / Phil Smith, Honeywell Building Solutions)

9:40 **Break**

10:00 **Concurrent Breakout Groups 1 & 2**

For each bulleted technical session above, facilitated discussions to reach consensus on a prioritized list of R&D areas. Address the following for each R&D area, in priority order:

- Baseline Performance
- Performance Targets and their significance
- Actionable Plan to include scope, end goals, milestones, schedules, and roles of participants

Noon **Lunch (Provided by the Workshop)**

1:00 **Concurrent Breakout Groups 1 & 2, Continued**

5:00 **Adjourn for Day 1**

5:30 **Networking Reception,** sponsored by CleanTECH San Diego

Day 2, Wednesday, August 31

7:30 **Continental Breakfast at the Meeting Rooms at Fifteen**

8:30 **Closing Plenary Session**

- **Report-out by spokesperson of each technical session (session 1 & session 2):**
  - Priority of R&D topic areas
  - For each R&D Area:
    - Baseline vs. R&D performance targets
    - Needs and significance
    - Actionable R&D plan

10:00 **Break**

10:20 **Closing Plenary Session, Continued**

- **Continued report-out by spokesperson of each technical session**
- **Feedback and facilitated discussions from attendees including recommendations and next steps**

11:40 **Closing Remarks**
Dan Ton and Merrill Smith, Program Managers, DOE Smart Grid R&D Program

Noon **Workshop Adjourn (Box lunch provided by the Workshop)**

Optional Tour

1:00 - 3:00 **UCSD**'s microgrid, 1.2MW of installed PV, and electric vehicle energy storage program facilities

Transportation Services:

Between Sheraton and The Meeting Rooms at Fifteen (~15 minute for a round trip):

August 30: Two shuttle buses are reserved, each with a capacity of 25
Departs Sheraton: 7:30, 7:40, 7:50, and 8:00 AM
Departs The Meeting Rooms at Fifteen: from 5:00 PM – 7:30 PM

August 31: Only one bus is available, with a capacity of 25
Departs Sheraton: 7:30, 7:45, and 8:00 AM
Departs The Meeting Rooms at Fifteen: from Noon – 1:00 PM

In addition, a driver with a passenger vehicle will be on call to transport attendees during the Workshop hours.

For the Tour:

Transportation will be provided for all tour participants and will include drop off at Sheraton after the tour ends.

Appendix B: List of Registrants

Charlie Vartanian
A123 Systems

Le Tang
ABB Inc.

Joe Heinzmann
Altairnano

Jennifer McKenzie
Amec

John Howard
American Electric Power

Jianhui Wang
Argonne National Laboratory

Frank Jakob
Battelle

Hassan Farhangi
British Columbia Institute of Technology

Wade Troxell
Colorado State University

Radian Belu
Drexel University

Peter Theisen
Eaton

Dennis Symanski
Electric Power Research Institute

Michael Clark
Encorp, LLC

Scott Kolek
Encorp, LLC

Tanya Burns
Energetics Inc.

Mustafa Biviji
Energy & Environmental Resources Group, LLC

W. Maria Wang
Energy & Environmental Resources Group, LLC

W-T. Paul Wang
Energy & Environmental Resources Group, LLC

Arvind Ravishunkar
Fairchild Semiconductor

Michael Steurer
Florida State University

John Kelly
Galvin Electricity Initiative

Terry Mohn
General MicroGrids, Inc.

DOE Microgrid Workshop Registrant List

Sakis Meliopoulos
Georgia Institute of Technology

Rick Rocheleau
Hawaii Natural Energy Institute

Phil Smith
Honeywell Building Solutions

Steven Pullins
Horizon Energy Group

Bruce Hedman
ICF International

Joseph Eto
Lawrence Berkeley National Laboratory

Chris Marnay
Lawrence Berkeley National Laboratory

Koeunyi Bae
Lockheed Martin

Christopher Boyer
Lockheed Martin

Scott Van Broekhoven
MIT Lincoln Laboratory

Hashem Nehrir
Montana State University

Keith Dodrill
National Energy Technology Laboratory

Mario Sciulli
National Energy Technology Laboratory

Ben Kroposki
National Renewable Energy Laboratory

Greg Martin
National Renewable Energy Laboratory

Ratnesh Sharma
NEC Labs America

Paul Savage
Nextek Power Systems

William Siddall
NextEnergy

Allen Hefner
NIST

Bill Elliott
NVESD

Aleksandar Dimitrovski
Oak Ridge National Laboratory

Thomas King
Oak Ridge National Laboratory

DOE Microgrid Workshop Registrant List

Burak Ozpineci
Oak Ridge National Laboratory

J Patrick Kennedy
OSIsoft LLC

Kevin Schneider
Pacific Northwest National Laboratory

Shalom Flank
Pareto Energy

Emir Macari
Sacramento State, College of Engineering

Thomas Bialek
San Diego Gas & Electric

Lee Krevat
San Diego Gas & Electric

Ben Schenkman
Sandia National Laboratories

Jason Stamp
Sandia National Laboratories

Juan Torres
Sandia National Laboratories

Leo Casey
Satcon

Mark Zeller
Schweitzer Engineering Laboratories

Darrell Thornley
Shaw Group

Yaosuo Xue
Siemens Corporate Research

Robert Yinger
Southern California Edison

Sunil Cherian
Spirae, Inc.

Jason Hopkins
Underwriters Laboratories

Vladimir Blasko
United Technologies Research Center

Stella Maris Oggianu
United Technologies Research Center

Byron Washom
University of California San Diego

Alexis Kwasinski
University of Texas at Austin

Reza Iravani
University of Toronto

DOE Microgrid Workshop Registrant List

Bob Lasseter
University of Wisconsin

Tarek Abdallah
US Army

Eric Lightner
US Department of Energy

Merrill Smith
US Department of Energy

Dan Ton
US Department of Energy

Manisa Pipattanasomporn
Virginia Tech, Advanced Research Institute

Laura Manz
Viridity Energy, Inc.