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

Summary Report:
2012 DOE Microgrid Workshop

July 30-31, 2012

Chicago, Illinois

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 on 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 Illinois Institute of Technology in Chicago, Illinois.

Executive Summary

The U.S. Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability (OE) held the Microgrid Workshop on July 30-31, 2012, at the Illinois Institute of Technology (IIT) facilities in Chicago, Illinois. This workshop was held in response to path-forward discussions at the preceding DOE Microgrid Workshop, held in August 2011, which called for sharing lessons learned and best practices for system integration from existing projects in the U.S. (including military microgrids) and internationally. In addition, the purpose of this workshop was to determine system integration gap areas in meeting the DOE program 2020 targets for microgrids and to define specific R&D activities for the needed, but unmet, functional requirements. These activities will serve as the basis for the DOE Microgrid R&D roadmap. The DOE program targets, affirmed at the August 2011 workshop and documented in the workshop report,[1] 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 four national laboratories, three universities, and two consulting firms involved in microgrid initiatives was assembled to develop the workshop process and sessions. Additionally, committee members provided nominations of experts and practitioners to the DOE for invitation to the workshop. The committee member roster and the workshop agenda are shown in Appendices A and B.

The workshop began with an international panel session, during which representatives from Europe, Japan, South Korea, and the U.S. provided an overview of microgrid development activities in their respective countries or regions. This was followed by a session with presentations of lessons learned and best practices from the following microgrid projects: Sendai (Japan); Microgrid with an Open, Scalable Architecture (Sandia National Laboratories [SNL]); Selected European Microgrid Demonstrations (Europe); Twentynine Palms Marine Base Microgrid (military); Santa Rita Jail (industrial); and Campus Microgrid at IIT (university). To guide the selection of these presentations and their content, workshop planning committee members developed a list of technical, economic tradeoff, and regulation and policy issues (Appendix C) for coverage in the "lessons learned and best practices" session.

Next on the agenda for the first day was a brainstorming session to identify a list of R&D topics, followed by determination of the top-12 topics for breakout session discussions the next day. Prior to the workshop, all registrants received a working list of system integration topics (Appendix D) and associated questions to be addressed (Appendix E), grouped under the "Planning and Design" and "Operations and Control" tracks. This working list was used to seek input from participants for any changes (additions, deletions, and consolidation of topics). The first day adjourned after assigning two of the top-12 R&D topics for each of the six breakout sessions.

The second and final day of the workshop consisted of six breakout sessions run in parallel to discuss the R&D plan elements for each R&D topic assigned. The breakout sessions were as follows: system architecture development, modeling and analysis, and power system design under the "Planning and Design" track; and steady state control and coordination, transient state control and protection, and operational optimization under the "Operations and Control" track. The workshop concluded with a combined session in which the selected session spokespersons reported the summary of their session discussions to the entire group. The report-out presentations consisted of the following: framing of the topic; current technology status; needs and challenges; R&D scope; and R&D metrics.

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[1] U.S. Department of Energy, DOE Microgrid Workshop Report, August 30-31, 2011, available at http://energy.gov/sites/prod/files/Microgrid%20Workshop%20Report%20August%202011.pdf.

The workshop had a total of 100 registrants, representing vendors, utilities, national laboratories, universities, research institutes, and end users. Among them, 13 representatives from eight foreign countries (Belgium, Canada, Germany, Greece, Japan, South Korea, Romania, and the UK) participated in the workshop. The list of registrants is shown in Appendix F.

All workshop presentations are available via links in the workshop program agenda (Appendix B). Conclusions from the breakout session discussions and the report-out presentations are summarized below.

Major Findings

The following are the key R&D topics, not in any priority order, identified by workshop participants as high priority for DOE microgrid R&D. These topics, each with a brief scope description, are presented under the two tracks: "Planning and Design" and "Operations and Control."

R&D Topics Relating to Microgrid Planning and Design

Session on System Architecture Development

- **Definition of Microgrid Applications, Interfaces, and Services.** Define the following: an ideal microgrid architecture, use cases, and interfaces to reference existing standards (interconnection versus communication versus information).
- **Open Architectures That Promote Flexibility, Scalability, and Security.** Develop interoperable distributed controls and flexible architecture to facilitate different applications.

Session on Modeling and Analysis

- **Performance Optimization Methods and Uncertainty in the Modeling and Design Process.** Develop a standard set of collaborative tools that addresses uncertainty, has a more holistic approach (to integrated energy systems, communications, vehicles, combined heat and power systems, etc.), and broadly assesses value streams; and validate the tools on both domestic and international systems.

Session on Power System Design

- **DC Power Distribution Systems.** Establish codes and standards for DC applications in residential, commercial, and industrial settings; develop standard design methodologies and software tools; develop DC system control algorithms; implement a push-and-pull strategy for DC microgrids, and develop advanced power electronics (lower cost, higher function and reliability).
- **Microgrid Integration.** Develop the following: a resource guide (i.e., handbook) to available products, costs, installation methods, valuation methods, etc.; standard and observable models to be used in modeling and analysis; standard analysis methods and software models; surety design methods and metrics for reliability and security; and advanced power electronics and advanced controls.

R&D Topics Relating to Microgrid Operations and Control

Session on Steady State Control and Coordination

- **Internal Services within a Microgrid.** Develop a standard set of hardware and software that supports the communication protocols and cybersecurity standards already developed to allow DER to plug and play; develop three-phase estimators based on phasor measurement units (PMUs) and compatible instrumentation for run time control; develop a better understanding of methods of decoupling frequency and voltage; and demonstrate a system that can synchronize and reconnect a microgrid under all edge conditions (high PV penetration) for all classes of microgrids.
- **Interaction of Microgrid with Utility or Other Microgrids.** Evaluate microgrids against other existing utility mitigation tools and schemes; evaluate potential effects of multiple microgrids on the stability of the grid and potential regulations, economic incentives, and control schemes that could be used to mitigate the negative effects; develop tools for distribution to manage microgrids and their resources in cooperation with other distribution resources (assets) in "RDO" (regional distribution operator); and develop a technical, operational, and economic model to demonstrate the value of microgrids to utilities through simulation and case studies.

Session on Transient State Control and Protection

- **Transient State Control and Protection.** Define impact of types of communication and identify requirements; develop 3-phase unbalanced dynamic stability analysis models and a Reference Study for transient stability analysis of microgrids; develop technically mature, commercially available autonomous transition control and protection concept and products that meet the defined capabilities; and validate standard microgrid component models for protection and transient studies.

Session on Operational Optimization

- **Operational Optimization of a Single Microgrid.** Develop real-time (RT) and near-RT controls that incorporate optimization; evaluate a variety of optimization techniques as applied to microgrid operations; and develop methodology for comparing microgrid baseline to optimized microgrid operations for potential input into business case analysis.
- **Operational Optimization of Multiple Microgrids.** Develop RT and near-RT controls that incorporate optimization between multiple microgrids; develop methods to negotiate objectives and optimizations between multiple microgrids (between different microgrid integrators); evaluate a variety of optimization techniques as applied to multiple microgrid operations; and develop methodology for comparing multiple microgrid baseline to optimized microgrid operations for potential input into business case analysis.

Engaging stakeholders in this workshop and the August 2011 workshop to seek input on R&D needs is a key element of the R&D management process practiced by the Smart Grid R&D Program. Valuable input on microgrid R&D has been attained through both workshops. The Program will deliberate internally to further refine R&D requirements and will develop a competitive funding opportunity announcement (FOA) to solicit projects to fulfill the requirements. The FOA topics and timing for issuance are pending available funds from annual appropriations.

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Introduction

The Smart Grid R&D Program, within the U.S. Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability (OE), convened this second Microgrid Workshop on July 30-31, 2012, in Chicago, Illinois. This followed the initial workshop in August 2011. Both workshops were designed to seek input from the microgrid community on ongoing and future DOE microgrid R&D efforts.

The purpose of the 2011 workshop was to convene experts and practitioners to assist the DOE in identifying and prioritizing R&D areas in the field of microgrids. Path-forward discussions at the workshop led to this 2012 workshop, designed for sharing lessons learned and best practices for system integration from projects in the U.S. (including military microgrids) and internationally. Further, the purpose of the 2012 workshop was to determine system integration gap areas in meeting the DOE program 2020 targets for microgrids and to define specific R&D activities for the needed, but unmet, functional requirements. These activities will serve as the basis for the DOE Microgrid R&D roadmap.

The DOE program 2020 targets, affirmed at the 2011 workshop, 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.

The Smart Grid R&D Program adopts the definition of the microgrid by the Microgrid Exchange Group (MEG);[2] namely, "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." For both workshops, this definition was used for identification of needs, challenges, and gap areas, as well as for definition of scope of activities, for microgrid R&D.

Workshop Organization

The DOE began the workshop effort by assembling a Workshop Planning Committee that included members from four national laboratories, three universities, and two consulting firms. The committee was tasked with developing the workshop process and agenda, nominating presenters for the international panel and "lessons learned and best practices" sessions, nominating experts and practitioners to the DOE for invitation to the workshop, and developing preparatory materials for the workshop. The committee member roster is shown in Appendix A, and the workshop agenda is shown in Appendix B.

The preparatory materials developed by the committee included the following:

- Technical, economic tradeoff, and regulation and policy issues to be covered in the "lessons learned and best practices" session presentations. The issues document (Appendix C) was used to guide selection of the following six microgrid project presentations: Sendai (Japan); Microgrid with an Open, Scalable Architecture (SNL); Selected European Microgrid Demonstrations (Europe); Twentynine Palms Marine Base Microgrid (military); Santa Rita Jail (industrial); and Campus Microgrid at IIT (university).
- A working list of R&D topics (Appendix D) and associated lists of questions for each topic (Appendix E) to be addressed at the workshop. The topics in Appendix D were used as a starting point for discussion at the brainstorming session. This list was refined with input from the participants to form the final, top-12 topics for ensuing breakout session discussions. Lists of questions in Appendix E were considered during breakout session discussions to formulate the R&D needs and scope of activities for their respective topics.

[2] The Microgrid Exchange Group comprises an *ad hoc* group of individuals working on microgrid deployment and research. Regular MEG meetings, in person or via teleconferences, are held for information exchange and sharing.

In addition, the committee prepared the following preparatory materials: a report-out presentation template that outlines the breakout session discussion process, and an example of a completed presentation. All preparatory materials were sent to workshop registrants before the workshop.

The six breakout sessions on the second day of the workshop were organized to run in parallel, with each assigned to develop R&D plans for two of the top-12 topics identified through the brainstorming session on the first day. The facilitation plan used in the breakout sessions is outlined below, with times allocated for defining each bullet element provided in parentheses:

Framing of the Topic (<15 minutes)

- Begin the session to clearly define the topic and set a boundary of what is and isn't included in the topic, so as to complement, and not to overlap with, the topics in other breakout sessions.
- Capture the definitions in succinct bullets on the template.
- The topic definition should be used by the facilitator to guide the ensuing discussion.

Current Technology Status (<20 minutes)

- Discuss the R&D baseline of where we are with respect to the topic. Discussions should cover the state of the practice, the state of the art, and current R&D activities.
- Capture the current status in succinct bullets on the template.

Needs and Challenges (<20 minutes)

- Discuss what is needed in this topic, with respect to meeting the DOE microgrid program goal, meeting new application or market sector requirements, meeting higher market penetration rates, etc. For each need identified, articulate why we need it. Capture the needs discussions in succinct bullets on the template.
- Challenges are related to why we are not there in respect to the needs identified. Since this is an R&D workshop, discussions should be constrained to R&D challenges, as opposed to policy and institutional challenges. Capture the challenges in succinct bullets on the template.

R&D Scope (<40 minutes)

- The scope discussion should clearly focus on what specific R&D activities should be conducted to overcome the challenges and meet the needs.
- The R&D scope should cover activities to be undertaken in the next 5 years, as that is the duration for the multi-year program plan. The budget required for carrying out the scope is outside of the interest of this workshop and should not be discussed.
- Capture an overview description of the scope on the template, with bullets accentuating specific R&D activities.

R&D Metrics (<40 minutes)

- Quantifiable technical performance and/or cost target milestones, with timeline by year, should be defined to trend the progress of R&D over its entire duration.
- The last milestone(s) should clearly reflect the technical performance target and/or the cost performance target defined for this R&D topic.
- The outcome is, when all is done, what difference the R&D makes. The outcome should be defined as the R&D impacts in near term and long term.

Two committee members were also assigned to each breakout session to facilitate and guide the session discussions. The workshop concluded with summary presentations by session spokespersons using the template developed by the committee.

Timeline

The assembled workshop planning committee conducted an in-person, kickoff meeting on January 18, in conjunction with the 2012 IEEE PES ISGT Conference in Washington, DC. The committee then established three work groups. One work group was tasked to develop the list of system integration issues important for lessons learned and best practices (Appendix C). The second work group was tasked to develop a working list of R&D topics (Appendix D) and lists of questions associated with each topic (Appendix E). The third work group was tasked to develop the breakout facilitation plan, the report-out template, and an example of a completed report-out presentation.

Many teleconferences were held by the planning committee to discuss the workshop process, agenda, presenters, and invitees, leading to the workshop event on July 30-31, 2012, at IIT.

Participants

Committee members nominated potential invitees who were then issued workshop invitations. The 100 registrants represented vendors, electric utilities, national laboratories, universities, research institutes, end users (including military bases, municipalities, and data centers), and consultants. Among them, 13 representatives from eight foreign countries (Belgium, Canada, Germany, Greece, Japan, South Korea, Romania, and the UK) participated in the workshop. The list of registrants can be found in Appendix F.

Products

The workshop resulted in two primary products:

- Presentations by panel members, invited speakers on lessons learned and best practices, and session spokespersons on summary of session discussions.
- This workshop report to be used by the DOE to further refine R&D requirements for development of the microgrid R&D FOA.

Opening Plenary

Dan Ton and Merrill Smith, DOE Smart Grid R&D Program Managers, kicked off the workshop by welcoming participants and acknowledging IIT for hosting this workshop. Dan stated that microgrid R&D is a key focus area of the DOE Smart Grid R&D Program. Other focus areas for the program include intelligent load management and distribution automation. He acknowledged the many attendees who also participated in the August 2011 workshop at the University of California in San Diego, during which the DOE microgrid program goals and key R&D areas in meeting the goals were discussed. This workshop focused on sharing lessons learned and best practices on existing microgrid projects in the U.S. and internationally. Following the information exchanges, this workshop was used to determine system integration gap areas, and define specific R&D activities with clearly defined scope and metrics to respond to the gap areas. These activities will serve as the basis for the DOE Microgrid R&D roadmap and will be incorporated into the Smart Grid R&D Program Multi-year Program Plan.

Dan then introduced the host representative, Dr. Mohammad Shahidehpour, who is the Center Director and is also a Bodine Distinguished Professor in the Electrical and Computer Engineering Department at IIT. Mohammad introduced Andrew Ross, Chief Operating Officer, State of Illinois. Andrew welcomed the participants of the workshop by giving an overview of the various smart energy development efforts undertaken by the State of Illinois.

Dan Ton continued the proceedings by introducing four panel members on international microgrid development: Nikos Hatziargyriou, Professor, National Technical University of Athens, Greece; Dae Kyeong (DK) Kim, Principal Researcher, Korea Electrotechnology Research Institute (KERI), Korea;

Tatsuya Shinkawa, Chief Representative, New Energy and Industrial Technology Development Organization (NEDO), Japan; and Merrill Smith, Program Manager, DOE. The panel members took turns delivering a presentation on an overview of microgrid development in the countries they represent (Europe, South Korea, Japan, and the U.S.).

All panel member presentations are available via web links by their names in the program agenda (Appendix B).

Session on Lessons Learned and Best Practices

Dan opened this session by introducing the six invited presentations on real microgrid development projects worldwide for lessons learned and best practices: Sendai (Japan); Microgrid with an Open, Scalable Architecture (SNL); Selected European Microgrid Demonstrations (Europe); Twentynine Palms Marine Base Microgrid (military); Santa Rita Jail (industrial); and Campus Microgrid at IIT (university). The ensuing brainstorming session would build on the six presentations and experience from all workshop participants to determine system integration gap areas.

All "lessons learned and best practices" presentations are available via web links in the program agenda (Appendix B).

Brainstorming Session to Determine a List of 12 R&D Topics

Jason Stamp, SNL, facilitated this interactive session to first identify a list of R&D topics and then to determine the final list of top-12 topics for focused discussions on the next day. Jason introduced the working list (Appendix D), developed by the workshop planning committee, as the starting point of discussions. Jason provided a summary of each topic on the list and solicited input from the audience. Greg Martin, National Renewable Energy Laboratory (NREL), captured the discussion points and revised the list accordingly. After recording all of the topics brought forth by the participants, consolidation steps were taken, followed by a show of hands to determine the top-12 topics. The topics were then organized into six breakout sessions (with two topics per session). The breakout sessions and their topics are shown in the table below.

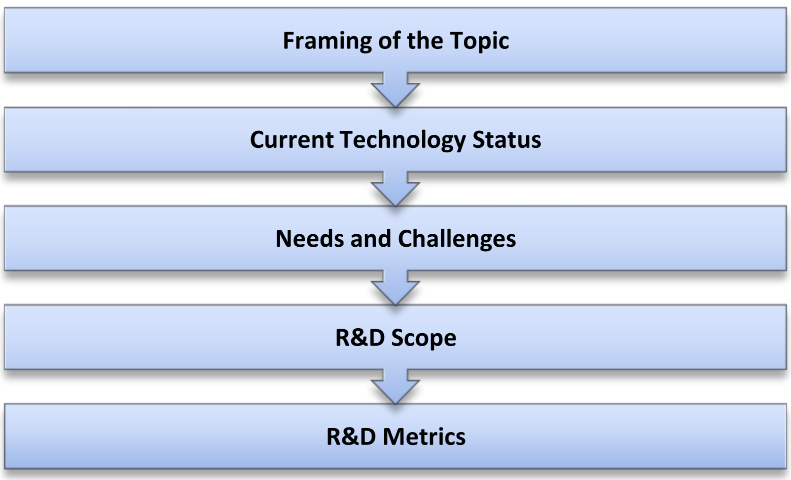
"Planning and Design" Track	"Operations and Control" Track
Session: System Architecture Development ▪ Definition of microgrid applications, interfaces, and services ▪ Open architectures that promote flexibility, scalability, and security	**Session: Steady State Control and Coordination** ▪ Internal services within a microgrid ▪ Interaction of microgrid with utility or other microgrids
Session: Modeling and Analysis ▪ Performance optimization methods ▪ Uncertainty in the modeling and design process	**Session: Transient State Control and Protection** ▪ Transient state control ▪ Protection
Session: Power System Design ▪ DC power distribution systems ▪ Microgrid integration	**Session: Operational Optimization** ▪ Operational optimization of a single microgrid ▪ Operational optimization of multiple microgrids

Six Concurrent Breakout Sessions

Two people were tasked to lead and facilitate discussions in each breakout sessions. They are primarily members of the planning committee, with a few from the national laboratories referred by the committee members. The session leads are listed in the table below.

"Planning and Design" Track	"Operations and Control" Track
Session: System Architecture Development *Session leads:* Scott Van Broekhoven, Massachusetts Institute of Technology (MIT) Lincoln Laboratory Danny Martin, NREL	**Session: Steady State Control and Coordination** *Session leads:* Jim Reilly, Reilly Associates Bob Lasseter, University of Wisconsin
Session: Modeling and Analysis *Session leads:* Chris Marnay, Lawrence Berkeley National Laboratory (LBNL) Greg Martin, NREL	**Session: Transient State Control and Protection** *Session leads:* Yan Xu and Travis Smith, both of Oak Ridge National Laboratory (ORNL)
Session: Power System Design *Session leads:* Jason Stamp and Ross Guttromson, both of SNL	**Session: Operational Optimization** *Session leads:* Ben Kroposki, NREL Kevin Schneider, Pacific Northwest National Laboratory (PNNL)

Following the facilitation plan described under the "Workshop Organization" section above, participants in each session then discussed the following elements for each assigned topic:



Summaries of discussions on each bullet element above were then captured in the report-out template, and session spokespersons were nominated to present the summaries at the closing plenary.

Closing Plenary

The closing plenary session included report-out presentations for each of the six breakout sessions by spokespersons chosen from each session. The report-out presentations are available by clicking on the topic(s) under each breakout session below.

Session 1: System Architecture Development

- 1a: Definition of Microgrid Applications Interfaces, and Services
- 1b: Open Architectures that Promote Flexibility, Scalability, and Security

Session 2: Modeling and Analysis

- Performance Optimization Methods and Uncertainty in the Modeling and Design Process

Session 3: Power System Design

- DC Power
- Microgrid Integration

Session 4: Steady State Control and Coordination

- Internal Services within a Microgrid
- Interaction of Microgrid with Utility or Other Microgrids

Session 5: Transient State Control and Protection

- Transient State Control and Protection

Session 6: Operational Optimization

- Operational Optimization of a Single Microgrid
- Operational Optimization of Multiple Microgrids

Closing Remarks

Dan adjourned the workshop by acknowledging IIT, the workshop planning committee, the sponsors for workshop receptions (S&C Electric Company and Willdan Energy Solutions), and all attendees at the workshop.

Appendix A:
Roster of the 2012 DOE Microgrid Workshop Planning Committee

- **U.S. Department of Energy**
  Merrill Smith
  Dan Ton (Committee Lead)

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

- **Illinois Institute of Technology**
  Mohammad Shahidehpour

- **National Renewable Energy Laboratory**
  Dave Corbus
  Ben Kroposki

- **Lawrence Berkeley National Laboratory**
  Chris Marnay

- **MIT Lincoln Laboratory**
  Scott Van Broekhoven

- **Oak Ridge National Laboratory**
  Tom King
  Yan Xu

- **Reilly Associates**
  Jim Reilly

- **Sandia National Laboratories**
  Ross Guttromson
  Jason Stamp

- **University of Wisconsin**
  Bob Lasseter

Appendix B: Agenda

AGENDA

DOE Microgrid Workshop

July 30-31, 2012

IIT Galvin Center for Electricity Innovation

10 W. 35th Street, 16th Floor, Chicago, IL 60615

Sunday, July 29

6:00-7:30 pm Pre-workshop Reception at the Galvin Center

Day 1, Monday, July 30

8:00 **Continental Breakfast at the Galvin Center**

8:30-9:30 am Opening Plenary Session

- **Welcoming Remarks**
  Andrew Ross, Chief Operating Officer, State of Illinois

- **Panel on International Microgrid Development**

  Dan Ton, Program Manager, DOE, USA (Moderator)

  Nikos Hatziargyriou, Professor, National Technical University of Athens, Greece

  Dae Kyeong (DK) Kim, Principal Researcher, KERI, Korea

  Tatsuya Shinkawa, Chief Representative, NEDO, Japan

  Merrill Smith, Program Manager, DOE, USA

9:30-3:00 pm Lessons Learned and Best Practices on Microgrid Development and Operations

9:30 **Sendai Microgrid (Japan)**

Satoshi Morozumi, NEDO

Keiichi Hirose, NTT Facilities

Hiroshi Irie, Mitsubishi Research Institute

10:15 **Break**

10:30 **Microgrid with an Open, Scalable Architecture**

Ross Guttromson/Steven Glover, Sandia National Laboratories

Day 1, Monday, July 30

9:30-3:00 pm Lessons Learned and Best Practices (continued)

11:15 **Selected European Microgrid Demonstrations**

Philipp Strauss, Fraunhofer IWES, Germany

Ernst Scholtz, ABB AG, Germany

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

1:00 **Twentynine Palms Marine Base Microgrid**

Sumit Bose, GE Global Research

Marques Russell, US Marine Corps

1:45 **Santa Rita Jail Microgrid**

Eduardo Alegria, Chevron Energy Solutions

2:30 **Campus Microgrid at the Illinois Institute of Technology**

Mohammad Shahidehpour, Illinois Institute of Technology

3:15 **Break**

3:30-5:00 pm Identification of Technical Topics for Further Definitization at Day-2 Breakout Sessions

3:30 **Brainstorming Session to Identify a List of Technical Topics of Interest**

Facilitated discussions to draw a list of technical topics of interest from attendees based on what they have heard from lessons-learned presentations and their own knowledge and experience. The preliminary list of topics developed by the Workshop Planning Committee and distributed to the attendees will be used as a starting point of session discussions to make additions, deletions, and changes.

4:30 **Identification of the Top-12 Technical Topics from the List for Day-2 Discussions**

Show of hands by attendees for voting each technical topic identified of interest to be either on the top-12 or non-top-12 list.

5:00-5:30 pm Organization of Day-2 Breakout Sessions

Two technical topics from the top-12 list will be assigned to a breakout session for Day-2 discussions. Each attendee will be asked to join one of the six breakout sessions established for Day 2; reassignment of attendees will be made, if necessary, for balanced, adequate representations in each breakout session. The facilitator/note-taker for each session will be introduced to session attendees.

5:30 **Adjourn for the Day**

6:30-8:00 pm Workshop Reception at the Museum of Science and Industry

Day 2, Tuesday, July 31

8:00 **Continental Breakfast at the Galvin Center**

8:30-1:30 pm Concurrent Breakout Sessions #1-6

For each technical topic assigned, facilitated discussions to develop an actionable plan. A list of questions developed by the Planning Committee should be referred to while developing the following action plan elements:

- Framing of the topic
- Current technology status
- Needs and challenges
- R&D scope
- R&D metrics

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

2:00-4:00 pm Closing Plenary

2:00 **Report-out by Spokesperson of Each Breakout Session (~15 minutes each, including Q/A)**

- Session 1a: Definition of Microgrid Applications Interfaces, and Services
- Session 1b: Open Architectures that Promote Flexibility, Scalability, and Security
- Session 2: Modeling, Analysis, & Design
- Session 3: DC Power and Microgrid Integration
- Session 4a: Steady State Control and Coordination – Internal Services within a Microgrid
- Session 4b: Steady State Control and Coordination – Interaction of Microgrid
- Session 5: Transient State Control and Protection
- Session 6: Operational Optimization

3:30 **Feedback and Facilitated Discussion from Attendees Including Recommendations and Next Steps**

3:50 **Closing Remarks**
Dan Ton and Merrill Smith, Program Managers, DOE Smart Grid R&D Program

4:00 **Workshop Adjourn**

4:00 – 5:30 pm Tour of IIT Microgrid (Optional)

5:30 Shuttle bus(es) returning to the Renaissance hotel

Wednesday, August 1

8:00 – 11:00 am Tour of S&C Facilities (Optional)

Appendix C: Issues Document

Day One Focus on Lesson Learned and Best Practices

Planning and Design

1. Define the electrical situation and stakeholder expectations (conceptualize the microgrid)
    a. Mission and load types/amounts:
        i. Tier 1A (critical/uninterruptible)
        ii. Tier 1B (critical/interruptible)
        iii. Tier 2 (partial service during utility outages)
        iv. Tier 3 (no service during utility outages)
    b. Existing electrical systems (LV, MV, diesels, switches, transformers, etc.)
    c. Renewable energy (existing/planned assets and environmental)
    d. Options for additional fossil energy
    e. Building controls and passive/active efficiency options (incl. CCHP)
    f. Communications (to support microgrid control)
    g. Regulations (federal/state/institutional)
    h. Potential grid interactions: economic behavior and ancillary services
2. Develop screening model, tools, and/or analysis (define what may be feasible – financially, regulatorily, aesthetically, etc. – for the project) with stakeholder input
3. Define key performance parameters in terms of quantitative metrics:
    a. Metrics for islanded conditions:
        i. Tier 1A/B load unserved
        ii. Improved electrical service for Tier 2 loads
    b. Metrics for utility-connected conditions:
        i. Utility energy usage deferred
    c. Metrics for either:
        i. Diesel (or fossil fuel) consumption deferred
        ii. Carbon (or GHG) generation deferred
    d. All of these are traded off against the microgrid cost
4. Define additional requirements depending on the situation (some examples are listed below)
    a. Some diesel generators must be manually reconfigurable to existing (non-microgrid) operations
    b. The microgrid must island and reconnect seamlessly (define the time periods)
    c. Power quality remains at acceptable levels (define applicable standards)
    d. Cyber security architecture must resist attack and conform to emerging standards, monitoring integrates with existing software and practices
    e. Operation of a fuel cell for district heating first and electrical energy production second
    f. New diesel tanks are limited to 3,000 gallons at sites X, Y, and Z
5. Perform microgrid economic analysis and reliability / performance optimization
6. Perform electrical network analysis: power flow, stability, dynamic performance
7. Develop initial plan for controls and protection

8. Develop cyber security architecture
    a. Administrative/procedural/technical controls
    b. Attach prevention/detection/recovery
    c. Test cases for cyber
        i. Usability: How difficult is it to install, maintain, and use the cyber security architecture? Does it function reasonably (i.e., it can't take 20 minutes to log into a system)?
        ii. Functionality: How well does the cyber security architecture function against possible attacks?
        iii. Transparency: Does the cyber security architecture interfere with normal operations (i.e., it can't introduce latency on a protective relaying channel)?
    d. Design is supported by test bed environments (perhaps of the simulated-emulated-physical sort) over microgrid design domains of controls, communications / networking, and the electrical energy system
    e. Test system assets can be retained to support red team/auditing practice
9. Analysis rollup (feedback between different phases/models or domains – physical, control, and cyber) including stakeholder input, followed by final decision making on design functional requirements

Technical Issues Related to Implementing a Microgrid

1. Method used to ensure loads and sources are balanced in island operation.
   When a microgrid is islanded, the real and reactive power (P & Q) being exchanged with the utility is abruptly forced to zero. This abrupt change requires the sources in the microgrid to change their P & Q output and/or loads to be shed or added. The same issue applies to island operation for changes in load demand or loss of a source. Also how is overload of individual energy sources in the microgrid prevented? Is under-frequency or other load control used?

2. Voltage and frequency regulation in islanded operation.
   When the microgrid is islanded, the voltage and frequency regulation provided by the utility is removed. What methods are used to provide voltage and frequency regulation while islanded? What are the requirements for acceptable frequency and voltage variability and speed of restoration?

3. Islanding and reconnection.
   One of the points in Microgrid Exchange Group (MEG) and the CIGRÉ C6.22 definitions of a microgrid[3] is the ability to island and reconnect. How closely does your project meet this definition? This can be done with fast static switches, mechanical breakers, or manually. In most cases the requirements of IEEE 1547 are also met at this interface. What criterion was used to decide when to island, and how was this achieved? How is reconnecting achieved? Any lessons learned relative to the utility's acceptance of the interface switch.

4. Onsite issue; installation and testing.
   Implementing a microgrid results in modification of original planning and design. Such issues as grounding, control systems, energy management systems, commission tests, unexpected cost, and others are of interest.

5. Protection.
   Protection can be a problem for a microgrid. For microgrids containing only inverter-based sources, the available short current can be limited to less than twice the nominal load rating. What was your approach to protection design and coordination for the microgrid? What protection strategies are applied in a microgrid (AC or DC) for both grid-connected and islanded operation?

Economic Tradeoffs

1. Economic tradeoffs during the design of the microgrid.

   Demonstration projects aren't intended to be financially viable, but how did consideration of eventual viability influence design choices?

   What considerations and objectives were explicitly non-economic, e.g., maximizing the renewable energy fraction, maintaining constant grid import/export, maximizing reliability, etc.?

   How much is the project costing, and how is it funded? Privately or publicly?

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[3] Microgrid definition by the Microgrid Exchange Group:

> 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.

Microgrid definition (in draft) by the *CIGRÉ C 6.22 Working Group: Microgrids Evolution Roadmap*:

> Microgrids are electricity distribution systems containing loads and DER, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.

High power quality and/or reliability (PQR) are often strong motivators of microgrid development. How was the value of PQR evaluated, and how did it affect demonstration design and equipment selection?

Disconnection can also be a major cost. How were performance requirements of switching determined, and what has been learned about alternatives?

How were actual or possible external relationships, such as potential demand response and ancillary services participation, considered?

2. Economic tradeoffs in operation of the microgrid.
   How is economic dispatch ensured and implemented under normal grid connected operation and while islanded?

3. Economic/technical tradeoffs with utility.

   Are grid imports and exports considered in an economic manner, i.e., are grid energy purchases considered as a competing source of energy, or are grid purchases controlled by other objectives, e.g., minimizing grid dependency?

   How significant a factor in project costs was dealing with utility interconnection?

   How were non-energy interactions with the grid considered, e.g., potential ancillary services revenue streams?

   How important was a consideration of inadequate grid PQR?

Regulation and Policy

1. What are regulatory barriers to a microgrid involving one or more "customer" sites?

Appendix D: Initial Working List of R&D Topic Areas Prior to Breakout Group Discussions

Planning and Design

Breakout Session 1: System Architecture Development

- Research Topic A: Microgrid / macrogrid interface definition
- Research Topic B: Architectures that promote flexibility
- Research Topic C: Open architecture (common integration framework)

Breakout Session 2: Modeling and Analysis

- Research Topic A: Cost and performance optimization methods
- Research Topic B: Uncertainty in the modeling and design process

Breakout Session 3: System Design

- Research Topic A: Microgrid stability with high RE penetration
- Research Topic B: Energy storage

Operations and Control

Breakout Session 4: Steady State Control and Coordination

- Research Topic A: Grid interconnection guidelines and microgrid services
- Research Topic B: Microgrid control and operation
- Research Topic C: DC microgrids

Breakout Session 5: Transient State Control and Protection

- Research Topic A: Transient state control
- Research Topic B: Protection

Breakout Session 6: Operational Optimization

- Research Topic A: Operational optimization
- Research Topic B: Operations of clusters of microgrids
- Research Topic C: Microgrid modeling

Appendix E: Associated Questions for R&D Topics Provided in Advance of the Workshop

Planning and Design

Breakout Session 1: System Architecture Development

- Research Topic A: Microgrid / macrogrid interface definition
    - At what level does the interface between the macrogrid and microgrid occur? Does the microgrid behave as a single controllable entity, or can the macrogrid communicate directly with microgrid sub-elements?
    - Are the available communication protocols sufficient, and if not what additional research is required?
    - What is the required latency in microgrid response to macrogrid signals?
    - Does the architecture recognize all revenue streams?
    - How can different elements within a microgrid be aggregated to participate in the ancillary services market?
    - What is required for a microgrid to be able to black start the macrogrid?
    - How do we ensure that the macrogrid / microgrid interface is cyber secure?

- Research Topic B: Architectures that promote flexibility
    - How do you design the distribution system to provide power to different locations depending upon need?
    - What are the obstacles to providing power off the microgrid to the surrounding community?
    - Does the initial design allow for multimode and changes post completion?

- Research Topic C: Open architecture (common integration framework)
    - What are the possibilities for a microgrid common integration bus (similar to enterprise integration bus)? A power integration bus like common DC or AC sources and loads?
    - What are the possibilities for vertically integrated information management systems that include all of the devices (e.g., storage, renewable energy, and EMS) and loads in microgrids?
    - How do we demonstrate the interoperability of legacy equipment, BAS integration, DER fleet, and external signals with microgrids? Legacy connect/disconnect technologies –?
    - How can we use existing test beds to assess candidate microgrid projects, e.g., NREL Energy Systems Integration Facility?

Breakout Session 2: Modeling and Analysis

- Research Topic A: Cost and performance optimization methods
  - What are the major tradeoffs encountered within the preliminary design process?
  - How do you optimize for both coupled and decoupled operations?
  - Are there simplified methodologies that can be used to winnow tradespace options?
  - How do you tie more detailed network analysis to the broad system optimization problem?

- Research Topic B: Uncertainty in the modeling and design process
  - How do you present and value designs given financial uncertainty (price of commodities, price for ancillary services)?
  - What are tools that can be employed to model and design for uncertainty?
  - What are methodologies that can be used to stress test designs?
  - What financial structures can / should be leveraged to reduce financial risk (futures, etc.)?

Breakout Session 3: System Design

- Research Topic A: Microgrid stability with high RE penetration
  - What are different control methodologies for multiple inverter based DERs?
  - Can demand response be used to increase the reliability of intermittent renewables on a decoupled microgrid?
  - What is the role of energy storage on a microgrid with intermittent generation resources?

- Research Topic B: Energy storage
  - How much energy storage is needed to ensure stability on an islanded microgrid with low inertia?
  - Can electric vehicles be used for balancing in a microgrid, instead of stationary batteries?
  - Can battery storage systems which are owned by customers in microgrids be used to achieve optimal battery operational strategies?
  - To what extent can storage be used to stabilize the microgrid to enable ancillary services?
  - Can concepts of virtual energy storage be combined with microgrids?
  - What is the proper balance between the distributed generation, loads, and demand response in the microgrid? What are the criteria for "sizing"?
  - How can energy storage on a microgrid participate in the ancillary services market?

Operations and Control

Breakout Session 4: Steady State Control and Coordination

- Research Topic A: Grid interconnection guidelines and microgrid services
  - How is a microgrid connected to the grid, and what are the operational requirements from the utilities? Is IEEE 1547 still applicable to microgrids or are new guidelines needed for microgrid interconnection?
  - How does a microgrid manage its own sources and loads? How does a microgrid communicate with the system operator, and what kind of services are expected from the microgrid?
  - What are the communications and controls required among the component capabilities in the microgrid (links among DR, BAS, diesels, loads, and MCC) and the distribution utility (links among EMS, BAS, utility, microgrid controller, and industrial metering, and demand response markets)?
  - What are the communications requirements and protocols within microgrid and between the microgrid (and its components) and the distribution utility?
  - Can the microgrid respond to ancillary signals and optimize system operations?
  - What are the possibilities for vertically integrated information management systems that include all of the devices (e.g., storage, renewable energy, EMS) and loads in microgrids?
  - What are the wide area monitoring devices (e.g., synchrophasors) and operational tools (e.g., visualization) required for real-time microgrid operations with distribution systems?
  - How are "Bump-less" and "Balance-less" transfers to/from the Area EPS accomplished?
  - What are the issues with respect to decoupled frequency and voltage control for the Area EPS?
  - What methods do we have for grid failure detection to allow the local EPS to drop off with early warning to spool up local EPS power sources?
  - What UPF control technologies are available for harmonic control?
  - Is there a market-based EMS operation for distribution companies?
  - What are the issues involved for virtual microgrid operations in a fully deregulated market where there are plural balancing entities on a single physical grid?
  - What are the issues related to the operational interface between utility EMS and customer (microgrid) EMS?
  - What are the ways in which to coordinate HEMS or BEMS on the demand side of a microgrid and communicating with the local area control system on the microgrid (HEMS and BEMS control demand instead of manual controls)?
  - What are the ways in which microgrid control technology can be used to integrate the operation of customer-side storage equipment for utility level needs?

- Research Topic B: Microgrid control and operation
  - How is the problem of decoupling frequency and voltage control in low inertial microgrids solved?
  - How do we manage the individual control of each phase output from inverters? Unified power flow controller?
  - How can battery-based balancing operations be used in a distribution utility's microgrid operation?
  - How can demand response be integrated into microgrid operations?
  - What are the methods to ensure loads and sources are balanced in islanding mode?
  - How is overload of individual energy source in the microgrid prevented?
  - Is under-frequency or other load control used?
  - Is black start capability required for a microgrid? How to perform a black start in a microgrid?
  - What are the roles of inverter-based source and electric machine-based source performing the frequency control and voltage control?
  - What are the control methods for each individual component and coordination among them to maintain the voltage and frequency stability? How much margin is needed for dynamic source and/or load changes, power dispatch, and power flow control, and how to do it?
  - How to implement load management? To what degree are the loads involved in microgrid control, and how are they controlled?

- Research Topic C: DC microgrids
  - What are the operational modes and transitions?
  - What adaptive control systems can be used to coordinate power electronics and switches?
  - What special DC system protection schemes are necessary in DC micro-grids (electro-mechanical circuit breakers, solid state circuit breakers, protective system design, ground fault location, and fault isolation)?
  - For hybrid AC/DC microgrids with multi-bidirectional converters, what control algorithms are necessary for the smooth power transfer between AC and DC links and for stable system operation under various generation and load conditions?

Breakout Session 5: Transient State Control and Protection

- Research Topic A: Transient state control
  - How does a microgrid detect different operation conditions (islanding, fault, source/load increase/decrease, etc.), both on the grid and in the microgrid? How does a microgrid respond to the change accordingly? How do all the components coordinate?
  - What criteria are used to decide when to island, and how is this achieved?

- What are the reconnection requirements? How is it achieved?
- What switchgear is suitable for a microgrid, fast static switches, mechanical breakers, or manual switching? What are the lessons learned relative to the utility's acceptance?
- Do we need to modify existing anti-islanding DER techniques for coupled microgrid operations?
- Do we need to develop new unintentional islanding techniques to handle larger numbers of DER in microgrids?
- How can microgrids coordinate disturbance response with the distribution utility?
- How to decouple frequency and voltage control in low inertial microgrids? Need 2x2 decoupled controllers for local EPS?
- Is individual control of each phase output from Inverters needed? A UPF on each phase (unified power flow controller) FACTS technology?
- What are the requirements for acceptable frequency and voltage variability and speed of restoration?

- Research Topic B: Protection
  - What are the issues and challenges? (topology, distributed resources, operation modes, dramatic load flow changes in both magnitudes and directions, limited fault current by inverters, and harmonics) Do we need to develop new protection and coordination methods to handle faults and abnormal conditions when grid-connected and inside microgrids?
  - How can high levels of inverter based DER be used for protection and coordination in microgrids? How can the microgrid controller and communication be helpful to protection? How does protection coordinate with other intelligent components in the microgrid?
  - What are best practices for protection, reverse power flow, and anti-islanding with multiple DER in a microgrid?

Breakout Session 6: Operational Optimization

- Research Topic A: Multi-objectives, quasi-dynamic operational optimization
  - Does the architecture recognize multiple objectives, e.g., reliability optimization, carbon minimization, ramp-rate limiting, demand charge reduction, and lifecycle costs?
  - Does the microgrid conceptual design optimize all other operational aspects of the system?
  - Does the conceptual design optimize operational aspects of the microgrid and distribution system, coupled and decoupled?
  - What are the characteristics of a real-time microEMS that optimizes grid performance for multiple objectives in real time?
  - What benefits can operational optimization provide to microgrids? What are the possible paths to microgrid operational optimization?

  - What optimization objectives should a microgrid shoot for? Fuel costs, renewable utilization, system losses. What are the constraints? P and Q balance, component capacities (P, Q, V), thermal limits, voltage and frequency variation ranges, and component operation conditions. How does the optimization process handle these entwined constraints and objectives?
  - How dynamic should a microgrid operational optimization should be?

- Research Topic B: Operations of clusters of microgrids
  - How should distribution system operators manage the operations of clusters of microgrids (e.g., several being run from one NOC)?
  - What are the different architectures (multiple microgrids could be connected in parallel or in series with smaller ones embedded in a larger one) and operation strategies?

- Research Topic C: Microgrid modeling
  - What microgrid component and system models are required?
  - What models are required for integrated microgrid and distribution system operations?
  - How can we use grid-constrained production simulation models / tools to design microgrids for optimal integration with distribution systems?
  - How to model non-machined-based energy resources and power electronics interfaces in a power system modeling and analysis?
  - Is a microgrid standard test system (similar to the IEEE standard transmission and distribution test systems) needed for benchmarking and evaluation of different analysis and optimization methods for microgrids?
  - How to aggregate microgrids in larger distribution system or transmission system dynamic models without losing their transient characteristics? Which is the appropriate approach? Model-based? Measurement-based? Combination?

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