Symposium on Secure and Resilient Microgrids – Baltimore, August 29-31, 2016

Conference Proceedings

Day 1 Summary and key themes

- Software tools need to be made with interoperability in mind. Military needs to be able to install microgrid software tools.
- There are many tools for microgrid, but how does it affect the distribution system? National Labs can help with gap, methodologies and algorithms, and should work with vendors so that people will buy these software tools.
- Collaboration between EPRI and the National Labs would be beneficial. It is important to create the transition from research to applications.
- Microgrids instigated by customers don't necessarily have economics as the ultimate objective. For example, the military's microgrid is not necessarily driven by cost.
- "Made in USA," there are more microgrids in underserved areas around the world than there are in the USA. This suggests taking a more international view of issues and opportunities.

Panel 1: Emerging microgrid use, applications and opportunities

This session covered perspectives on primary power delivery challenges faced by different players, and how microgrids play a role in addressing these challenges. The panel focused on technological gaps and policy challenges to increase microgrid adoption.

In summary, presenters agree that microgrids are constantly evolving systems that face challenges due to system complexity, resiliency to severe weather, and political/regulatory infrastructure. Several microgrid systems already exist, and their experiences can make us more efficient at designing future microgrids.

Merrill Smith (*Department of Energy -- Office of Electricity and Energy Reliability (OE)*)

- The OE's role is to ensure the development of a resilient, reliable and flexible electricity system, and play a role in emergency response. The OE plays a role in helping modernize the grid by focusing Smart Grid Research and Development in four areas:
    - Microgrids
    - Advanced distribution management system
    - Resilient electricity grid
    - Market-based control signals
- Microgrid research efforts include tools, controls, device and integrated testing, standards, and demonstrations
- Microgrids will play a key role in the development of smart cities, and control systems are at the heart of microgrids
- OE has demonstrated multiple microgrids, and it is important to identify and research the gaps in technology and knowledge.

Gary Morrissett (Department of Defense) on *MCAGCC 29 Palms Microgrid*

- 29 Palms microgrid is a 26 MW system that includes combined heat and power systems (CHP), energy storage and PV capacity, and been recently refurbished along with a line upgrade.
    - Fuel supply is used for back-up
    - For cybersecurity, the system is isolated from the internet using fiber communications.
    - The system automatically synchronize with the grid after loss of power or islanding.
- A diverse set of skills is required in order to be able to build microgrids; however, expertise is distributed, so it is a challenge to find and recruit the appropriate people for implementing the microgrid.
- Two lessons learned to highlight:
    - Keep it simple: When a system is too complex, then the outages last much longer. For example, the 12.47K system design was much more complex than the 34.5K system.
    - Maintenance is important, and for secure operation of the microgrid, it is imperative to make sure that the right people do the maintenance, building and design.
- Upcoming challenges to address: Interaction with Southern Edison in order to get credit for variable PV generation.

John Murach (Baltimore gas and electric) on *BGE's Public Purpose Microgrid Pilot Proposal*

- Started with the question: How do we do to the system to adapt and be resilient to severe weather events? Following major outage, it is important to allow people access to key services (e.g. building services, banks, medicine, food, shelter).
- BG&E could build generation to meet demand. Started with 2 pilot proposal microgrid systems, with possibility to 8-10 for BG&E's territory once lessons are learnt on the first two. The initial grid design uses natural gas only, and can integrate renewables and storage if later deemed beneficial/fit. Site proposals included:
    - Edmondson Village (Baltimore city), which allow 676,000 people within 5 miles. The site would be appropriate due to past issues, proximity to services such as schools and grocery stores.
    - King's Contrivance Village Centre (Howard county): allows 217,000 residents within 5 miles. Access to shelter via churches and school, with convenient road access. History of longer duration of outages during significant weather events.
- PSC denied BG&E's proposal without prejudice with the following issues:
    - Concern about charging all customers instead of just businesses. Since the benefit is for the whole community, then cost should be charged for everyone.
    - Required more engagement with customers and site selection.
    - What happens during coincident natural gas outage?

Dave Barr (Burns and McDonnell) on *Emerging microgrid use, applications and opportunities*:

- Challenges in power delivery are driving microgrid development: Aging transmission/distribution systems; regulatory and financial obstacles; vulnerability to disruption; human threats; renewables intermittency; demand for grid services.

- Microgrids are evolving:
    - Reduced reliance on back-up generators
    - Generation source can be integrated, with more focus on grid-tied operations
    - Electric vehicles are now players in the electric grid.
    - Military and intelligence community also drive microgrid development.
- Key challenges for microgrid development include:
    - Figuring out who owns the assets and who has rights to assets. Policy can be a huge hindrance to improve the quality of service.
    - Changes in rate structures can impact microgrid design.
    - Automation adds complexity to the system, as stakeholders must have increased understanding of impacts of their actions.
    - Critical assets need to be tested under more realistic conditions.
    - Microgrids are continuously evolving and operators must have a continuous and transitional understanding of new components coming into the microgrid.
    - Difficult to make people to monetize the value of microgrids from the resiliency perspective.

Phillip Barton (Schneider Electric) on *Helping customers make the most of their energy*

- Schneider electric is the largest medium and low voltage systems supplier in the world, with the largest microgrid being campus customers (e.g. data centres, health care). They partner with other organizations to build microgrids.
- Key challenges:
    - Many adverse weather events including hurricanes and tornadoes (US has 70% of the world's tornados)
    - Getting people to change shift in focus from traditional microgrids to advance microgrids (e.g. using energy storage and improved communication infrastructure)
    - 90% of microgrids are retrofit, which can be more challenging than designing them from a blank slate. As a result, microgrid design tends to be very diverse, but there are some patterns that start to emerge.
    - Community microgrids are much more difficult and complex than campus microgrids. Although technical designs are similar between campus and community microgrids.
    - Many engineers fail to consider switching and grounding issues in microgrid design. Additional protection is required due to the bidirectional power transfer.
- Schneider fits unique microgrid design can fit under certain buckets, which can reduce soft costs:
    - Advance microgrid with CHP/rotating machine anchor: 6 microgrids 1-25 MW
    - Advance microgrid with battery anchor: 3 microgrids (1-1.25 MW)
    - Traditional/Single DER microgrid: 10 microgrids (1-10 MW)

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Panel 2: Microgrid lessons learned and current gaps

This session presented lessons learned based on field experience, covering design, operations and economics.

Michael Winka (New Jersey BPU) on *Lessons learned from the state/regulatory perspective*

- The Public Utilities Commission's (PUC) main mission is to protect customer's interest by charging electricity at a fair, reasonable rate.
- Defined Distributed Energy Resources (DERs) and microgrids. There is a microgrid classification system:
    - PUC does not regulate level 1 (single customer) or level 2 (single customer campus), but regulates level 3 (multiple customers)
    - It is important to develop proper rate infrastructures that are fair for customers. There are guidance documents that focus on how to develop the best tariff guidance. RAP and NARUC provide guidance policies for rate design.
- Offsite sales of heat can be done privately, but sales of electricity must be done via existing electricity infrastructure

Merrill Smith (Department of Energy) on *Microgrids lessons learned – so far*

- Lessons learned are categorized:
    - Tools and modeling: 1) Field tests are more complicated than performing simulations – many issues need to be considered; 2) Models can never perfectly represent all details of the system; 3) More verification and validations of model performance is needed.
    - Microgrid demonstrations:1) Regulations must be fully understood as they can impact installation and operation; 2) System ownership and operations must be clearly defined; 3) Operator training and commitment is essential; 4) System testing should replicate conditions for each mode of anticipated microgrid operation; 5) Maintenance of equipment and control systems is imperative; 6) Cybersecurity must be part of the design and thoroughly tested; 7) Single points of failure should be avoided; 8) 3rd party owned assets add complexity; 9) Existing Infrastructure (distribution, generation, controls) can introduce additional challenges to the design and operation.
    - Control systems: 1) Control systems are essential element and commercial products are needed; 2) Control systems need to have proven results; 3) Integration of multiple control systems (new and existing) can be challenging.
    - More lessons: 1) Microgrids are most beneficial when specific conditions or needs exist; 2) Need to monetize all benefits of microgrids for commercial viability; 3) Energy storage may play a large role
- Remaining challenges: Microcontrollers and integration of renewable energy; interoperability; commercial viability; verification and validation of model performance; Market entry requirements; tariffs; interconnection rules; investment incentives.

- Modeling tools include: Energy Surety Microgrid (ESM); Microgrid design toolkit (MDT); Distributed Energy Resources-Customer Adaptation Model (DER-CAM), and under development tools for remote/offgrid microgrids.

Harold Sanborn (ERDC-CERRL) on *Smart Power infrastructure demonstration for energy reliability and security (SPIDERS) Lessons and observations*

- The business and people are the main barrier to microgrid development rather than technology gaps. We need to be able to transmit information to customers in a visual and appealing manner (e.g. like Uber). Thus it is important to communicate with essential players and synchronize all the different pieces of the puzzle before commissioning.
- The objectives of the SPIDERS program is to improve energy security, increase renewable energy, reduce environmental impact, and increase cybersecurity, by following good design protocols:
    - Minimize existing infrastructure and maximize use of functional assets, and upgrade when necessary;
    - Avoid complexity where possible and reduce failure points;
    - Minimize disruptions for installation operations during construction and testing;
    - Maintain N+1 generation redundancy for critical operations;
    - Do no harm by building-in failsafe modes to revert to traditional (facility-dedicated) back-up power systems
    - Design for future expansion
- SPIDERS Phase 1 achieved fuel savings, black start operation and synchronized diesel generators over fibre.
- SPIDERS phase 2 had success with Electrical vehicle (EV) integration with charging stations and improved cyber security architecture.

Rob Hovsapian (Idaho National Lab) on *Overview of microgrid research, development and resiliency analysis*

- The group is shifting the focus of testing from simulations to real-time systems, by considering the thermal inertia in electrical systems. It is important to focus on a holistic systems engineering approach to deal with inertia.
- Microgrid management systems can operate either in islanded mode or in grid connected mode. Microgrid management systems can now operate with dynamic calculations of inertia and adapt accordingly.
- Current projects include making sure that critical infrastructure remain operational following critical event. Test cases include
    - interaction between multiple microgrid
    - Interconnection of distribute energy resources (DER)
    - Oscillation between systems
    - Demand response hacks

  - Less modelling and more controller-hardware-in-the-loop

John Tourtelotte (Rivermoor Energy) on *Municipal/Community*

- Northampton had a period of outage, so Rivermoor Energy collaborated with Northampton and Sandia to address cases of critical assets and resiliency.
- Stakeholder process allowed residents to define their own priorities during flood events, which included building dikes, maintaining health care system, etc.
- Rivermoor Energy defined problems and identified that back-up generators were insufficient for addressing system risks. Northampton improved their systems and became a template for making more resilient power systems in case of critical outage events, so they can operate over a 10-day period in islanded operations.
- Hospital CHP system (multi-fuel source capability) can provide heating and electric power to a shelter and to department headquarters. This makes a redundant campus microgrid. Siting requirement required expandability and proximity to critical infrastructure.

Session 3: Emerging system design requirements – security, resiliency and reliability

This session discussed the major performance elements and corresponding metrics that were taken into account in microgrid design.

Troy Warshel (OSD EIE) on *Critical mission energy assurance*

- In war tactics, the sole focus is to kill the enemy and break their toys. Energy is becoming an increasingly important "toy", as the amount of energy required to run the Vietnam war was minimal; now it is up to 50 gallons per war fighter per day.
- Current state: One generator for one tent, and it's loud. With microgrid, we can better manage our resources and have high energy reliability. It's not about saving fuel for the sake of saving fuel; rather it's about making sure that we get the resiliency for army operations.
  - Return on investment doesn't really have meaning when dealing with army and military services. It's about keeping people alive, therefore, in the wake of technology and improved enemy intelligence, it is important to distribute army resources.
  - Renewable energy can be considered useful, not because it is better for the environment, but because it reduces the need to ship fuel in (at some risk).
- Microgrids can also improve the local economy and build partnerships, which can have detrimental effects on the enemy. The need for power will go through the roof in the future (e.g. rail guns), so this will further the need for microgrids.

David Lawrence (Duke Energy) on *Securing microgrids, Substations, and Distributed Autonomous Systems*

- Recently started working on distributed microgrid functions and with a focus on security and communication issues in this presentation.

  - Duke Energy's Mount Holly lab has been designed to provide a reference design for Microgrid deployment.
- It's been shown that previously, if you could break into a substation, you can control the local grid. As a result, increased security includes higher fences, fibre, bulletproofing, firewalls etc.
  - Physical security of substation physical assets increases with increased wall width.
- Another goal is to improve communications, such that microgrids can be made more reliable and cost effective.
  - Open field message bus provides local communications and supports distributed intelligence.
  - Simulations of third party microgrid operations.
  - Concerning requirements, It's important to know prioritized parameters from other entities. Internal parameters need not necessarily be shared.

Jason Stamp (Sandia National Lab) on *Cyber security R&D for microgrid*

- Control systems architecture is becoming more standardized over time (e.g. Windows architecture).
- Test environments are necessary; an environment to play in. We need people to attack the model microgrid in order to see how resilient it is to cyber-attacks. Testing can be made cheaper by having a cyber-physical set-up (SCEPTRE):
  - Cybersecurity data exchange design includes designating actors, describing data flows using tables, assigning enclaves, developing functional domains, and designing cyber-security features.
  - A quantitative cyber-security metric is used to define the performance of various software tools and microgrid communications.
- Detection is a huge opportunity in cybersecurity to decrease response time to improve cyber-security.

Mike Hightower (Sandia National Lab) on *DOE and DOD definitions and metrics*

- There's a misconception that there's no definition on security, smart grid and microgrid, but these things have been defined.
  - The smart grid definition includes many points such as demand response, energy storage, renewables, etc.… however, it does not include safety. We can do all of the above without a smart grid; however, a microgrid can do more with less resources.
  - Lincoln labs and DOE have similar definitions for advanced microgrids. IEEE 1547.4 further define microgrids via the term **distributed resource island systems**.
- Definition of **energy security** (Public Law 112-81): "Assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet mission essential requirements."
- Definition of **mission assurance**
  - (Public Law 112-81): "Prioritized to provide power for assets critical to mission essential requirements on the installation in the event of a disruption.

  - (DODD 3020.40): "A process to protect or ensure the continued function and resilience of capabilities and assets, including personnel, equipment, facilities, networks, information and information systems, infrastructure and supply chains—critical to the execution of DOD mission-essential functions in any operating environment or condition."
- Definition of **energy resilience,** mostly focus on recovery and response due to disruption (Presidential policy directive 21, Army new ES3, and DHS 2013)

Mohammed Shahidehpour (Illinois Institute of Technology) on *Microgrid market operations with distribution system operators*

- DC microgrids may actually win over AC microgrids, due to loads increasingly using DC power, such as PV and electrical demand.
- Load shedding at the microgrid level does not necessarily correlate with transmission level.
- How do we price the elements of microgrids? Location marginal pricing (LMP) can perhaps give better insight on the value of microgrids. However, LMP is much more difficult at the distribution level because of three phase imbalance.
- Distribution system operator (DSO) can manage energy and be a partner for energy management in the future. Independent system operators (ISO) interact with DSO and microgrids/load aggregators with demand response (DR) flexibility. In turn, demand response can significantly benefit the microgrid and the grid in general via load shifting
  - Case study 1: The microgrid at IIT saves about 1 million dollars per year.
  - Case study 2: CSMART made a nanogrid within a building that includes both AC and DC, such that lights and other equipment run on DC. It was possible to reduce the number of lights required while ensuring that the space was better lit. .

Session 4: State of modelling, simulation and analysis tools for microgrids

This session discussed current available toolsets, their functionality, and areas where further research or improvement is needed.

Dean Weng (EPRI) and **Andres Cortez** (EPRI) on *Overview of economic-based and design-based tools*

- Described the purpose of feasibility assessment as a first-order cost-benefit assessment that considers resiliency, costs, DERs and other aspects.
- The study process starts with a preliminary assessment and data collection, followed by modelling and finally cost-benefit analysis. In the modeling process, we need to figure out which assumptions to make on the system, when and how to make decisions to allow different microgrid operating modes. Evaluating how much aspects are worth, and offer price signals accordingly.
  - It is important to model technical objectives and constraints that customers do not consider.

- Modelling process requires input parameters; objectives and constraints are required to define the model; output gives the optimal DER mix and capacity, DER dispatch, investment and financing and quantitative cost/benefit assessment.
    - In creating the modeling process, it is important to decide how to relax the optimization problem in order to make the problem tractable and allows us to make decisions on the subject
    - Systems are hard to model, but easy to test, so if it fails the test, then model needs to be revised accordingly.
- DER-CAM is a mixed integer linear programming (MILP) bi-level deterministic optimization model that is computationally intensive that optimizes dispatch and sizing. It provides steady-state power flow approximations, emergency day-types. Uncertainty can be handled using se3nsitivity analysis by using individual scenarios.
    - Feasibility studies have been done in 9 different locations.

John Eddy (Sandia National Lab) on *Microgrid Design Toolkit*

- Microgrid Design Toolkit (MDT)'s purpose is to be a decision-support tool for microgrid designers in early stage of processes. There's a combinatorically large set of ways to design a microgrid, and MDT provides a way to find and visualize microgrid designs.
- Some users of MDT include Marine Core, SPIDERS programs, City of Hoboken, UPS World Port facility in Louisville KY, and back-up power systems assessment in New Orleans.
- MDT allows you to fix certain microgrid topologies, and allows a multi-objective programming that outputs a Pareto frontier. The tool can answer questions such as:
    - Should existing generator on building be replaced?
    - Should we install a new redundant back-up feeder on our microgrid?
- MDT is non-deterministic by running discrete event simulation.

John Glassmire (National Renewable Energy Laboratory) on *HOMER Energy*

- HOMER takes generation resources with DERs and figures out how to operate. It is the only commercial tool for microgrid design.
    - HOMER bridges the technical (power engineers) and economic (financiers) aspects to balance between centralized and distributed systems.
    - Market applications include grid-tied resilience, emissions reductions, back-up for unreliable grids, and remote systems.
    - It was found that best microgrid design depends on resources available.
    - HOMER considers reliability, dispatch choice, and uncertainty via sensitivity analysis.
- Design is a cyclical refinement towards the final design. Early stage design is cheap and goals are not firm, whereas late-stage design use more granular data.
    - Elimination of bad designs leads to saving money. Thus, by eliminating bad designs early, costs can be reduce.

Mobolaji Bello (EPRI) on *Micro grid designs*

- It is important to consider whether DER regulates voltage or frequency, and gain insight on relevant codes and standards
- The process of microgrid design requires data collection, modelling, evaluation of impacts, and finally commissioning and operation of the microgrid
    - Model needs to be validated to ensure that it applies.
    - In order to do detailed analysis, it is important to have a good idea of the objectives and parameters. Load flows need to be verified, along with protection analysis and dynamic studies
    - Requirements of generation types are different, so the model needs to account for that, as well as the operation modes of each generator.
- Use cases include ConEd and SCE. The former is highly meshed, while the latter is radial and unbalanced.
    - Tools used included OpenDSS and PowerFactory for steady-state and fault

Session 5: Technology provider/commercial tools/developers present

This session featured microgrid software and tools and presentations by vendors. The vendors featured tools by Xendee, Schneider Electric, the US Green Building Council, and GE.

Adib Nasle (Xendee) on **Empowering clean energy**

- Xendee develops software solutions for microgrid investments to fill the need of tools that are collaborative and that are open in interactions.
    - Xendee believes that these soft costs can be reduced by 50% or more.
    - The microgrid planning process is a bit of a shot in the dark that requires a set of topic-specific software; XENDEE is working to solve that by automating the design process.
- Technologies such as Google Maps are used to help automate and visualize data. Information is open and interoperability help prevent silos for software. Features:
    - Line lengths are automatically calculated
    - Import of load shaving dating
    - Changes are monitored in real-time, so managers can focus on reducing soft costs
    - Protection coordination
    - Future development includes dynamic simulations

Jayant Kumar (GE) on **Philadelphia Navy Grid: An innovative Mini-City microgrid.**

- Navy Yard went from 60000 to 3000 people since World War II, before gentrification.
    - Campus connected to two substations, and will become a 60 MW campus soon
    - Energy Master Plan document provides some analysis. Outcome of planning to grow from 30 MW to 60 MW:

  - Business-as-usual case would be to get all the extra demand from PECO; however, the alternative case of using a microgrid with demand response proved to be more efficient.
- Operation centre design:
  - Mini City Micro Grid Network operation centre acts as a supervisory microgrid management centre
  - Analysis on retrofits required
  - The centre needs to interact with the PECO and the PJM control rooms
  - Currently, GE is in the process of innovating microgrid control

John Glassmire (HOMER)

- HOMER simulates assets, creates a simulation with energy balance, then optimizes to find the least cost for microgrid design. Sensitivity analysis evaluates the effects of error and uncertainty.
- Flexible data requirements allow rough estimates for general analysis when better data is not available.
- Rates modelled include: time of use pricing, real-time rates.
- Provides visualization tools for optimization system design. For example:
  - Trade-off in investments due to pricing
  - Trade-off between renewable fraction and system cost
  - Back-up power requirements.

Phillip Barton (Schneider electric)

- Demonstrated a near real-time demand response system that allowed visualization of energy consumption and production from various sources
- Primary: sub-second control. Secondary control: SCADA and other critical systems. Tertiary control: Modes of operation, economic optimization.
- Data is pulled from the internet to create forecasts on generation and demand, so that it is possible to visualize actual and forecast data on a single page.

Ryan Franks (GE) on **Performance Excellence in Electricity Renewal**

- GBCI integrates values from PEER, WELL, GRESB, SITES, EDGE and LEED to reduce electricity waste in the US
- PEER was a collaboration between academia and industry, and focuses on four metrics:
  - Energy efficiency (source energy intensity, CO_2, NOX, SO_2, Water, Waste)
  - Operational effectiveness (Load duration curve, system energy efficiency, demand response.
  - Reliability and resiliency (Availability, damage prevention, alternate source of supply, redundancy and automation, islanding)
  - Customer contribution (AMI, HEMS, renewables, clean power, demand response)
- Industry is the main set of PEER customers as helps with value and gap analysis, but also has applications in campuses and cities.

- PEER can be leveraged to create a business case, funding strategy or implementation plan.
- Registered projects include screening, improvement toolkit, application workbooks, and other great tools.

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DAY 2

Day 2 Summary and key themes

- People with a business case have a prime objective of generating profit from microgrids; whereas those with mission cases may have other objectives. Designing a business case requires an accurate assessment on monetizable and non-monetizable costs and benefits such as reliability and resiliency, as well as a strategy for convincing a financier.
- Microgrid controller design and communication can impact the operations of the microgrid, and therefore need to be tested. Some elements that need to be considered includes frequency and voltage regulation, as well as demand response and energy storage.
- Testing microgrids is expensive, yet simulations may not accurately represent system dynamics. Thus, it is important to strike a balance between full simulations of software tools and testing on fully implemented microgrid systems. Hardware-in-the-loop (HIL) testing, as well as other methods that hybridize hardware and software testing, offers a compromise between these trade-offs.
- The ability to island and to communicate with diverse devices are critical components of microgrids, yet there are very little standards for microgrid communications and islanding operations. IEEE PAR 3020.7, IEEE PAR 3020.8, IEEE 1547 and the Tactical microgrids standards consortium (TMSC) attempts to improve standards on islanding operations and interoperability.
- It can be challenging to properly site microgrid plans based on value metrics that are poorly defined. As a result, navigating the sociopolitical landscape of resilient electricity provision can be difficult.

Session 1: Benefit analysis and business case for microgrids.

This session focused on business models and business cases, as well as cost-benefit methodologies for evaluating microgrids. How do we do the math to evaluate a technology?

Ken Horne (Navigant) on *resiliency to solvency: Building a business case for public purpose microgrids*

- As problems solvers, we often focus more on the how question rather than the why? Energy security and reliability can have large benefits for society.
- Hurricane Sandy affected 200000 businesses, had 65 billion dollars of damage and 159 people died from it. A microgrid played a role in keeping a hospital open during this period.
- Customers are increasingly interested in microgrids, and there is a growing willingness to pay for microgrids.
- Business case is all about convincing a financier. The ability to island a grid is capital intensive (independent self-supply and local control and redundancy) but delivers mostly non-economic benefits (resiliency and security). How do we build the business case? Therefore, it is necessary to find an additional stream of revenue if we are to develop a business case. Business case remedies include:

- Blue sky operation and asset optimization
- Creation of new products and services
- Expansion of the pie
- Monetization of social good services

Jeffrey Roark (EPRI) on *EPRI's Integrated Grid Initiative*

- EPRI put out a report on the cost and benefit framework on integrated grids. The cost-benefit process converts impacts to cost-benefit components. Several types of analyses exist: Economic analyses, financial analyses, and utility financial analyses.
- The methodologies for cost-benefit analyses differ based on the specific type of customer being served, but in general we evaluate the cost at a baseline, followed by evaluating additional layers with varying levels of technology. As a result, it is possible to evaluate the incremental benefits and cost of implementing the microgrid.
- Microgrids are NOT required for DER or produce benefits, so it is important to focus on their main value proposition: Resilience and reliability.

Stephen Knapp (Power Analytics Corp) on *Integrated design and financial model*

- Power Analytics is a software-agnostic company that focus on how to operate a microgrid in parallel with the grid. Utilities want assurances that they can collaboratively work with microgrids.
- The Energy Alignment Plan examines the power optimization and economic optimization, by comparing the performance of a small grid in parallel operation with the grid under various conditions.
- The financial model goes through a process of gathering data, model the performance value and creating visualization tools.

Annabelle Pratt (National Renewable Energy Laboratory) on *DOE – OE Microgrid Cost-Study*

- The presentation focused on only the cost component of developing a microgrid, not the benefits. The objective is focused on the components, integration and installation costs in the US. The intended outcome of the study is to improve transparency and standardization in reporting of microgrid costs.
- Generalizing costs can be challenging due to the unique nature of various microgrid designs. Data collection includes market-research from companies such as Navigant, Homer Energy and GreenTechMedia. Also, several companies have shared their proprietary data, which would be kept anonymous in the report.
- Preliminary results show non-linear relationship concerning sizing and operations of microgrid design. Data collection is slow and is tedious

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Session 2: Decentralized Operation and Control

This session described concepts for application of local controllers for microgrids and the main grid.

Alex Rojas (Ameren) on *Architectures, communication, interfaces and requirements.*

- Systems engineering uses a Requirements Analysis Process, which first identifies stakeholders, in order to set up microgrid architecture. These stakeholders may include consumers, utilities, and even neighbors. The requirements may include green branding, educational tools, energy security, reliability, emergency services, energy policy targets, or renewables integration.
- Two types of stability need to be considered for system stability: Frequency stability and voltage stability.
  - Typically, frequency stability is not an issue due to large inertia; however, it can be a challenge in areas such as Alaska and Hawaii. Since frequency is so tightly couple with flux, deviations in frequency can cause equipment damage.
  - Voltage needs to be kept within a certain range for all customers, so control is important to maintain the range.
- Three levels of control, with different temporal scales, provide various functions for grid interactions. Tertiary control is the most strategic level, and fulfills forecasting, optimization and modelling functions, and are software driven.
- Effective cyber secure communications interfaces with microgrid loads, central offices and other entities.

Jayant Kumar (General Electric) on *Microgrid controller coordination with building automation and grid protection*

- Controller coordination process begins with an investigation of loads and generating units, and switching and fault. Following this, the GridLAB-D simulating environment calculates characteristics of the resulting systems (e.g. sags, transients, voltage imbalances).
- The software provides coordination signals for adaptive protection management, rather than actual solving protection problems, thus, this allows the people in protection to better focus and address issues.
- Building automation is the second function. Building Energy Management Systems (BEMS) are currently focused on lighting and HVAC, but is expected to increase capabilities in the future. Currently, BEMS does not manage energy storage and onsite generators. Functions of BEMS include the following:
  - Demand response (Price-based response and demand reduction)
  - Frequency responsive Spinning Reserve (response to deviations of frequency)
  - Supplemental Reserve (Restore load/generator balance)
  - Load Following: (Hour-to-hour load/generation balance)
  - Regulation (Minute-to-minute load/generation balance)
- The capabilities of GE's product is tested on the GRIDSTAR test system.

Ben Hollis (Oak Ridge National Laboratory) on *CSEISMIC: An open-source microgrid controller*

- Typical microgrid control scheme includes a utility, microgrid, and nanogrid within the microgrid.
- Complete System-level efficient and interoperable solution for microgrid integrated controls (CSEISMIC) is an LabVIEW-based open-source microgrid control software that allows islanding operation, resynchronization/reconnection, energy management and ancillary services. The software can be installed onto microcontrollers in order to improve the system.
  - Example: Energy storage controller uses modulation signals to manage energy, using a state machine for modes of operation.
  - Test results from lab testing environment: voltage control recovers within 3-5 cycles; resynchronization occurs seamlessly.
  - CSEISMIC 2.0 will have a new communications architecture to support peer-to-peer communications, new menus and other features.
- Current projects:
  - Advanced Manufacturing and Integrated System (AMIE) is a 3R printed PV house/EV system that could act as a nanogrid
  - Connected Communities (Southern Company), with field deployment in Alabama and Georgia.
  - Industrial Microgrid Design and Analysis (Uninterruptible Power Supply)

Kevin Cunic (Scheider Electric) on *DER control*

- Schneider's software tool allows secondary and tertiary control of microgrid, and provides visualization tools, such that it is possible to see generation and demand of different components of the system.
  - The microgrid controller allows automated operation
  - Contains a demand-response component
  - Allows management of energy storage
  - Customers demand severe event (e.g. storm) forecasting, such that energy storage and resources can prepare for islanding

Session 3: Developing and applying standards

This session reviewed and provided updates on standard development efforts related to microgrids, with a focus on the IEEE 2030.7, IEEE 2030.8, IEEE 1547 and work from the Department of Defense Microgrid Standards Working Group.

Ward Bower (Ward Bower Innovations) on *PAR 2030.7 Draft Standard for Specification of Microgrid Controllers.*

- Ward started by defining the difference in jargon between the 2030.7 standards group and the general microgrid community, and defined the working roles of the microgrid controller: Responsible for monitoring the state of the system and notify the protection system if appropriate
- The PAR2030.7 standards specify the three functional levels of microgrid energy management systems (MEMS) include grid interface, operations and local devices.
    - It outlines the steps for planned islanding, unplanned islanding, and reconnection to the grid.
    - Measured quantities (e.g. voltage, frequency) are measured on both sides of the interconnection.
    - The P2030.7 must be compatible with P2030.8
    - There is a dispatch function with many software loops that dictates dispatch order.
- There is discussion to combine the current 4-level control scheme down to a 2-level control scheme.

Ward Bower (Ward Bower Innovations) on *PAR 2030.8 Draft Standard for Specification of Microgrid Controllers.*

- The PAR 2030.8 is closely tied to the 2030.7, and focuses standards for testing. IEEE 1547 is being re-written to include terminology and microgrid requirements.
- PAR 2030.7 and PAR 2030.8 do not cover communications, as there are already plenty of communication standards available.
- A paper, "The advanced microgrid" was published by SANDIA, which provides many of the necessary terms.
- IEEE PAR 2030.8 scope is to determine testing procedures and metrics for microgrid interconnections. A draft is expected by the end of 2017.

Tom Key (EPRI) on *IEEE 1547 in microgrids*

- IEEE 1547 now allows, but does not require, grid support from DG and Storage. This means voltage regulation, dynamic (abnormal) frequency and voltage ride thru functions, also adjustable trip limits.
- These changes in the new revised 1547 standard will affect and perhaps complicate microgrid operations. For example, ride-through requirements tends to conflict with anti-islanding detection and distributed voltage regulation tends to conflict with central control.
- The new requirements and limits are expected to come out for review in the next couple of month. One of the sections addresses microgrids. Settling on a new 1547 standard will take more than a few months and will definitely include voltage regulation and under/Over-voltage frequency ride-through, and power quality requirements.

Tom Bozada, DOD Microgrid Standards Working Group on *Tactical microgrids standards consortium* (*TMSC) Overview*

- Nano-scale microgrid might be as little as a vest worn by a soldier, and can have an impact of saving lives.
  - We don't know in advance what is the power demand at the tactical level.
  - Due to tactical advantages between distribution and centralization of loads and generators, it would be beneficial to have dynamic self-organizing electrical systems.
- The TMSC standards have objectives:
  - Safety, protection and human factors
  - Electrical interconnection
  - Communications, control, and cybersecurity
- The standards are much more specific than IEEE 1547 and 2030.8, and was developed over time and fairly independent of the other standards, due to history and difference in missions. However, it does use multiple industry standards from ANSI, OASIS, IEEE and other parties.
- The TMSC workspace includes 2/3 industry, and a few academics, and is currently focused on testing applicability of standards and cybersecurity of tactical microgrids. Future milestones include completing approval for military standard.

Session 4: Testing and performance verification

This session reviewed emerging performance metrics, test protocols and experience.

Abraham Ellis (Sandia) on *Microgrid verification at DOE National Labs*

- Microgrids are coming of age as they develop maturity, which means that there are multiple opportunity and drivers. One example is the demand for resilience and differentiated reliability. However, there are also challenges associated to it.
- Microgrids must cross the valley of death: Government and university funding is decreasing, and industry funding hasn't quite picked up yet. Thus, it is a challenge to bridge a chasm in funding. Demonstrations and pilots can expose gaps and reduce risk, which can somewhat mitigate the above challenge.
  - Lab-based demonstration allowed for islanding detection.
  - SPIDERS demonstrated cyber security architecture
  - Coordinated DER control demonstration allowed continued operation under unplanned disconnection
  - Civilian sector critical infrastructure resilience projects focus on human elements and policy
- Goal of the GMLC Projects is to establish a testing network that acts as a lab-based resource for standards-based testing; results would be available in an open library.

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Eric Limpaecher (MIT Lincoln Laboratory) on *Microgrid Hardware-in-the-Loop Laboratory Testbed and Open Platform (HILLTOP)*

- The goal of HILLTOP is to improve economics of microgrid deployment by:
    - Allowing testing before implementation, thereby reducing the cost of deployment of microgrid technology.
    - Reducing the cost of equipment damage during implementation
    - Allowing the testing of vendor equipment.
- HILLTOP has advantage over pure-simulations because it uses real equipment with implementation in real-time, yet cost less than full scale deployment. This is achieved by tricking the microcontroller to believe it is controlling a real device.
- Vision for the platform is for engineers to use as proof-of-concept, a standards/test, and a deployment platform. There have been significant interest in joining so that people have access to performance data in a members-only repository.

Annabelle Pratt (National Renewable Energy Laboratory) on *Site-specific controller evaluation on HIL*

- NREL is the only national lab focused on renewable energy and energy efficiency. Labs are located in Denver and Golden, Colorado. They allow people to use test equipment invested in by the Department of Energy.
- Microgrid control system objectives: manage microgrid assets to meet interconnection requirements (e.g. as outlined by the IEEE 2030.7 and additional customer requirements) and compare the performance of microgrid controllers.
- The next step is the evaluation of site-specific compliance (will a specific microcontroller be able to manage another specific microgrid design based on pre-tested components). NREL provides capabilities for CHIL+PHIL testing:
    - CHIL+PHIL Example 1: Battery energy storage system and battery inverter testing at Buffalo Niagara Medical Campus (BNMC). Simulated signal is transformed into 480 V, 3-phase signal for testing.
    - CHIL+PHIL 2: Inclusion of a feeder, energy storage, and 26 MW PV plant to supplement Borrego Springs community microgrid. PV load following capabilities were tested.

Adib Nasle (Xendee) on *Microgrid commissioning automation for critical infrastructure*

- This case study illustrates the importance and use of cloud computing for microgrids.
- Shared common vision with FAA to development of software, concerning communications. The goal is to reduce the cost of implementation.
- Key challenges identified includes dealing with security and collaboration. This was complicated by the fact that all stakeholders have their own objectives and processes.
- Airport towers handle take-off and landing up until 5000 ft of elevation, and eventually, beyond 15000 ft information is handed off to a centre that can handle 500000 aircrafts. These centres

are critical, so microgrids were used so that it could island from the grid without negative impacts.

- The design of the microgrid needed to be easy to use and to be software independent. A challenge includes the trade-off between accessibility and security, while communicating information in real time. FAA needed ability to change permissions without requiring the IT department, and also needed complete tracking. Thus, security had to be approached from a multi-layer perspective.

Session 5: Utility microgrids: Integration and Implementation Challenges

This session highlighted lessons learned from ComEd and PECO in their microgrid design and proposals.

Manuel Avendano (ComEd) on *Utility-owned public purpose microgrids*

- ComEd Microgrid Pilot Program invested a quarter billion dollars in Chicago to develop 5 public purpose microgrids (including government buildings and airport).
    - In particular: Bronzeville pilot will serve a mixture of critical loads and emergency shelters, by including 10 MW of energy storage and generation into the microgrid.
- Microgrid controller development project:
    - Tertiary centralized control can do central dispatch of DERs
    - Minimum technical requirements include disconnection, resynchronization, power quality control, protection, and generation dispatch.
- Microgrid-Integrated Solar-Storage Technology (MISST) project:
    - Smart inverters for solar PV/battery storage to achieve better economic, resiliency and reliability outcomes in microgrids.
    - Allows grid connection, smart inverters, demand response and other features.

Scott Manson (SEL): Practical implementation of microgrid control of non-dispatchable resources

- High standards of testing and modeling at SEL:
    - Accurate models include hydraulics and other components that cannot simply be modelled using circuit basics. The electrical system is trivial compared to the complexities on mechanical systems.
    - All equipment must be HIL tested before approving the equipment
- Real power systems do not behave like theory:
    - Inverter-based generation capacity has limited overload capacity. Generators can provide more short term power than inverters. As a result, frequency falls fast, then fast load shedding is required to prevent system instability.
    - Equipment has limited measuring capabilities for measuring low values of power and reactive power, so power factors can vary wildly in those conditions. As a result, adaptive mechanisms are required.

- Important question: How much responsive generation is required to ensure stability? These values differ very differently depending whether we are applying it to the grid or a microgrid

Bill Becker (Spirae) on *Microgrid Controller Testing and Lessons Learned at Borrego Springs*

- Spirae focuses on adapting to the decentralization of the grid. Some of these resources may not even have a common point of coupling.
- The energy resource manager of the Wave software can be applied to microgrids. Some project samples include the following:
    - Cell controller microgrids in Denmark. Demonstration of islanding from grid with a 1-second trigger, with market interfacing capabilities. Ran into scalability issues.
    - FortZED/RDSI project in Colorado also developed a microgrid but also ran into scalability issues.
    - Moving forward, a catalog was built to reduce integration time. Borrego Springs improved integration with microgrid controllers and solar farm. Asset integration was considered difficult.
- Common themes:
    - Control strategies is the easiest part;
    - Integration to assets is difficult (each has unique characteristics)
    - Integration to other systems is custom each time
    - Projects don't develop themselves.

Mike Hightower (Sandia) on *DoD Advanced microgrid integration challenges with utilities*

- Advance microgrid operations may seem to be a win-win, but the DoD wasn't sure why utilities wouldn't deal with bases in grid-tied mode to provide grid services. In fact, only two bases have provided grid services: During severe thunderstorms, these bases will disconnect specifically to support the grid. Conclusion: Concept of microgrids on military bases are good, but implementation is bad.
- There are no major technical implementation and operation challenges. Microgrid and renewable integration is not an issue. Often, issues regarding DERs and microgrids on bases are just misdesigned or people are not properly trained to operate them.
- Many microgrids are not participating demand response due to the lack of metering infrastructure, yet it is considered a low-hanging fruit.
- Potential strategies to address these gaps:
    - Design and operation standards for interoperability are required for microgrids in military bases
    - Take a much more proactive approach to encourage utilities to incorporate Army advanced microgrids as part of utility Smart Grid initiatives

Eric Stein (PECO) on *Overview and Scope of Concordville Microgrid*

- Peco Energy is an Exelon company that serves the Philadelphia area and suburbs. It was a challenge to upgrade a an existing utility grid with microgrid capabilities due to retrofitting.
    - Peco presented a 5-year plan to the Public Utility Commission to upgrade obsolete assets and improve reliability.
    - Considered approximately 60-70 projects, and site selection was a challenge. But finally, a site was selected with desired characteristics, with a decision from the PUC in early 2017.
- Peco microgrid project includes two microgrids interacting with each other, with the ability to fully island.
    - Microgrid 1 has a capacity of 4.6 MW with 1.2 MW of rooftop solar capability, while microgrid 2 has a 4.0 MW capacity.
    - Ancillary service revenues will be re-invested.
    - In the event of an outage, all customers will have restored power within 10 minutes.

Travis White (PECO) on *Concordville Microgrid Feasibility*

- Understanding load profile is critical to feasibility analysis; however, it is difficult to acquire data.
- DER-CAM tool is used to optimize design and power flow of microgrid design.
- Objectives are to
    - Support DER-CAM tool development and enhancement for utility use
    - Provide feedback on how to make tool more effective and easier to use
    - Support EPRI's integrated grid vision to move forward
- Challenges include extracting demand data and extracting infrastructure information for power flow modeling.

George Sey (PECO) on *Utility integrated microgrid framework and challenges in the Concordville microgrid*

- The microgrid site was selected because it contained all services required: fire services, medical needs, shelter, town centre, gas, etc.
- The close connection between the two microgrid sites allows power to be shared between the two in case there are faults or generation failure. However, much reconfiguration was required in order to achieve this.
- Challenges from the utility perspective:
    - Overarching framework: creating a common point of coupling was difficult
    - Demand data granularity: Acquiring customer loads at 15 minute intervals at each section.
    - Island mode operational pillars.

Andrew Reid (ConEd) on *Integration challenges in urban environment*

- ConEdison's service territory covers 604 square miles and serve approximately 9 million customers, and most of the system is underground in a meshed network.

    - Load changes location throughout the day.
    - Outstanding issues to consider with community microgrids: Distributed Generation utilization, conductor reliability, and other issues.
- ConEdison's hypothesis was that active management of DER was more efficient than business as usual case.
    - PVL model was translated to Open DSS in order to analyze an hourly time series analysis with 5800 load objects.
    - Microgrid boundary contains four loads and generators.
    - Network protection and switching actions occur in the same pattern each season, so it provides some level of predictability.

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Feedback on symposium

- DOD + DOE:
    - It was good to see the diversity in this conference for the first conference; however, in the future, it would be better to be more focused.
    - It would have been better to have a blend on military and commercial elements throughout the symposium rather than have one day focused on each.
- Diversity in users of the microgrid:
    - Good to have all of the voices together because it highlights the importance of the various perspectives… utility, users, operators, regulators, etc. Academics can capture technical and policy issues.
- Answering the "how" question instead of the "why" question:
    - Very useful to focus on the "how" because the people are more technically focused
    - Conversely, it's important to make the economic case, and answering the "why" question may allow the development of the business case. It's important to balance technical costs and benefit.
    - It's difficult to monetize the aspects of benefits and cost of microgrid. It could be useful to focus a bit more on that for future conference. How do we value resiliency?
    - Shift towards the "how" because we had a lot of "why" this year.
    - Have more breakout sessions where it would be possible to focus in on specific areas. Perhaps a breakout session focusing on National Labs and addressing the "valley of death"
    - "how" do we decide the metrics and defining how these goals, objectives and metrics are weighted.
- How do we turn workshops into making a difference and improving communication channels between the different players. How do we share best practices?
    - Individual detail brought back to the group. Results from military bases were eye opening, and they seem to be able to move forward faster. It would be good to have information consolidated.
    - Dealing with resiliency: What are we planning for? 20 feet of water? 200 mph winds? How do we decide these things?
    - Use case: When residents and commercial are mixed. When there's an outage, how many people are going to the office and go to work, even if they have power?
    - Military installations are thinking of casting a wider net in terms of the services they are offering to parties who need electricity and energy.
    - Why are we doing this? Who is the microgrid for? Probably social scientists or academics have information on questions about who shows up to work following a disaster.