Army Research Laboratory

Advanced Microgrid Concepts and Technologies Workshop

by Dr. Edward Shaffer, COL Paul Roege, and Dr. Tsvetanka Zheleva

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14. ABSTRACT

This report summarizes the activities at the Advanced Microgrid Concepts and Technologies workshop hosted by the U.S. Army Research Laboratory (ARL) on June 7–8, 2012, in Washington–Beltsville, MD. The workshop gathered experts from academia, national labs, Department of the Army (DA), and industry to assist the Army in identifying and prioritizing research and development (R&D) areas relevant to microgrid technologies. The workshop consisted of six technical sessions in the areas of Power Components and Power Conditioning, Energy Storage and Generation, Power Sensing, Prognostics and Diagnostics, and Communications, Control and Cyber Security. A special session on Scalable Energy Networks, followed by a discussion, focused on this new state-of-the art concept, which suggested a new architecture for energy, exploring the parallels between the energy and information domains. During the four breakout sessions, experts in the field in the aforementioned six technical topics discussed issues, lessons learned, and paths forward for future Army microgrids R&D.

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Executive Summary

The criticality of energy in enabling Army capabilities has been recognized and reinforced in recent years through the emergence of "Operational Energy" doctrine and strategy.[1,2] Operational Energy is defined as the "energy required for training, moving, and sustaining military forces and weapons platforms for military operations". The term includes energy used by tactical power systems, generators and weapons platforms. The tenets of Department of Defense (DOD) and Army Operational Energy Strategy include:

- More fight, less fuel: Reduce the demand for energy in military operations. Military missions require large and growing amounts of energy with supply lines that can be costly, vulnerable to disruption, and a burden on Warfighters.
- More options, less risk: Expand and secure the supply of energy to military operations. Most military operations depend on a single energy source, petroleum, which has economic, strategic, and environmental drawbacks. In addition, the security of the energy supply infrastructure is not always robust.
- More capability, less cost: Build energy security into the future force. Current operations entail more fuel, risks, and costs than are necessary, with tactical, operational, and strategic consequences.

One of the top targets of the DOD's "Operational Energy Strategy: Implementation Plan" dated March 2012 is to "Promote Operational Energy Innovation." In order to accelerate technical progress, the Department and services are identifying energy-relevant technology areas requiring additional investment and aligning science and technology (S&T) investment portfolios addressing operational energy challenges and opportunities. Future operational microgrid development requires underpinning technology research addressing this target. To provide a forum for the Army energy and power technical community to assess the current status of research and development (R&D) within the microgrid area and identify potential areas for additional research focus, the U.S. Army Research Laboratory (ARL) hosted an Army workshop on Advanced Microgrid Concepts and Technologies on June 7–8, 2012, in Beltsville, MD. The Operational Energy strategy requires more holistic and integrated use of energy on the battlefield. Microgrid and related technologies offer potential to further reduce fuel consumption, improve power management, and more efficiently utilize power for platforms and applications. The Army, through the Research and Development Engineering Command (RDECOM) Power and Energy Technology Focus team (P&E TFT), and Assistant Secretary of

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[1] Power and Energy Strategy White Paper; Army Capabilities Integration Center—Research, Development and Engineering Command; Deputy Chief of Staff, G-4, U.S. Army, 1 April 2010.

[2] Operational Energy Strategy Implementation Plan; Department of Defense, March 2012.

Defense for Research and Engineering (ASD [R&E]) through the Energy & Power Community of Interest (E&P COI), have been tasked to identify S&T gaps for Operational Energy and recommend options to address these gaps.[3] The microgrid area in particular requires more in-depth technical scrutiny to determine appropriate areas for in-house Army and DOD research.[4,5,6]

The workshop consisted of six technical sessions in the areas of Power Components and Power Conditioning (PC&PC), Energy Storage and Generation, Power Sensing (PS), Prognostics and Diagnostics (P&D), and Communications, Control and Cyber Security. A session on Scalable Energy Networks, followed by a discussion, focused on this new state-of-the art concept, which suggested a new architecture for energy, exploring the parallels between the energy and information domains. During the four breakout sessions, experts in the field in the aforementioned six technical topics discussed issues, lessons learned, and paths forward for future Army microgrids R&D.

Major Findings:

The following are major R&D topics and action items identified by the workshop participants as being of high priority for Army microgrids in the following four areas:

1. **PC&PC:**
    - Define major ARL focus for PC&PC—wide-bandgap switches, passive materials and components to reduce size and weight, bidirectional converters
    - Determine Army priorities for direct current (DC) versus alternating current (AC) microgrids
    - Determine modularity requirements for Army microgrids
    - Define/determine microgrid architecture and/or different microgrid architecture types
    - Integrate size, weight and power (SWaP) into criteria
    - Determine microgrid use cases and compare use cases versus major microgrid performance criteria and metrics
    - Determine major differences between tactical and installations microgrids, and focus on the tactical domain

[3] Initial Capabilities Document for Operational Energy for Sustained Ground Operations; Department of Defense, 27 March 2012.

[4] Scalable Energy Networks to Promote Energy Security, COL Paul Roege. *Joint Forces Quarterly* **2011**, 62, pp. 125–130.

[5] Piagi, P; Lasseter, R. *Microgrid: A Conceptual Solution*; PESC'04; Aachen Germany, 20–24 June 2004. University of Wisconsin–Madison.

[6] Piagi, P; Lasseter, R. *Control and Design of Microgrid Components*; Project report from the Power Systems Engineering Research Center, PSERC Publication 06-03; University of Wisconsin–Madison, January 2006.

- Coordinate work with external organizations (U.S. Department of Energy [DOE], National Institute of Science and Technologies [NIST]) on standards and interfaces

2. **PS and P&D:**
   - Define the parameter space for P&D or microgrids
   - Identify critical issues and data requirements
   - Examine existing datasets/use cases
   - Determine the sensors, data rates and experiments, and the data needed to evaluate and demonstrate the new P&D technology
   - Define processing streams (e.g., phasor processing related to specific P&D analysis)
   - Develop standardized diagnostic interfaces into "intelligent" gensets and loads
   - In a long run–embed proven sensors and P&D tools into next generation generators, power distribution components and intelligent loads

3. **Energy Storage and Generation and Renewable Energy Sources:**
   - Develop high-energy density energy storage and generation components deployable and modular
   - Develop standard requirements for energy storage and generation for military microgrids
   - Evaluate feasibility and develop next generation energy storage technologies—superconductor magnetic energy storage (SMES) devices
   - Explore and develop alternative routes to fuel
   - Develop next generation waste-to-energy technologies
   - Address renewables and energy storage for efficient utilization of renewables
   - Develop metrics for energy storage
   - Address storage technologies and limitations
   - Develop and explore existing models to allow better understanding of use case scenarios

4. **Communications, Control and Cyber Security for Microgrids and Scalable Energy Networks:**

    - Improve system flexibility and visibility via a holistic model that decouples development of hardware designs, operating systems, applications and energy flows, and maintains visibility across these domains
    - Develop distributed intelligent agents that support stable and resilient system behavior
    - Construct new energy pricing schema that includes a range of important system parameters: source, reliability, quality, timing, shortage
    - Explore parallels and differences between information system architecture and corresponding energy concepts
    - Explore new energy architecture that is leading toward the "fusion" of energy and information
    - Develop a holistic approach utilizing the relationship between the efforts on smart grid systems and standards, hybrid energy systems, network and controls
    - Involve community and stakeholders in developing business cases, priorities and practices

The workshop had a total of over 80 participants from universities, national laboratories, industry, and DOD organizations.

The presentations are available at the Advanced Microgrid Concepts and Technologies Workshop Web site: http://arlevents.com/microgrids2012/.

1. Introduction

1.1 Background

The U.S. Army Research Laboratory (ARL) hosted an Army workshop on Advanced Microgrid Concepts and Technologies on June 7–8, 2012, in Washington–Beltsville, MD. The purpose of the workshop was to provide a forum to review the current status of research and development (R&D), while providing insight into additional potential research focus areas for military microgrids. The emerging Operational Energy strategy requires a more holistic and integrated use of energy on the battlefield. Microgrid and related technologies offer the potential to further reduce fuel consumption, improve power management, and more efficiently utilize power for platforms and applications. The Army, through the Research, Development and Engineering Command (RDECOM) Power and Energy Technology Focus Team (P&E TFT), and the Office of the Secretary of Defense (OSD) through the Energy and Power (E&P) Community of Interest (COI), have been tasked to identify science and technology (S&T) gaps for Operational Energy and recommend options to address these gaps; the microgrid area requires more in-depth technical scrutiny to determine appropriate areas for in-house Army and Department of Defense (DOD) research.

This forum also served to engage external experts within the technical community to address unique challenges and opportunities associated with developing and integrating mobile, reconfigurable distributed energy resources. As a follow-on to the P&E TFT Microgrid Workshop held in October 2010, this forum provided an opportunity for more in-depth technical exchange regarding key issues. It is expected that the information gained from this workshop will help shape the Army's investment in microgrid S&T for military operations.

Dr. Ed Shaffer (RDECOM P&E TFT lead and Army principal on the OSD E&P COI) was the General Chair for this event, with co-chair COL Paul Roege at Army G4 (Army proponent for Operational Energy). Technical Chair for the workshop was Dr. Tsvetanka Zheleva, ARL's Microgrid Program Lead. A workshop planning committee involved Branch Chiefs and Team Leads from ARL working on microgrid relevant technologies. The organizing committee members nominated keynote speakers for the general session and speakers in the technical sessions of the workshop, mostly from leading groups from academia and national labs working in various areas of microgrid technologies.

A *microgrid is an integrated energy system* consisting of multiple sources, a distribution system and multiple loads. It includes an interconnectable, grid connectable, or intentionally islanded mode; ideally with, intelligent smart management and control (interface-capable and coordinated system, with automatic protection and reconfiguration features). In a military sense, the definition for microgrid, developed by the RDECOM P&E TFT, is: "A microgrid is a group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that acts as a single controllable entity and capable to store, distribute, manage, import and export power, and interfaces with other relevant grids." From the U.S. Department of Energy (DOE) Microgrid Exchange Group the strict definition (from a utility perspective) of 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 either grid connected or islanded mode." Given this context, the Advanced Microgrid Concepts and Technologies Workshop intended to address many of the issues related to the development of the Army microgrids.

Day One of the workshop consisted of the general plenary session, followed by three technical sessions and a facilitated discussion session. Dr. Ed Shaffer, from ARL gave the opening plenary talk on "Focusing Army S&T for Operational Energy & Microgrid Challenges." Mr. Stephen Bossart from DOE gave a plenary talk on "The DOE Prospective on Microgrids," followed by Prof. Bob Lasseter from the University of Wisconsin, who talked about "Advanced Microgrid Concepts," and Dr. Jason Stamp from Sandia National Laboratories, who gave an "Overview on the SPIDERS Program." Following the general plenary session were the technical sessions on power components (Chair: Dr. Paul Barnes), power conditioning (Chair: Mr. Bruce Geil), and scalable energy networks (Chair: COL Paul Roege). COL Paul Roege gave the opening general talk on "Scalable Energy Networks Concept" for the scalable energy networks session. After the technical talks in this session there was a facilitated discussion on the scalable energy networks, chaired by COL Roege and Dr. Shaffer. There was also a poster session during the breaks with posters from ARL scientists and engineers presenting state-of-the art R&D in microgrid relevant technologies.

Day Two of the workshop consisted of four technical sessions on: energy storage and generation, renewable sources (Chair: Dr. Cindy Lundgren); power sensing (Chair: Mr. Dave Hull); prognostics and diagnostics (P&D) (Chair: Dr. Kwok Tom); and communications, control and cyber security (Dr. Raju Namburu). Following the technical sessions, the workshop Chair, Dr. Ed Shaffer, gave an overview/summary from the findings from the October 2010 workshop and general directions for the breakout sessions. There were four short presentations with focus on major technical challenges, lessons learned, and the path forward for microgrids from the National Institute of Science and Technologies (NIST) (Dr. Al Heffner); the U.S. Air Force Research Laboratory (Mr. Lukas Martinez); Communication Electronics Research and Development Engineering Command (CERDEC) (Dr. Chris Wildman, Ms. Marnie De Jong); and Massachusetts Institute of Technology (MIT)–Lincoln Laboratory (LL) (Dr. Scott Van Broekhoven). After that, four breakout sessions conducted in parallel were focused on the following four technical areas: (1) Power components and power conditioning (PC&PC); (2) Power sensing (PS) and prognostics and diagnostics (P&D); (3) Energy storage and generation, and renewable energy sources; and (4) Communication, control and cyber security, and scalable energy networks. There were general questions for all participants during the breakout sessions focused on more strategic and organizational issues, while the technical questions were focused on more specialized issues within the working groups. The chairs for the breakout sessions reported the findings from their respective sessions to all. The workshop ended with the closing remarks from Dr. Shaffer summarizing the major outcomes of the workshop and the path forward.

The key findings from the government session, including the breakout discussions, are summarized in the Major Findings section. The presentation summaries are outlined in section 2. The agenda for the workshop is listed in *Appendix A. Advanced Microgrid Concepts and Technologies Workshop*. The abstracts from the presentations are consolidated in *Appendix B. Presentations' Abstracts*. The abstracts from the poster session are listed in *Appendix C. ARL Poster Session—Abstracts*. The list of participants and their affiliations are listed in *Appendix D. Attendees List*.

1.2 Major Findings

The following are the major R&D findings from the workshop summarized during the Scalable Energy Networks session and the follow-on discussions on day one (Chaired by COL Paul Roege) and the Government session on day two (Chaired by Dr. Ed Shaffer)

1.2.1 Scalable Energy Networks Session: General Concept for New Global Energy Architecture and Key Findings

The state-of-the-art concept of Scalable Energy Networks suggests a new architecture for energy and related information systems, which emulates the information domain by defining separate "layers"—such as system, control, application, and transport—as represented in the Open System Interconnect (OSI) model. The proposed schema would enable fluid interaction and flexible coordination among system components and energy of all forms through establishment of useful taxonomies, control algorithms, protocols, and standards. Fully manifested, scalable energy networks would simplify system design and operation through "plug and play" connectivity, yet increase flexibility, scalability, and resilience within the energy domain, as OSI has done for information. Moreover, the new architecture approach would facilitate implementation of new business models that support a more resilient and participative energy market through new pricing and decision mechanisms informed by real-time situational information.

The scalable network architecture would facilitate not only real-time, decentralized management of energy applications, but also the coordinated interchange and management of energy among different forms and at different levels to support diverse applications. Stored thermal energy within "smart buildings," electrical vehicle batteries plugged into charging stations, and distributed natural gas sources would interact seamlessly to contribute to, rather than detracting from, stability of local, regional, and national energy networks in an interactive manner. This behavior would emulate the Internet, with real-time localized control decisions being made based upon application needs and composite pricing information. Resilient, decentralized control would implement behaviors and priorities informed by respective applications, while networks form and reform in a dynamic manner. Finally, energy conversion, storage and distribution components would be systematically arranged to optimize their respective characteristics such as entropy and time constant.

This new concept requires integration of principles that are currently being developed among distinct fields of research, and synthesis of unifying approaches. Manifestly (network by nature) such scalable systems will require a resilient, distributed control schema manifested in intelligent agent control. Economics inform methodologies for real-time decision-making and system management; pricing theory provides at theoretical, if not a literal basis for individual decisions and for performance metrics. The effective integration and management of interactions among different types of energy processes (thermal, chemical electrical, etc.) is represented in an expanding field of "hybrid" energy concepts. End use considerations and demand will provide dynamic feedback to energy management processes. Ultimately, the entire architecture exists to meet the needs of, and interface with, individuals and communities to support life and commerce. Therefore, the architecture must evolve in concert with both ergonomics and stakeholder values, in order to create a useful result.

The scalable energy network session provided an opportunity to expose leading-edge research in several such areas, and followed by discussion about steps needed to advance toward practical application. Presentations aligned with these component areas are described in the following section.

1.2.2 Government Session: General Discussion Topics and Key Findings

Dr. Ed Shaffer provided guidance and direction for the R&D discussions during the general Government session and the followed breakout sessions.

Major issues discussed during the general talks of the Government session were technical challenges, lessons learned, and path forward for military microgrids.

- General and technology areas in which clarification is needed:

  General Topics:

  - What are the biggest challenges (technological and non-technological) to developing Army microgrids?
  - In what technologies and which directions should the focus be for networked energy and microgrid research for the Army S&T organizations?
  - In 5 years, what will Army operational energy microgrids look like? In 10 years? In 30 years?

- What are the pathways and roadblocks to making microgrids into programs of record?

Technology Topics:

- Microgrid metrics, standards, health, and performance criteria
- Communications between controls, sources, storage, loads—cyber security
- Modeling and simulation for microgrids, dynamics, reliability, validation and verification, operational microgrid optimization
- S&T areas that can/should be leveraged from other efforts (academia, industry, DOE, other agencies, etc.) for future military energy systems and related operational energy needs
- Most compelling power and energy sensing, information technology (IT) and related technologies are needed for enabling future military energy networks, and why
- Communications and sensing protocols
- Metrics for microgrids (Who develops them? Panel of experts?)
- Cyber security in microgrid software and control systems
- Modularity and plug and play
- Reliability of microgrid components
- Architecture specifics
- Degree of autonomous control that can be expected
- Best approach to leveraging "Smart Grid" technologies

- Definition of Tactical Microgrid Elements—key technology gaps and path forward issues (Dr. Scott Van Broekhoven, MIT–LL):
  - Definition of system elements—distributed energy resources, loads, grid distribution system, distribution node, components:
    - Need to define the basic architectural elements of the tactical power system in order to create a long-term technology development roadmap
  - Path forward:
    - Standardize use cases including load profiles from real-world data:
      - Need to include the evolution of the tactical power system over the lifetime of a base

- Will provide a common basis for comparing the performance of different solutions

- Determine what metrics should be used to evaluate microgrid performance
- Define the key system elements and interfaces
- Develop a technology roadmap for tactical power systems that includes near- and long-term goals for each key system element

- Army Tactical Microgrids (Dr. Chris Wildman, Marnie DeJong, CERDEC):
  - Technical challenges:
    - Grid communications and controls
    - Plug and play
    - Open architecture
    - Standardization
    - Physical medium for communications (reliable, rugged, etc.)
    - Connecting various sources to a common grid
    - 120/208 V 50/60/400 Hz
    - Tactical Quiet Generators (TQG's), Advanced Medium Mobile Power Sources (AMMPs), commercial, utility
    - Direct current (DC) (renewables, energy storage)
  - Lessons learned:
    - Power line communication (PLC) is susceptible to Electromagnetic interference (EMI), jamming, adversary threats
    - Ethernet communications reliable, proven, meets information assurance (IA) requirements, has communication protocols that enable tactical ad hoc environment
    - Alternating current (AC) grid is a near-term solution (simple, proven capability)
    - Need to implement communication standards to enable an open architecture
    - Become contractor agnostic
    - Competitive bidding/better buying power
  - Path forward:
    - Communication standardization with MIT–LL

        - Power electronics development
        - Multifunction (dual-mode) power converters: bidirectional, grid-tie, and islanded operation
        - Environmental requirements and ranges for communication, controls and energy storage technologies—meet high-/low-temperature requirements, ruggedness (drop, vibration, transportation, dust, etc.)

- U.S. Air Force Microgrids (Lukas Martinez):

  Key takeaways and technology gap questions:

    - Fuel reduction and cost savings:
        - How cost beneficial is it to integrate renewable energy sources into the grid?
        - Does it provide power efficiency to substantially impact the reduction in grid power consumption?
    - Logistical footprint:
        - How easy is the equipment to deploy?—photovoltaic (PV) technology, energy storage, and wind-power density per unit square area and weight
        - Is it feasible, reliable, and worth it?
    - Energy Storage:
        - Battery chemistry—Lead Acid, Li-Ion, Ni-Cad—practical charge and discharge capability
    - Deploy-ability:
        - Setup/installation time—integrate-ability, maintainability, training, and safety

- Storage, DER and microgrid standards for Smart Grid (Dr. Al Heffner):

  In cooperation with the DOE, National Electrical Manufacturers Association (NEMA), Institute of Electrical and Electronics Engineers (IEEE), Government-Wide Acquisition Contracts GWAC, and other stakeholders, NIST has ". . . primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems . . ."

  Smart Grid DER/Storage Standards:

    - Identify Smart Grid standards and interoperability issues/gaps for:
        - Integration of renewable/clean and distributed generators and storage

        - Operation in high-penetration scenarios, weak grids, microgrids, DC grids
        - Including interaction of high-bandwidth and high-inertia type devices
    - Of particular importance are Smart Grid functions that:
        - Mitigate impact of variability and intermittency of renewable generators
        - Enable generators and storage to provide valuable grid supportive services
        - Prevent unintentional islanding and cascading events for clustered devices
    - Lessons learned:
        - Grid supportive functions at microgrid/energy management system (EMS) premises connection:
            - Premises local EMS with no ability to remote disconnect
            - Microgrid with EMS and ability to disconnect/reconnect from area electric power systems (EPS)
            - Power electronic flow controller interconnected microgrids
            - Power electronic converter interconnected DC microgrids/DC circuits
            - Tactical mobile microgrid, village power (infrequently or loosely connected)
    - Management of Distributed Renewables, Generators and Storage (DRGS) devices within microgrids and premises EMS:
        - Interoperation of grid-paralleled synchronous generators for exporting power or soft-load transfer of power source
        - Interoperation of emergency generators with distribution and microgrid automation and protection devices
        - Interoperation of inverter-based generators with synchronous machine generators/loads within weak grid and microgrid scenarios
        - Operation of DC microgrids' and DC circuits' power conditioning system
    - Recommendations:
        - Common understanding of how microgrids impact the function, control and physical attributes of the macrogrid and each other in nested hierarchical network configurations
        - Common scope setting definition of a microgrid
        - Common set of classifications/subdivisions and functionalities of microgrids

- Approach is to utilize “naming” convention that recognizes a similar scale/level/functionality between the data/telephony and power domains

1.2.3 Government Session: Discussion Topics and Key Findings for the Breakout Sessions

The government session was divided in four breakout groups working in parallel:

- Group A: PC&PC
- Group B: PS and P&D
- Group C: Energy storage and generation, and renewable energy sources
- Group D: Communications, control, and cyber security for microgrids, and scalable energy networks

All groups had a list of six general questions, same for each group, and a list of three or four specific for the group technical questions.

General Questions:

- What S&T areas should be leveraged from other efforts (academia, industry, DOE, other agencies, etc.) for future military microgrid systems to meet operational energy goals?
- Should there be a working group for microgrid-related topics? What are the desired outcomes from such a working group (e.g., lessons learned from microgrid test beds)?
- How do microgrid technologies respond to the priorities for operational energy strategy: reliability, efficiency, fuel, and cost savings?
- What are the unique contributions of the Army and DOD toward developing future microgrid capabilities, while leveraging opportunities from DOE and other government agencies (OGA), industry, and academia?
- Should we develop a standard for modularity of microgrids?
- Should there be a panel of subject matter experts develop metrics for microgrids?

The guiding technical questions, relevant to RDECOM’s S&T directions for mid- and long-term research opportunities, and specific for each group, are shown in table 1.

Table 1. The guiding technical questions, relevant to RDECOM's S&T directions for mid- and long-term research opportunities.

Group	Technical questions
Group A: Power components and power conditioning (PC&PC)	• What are the key metrics for military microgrid components (power converters, switches, etc.) and how do they differ from industry? • What are the desired characteristics of modularity for power electronics and distribution modules? • What are the future power electronic devices and components needed to support that modularity?
Group B: Power sensing (PS) and prognostics and diagnostics (P&D)	• How do we define P&D for microgrids? What is the extent of P&D needed? • How can we take advantage of advanced sensing S&T to improve the operation and reliability of future adaptive power networks (efficiency, fault control, load shedding, etc.)? • How can we integrate power sensing, P&D, and power electronics for microgrid systems? What are the future research directions?
Group C: Energy storage and generation, and renewable energy sources	• What are the energy storage issues for microgrids that the Army should be developing that industry is not working on? Please list assumptions (e.g., distributed vs. centralized control). • What are the issues and challenges for integrating renewable energy to energy storage into microgrids, and what are the research implications? Please address S&T approaches to address instabilities associated with high penetration of renewable energy into a microgrid. • What ideas should be explored for integrated multi-structural designs for advanced energy storage and generation, and energy harvesting?
Group D: Communications, control and cyber security for microgrids, and scalable energy networks	• What degree of automation is needed for future microgrids and what are the technical components required to achieve that? • What S&T do we need to ensure cyber security on future microgrids? • What are the specific communication and security protocols that should be accepted or developed for military microgrids and what research is required? What is the right balance of communications and security? • How would you standardize the interpretation of control signals for microgrids?

1.2.3.1 Key Findings from the General Questions

What S&T areas should be leveraged from other efforts for future military microgrid systems to meet operational energy goals?

- Communications and security, standards, modeling
- We should look at prior and ongoing investments in the U.S. Navy electric ship program, the Idaho National Laboratory (INL) experimental grid, and several emerging microgrid test beds

Should there be a working group for microgrid-related topics? What are the desired outcomes from such a working group?

- Need a formal tactical microgrid definition if a working group at this level is to be formed
- Some example distinctions between tactical and other microgrids include:
    - No or limited trained support personnel
    - Time constant on changes to actual sources and loads (days/weeks versus years)
    - Dynamic
    - Harsh/hostile environment
    - Ad hoc
    - Size less than 1 MW, less than 600 people

How do microgrid technologies respond to the priorities for operational energy strategy: reliability, efficiency, fuel, and cost savings?

- Should provide lighter more efficient control of energy
- Can provide feedback on actual energy use:
    - Power electronics provide the ability to control and regulate power usage through policy
    - Sensing, P&D, user interfaces, and real-time control

What are the unique contributions of the Army and DOD toward developing future microgrid capabilities, while leveraging opportunities from DOE and OGA, industry, and academia?

- We are our own customer and have unique requirements that can only partially be met with current technologies/research
- We are also our own test bed and can evaluate technologies in real-world applications especially for small operations
- We operate under extreme conditions not seen by other groups
- We are less cost sensitive and more performance driven then other operations
- ARL E-field sensing team has unique capabilities related to:
    - Phasor processing and related analyses
    - E-field sensor design and characterization (especially for stand-off sensing systems)
    - Physics-based 3-D field modeling and simulation capabilities

- The ARL P&D team has unique capabilities related to statistical analysis techniques

Should we develop a standard for modularity of microgrid?

- Not sure that we can until definitions and standards for microgrid size and operation are better defined
- This can be a challenge for the Army since ad hoc grids are the norm and in foreign operations might stay the norm to allow local capabilities to be utilized
- Yes, we recommend starting with an intelligent distribution node, including specifications for functionality, user and machine interfaces, etc. (PS and P&D)

Should there be a panel of subject matter experts to develop metrics for microgrids?

- There is a need to better define microgrid size and operation within the Army:
  - There are several panels already developing metrics for many of the microgrid systems including communications, electronics, and others
  - This panel would have to be very carefully defined to prevent too much overlap and wasted effort
- Yes, we can add unique value relative to existing standards committees by measuring and estimating the operational status in a military context (PS and P&D)
- In the future command and control (C2) context, energy (and electric power) is simply another resource; however, developing the tools and techniques to manage that resource in a fast-paced, hostile environment will not be simple (PS and P&D)

1.2.3.2 Key Findings from Group A: Power Components and Power Conditioning (PC&PC)

What are the key metrics for military microgrid components (power converters, switches, etc.) and how do they differ from industry?

- Environment concerns: temperature, hostile, and harsh environments
- Smaller systems that are robust and allow graceful degradation of operation
- Modules that are scalable systems and are also inherently safe
- AC versus DC microgrids: The Army will probably stay with AC as the primary source with some DC for storage and renewable—do not see Army moving away from AC anytime soon due to commercial-off-the-shelf (COTS) and legacy issues.

What are the desired characteristics of modularity for power electronics and distribution modules?

- Small and light weight
- Simple to use (plug and play both from an installation and operation perspective)
- Scalable to allow additional capabilities through the addition of power distribution modules
- Indepth P&D to provide a robust and resilient system that gracefully degrades.
- Safe system
- Bidirectional power input/output
- Distributed intelligence
- Learned behaviors

What are the future power electronic devices and components needed to support that modularity?

- Wide-bandgap switches
- Passive materials and components to reduce size and weight
- Solid-state circuit breakers
- Intelligent power device modules (graceful degradation)
- Bidirection converters to allow sources or loads to be plugged in at any point
- Technology to determine loads and sources types
- High-voltage direct current (HVDC) circuit breakers
- Distributed PV systems
- Next generation control systems that not only provide adaptable and predictive control but allow learned behaviors, provide P&D at all levels—support better understanding of grid operation along with providing logistics information on consumable and maintenance needs

1.2.3.3 Key Findings from Group B: Power Sensing and P&D

How do we define P&D for microgrids? What is the extent of P&D needed?

- P&D include sensors, signal processing, and statistical analyses to identify and predict latent problems before they become system failures:
    - Some examples include cable faults, overloads, genset failures, and load failures

    - Interval data may be sufficient for time of day metering and other “smart grid” and Supervisory Control and Data Acquisition (SCADA) applications, but may not be sufficient for identifying and correcting many latent problems in critical infrastructure before they become cascading failures

- We need to take the following steps:
    - Identify the critical issues and data requirements for P&D (e.g., versus controls)
    - Examine existing datasets (e.g., from Afghan microgrids and standard DES base cases)
    - Determine the sensors, data rates, and experiments (e.g., Ft. Sill, OK, microgrid test bed) and the environmental and ground-truth data needed to evaluate/demonstrate new P&D technology
    - Define processing streams (e.g., phasor processing leading to specific P&D analyses)—and test and evaluate/demonstrate in a “realistic” environment

How can we take advantage of advanced sensing S&T to improve the operation and reliability of future adaptive power networks (efficiency, fault control, load shedding, etc.)?

- ARL is demonstrating emerging tools for sensing and analyzing “real-world” electric power loads in a circuit, house, lab, etc.
- We can apply these tools to buildings, campuses, and tactical microgrid test beds
- In the near term (next 1–4 years), the target transition products could include “bolt-on” sensors with COTS networking
- In the longer term (5–10 years), proven tools can be imbedded with next-generation generators, power distribution components, and intelligent loads

How can we integrate power sensing, prognostics and diagnostics, and power electronics for microgrid systems? What are the future research directions?

- Medium-voltage (MV = 15-kV class), clamp-on voltage and current sensors with energy harvesting, local processing, secure RF communications—variants could be developed for 4160-, 1320-, 480-, and 120/240- or 120/208-V class power.
- There is a need for emerging power electronics for some of these sensors, specifically in the 300–600 VDC class.
- The study of gensets, A/C units, etc., using “bolt-on” or “plug-in” sensors (with data acquisition, processing, and communications).
- Develop standardized diagnostic interfaces for “intelligent” gensets and loads, not unlike the diagnostic ports for car engines, etc.

- Explore collaborations with commercial and industrial companies, metering manufacturers, and utilities for prototype testing—the idea is that the Army will not only be a technology developer, but will also be an "early adopter" of this kind of technology.

1.2.3.4 Key Findings from Group C: Energy Storage and Generation, and Renewable Energy Sources

What are the energy storage issues for microgrids that the Army should be developing that industry is not working on? Please list assumptions (e.g., distributed versus centralized control):

- Deployable—Army needs very high-energy density versus low cost for DOE:
    - New chemistries, better air cathodes
- Modular
- Fuel efficiency driver for grid:
    - No standard requirements—who is developing standards?
    - It depends on application, size, and mission
    - It depends on the grid architecture
- Reliability/safety issues that affect energy density
- Plug and play—Soldier safe technology solutions
- Embedded solid-state DC circuit breakers/fault protection
- Superconducting magnet energy storage (SMES) systems

What are the issues and challenges for integrating renewable energy to energy storage into microgrids, and what are the research implications? Please address S&T approaches to address instabilities associated with high penetration of renewable energy into a microgrid.

- Cost—deployed, form factor, Soldier safe
- Forecasting renewable performance, matching energy need versus resource:
    - Need to change culture—willing to turn off a generator and rely on other sources
- Energy surety
- Power electronics/solid-state
- Alternative routes to fuel
- Small reactors—gas to liquids, bio routes to fuel
- Waste to energy—heat, garbage

- Alternative to routes to fuel—indigenous sources (chemical storage):
    - Integrate H_2 into grid, other fuels
- Need power and energy density storage for transients
- Real estate limitations—high-efficiency devices
- Thermal management

What ideas should be explored for integrated multi-structural designs for advanced energy storage and generation, and energy harvesting?

- Data integration
- Centralized or decentralized control
- Energy Surety
- How to integrate storage?
- Vehicle to grid—DOD attractive
- What are the requirements?
- Multi-structural designs
- Integrated PV/storage/smart
- Alternative routes to fuel—fuel storage/conversion

1.2.3.5 Key Findings from Group D: Communications, Control and Cyber Security for Microgrids, and Scalable Energy Networks

What degree of automation is needed for future microgrids and what are the technical components required to achieve that?

What S&T do we need to ensure cyber security on future microgrids?

What are the specific communication and security protocols that should be accepted or developed for military microgrids and what research is required? What is the right balance of communications and security?

How would you standardize the interpretation of control signals?

Working group discussion that synthesized and critiqued concepts, identified important principles and architectural components/standards and, most importantly, proposed subsequent work needed to advance understanding. Significant discussion explored notions such as:

- How distributed intelligent agents could support stable and resilient system behavior by making independent decisions based upon awareness of localized conditions and a composite system variable represented as “price.”
- The potential to construct a new energy “pricing” schema that represents a range of important information, such as: source, reliability, quality, timing, and scarcity—which in turn, could facilitate system stability. Moreover, such a scheme could enhance investment portfolios that promote resilience, sustainability and other desirable attributes not well supported in current schema with very little differentiation.
- The opportunity to improve system flexibility and visibility of performance by replacing those existing system-wise design concepts with a holistic model that maintains visibility of energy across domain boundaries and decouples development of hardware designs, operating systems, applications, and energy flows.
- The parallels and differences between information system architecture and corresponding energy concepts; for example, information “packets” are unique, which requires each packet to reach the unique destination address, while energy “packets” will be interchangeable with others of similar attributes. An example implication would be that energy “packets” need not reach the end use; they simply need to displace the next one (much like electrons in an electrical circuit).
- The growing relationship between energy and information that appears to be leading toward a “fusion” energy and information in this new architecture.
- Potential collaboration among ongoing initiatives, such as development of “smart grid” system and standards, hybrid energy systems, network and control concept development, and community/stakeholder involvement in developing business cases, priorities, and practices.

Important follow-on work will include pilot projects and research, including:

- The collaboration to identify a diverse set of real-world energy network use cases at multiple scales
- Expert mapping of business rules and priorities for real network use cases
- The definition of architecture “layers” and metrics that are agnostic with respect to energy forms and processes
- The development of candidate standards and protocols that correspond to architecture layers
- Analysis and development of new “pricing” models that manifest multiple value functions identified in business rules

- The design and operation of small scale "nano grids" that demonstrate self-management among the network, and continued operation as sub-networks when individual energy/information connections are disrupted
- The demonstration/simulation of energy control networks using distributed intelligent control to investigate stable, resilient behavior

1.3 Closing Remarks

Dr. Ed Shaffer adjourned the workshop by acknowledging the organizers and all of the attendees. Subsequent discussions summarizing the outcomes from the workshop lead to the following recommendations for the follow-up actions:

- Prepare technical report: with executive summary, key findings and recommendations.
- Incorporate suggestions from outbreak sessions and summaries from presentations for key findings.
- Develop list with topics and Points of Contact (POC) for potential collaborations based on feedback: with universities, national labs, industry.
- Establish understanding of use cases for microgrids: CERDEC (HI-Power), Sandia (SPIDERS).
- Follow up meetings and plans for actual collaborations
- Establish microgrid working group with subject matter experts (or a committee) within ARL and RDECOM organizations, and extended with members from key participants for information sharing, coordination of efforts for R&D on microgrids, and support and guidance to Department of the Army (DA) organizations.
- Develop metrics for microgrids.
- Include microgrid topic in Broad Agency Announcements (BAA).
- Develop microgrid-relevant Small Business Innovation Research (SBIR) topic(s).
- Work with P&E TFT for coordination, assistance, and update.

2. AMCT Workshop Presentations Digest

2.1 Focusing Army S&T for Operational Energy and Microgrid Challenges—Dr. Ed Shaffer, U.S. Army Research Laboratory

Dr. Ed Shaffer delivered the opening plenary talk on Army S&T for operational energy and microgrid challenges. Dr. Shaffer discussed the operational energy gaps and challenges, and the Army microgrid efforts in response to those challenges. Further, Dr. Shaffer described the basic microgrid characteristics for different applications: tactical, operational and strategic, and gave the overall Army vision for tactical microgrids. Also, he described the R&D challenges for future Army microgrids and summarized the key S&T focus areas for future military microgrids: intelligent power management, alternative energy solutions, and demand-side management. Following are the key discussion points:

- Operational energy gaps:
  - Improved Soldier power
  - Energy management processes
  - High-efficiency energy conversion
  - Tactical energy conversion and distribution
  - High-power, high-density energy storage
  - Power sources interoperability
  - Alternative energy sources

- Army microgrids efforts—roles and responsibilities (see figure 1).

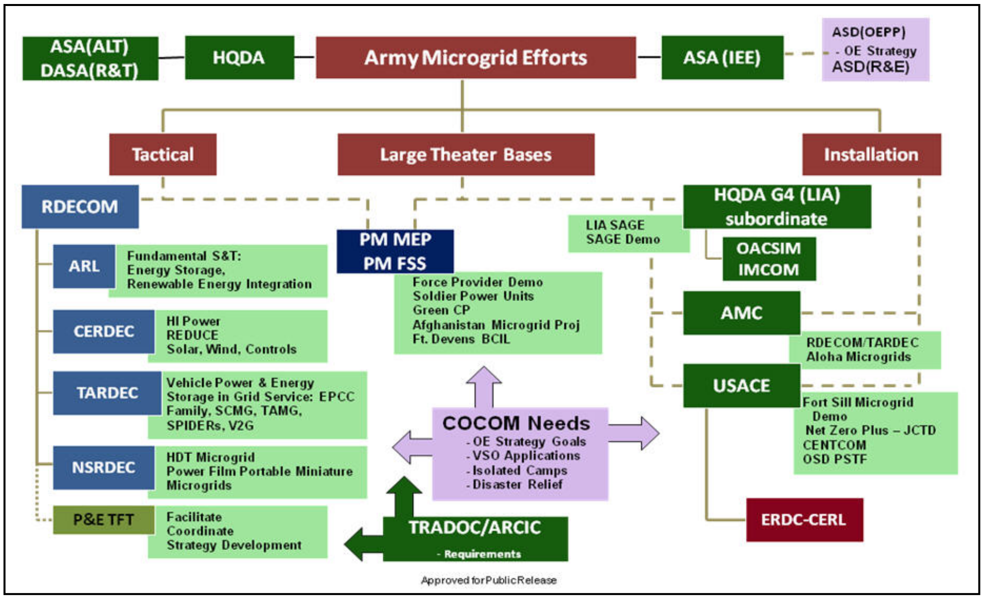


Figure 1. Army microgrids efforts—roles and responsibilities.

- Military microgrids characteristics (see figure 2).

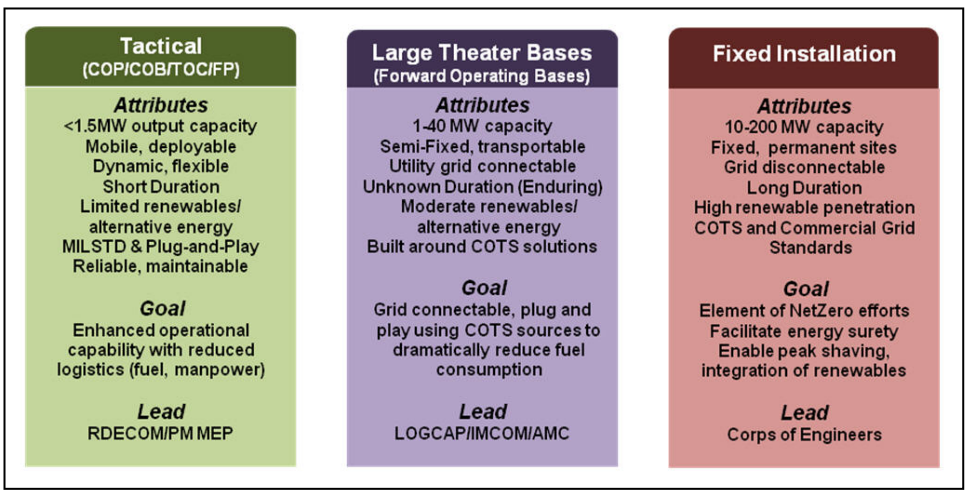


Figure 2. Military microgrid characteristics.

- Tactical microgrids vision:

  Develop expeditionary microgrid technologies to provide:

  - Improved reliability and availability of electrical power
  - Reduced fuel consumption
  - Improved ease of deployment through reduced setup time

- Lower maintenance and reduced life cycle costs
- Improved mission effectiveness, command energy visibility and reduced attendant energy manpower

- Desired microgrid characteristics:
  - Increased power integration flexibility (ability to integrate local grids, renewables, vehicles, military/commercial generators)
  - Ability to reconfigure command and control (C2) systems to accommodate mobile loads entering or leaving the energy network
  - Ability to manage non-critical loads so that critical loads are maintained—continuity of operations
  - Accommodate mix of legacy, upgraded, and new sources, loads, and storage
- Adaptive scalable energy networks:

  The adaptive scalable energy networks are highly integrated and automated energy sharing networks for *Smart Battlefield Energy on-Demand (SmartBED)* with the following architecture features:
  - SmartBED Automation Devices (SBAD)—networked hardware/software agents managing local energy devices
  - Energy situational awareness (sources, storage, loads)
  - Fault prediction, diagnosis, mitigation—safe reconfiguration
  - Enabling multiple topologies (star/spoke, linear, redundant) via SBAD energy cells
  - Optimizing renewables, sources, storage
  - Agent coordination and negotiation among energy resources entering and leaving local cells
  - Artificial Intelligence—enabled by high-density, rapid-response advanced power electronics
- R&D challenges for future Army microgrids:
  - Intelligent and adaptive—leveraged IT structure:
    - Architecture with inherent adaptability (capability enhancing attribute)
    - Enabling energy device self awareness
  - Managed services, controls, and safety:

        - Automating configuration/reconfiguration (military unique attribute)
        - Distributed agent control and dispatching (military unique attribute)
        - Dynamic turndown of sources, renewables, energy storage
        - Fault tolerance/recovery, stability, security
    - Universal connectivity:
        - Interfaces and standards (capability enhancing attribute)
        - Integrating sensing, IT, conditioning, intelligent power management (IPM)
        - Modular, adaptable microgrids that can be combined in any number of sequences/configurations (military unique attribute)
    - Physical attributes:
        - Reduced footprint/size, weight and power (SWaP)

2.2 DOE Prospective on Microgrids—Steven Bossart, Department of Energy

Mr. Steven Bossart gave the plenary talk on microgrids from DOE prospective. The presentation included microgrid goals, definitions, and concepts; microgrid demonstration projects; microgrid R&D projects; collaboration with military microgrid projects; and microgrid R&D needs. Operational Energy performance target for microgrids is to develop commercial-scale (<10 MW) microgrid systems capable of reducing outage time for critical loads by 98% at a cost comparable to non-integrated baseline solutions (i.e., uninterruptible power supply (UPS) plus diesel genset), while reducing emissions by 20% and improving energy efficiency by 20%. Key discussion points follow.

- Common objectives among DOE's microgrid projects:
    - Reduce peak load
    - Benefits of integrated DER (i.e., distributed generation, e-storage)
    - Ability to integrate variable renewables
    - Operate in "islanding" and "grid parallel" modes
    - Import and export capabilities
    - Two-way communications (frequency, verification, data latency)
    - Data management
    - Price-driven demand response
    - Dynamic feeder reconfiguration

- Outage management (i.e., number, duration, and extent)
- Volt/VAR/frequency control
- Balance distributed and central control
- Cyber security
- Interconnection and interoperability
- Defer generation, transmission, and distribution investments

- List of High-Priority R&D Projects from the DOE Microgrid Workshop (see table 2).

Table 2. List of high-priority R&D projects from the DOE Microgrid Workshop.

Impactful R&D Areas	High-Priority R&D Projects
Standards and Protocols	Universal Microgrid Communications and Control Standards
	Microgrid Protection, Coordination, and Safety
Systems Design and Economic Analysis	Microgrid Multi-objective Optimization Framework
System Integration	Common Integration Framework for Cyber Security/Control/Physical Architectures
Switch Technologies	Legacy Grid-Connection Technologies to Enable Connect/Disconnect from Grid
	Requirements based on Customer and Utility Needs
Control and Protection Technologies	Best Practices and Specifications for Protection and Controls
	Reliable, Low-cost Protection
Inverters/Converters	Topologies and Control Algorithms for Multiple Inverters to Operate in a Microgrid
	Advanced Power Electronics Technologies

2.3 Advanced Microgrid Concepts—Prof. Robert Lasseter, University of Wisconsin

Prof. Bob Lasseter's presentation focused on the current state-of-the-art of advanced microgrid concepts and related technologies, and their application for stationary and forward operating bases (FOBs). Prof. Lasseter discussed the complexity of the problem to manage the wide dynamic set of DER and control points, and the efficient solution, which is to break their networks down into small nodes, i.e., microgrids. Key discussion points follow.

- Advanced microgrids features:

  Microgrid is a system with clearly defined electrical boundaries containing sources and loads which:

  - Seamlessly island and re-synchronize to the network
  - Support high penetration of DER

- Support use of waste heat
- Promote plug-and-play sources
- Support renewable sources
- Enhance system efficiency and reliability
- Promote self-healing
- Eliminate need for fast central controls

- Microgrid control responses (see figure 3).

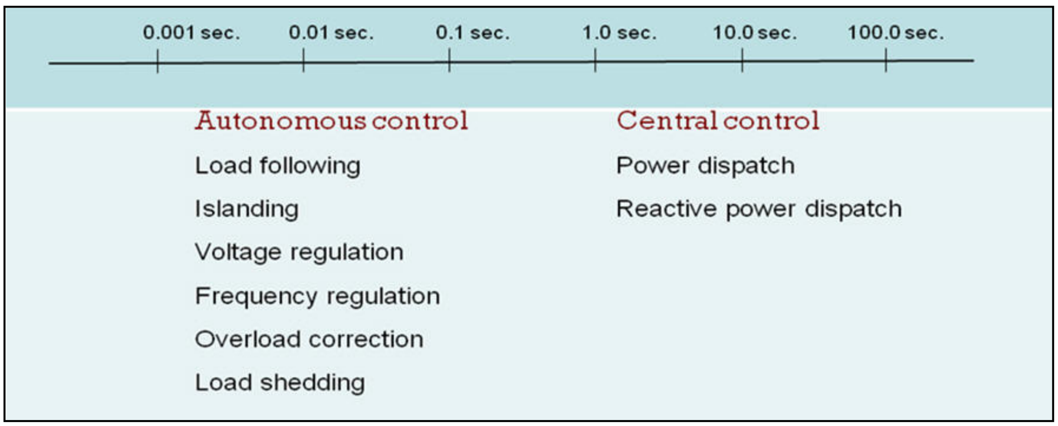


Figure 3. Microgrid control responses.

- The Consortium for Electric Reliability Technology Solutions (CERTS) microgrid concept:

  Promotes intentional islanding:

  - Clusters loads with DER
  - Enables islanded DER units to coordinate output autonomously to meet load demand
  - Provides for load shedding when needed
  - Ensures stability for multisourced systems
  - Seamlessly separates and automatically re-synchronizes with the grid

  Designed for high reliability:

  - Ensures redundancy: n + 1 sources
  - Based on autonomous local control for fast events (no central controller)
  - Minimizes engineering errors/cost/and maximizes flexibility: uses plug-and-play peer-to-peer models

- CERTS based DER: basic building block:
    - Provides a standard building block for Stationary Bases or Forward Operation Bases
    - Each microgrid can have different mix of energy resources; micro-turbines, storage, renewables, fuel cells, etc.
    - Plug-and-play model (allows for optimal site mix of DER without re-engineering)
- CERTS demonstrations: American Electric Power (AEP)/CERTS Microgrid test bed, Santa Rita jail, the Sacramento Municipal Utility District (SMUD) microgrid project
- Critical technical issues requiring further R&D:
    - Autonomous control for the fast transients
    - Elegances of the plug-and-play concepts and how they greatly reduce the complexity of the problems
    - Life time improvement research for Silicon Carbide (SiC)
    - Prognostic for microgrid components
    - Failure proof inverters
    - In high-voltage DC transmission systems there is redundancy in the short circuit ratios (SCRs) allowing ~ 10% loss without equipment shutdown. This is due to the fact that SCRs fail in "off mode" (open) allowing extra SCRs to be used in parallel
    - R&D of devices that can be used in series and fail in closed mode (short) would be helpful
    - New inverter circuits that allow loss of devices without shutting down

2.4 Smart Power Infrastructure Demonstration for Energy, Reliability, and Security (SPIDERS) Program—Jason Stamp, Sandia National Laboratories

Dr. Jason Stamp discussed the SPIDERS project and the three microgrids built, each with increasing capability, which will function as permanent energy systems for their sites. The presentation discussed the design methodology and the current status at the three SPIDERS sites. Major discussion points follow.

- Objectives for the microgrids:
    - Improve reliability for mission-critical loads by connecting generators on a microgrid using existing distribution network.
    - Reduce reliance on fuel for diesel power by using renewable energy sources during outages.

- o Increase efficiency of generators through coordinated operation on the microgrid and less excess capacity.
- o Reduce operational risk for energy systems through a strong focus on cyber security for the microgrid.
- o Enable flexible electrical energy by building microgrid architectures, which can selectively energize loads during extended outages.
- o Develop business cases for microgrid and renewable energy investment for non-islanded operation.

- SPIDERS overview (see figure 4).

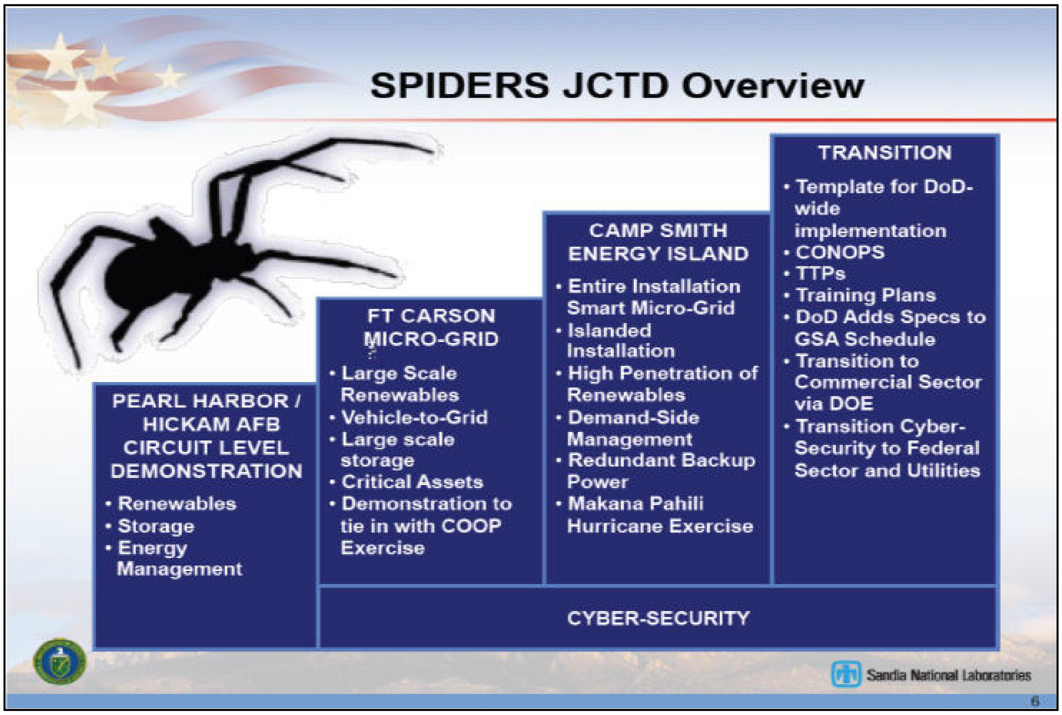


Figure 4. SPIDERS Joint Capability Technology Demonstration (JCTD) overview.

- SPIDERS EMS technical approach (see figure 5),

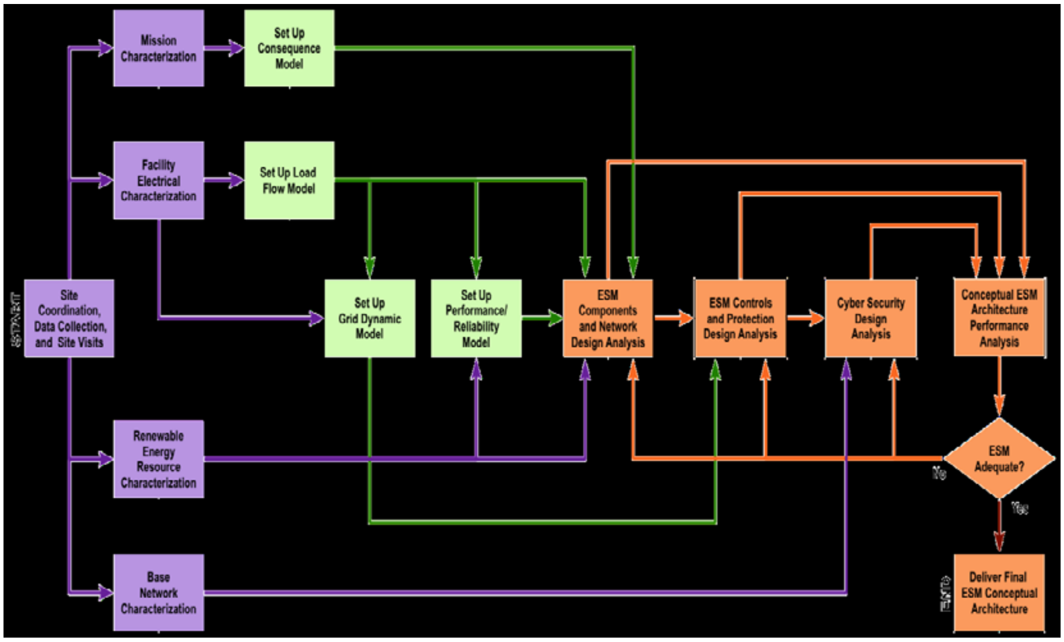


Figure 5. SPIDERS EMS technical approach.

  - Design Phase:
    - ➢ Conceptual design—what are the microgrid requirements and what energy assets are needed?
    - ➢ Preliminary design—what are the microgrid functional requirements? How do we control and secure it?
    - ➢ Detailed design—create a buildable construction specification, teaming with industry.
  - Installation and Testing
  - Operation and Transition
- Microgrid Models:
  - Consequence model (CM)
  - Load flow model (LFM)
  - Grid dynamics model (GDM)
  - Performance/reliability model (PRM)

- Metrics:
  - Critical load not served—all must have sufficient energy to ensure critical missions
  - Diesel consumption—renewable energy and storage systems defer (postpone) diesel consumption during utility grid failures when diesel backup generation is needed
  - Carbon generation deferred—the renewables help lower the carbon "footprint" of the base during microgrid operations
  - Priority load support—during extended outages
  - Keep penetration of renewable energy to a manageable level
- EMS analysis:
  - Components and network design analysis (CNDA)
  - Controls and protection design analysis (CPDA)
  - Cyber security design analysis (CSDA)
  - Conceptual EMS architecture performance analysis
- Cyber security design:
  - Controls use cases:
    - Automated grid management and control—frequency, voltage, load management, etc. (anything automated, second-to-second requirements)
    - Supervisory control—human-in-the-loop grid management (i.e., base command decides to energize priority load)
    - Protective relaying—specific channels dedicated to coordination between relays (also automated, time sensitivity on the order of cycles)
    - Microgrid configuration management—remote device (re)configuration, downloading fault data, engineering configuration and management, etc.
    - Connections to other systems: with utility systems for ancillary services, and with building systems for efficiency/load management
  - Controls design must ensure expected microgrid performance meets standards for power quality, voltage, frequency, protection, etc.
  - Protect the *Data* and the *Functionality* associated with these

2.5 FREEDM System: From Microgrid to Energy Internet—Prof. Alex Huang, North Carolina State University (NCSU) FREEDM Systems Engineering Research Center (ERC)

Prof. Huang provided an overview of the research conducted at the National Science Foundation (NSF) funded FREEDM Systems Center. The FREEDM System is a novel architecture suitable for plug-and-play of distributed renewable energy and distributed energy storage devices. Key technologies required to achieve the vision for sharing of the energy, i.e., the "Energy Internet" were discussed. Among many of the key technologies, the development of advanced power semiconductor devices and power electronics systems was discussed. Major discussion points follow.

- Current status—current system lacks:
  - Distributed control
  - Communication
  - Controllable transformer
  - Storage
  - Fast fault protection
- Next generation microgrids require:
  - New power devices—post silicon devices (5× size reduction, 10× weight reduction)
  - Better storage—advanced storage
  - New systems theory—system theory, modeling and control
- Demonstration:
  - Solid-state transformer (SST) and software:
    - Input: medium voltage AC (7.2 kV AC)
    - Output: LVAC 1 (240 VAC, 60 Hz), LVAC 2 (120 VAC, 60 Hz), LV DC (400 VDC)
- Benefits to utility company:
  - Easy integration of renewables
  - Make renewable dispatchable
  - Instant demand side management 1% voltage reduction = 0.8% demand reduction
  - Improve grid efficiency 5 to 10% loss reduction due to VAR (according to ABB Inc.)

- Improve grid reliability and availability
- Grid voltage control
- Built-in advanced metering infrastructure function and health monitoring function
- Built-in EMS function

• Strategic research plan (see figure 6).

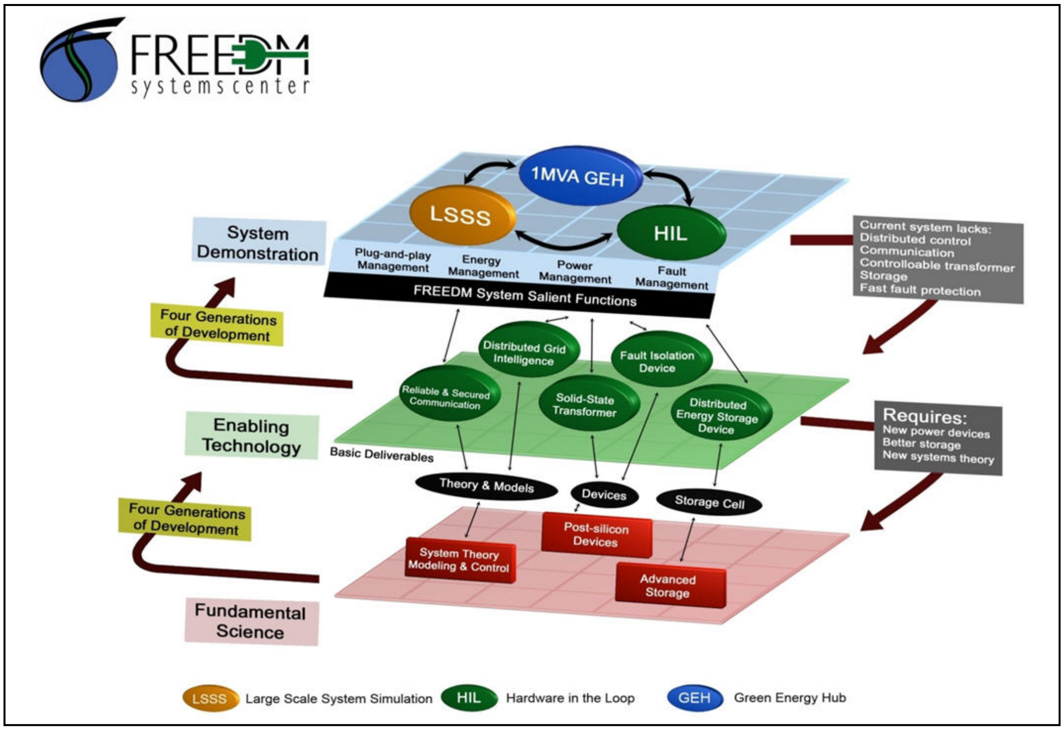


Figure 6. Strategic research plan (diagram).

2.6 Power Electronics for Energy—Storage Interface—Stan Atcitty, R. Kaplar, Sandia National Laboratories

• Goal of the program:

- Develop and evaluate integrated energy storage systems.
- Develop batteries, SMES, flywheels, electrochemical capacitors, and other advanced energy storage devices.
- Improve multiuse power conversion system (PCS), controls, and communications components. The PCS is a key component of the energy storage system. It can represent 20 to 60% of the total system cost.
- Analyze and compare technologies and application requirements.

- o Encourage program participation by industry, academia, research organizations, and regulatory agencies.
- Power electronics (see figure 7).

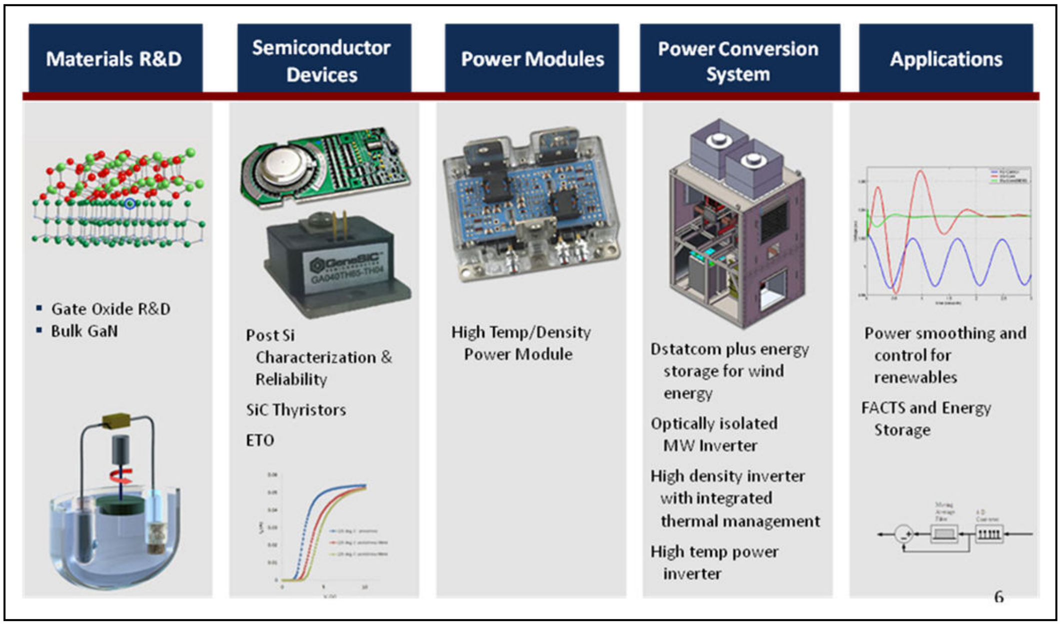


Figure 7. Power electronics.

- Needs:
    - o Reduce install cost/kW
    - o Decrease size and weight especially for transportable systems
    - o Improve integration control
    - o Increase reliability
    - o Increase efficiency
- PCS needs:
    - o Lower installed cost/kW
    - o Increased round-trip efficiency
    - o Increased reliability
    - o Reduced size and weight, especially for transportable systems
    - o Multiuse PCS for a variety of DER/energy storage technologies and applications
    - o Improved controls and adaptability

- Improved manufacturability (to increase manufacturing volume)

- Power electronics:
  - Materials R&D—gate oxide, bulk Gallium Nitride (GaN)
  - Semiconductor devices (Post Si—characterization and reliability), SiC Transistors, gate turn-off (GTO) thyristirs and transistors
  - SiC and GaN advantages—lower switching and conduction losses; higher-voltage operation; high-temperature operation (especially SiC); smaller system size, reduced weight
  - Power modules—high-temperature /high-density power modules
  - PCS

- Emerging and future improvements:
  - Transportable energy storage systems are becoming more attractive necessitating smaller, lighter, more reliable PCS designs:
    - Transformer-less, grid-tied PCS designs (e.g., multilevel converter topologies) are emerging.
    - New PCS topologies are being developed to reduce the size of the magnetic to reduce electrolytic capacitor use; and, in some cases, to eliminate the use of DC-link capacitors.
    - Semiconductors continue to improve—3- and 2-terminal post-silicon semiconductors (e.g., SiC and GaN) are becoming available. These devices will increase inverter performance by requiring less thermal management and fewer passive components; increasing efficiency; providing high-voltage blocking; and using higher-switching speeds.
    - Advancements in magnetic materials have resulted in higher ratings for operating flux densities (lower copper losses) and temperatures.
    - Wire bondless semiconductor switches are emerging and starting to show improvement in switch reliability.
  - High-level controls for multiple DER and storage components are being developed:
    - Inverter manufacturers are adding more value-added Smart Grid features (e.g., voltage support).
    - Inverter controls are being refined for new energy management schemes with proper energy storage or DER integration and grid support.

- A multiuse PCS for energy storage or DER integration are being developed.

- Many improvements are making inverters more commercially attractive and easier to use:
  - PCS packaging is improving—they are more reliable and easier to service in the field.
  - Better sensor technology combined with improved P&D health management systems (firmware and software) are reducing downtime.
  - Remote control and communication capabilities are becoming more common and reliable.
  - Long-term PCS reliability is improving, particularly for automotive applications. Currently a 10-year warranty (5 years with a 5-year option) is standard for PV inverters. Near-term targets are 15 or 20 years. Ideally users would prefer a 30-year lifespan.
  - Manufacturability is improving.

2.7 State-of-the-Art SMES for Grid Applications—Qiang Li, Brookhaven National Laboratory

Dr. Qiang Li discussed the status and future outlook of SMES for increasing capacity, reliability, and efficiency of the power grid. Making SMES into a long-term energy storage solution requires the performance of each of the individual subsystems to be propelled far beyond the present state of the art. Also, discussed were the status and future prospect of grid SMES, as well as major challenges. Highlights from the DOE Advanced Research Projects Agency-Energy (ARPA-E) grid SMES project led by ABB Inc. were presented as well. Major discussion points were discussed (see figure 8 and the following list).

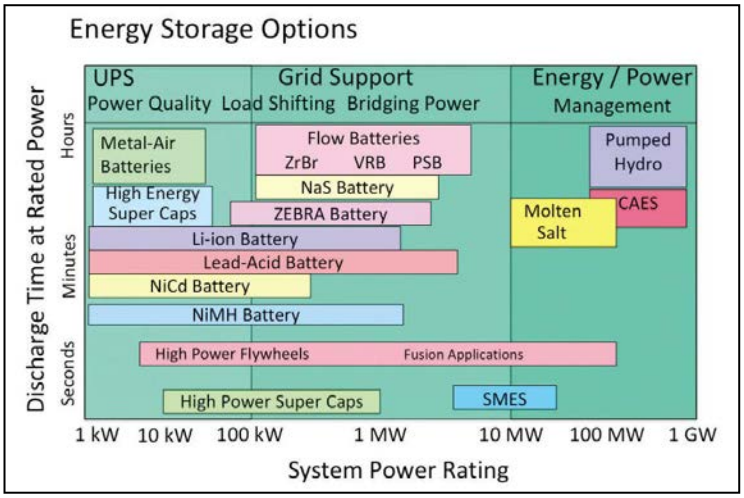


Figure 8. Energy storage options.

- SMES for tactical microgrid—Objectives:
  1. Geometry—e.g., 10MJ SMES in a trailer
  2. Wire requirements—stress, Bmax Je requirement (2G wire)
  3. Higher-operating temperature—e.g., 20 K
  4. Higher-ramping rate—full discharge from minutes to seconds
  5. Voltage and current—e.g. 600 DC V, 240–480 AC microgrid
- Components and system integration (Hardware):
  - High-performance 2G wires
  - Superconducting switches and power electronics (Objectives 3, 4, 5)
- Modeling (Software):
  - Component and system component optimization (Objectives 1–5)
  - Wire and system efficiency (Objectives 3 and 4)
- Current status: all SMES use low-temperature superconducting (LTS) wires and operate at 4.2 K (liquid helium) and work for a few seconds.
- SMES system with direct power electronics interface for grids (see figure 9).

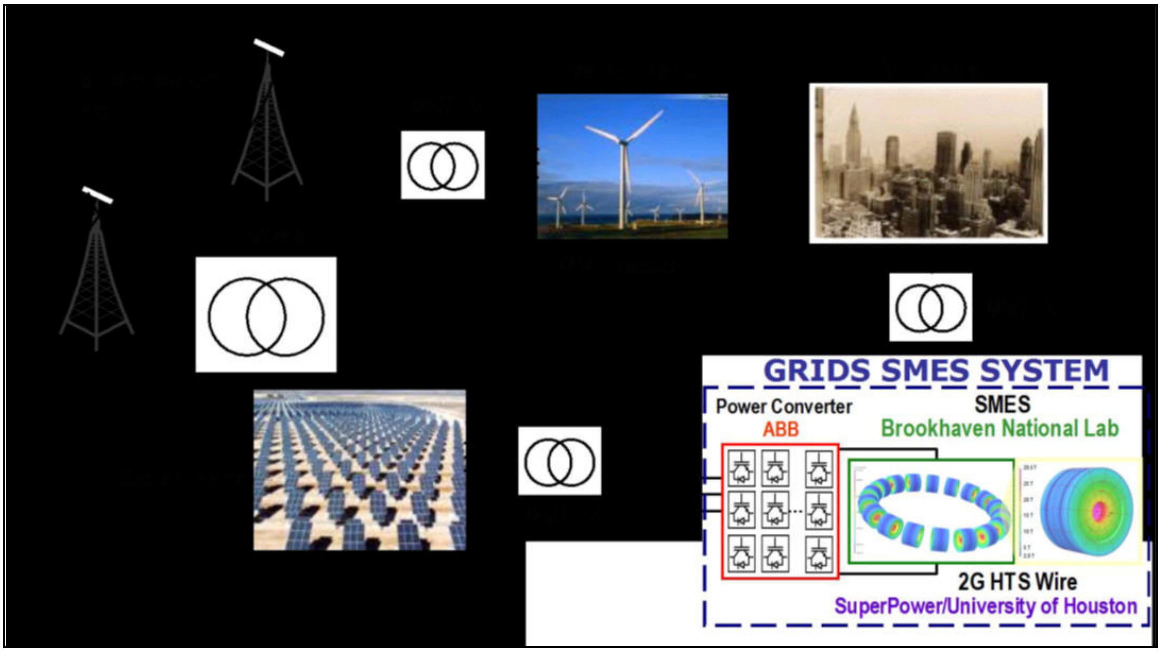


Figure 9. SMES system with direct power electronics interface for grids.

- Grid SMES advantages:
  - Fast dynamic response
  - Nearly infinite cycling
  - Magnetic energy ~B2—stored energy
  - No energy loss
  - Size ~R2, (~R3 batteries)
  - Solid-state operation
  - Environmental friendly
- Technology Advances:
  - Ultra-high-field (24–30 T) magnet
  - Prototype (20 kW, 2.5 MJ)
  - 2G high-temperature superconductor (HTS) wire with critical current Ic >600 A
  - Modular, scalable converter concept for direct connection to medium voltage grid with high-round trip efficiency (>85%)

2.8 AC and DC Future Electronic Energy Networks—Research Directions—Paolo Mattavelli, Virginia Tech

Prof. Mattavelli presented a possible future AC and DC electronic power distribution system architectures in the presence of renewable energy sources. The proposed nanogrid–microgrid–grid structure achieves hierarchical dynamic decoupling of generation, distribution, and consumption by using bidirectional converters as energy control centers. A few concepts for modeling, analysis, and system-level design of such systems, including power flow control, protection, stability, and subsystem interactions were presented. Key discussion points follow.

- Electronic Power Distribution System (see figure 10).

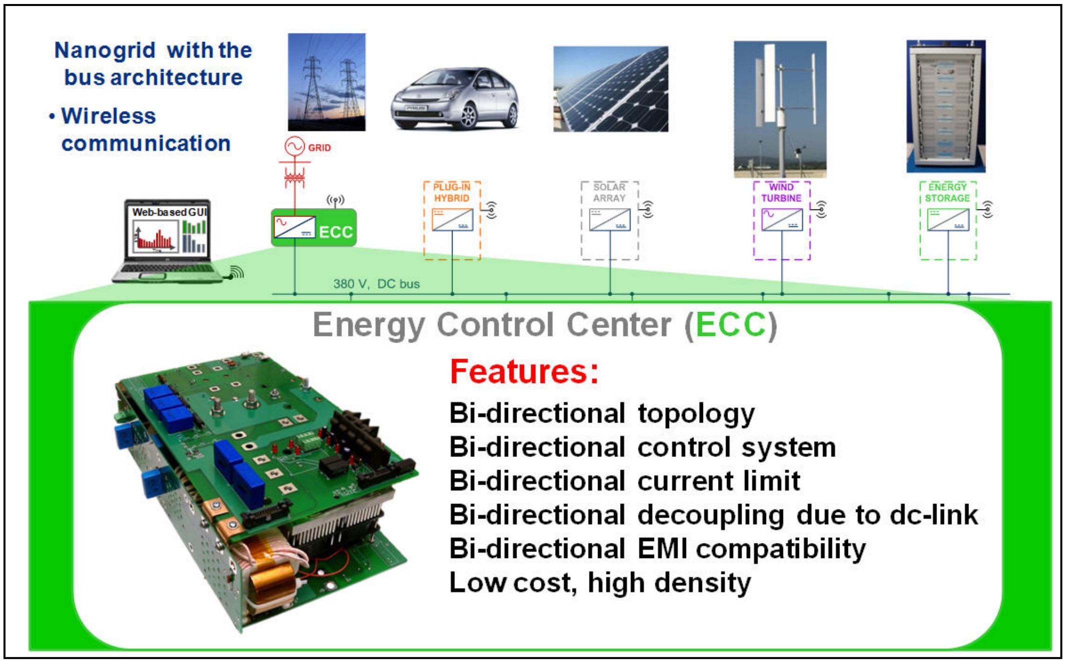


Figure 10. Electronic power distribution system.

- All electrical energy processed through electronic converters:
  - Variable frequency starter/generator—eliminates gearbox
  - Variable speed drives for Energy Control System (ECS)—eliminates pneumatics
  - High-frequency voltage step-up/down—less copper and iron
  - Electrical actuation—reduces hydraulics
- Research Directions:
  - Power electronics-enabled network architectures:
    - Dynamically decoupled, hierarchically interconnected, smart-grid and a network of small-, mini-, micro-, and nanogrids, instead of single, constant-frequency AC, grid
    - Distributed generation, storage, loads, and intelligence
    - Stability based on impedances in AC and DC grids
  - High-power and high-power density converters:
    - New materials, active and passive devices, thermal management
    - High-density integration and packaging

    - Safety and reliability:
        - Safety and protection
        - Reliability and lifetime in power electronics converters

2.9 Solar Variability, Forecasting and Modeling Tools—Prof. Jan Kleissl, University of California (UC), San Diego

Prof. Kleissl discussed advanced planning for microgrids with high penetration of variable renewable generation (VRG) sources, such as solar and wind, for optimization of microgrid economics and reliability. Variability of VRG such as ramp rates and ramp magnitudes should be counter-balanced by other generators or storage systems. Advanced solar forecasting tools developed and demonstrated at UC San Diego microgrid were discussed. Major discussion topics follow.

- Solar forecasting:
    - Goal—reduce reserve requirements and integration costs
    - Horizon—intra-hour (5-min dispatch, 15-min pre-dispatch)
    - Tools—sky imagery, stochastic learning
    - Ground-image based forecasting:
        - High-time resolution coverage
        - Granular spatial resolution—multi-megapixel cameras
        - Reasonable coverage (~15 km^2) cloud field dependent
        - Short time-horizon—10 to 20 minutes
    - Cloud motion vectors:
        - Apply cross-correlation method to coordinate–transformed sky image
        - Retain only vectors for which high correlation is obtained
        - Assume homogeneous cloud velocity

- Sky imager forecast (see figure 11).

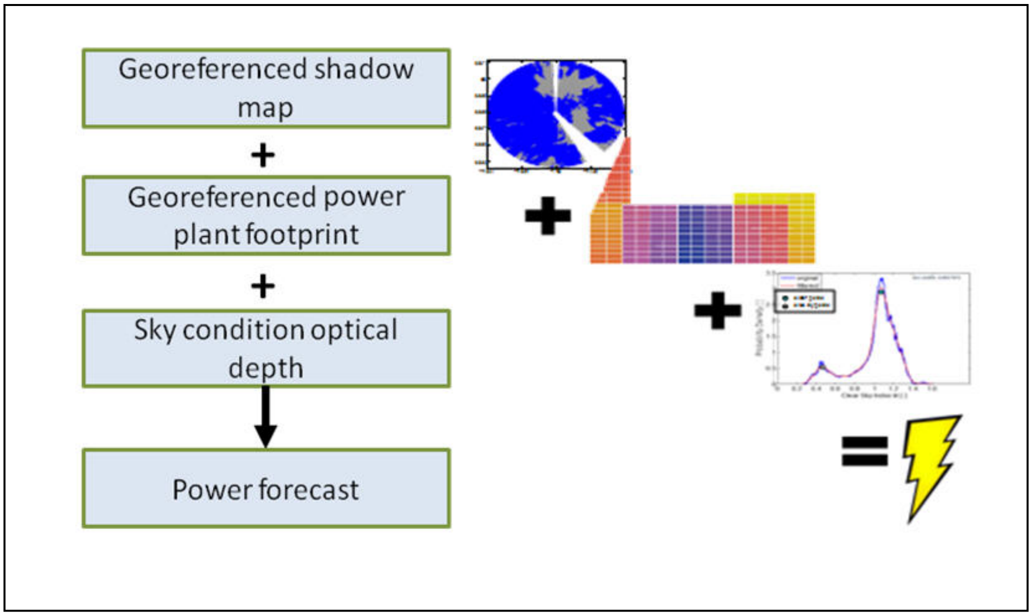


Figure 11. Sky imager forecast.

UC San Diego—Sanyo prototype produces high-quality sky imagery:

- Major Improvements:
  - High-dynamic range:
    - More accurate cloud fields
    - Allows for more reliable thin cloud detection
  - No shadow band necessary:
    - 10% more imagery available
    - Interpolation errors eliminated
  - Controllable image capture process:
    - Multiple exposures to create composite reduces data loss to sun saturation
- Forecasting irradiance:
  - More accurately capturing the cloud field will result in better irradiance forecast performance

- UC San Diego forecast engines (see figure 12).

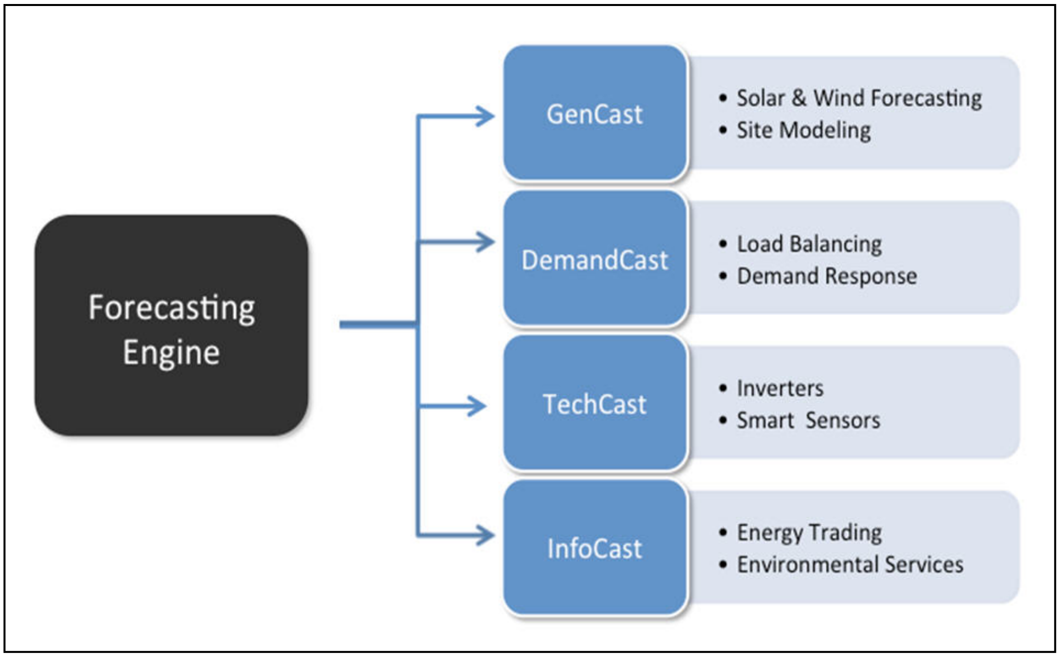


Figure 12. UC San Diego forecast engines.

- More advanced forecasting techniques:
  - Artificial Neural Networks (ANN)
  - ANNs optimized by Genetic Algorithms (GA/ANN)
  - GA/ANN with Fractional Order preprocessing (ENIO™)

2.10 Next Generation Power Electronics for Renewable Applications with Onboard State of Health Estimator—Prof. Faisal Khan, University of Utah

A solar cell inside a PV panel inherently produces DC output, which needs to be processed and inverted for AC applications. Power converters used in PV systems are made of discrete components and are not suitable for mass production. Prof. Khan discussed the research at the Power Engineering and Automation Research Laboratory (PEARL) team at the University of Utah, and their effort to introduce a breakthrough technology to generate 120 V/240 V AC output directly from the solar panel. Also, Prof. Khan discussed a state-of-the art non-intrusive technique as well a mathematical analysis aimed to quantify the state of health (SOH) of live power converters. Key discussion topics were:

- Grid synchronized PV power system—constructed from a group of power converters—a DC-DC converter ensuring the maximum power point tracking (MPPT) cascaded by a grid synchronized inverter

- Issues with PV power system:
    - Power converters used in PV systems have shorter life compared to the PV panels.
    - Key factor limiting the life of a PV converter is the electrolytic capacitor used across the DC bus for energy decoupling.
    - Insufficient power Metal Oxide Semiconductor Field Effect Transistor (MOSFET) reliability.
- Next generation PV power system—all embedded components:
    - In order to increase the converter reliability and watts per dollar, the active and passive elements of a power converter (especially capacitors and active switches such as MOSFETs, Junction Field Effect Transistors (JFETs) or Insulated Gate Bipolar Transistors (IGBTs) could be embedded on the same substrate material used for fabricating the p-n junctions in the PV panel.
- Converter reliability issues:
    - Capacitor equivalent series resistance (ESR) increases and capacitance decreases due to aging.
    - Accidental high-voltage applied at the gate terminal increases the threshold voltage.
    - MOSFET ON—state resistance changes due to thermal aging.
    - Degradation at the contact area of bonding wire such as metallization, and at the die solder layer occur due to thermal aging, which are reflected in the change in MOSFET RDS.
    - Threshold voltage, transconductance, and collector-emitter ON voltage changes due to aging of IGBTs.
- Sources of component failure used in a power converter:
    - Electrolytic capacitors due to aging in power converters
    - Semiconductor switched due to aging in power converters
- Capacitor failure due to:
    - High-voltage—capacitance value decreases and ESR value increases
    - Transients—leakage current increases and internal short circuit may occur
    - Reverse bias—leakage current increases with loss of capacitance and increase in RESR
    - Vibrations—the effects are internal short circuit, capacitance losses, high-leakage currents–increase in RESR and open circuits

  - High-ripple current—internal heating occurs and increase in core temperature results in gradual aging of capacitors

- State-of-the-art solutions:
  - Based on offline measurement techniques—existing real time techniques are suitable for detecting degradation of a particular component, not applicable to estimate health state of overall converter.
  - A new reflectometry based solution is proposed.
  - Spread Spectrum Time Domain Reflectometry (SSTDR) is a combination of Time Domain Reflectometry (TDR) and spread spectrum, generates data depending on the path impedance of various current paths of the converter.

- Summary:
  - The reliability, efficiency, and controllability of PV power systems can be increased by embedding the components of a typical power converter on the same Si substrate of a PV cell.
  - The effect of light exposure on converter switches embedded on the PV substrate has been analyzed to understand the converter behavior at various illumination conditions.
  - Only the key features of a switch such as threshold voltage, breakdown voltage, and output characteristics have been considered at this point.
  - The threshold voltage of the switches remains the same at dark and with light exposure; whereas, the breakdown voltage was slightly decreased by any light exposure.
  - The conductivity of the switches slightly increased due to the extra carriers generated by light exposure.
  - This project will introduce a non-intrusive measurement and computation technique to estimate the state of health of *live* power converters.
  - SSTDR was applied in a single phase AC-AC converter between different test point pairs and corresponding correlated output for different path impedances were obtained.
  - In addition, the test results suggest that this technique could be used to identify the aging of the entire power converter once numerical computation is performed with the impedance matrix.
  - A “reference matrix” could be constructed from a non-aged power converter for comparison purpose.

- By comparing these two matrices, it is possible to identify the impedance variation in various current paths due to aging and predict the relative state of health of the converter.

2.11 Scalable Energy Network Concept—COL Paul Roege, Department of the Army (DA)

COL Roege introduced a new visionary concept for scalable energy networks. He introduced the operational energy functions, tactical energy networks, and the state-of-the-art concept for the parallel between information and energy. In similarity to the modern day information system, the energy system will encompass an integrated architecture where energy would be collected, stored, converted, redistributed, and used in a plug-and-play manner. This visionary construct would encompass all forms of energy—electrical, chemical, thermal, or kinetic—enabling seamless conversion and exchange. Major discussion points follow.

- Operational energy functions:
  - Enable operational capabilities
  - Manage and prioritize energy
  - Network energy sources
  - Simplify energy logistics
  - Understand and integrate local resources
  - Manage fuel costs
- Information and Energy—parallel and interconnected (see figure 13).

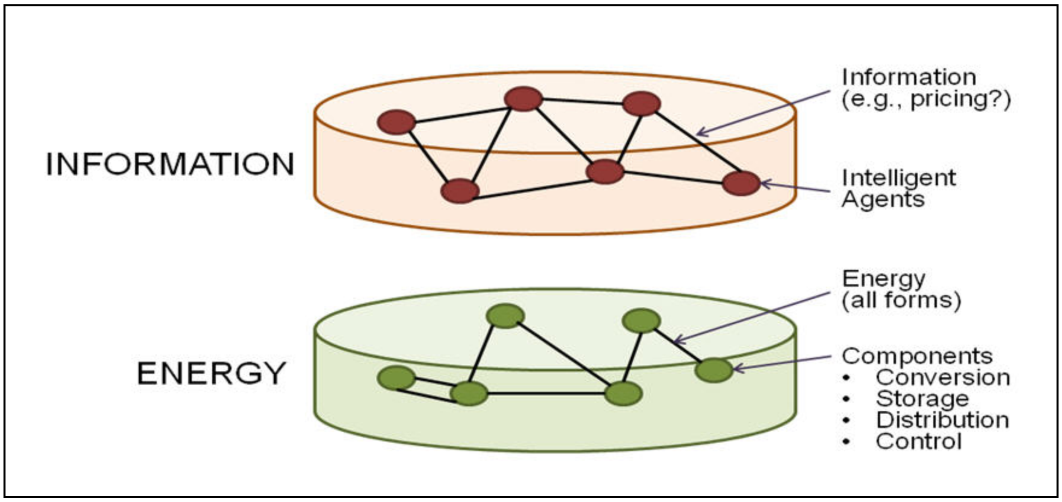


Figure 13. Information and energy (parallel and interconnected).

- Layered architectures for information systems and for energy systems (see figures 14 and 15).

	Data unit	Layer	Function
Host layers	Data	7. Application	Network process to application
		6. Presentation	Data representation, encryption and decryption
		5. Session	Interhost communication
	Segments	4. Transport	End-to-end connections and reliability, flow control
Media layers	Packet	3. Network	Path determination and logical addressing
	Frame	2. Data Link	Physical addressing
	Bit	1. Physical	Media, signal and binary transmission

Information Systems
(OSI Model, ISO/IEC 7498-1)

Figure 14. Layered architecture for information systems.

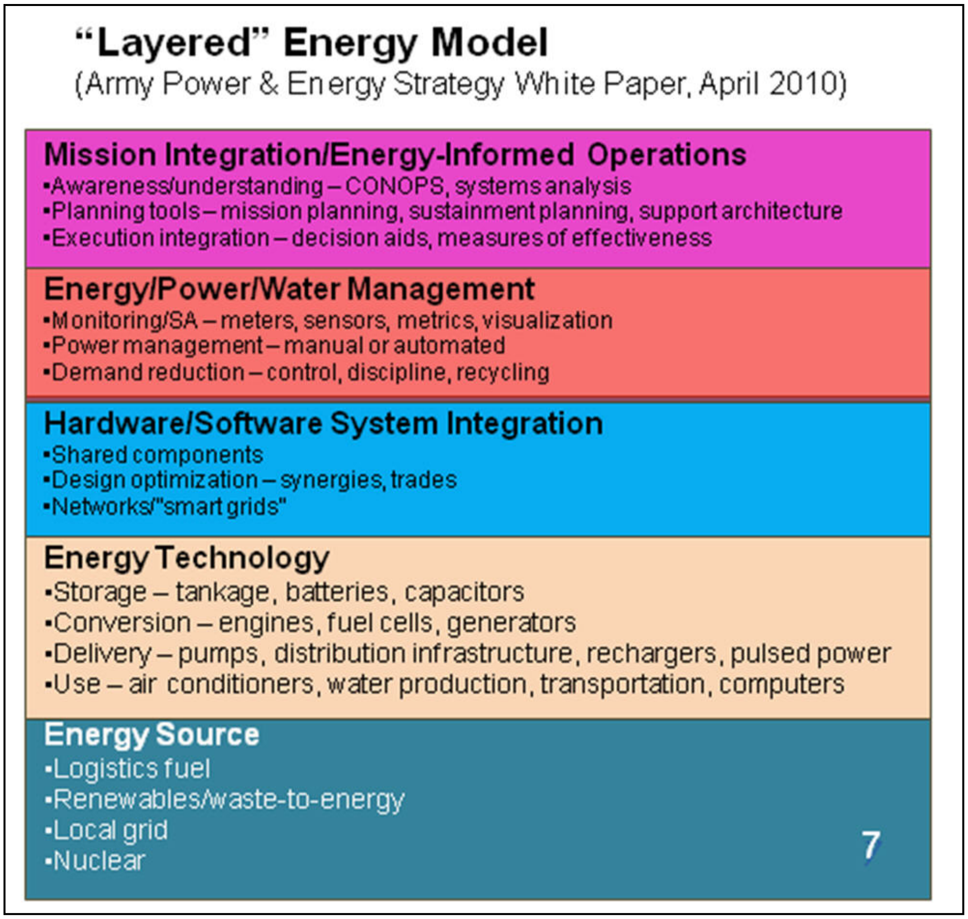


Figure 15. Layered architecture for energy system.

- Scalable energy networks:
  - Integrate energy in all forms
  - Allow scaling at all levels
  - Derive flexibility and resilience from decentralized control
  - Manage energy based on diverse attributes
  - Enable optimization of long-term objectives
  - Facilitate universal participation
- Path forward:
  - Refine and communicate the concept
  - Identify important participants
  - Identify development needs

- Scope and implement demonstrations
- Mobilize resources

2.12 Local Power Distribution (Nanogrids)—Bruce Nordman, Lawrence Berkeley National Laboratory (LBNL)

Dr. Nordman described a bottom-up network model of power distribution that can enable capabilities that the traditional grid model cannot deliver. His talk described local power distribution in which loads are connected to and communicate with a "nanogrid" that may have local storage and sets a local price for electricity. Nanogrids can scale to any size; they can be connected to each other, to local generation, to microgrids, or to the utility grid. Major discussion points follow.

- OSI Model equivalent for energy (see figure 16).

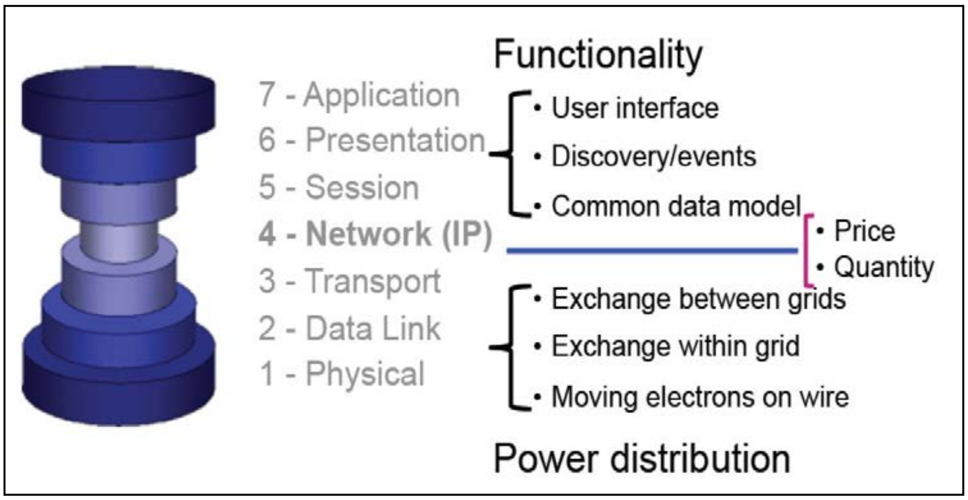


Figure 16. OSI model equivalent for energy.

- Power distribution:
    - Technology/infrastructure that moves electrons from devices where they are available to devices where they are needed
    - Important similarities between moving bits and moving electrons
    - Important differences between moving bits and moving electrons—all bits/packets are different; all electrons are the same
- Needed system requirements (from P. Roege, Joint Force Quarterly [JFQ]):
    - Scalable
    - Resilient

    - Flexible/Ad hoc
    - Interoperable
    - Renewable-friendly
    - Cost-effective
    - Customizable
    - Enable new features
    - Enable new applications
- Needed system capability:
    - Optimally match supply and demand (price)
    - Match reliability and quality to device needs
    - Enable arbitrary and dynamic connections devices, generation, storage, and “grids,” “plug and play,” networked
    - Efficiently integrate local renewables and storage
    - Work with or without “the grid” (or any other grid)
    - Use standard technology
- “Distributed” power distribution:
    - Network of “grids” of various sizes
    - Grids are managed locally
    - Generation and storage can be placed anywhere
    - Interfaces between grids:
        - Enable isolation
        - Enable exchanging power any time mutually beneficial
    - Distributed power looks a lot like “Internet”—a network of grids (“intergrid”)
    - Peering exchanges can be multiple, dynamic
    - With reliability at edge, core can be less reliable
- What is a “nanogrid”?—a very small electricity domain:
    - Like a microgrid, only (much) smaller

- Has a single physical layer (voltage, usually DC)
- Is a single administrative, reliability, and price domain
- Can interoperate with other (nano, micro) grids and generation through gateways (see figure 17)
- Wide range in technology, capability, capacity

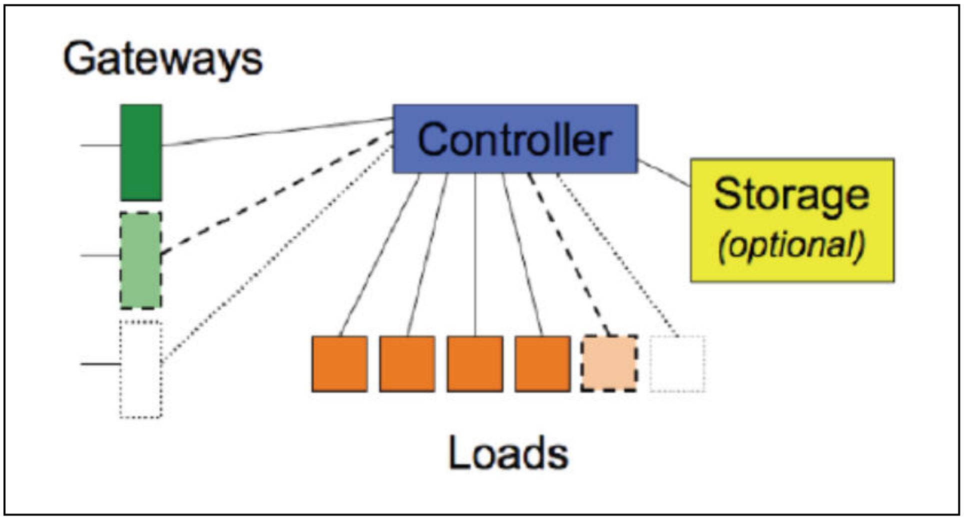


Figure 17. Gateways.

- Existing nanogrid technologies:
  - No communications:
    - Vehicles—12 V, 42 V, 400 V, etc.
    - eMerge—24 V, 380 V
    - Downstream of UPS—115 VAC
  - With communications:
    - Universal Serial Bus (USB)—5 V
    - Power over Ethernet (PoE)—48 V
    - HDBaseT—48 V
    - Proprietary systems
  - Power adapter systems (emerging):
    - Wireless power technologies
    - Universal Power Adapter for Mobile Devices (UPAMD)—IEEE

- Nanogrids do NOT (but microgrids Do):
  - Incorporate generation (?)
  - Optimize multiple-output energy systems, e.g., combined heat and power (CHP)
  - Provide a variety of voltages (both AC and DC)
  - Provide a variety of quality and reliability options
  - Connect to the grid
  - Require professional design/installation
- Examples:
  - Village example
  - FOB example (see figure 18).

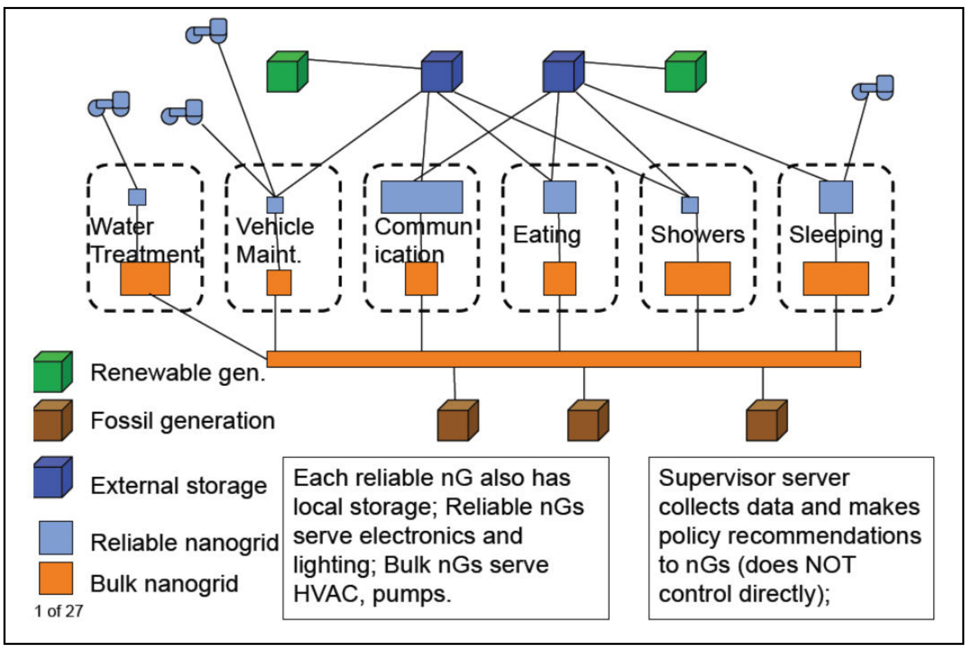


Figure 18. FOB example.

- The way forward:
  - Better document existing nanogrids:
    - Technologies, capabilities, applications, deployment, etc.
  - Define a "meta-architecture" for controllers, gateways, prices, etc.
  - Define specific gateways (voltage, communication)

    - Define nanogrid implementation for existing technologies
    - Create working nanogrids–loads, controllers, gateways
    - Create a nanogrid simulator
- Summary:
    - Nanogrids can optimally match supply and demand:
        - Price: internally and externally
    - Nanogrids can be key to success of microgrids:
        - Can be deployed faster, cheaper
    - Need to be standards-based, universal
    - Key missing technologies: pricing and gateways
    - Nanogrids are a “generally useful technology”

2.13 Resilient Control Through Distributed Intelligent Agents—Craig Rieger, INL

Dr. Craig Rieger described multi-agent analysis approach to decompose complex relationships between chain of management, engineering, and regulatory individuals that affect the idea of operation for a facility and its associated industrial control system(s) (ICS). He proposed a conceptual breakdown of the human and control/cyber elements that must be performed on real-world examples to demonstrate how these multi-agent designs can be applied. This research takes a propose framework for hierarchical design, using researchers in complex systems, control systems and human systems, and applies it to a microgrid example for codification of design elements. Key discussion points follow.

- Overall Resilience Considerations:
    - Human interaction challenges
    - Goal conflicts
    - Unexpected condition adaptation
- Human Interdependencies Element:
    - Malicious and benign human interactions affect critical infrastructure
    - Therefore a timely understanding of these interdependencies is needed
    - Human aspect is complex to characterize
    - Multi-agent analysis provides an approach to codify these complex relationships

- Layers in human interdependencies (see figure 19):
  - Management
  - Coordination
  - Execution

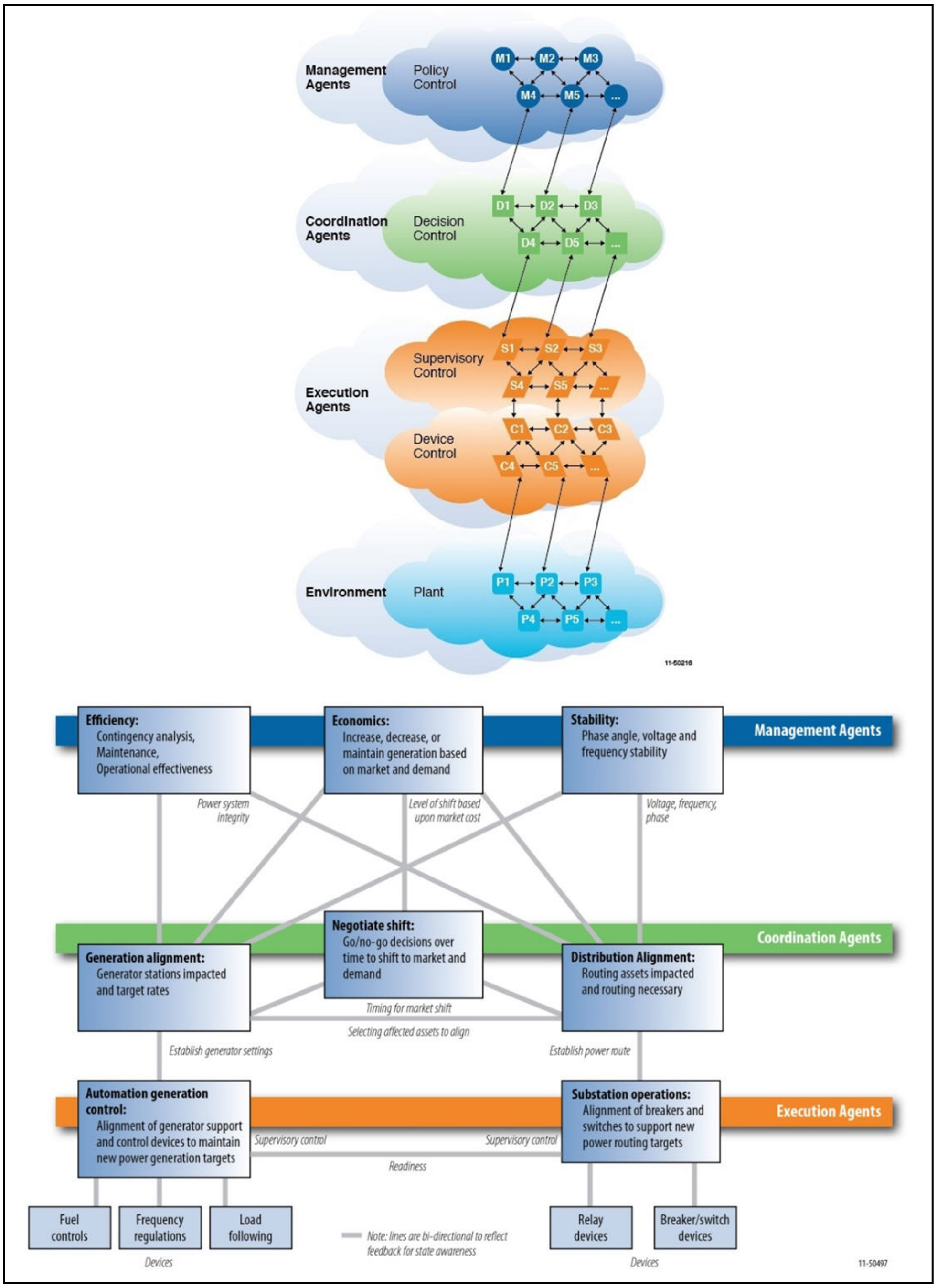


Figure 19. Layers in human interdependencies (diagram).

- Resilient control aspects (see figure 20).

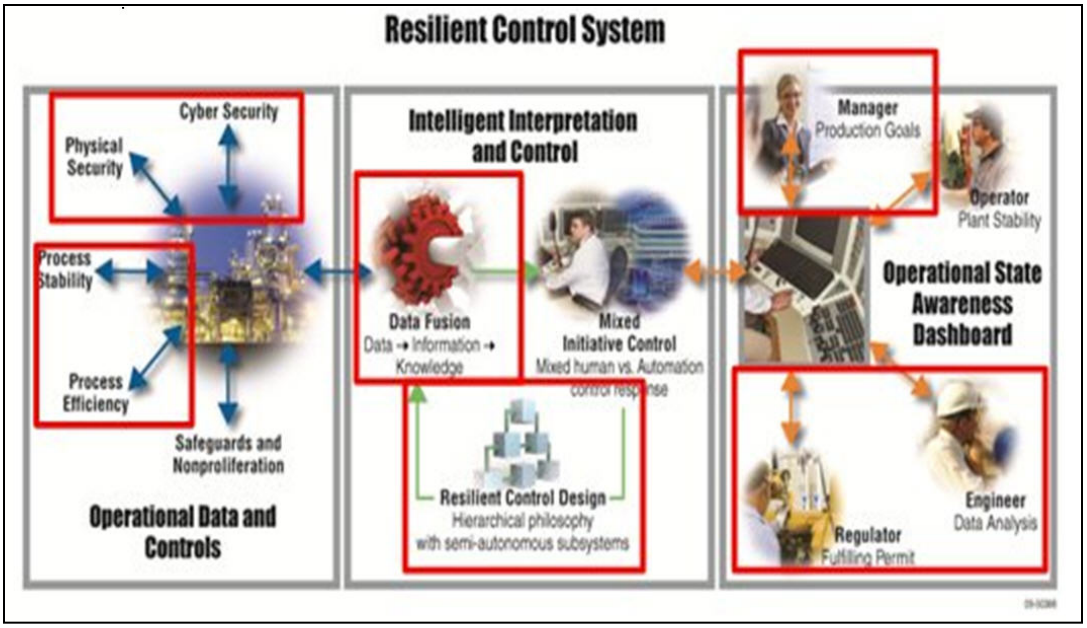


Figure 20. Resilient control system.

- Decompose data for a power system operation:
  - Performance criteria, regulatory constraints, and physics-based limitations
  - Fusion metrics drive performance and realignment of assets to fulfill mission objectives
  - Ensure unintentional or unrecognized relationships are addressed
- Integrate decomposition:
  - Human and control system interdependency information embedded into computational intelligence tools
  - Develop a control system framework for an automated tie from desired performance to control system asset coordination
  - Malicious behavior and event influences on interactions characterized in decision basis for coordination

2.14 New Electronic Design Automation (EDA) Tools for Efficient, Reliable, and Resilient Microgrid: Towards Energy Informed Plug-and-Play Power Systems—Prof. Ivan Celanovic, MIT

Prof. Celanovic described approach to overcome major challenges to design, build, control, test, and configure microgrids. He presented a new approach to EDA based on ultrahigh-fidelity real-time hardware-in-the-loop (HIL) emulation platform for power electronics, renewables, and microgrids in general, that enable completely realistic, large-signal modeling of all the dynamical processes (from micro seconds to minutes and hours).

- Microgrid challenge—Plug-and-play power architecture (see figure 21):
  - Next generation microgrids
  - Plug-and-play power—intelligent sources and loads
  - Plug-and-play control—reconfigurable architecture
  - "On the fly" reconfiguration
  - Power electronics handles power flow interfaces
  - Real-time reconfigurable control network for information
  - Optimized system level performance via supervisory controls
  - Seamless transitions from islanding and grid connected modes

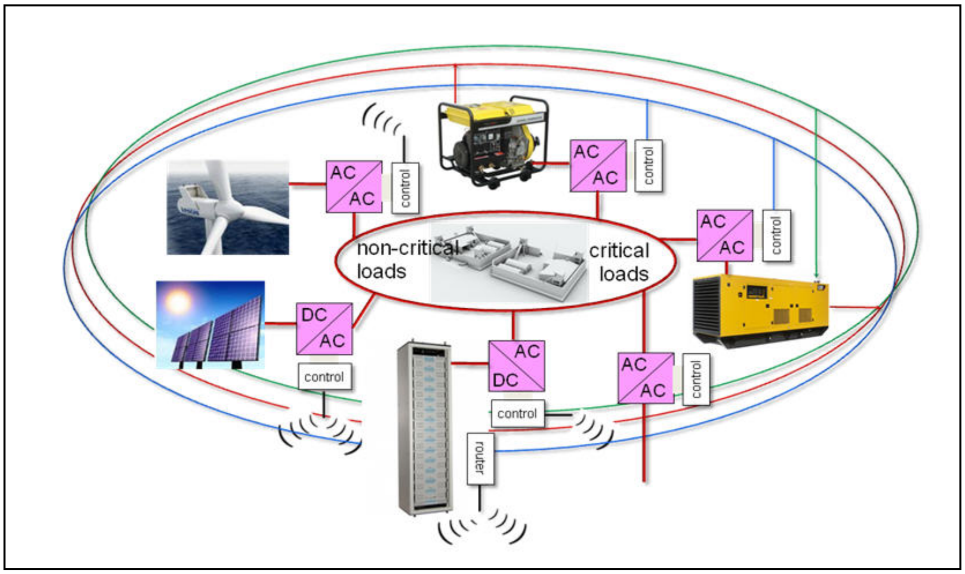


Figure 21. Plug-and-Play power architecture.

- Microgrid is complex cyber-physical system:
  - Power electronics controls the flow of power *(V, I, f)*
  - Interface between grid and electro-mechanics (i.e., spinning machinery)
  - Tight coupling between real-time control and power processing

- Design, optimization, and testing of smart grid plug and play and control:
  - Design and testing of smart grid is difficult and expensive
  - Time constants span from microseconds to hours
  - Multilayer control strategies
  - Very complex system dynamics and interactions (stability)
  - Testing variable operating points (including faults) is prohibitively expensive
  - High-level control strategy optimization and realistic operational scenario evaluation difficult
- Complex architecture: both power and information
- Real-time emulation needs to address high fidelity and scalability:
  - Comprehensive testing and optimization platform
  - Fault injection and reliability evaluation
  - Safety critical equipment in many applications
  - Testing requires expensive high-power labs—time consuming
- Real-time processor architectures for power electronics emulation (see figure 22):
  - Application specific
  - Multicore
  - Programmable
  - Scalable
  - Fixed simulation time step

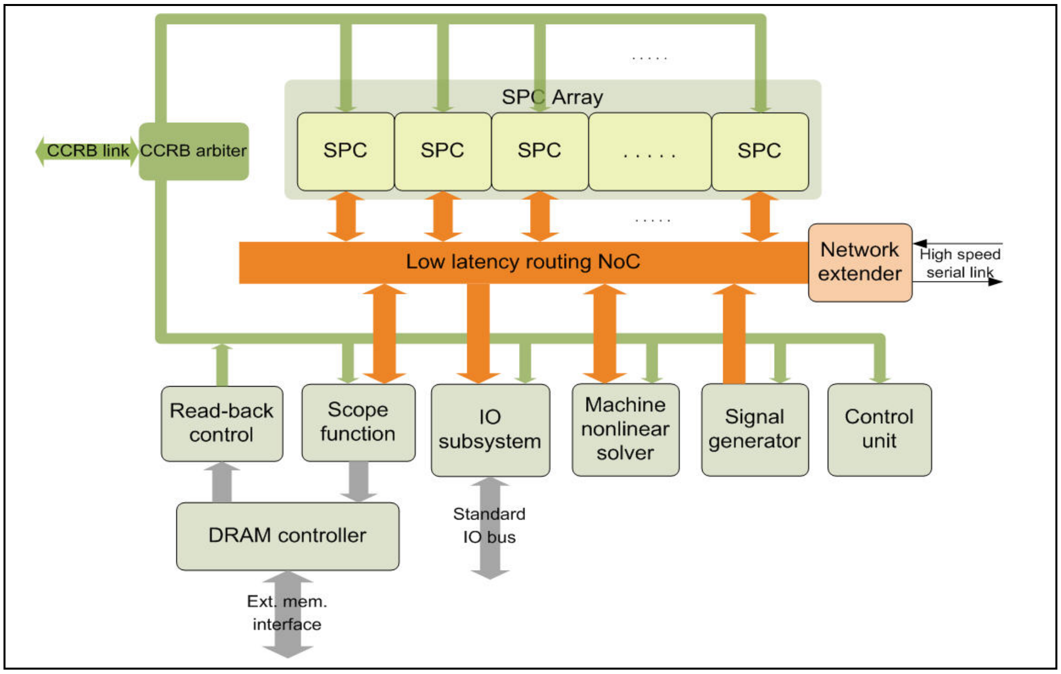


Figure 22. Real-time processor architectures for power electronics emulation

- Real-time emulation and HIL enables easy control design:
  - Ultrahigh-high-fidelity virtual microgrids system emulators (comprehensive and accessible virtual test bed)
  - Development and test environment
  - Training environment
  - Fault injection
  - Low-cost systems enabling developer ecosystem

2.15 Price Based Energy Network Architecture—MAJ Isaac Faber, United States Military Academy (USMA)

MAJ Isaac Faber described the concept that price can guide energy production and consumption efficiently in distributed networks. While a re-engineering of the electrical system along the lines of the Internet could yield potentially significant benefits, there are major differences between the information and energy systems. These differences would require a significantly different architecture. The key difference is the replacement of bandwidth with a price based energy routing scheme. MAJ Faber proposed a concept that many of the issues of future energy security can be addressed through the development of an updated architecture based on pricing information. He described an approach to develop, at a system level, a method for communicating pricing in order to dictate the flow of energy through the network. Key discussion topics were:

- Preliminary architecture (see figure 23).

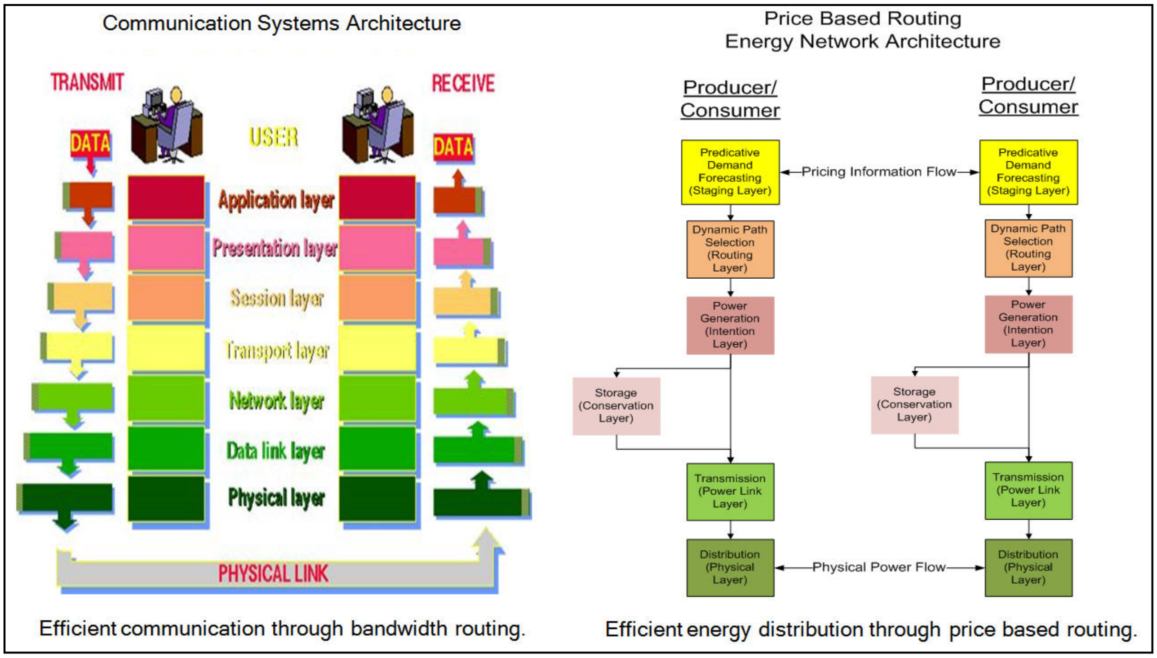


Figure 23. Preliminary architecture diagram.

- Price based energy routing—energy network architecture:
  - o Predictive demand forecasting (staging layer):
    - ➢ A mesh communication layer must overlay power grid to facilitate communication of demand preferences
    - ➢ Specific demand preferences will serve to create new markets to entice more products of energy
    - ➢ Prices affected through regulation or policy
  - o Dynamic path selection (routing layer):
    - ➢ Similar to routing in communication networks "Path Selection" routers will aggregate demand preferences of consumers and supply abilities from producers and build an energy load plan accordingly.
    - ➢ Producers will be given instructions for specific power generation and consumers will receive a price based on their demand profile at *equilibrium pricing*.
  - o Power generation (intention layer):
    - ➢ Producers will generate power in accordance with information received from the routers.

  - Storage (conservation layer):
    - Energy storage will be necessary in this architecture due to the flexibility of potential demand.
    - Storage is also likely necessary due to the high variability and correlation of existing renewable energy sources.
  - Transmission (power link layer)
  - Distribution (physical layer)
- Systemic considerations of price based routing:
  - Security, health, and safety
  - Technological, ecological, historical, moral/ethical
  - Economic, political, legal, cultural, emotional
- Summary:
  - Price based routing can serve as *the* method to efficiently allocate energy from producers to consumers.
  - Use of preferences can and will create new market participants, which will speed the improvement and advancement of energy infrastructure.
  - System level considerations can easily be integrated into this type of architecture.
- Way ahead:
  - Development of preliminary demand algorithms
  - Development of preliminary producer algorithms
  - Proof of concept discreet event simulation
  - Continued refinement of architecture

2.16 Hybrid Energy Systems Applied to Microgrids—Mike McKellar, INL

Dr. Mike McKellar described INL's approach to Hybrid Energy Systems (HES). HES combine the advantages of different energy sources—such as renewable, conventional and unconventional fossil, and nuclear sources—to gain efficiencies through advanced integrated system controls and engineering technologies. Such approach improves a given system's or process's environmental and energy performance. In his talk Dr. McKeller discussed HES process integration, various HES designs, model for electric grid strategies, and R&D challenges and needs. Major discussion points follow.

- HES characteristics:
  - HES use one or more primary energy sources to produce a variety of desired energy services and mainly electricity, transportation fuels, and merchant chemicals or commodities.
  - HES target clean energy is in the total energy portfolio, not just electricity generation.
  - HES combine clean energy sources with traditional carbon-based conversion system to produce clean energy services.
  - HES help attain energy security, environmental sustainability, and economic stability on a national level by building integrated systems that exploit complementary characteristics of various energy processes to help address energy security challenges in grid level storage, gas-to-liquids, more efficient integration of renewables, and capital deployment efficiency; excess energy is converted to chemical storage.
  - HES overcome random variation in demand and resource production cycles that are a barrier to build-up of renewable energy assets and result in inefficient use of capital.
  - HES help smooth the random fluctuations in gird demand and renewable power generation.
- HES process integration:
  - Utilize dynamic process modeling and systems design and optimization tools developed by INL.
  - Test beds have been setup to commence development of advanced monitors and controls for the HES.
  - The models will help indentify component and component integration testing that is needed to validate the model—or to develop and demonstrate key enabling equipment.
- Questions about energy security and renewables—reliable energy is a balancing act—Optimization Analysis of Strategic Integrated Energy Systems (OASIES) provide answers to some of these questions:
  - How do installations offset assured access with energy security?
  - How do installations balance renewable/alternative generation with reduced environmental impact?
  - On-site generation or off-site generation? Is off-site generation secure?
  - What if there are no renewable resources on the installation?
  - How do installations effectively reduce energy consumption?

- Hybrid Energy Design:
  - Planning Platform:
    - User selects technology mix: Nuclear, BioPlant, HydroPlant, Battery
    - User inputs demand levels
    - Model Calculates: Costs (Capital, Operational), Emissions (NOx, CO, PM10, PM2.5), Power, Energy Resilience
  - Optimizing Platform:
    - User inputs goals
    - Genetic Algorithm selects components: Nuclear, BioPlant, HydroPlant, PrimeMover, Battery
    - Based on:
      - MIN (Costs)—Capital, Operational
      - MIN (Emissions)—NOx, CO, PM10, PM2.5
      - MAX (Power)
      - MAX (Energy Resilience)
    - Results in a set of Alternative Hybrid Energy Designs
  - Transient Platform:
    - User inputs general goals
    - Genetic Algorithm selects components:
      - Nuclear, BioPlant, HydroPlant, PrimeMover, Battery
      - Simulation operates components driven by hourly electrical demand curve
      - Evaluate Objective Functions
      - Results—Candidate Designs
- Examples:
  - Cost of electricity (solar, wind, biomass, nuclear, natural gas, coal)
  - Comparison of steam and electricity prices (does not include reduction incentives)
  - Unconventional liquid fuels options: coal gasification, biomass gasification, steam-methane reforming, high-temperature steam electrolysis, coal pyrolysis, biomass fast

pyrolysis, oil shale retorting, petroleum distillation, biomass hydro-thermal pyrolysis (HP)—oil sands steam gravity drainage, ethanol production, biomass torrefaction, biomass drying

- Alternative use—nuclear hybrid system to offset fluctuations in wind or solar power

- Model for Electric Grid Strategies (MEGS):
  - Designed to address problems of integrating intermittent generation and load
  - Simulates the most salient power system physics:
    - Fine temporal resolution: 100 ms transients
    - Multi-scale: up to 24 h of dynamics for 1 MW to 10 GW systems
    - Fast: <1 min run time
  - Completely developed in-house in less than six months:
    - Uses hybrid modeling technique to manage complexity
    - Simulations may be published to the Web or run stand-alone
    - Simulations can be easily customized for various scenarios (e.g., FOBs)
- R&D challenges and needs:
  - Architecture identification based on local/global requirements and constraints
  - Feasibility, life cycle and economic assessment of identified energy solutions
  - Dynamic analysis, optimization and testing of selected energy solutions
  - Graded approach to identify design, and evaluate architectures
  - Development of dynamic modeling tools to address and develop modeling and simulation methods
  - Enabling technology development and demonstration:
    - New heat delivery systems
    - Topping heat cycles for temperature amplification
    - Thermal energy storage systems
    - Biofuels HES and other architecture design
    - Hybrid hydrogen production processes
    - In-line instruments and controls

- High-temperature materials and component development

- HIL test bed (see figure 24).

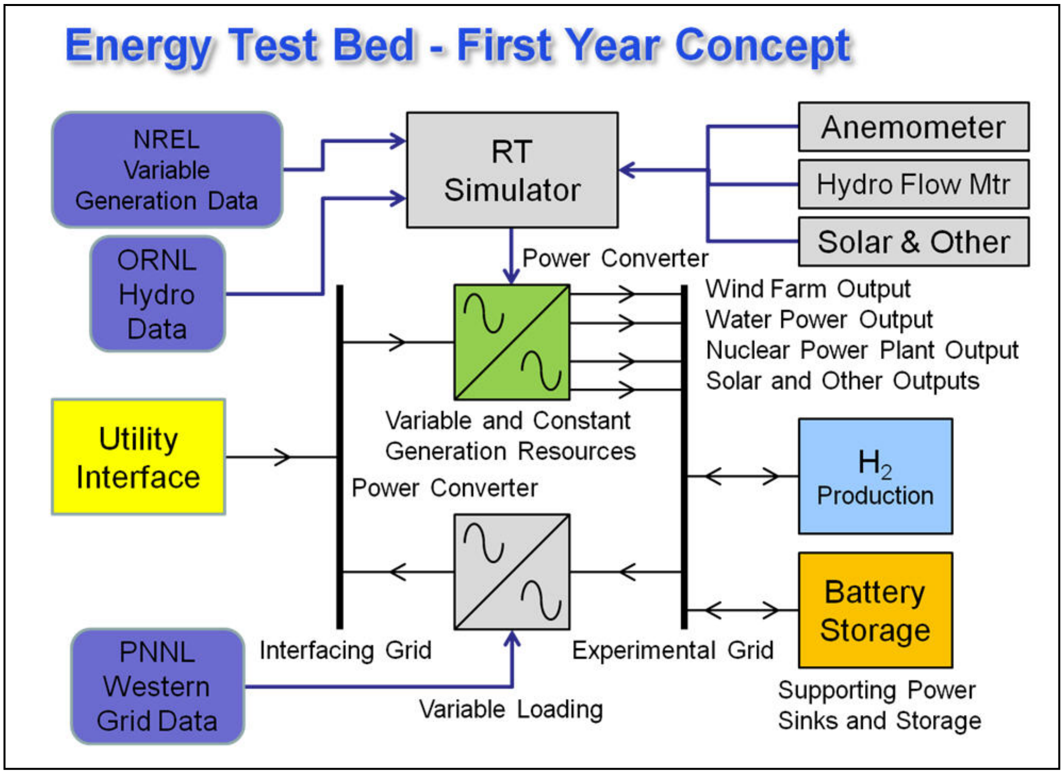


Figure 24. HIL test bed (energy test bed first year concept).

2.17 End Use Loads as Active Participants in the Scalable Energy Networks—Richard Brown, LBNL

Dr. Richard Brown discussed the difference between the traditional power systems and the scalable energy networks. The latter can take advantage of the fact that end-use devices (e.g., cooling equipment, appliances) can increasingly adapt their energy use to local conditions (including power system state, user needs, weather, etc.). Dr. Brown's talk reviewed buildings sector as an example of how intelligent devices and buildings can work interactively with the power grid (and building occupants) to manage peak loads, reduce costs, and ease the integration of intermittent renewable power sources. Military contingency basing was another use case with energy end-uses that are similar to buildings, and an even greater need for power demand management.

- Power attributes of end-use loads (see figure 25):
  - Power quality and reliability (PQR) needs
  - Service shiftability
  - Ability to store energy (e.g., battery) or work (e.g., dynamic voltage restorer)
  - Ability to accept direct DC power
  - Price-responsiveness
  - Ability to use multiple fuels (electricity, fossil fuel, waste heat)
  - Ability to capture waste heat
- Loads differ in power quality and reliability requirements.

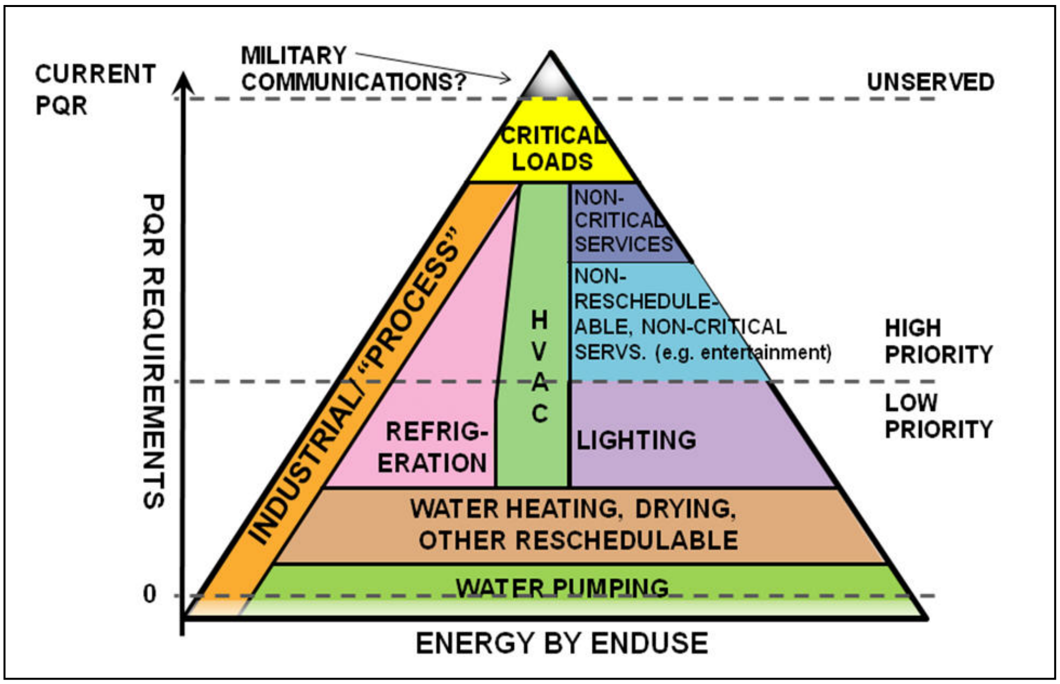


Figure 25. PQR requirements and energy by end use.

- Future smart buildings characteristics:
  - Reconfigurable topology
  - Control pushed further out into network (distributed or device-level control)
  - Interoperable systems
  - Internet Protocol (IP) networking
  - Requires building equipment and devices that are more flexible and intelligent

- Technologies to enable active end-use devices:
  - Standardized communication technology for power distribution (and device control?) within a grid
  - Sensing:
    - Power consumption
    - Service demand and delivery
  - Service modulation (control of energy service delivered)
  - User interfaces:
    - Express service demands
    - Control shiftability
- Summary:
  - End-use loads vary in their ability to be active participants in the power network.
  - Power network and the end-use devices themselves need to be designed to take advantage of these unique capabilities.
  - Smart buildings need better integration, better devices.

2.18 The Perfect Grid—Mr. Kurt Yeager, Perfect Power Institute

Mr. Kurt Yeager described the concept of the Perfect Grid—a truly intelligent electricity grid that creates and maintains a fully integrated electricity network that instantaneously diagnoses and resolves service problems as they arise, and enables the real-time exchange of energy and information between utilities and all their customers. This includes providing an instantaneously accurate, reliable, and secure two-way flow of electricity and information giving all customers an unprecedented level of control over their energy use while eliminating the quality and cost barriers inherent in today's obsolete electricity infrastructure. These Perfect Power Microgrids also enable the integration of local clean distributed electricity resources as practical electricity generation assets. Key discussion points follow.

- Mission of the Perfect Power Institute: "*Improve the competitiveness of our nations' cities and businesses by* <u>*helping electricity industry leaders build the capability to*</u> *dramatically improve power system reliability, efficiency and environmental performance. Improvements paid for by eliminating waste and engaging customers*."
- Transforming the electricity grid for the 21st century (see figure 26):
  - Electronically monitor and control the power system

- Integrate electricity and communications
- Transform meter into a two-way consumer services gateway
- Incorporate renewable and distributed resources
- Reintroduce DC circuits/microgrids
- Enable smart, efficient end uses

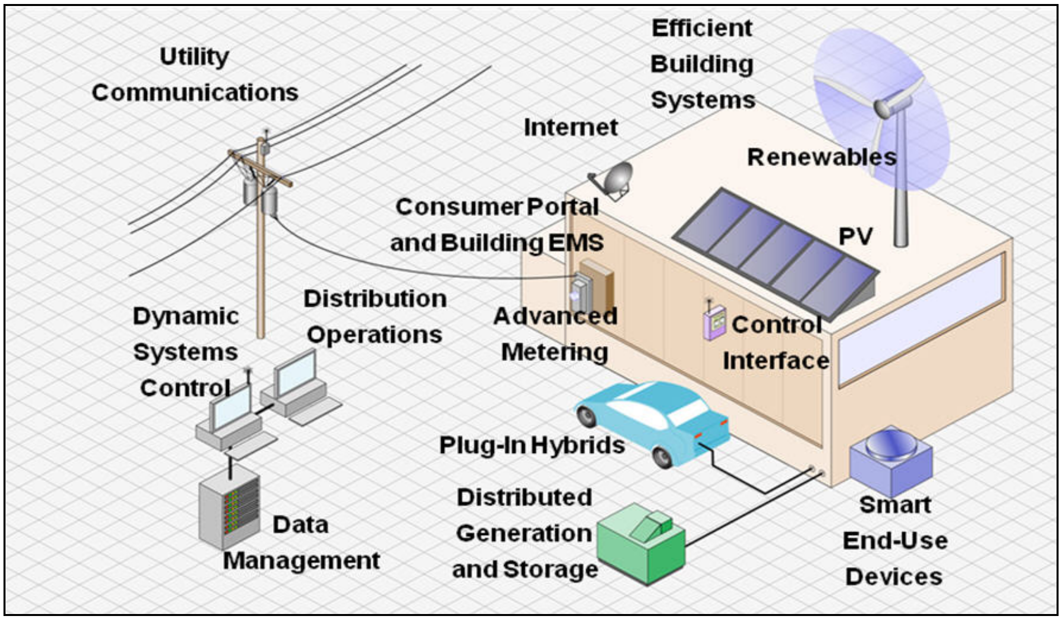


Figure 26. The perfect grid—illustrated.

- Many elements of a "more perfect" electricity system are already available:
  - Supply:
    - Small-scale local generation (e.g., rooftop solar panels) to lessen transmission distances
    - Cogeneration of electricity and heating that significantly reduces waste
  - Delivery:
    - High-efficiency systems that reduce transmission losses
    - Smart switches that reduce outages by automatically identifying and isolating faults and interruptions
  - Use:
    - Smart meters that discount off-peak electricity

- High-efficiency smart thermostats and appliances that automatically adjust to reduce costs and usage

- Perfect Power Institute grid design leadership strategies:
  - Develop comprehensive grid design and performance assessment system.
  - Assist early adopters to achieve and document success, and build wider support.
  - Develop and communicate case studies, prototypes and best practices.
  - Develop a training and learning system to inspire and educate professionals and leaders.
- Perfect power design categories:
  - Reliability:
    - Ensures that the quality and safety are not compromised in the quest for lower cost energy.
  - Consumer Empowerment:
    - Leverage and engage customers as partners, actors, and investors in sustainable power.
  - Cost:
    - Identify and eliminate waste and get more value out of spending/investment.
  - Efficiency and Environment:
    - Promotes environmental responsibility and energy efficiency
- Why establish new metrics and design considerations?:
  - Uncover innovative approaches
  - Build trust, credibility, and customer satisfaction
  - Make the case for investment by revealing waste
  - Benchmark to global standard, reveal gaps
  - Common language for collaboration with stakeholders
  - Education tool for leaders, professionals, operators
  - Competitive differentiation
  - Verify that projects deliver outcomes that matter

- Establish accountability for suppliers
- Shifts the focus to performance outcomes

- Policy implications:
    - Focus on consumer-societal benefits
    - Seamless supply/demand interconnect
    - Consumer empowerment
    - Dynamic pricing
    - Help utilities deal with the inevitable
    - Universal real-time pricing
    - Distributed generation microgrids
    - Retail service competition

2.19 Safe Li-ion batteries for Microgrids—Karim Zaghib, Institut de Recherche en électricité d'Hydro-Québec (IREQ)

Prof. Zaghib discussed his research of safe Li-ion batteries for microgrid. The carbon-coated $LiFePO_4$ Li-ion oxide cathode has been studied for its electrochemical, thermal, and safety performance. Hybrid Pulse Power Characterization (HPPC) test performed on $LiFePO_4$ 18650 cell indicated the suitability of this carbon-coated $LiFePO_4$ for high-power hybrid electric vehicle (HEV) applications. The heat generation during charge and discharge at 0.5C rate, studied using an Isothermal Microcalorimeter (IMC), indicated cell temperature is maintained in near ambient conditions in the absence of external cooling. Thermal studies were also investigated by Differential Scanning Calorimeter (DSC) and Accelerating Rate Calorimeter (ARC), which showed that $LiFePO_4$ is safer, upon thermal and electrochemical abuse, than the commonly used lithium metal oxide cathodes with layered and spinel structures.

NO PRESENTATION AVAILABLE

2.20 Intelligent integrated energy storage for renewable power sources—Frank Cozza, A123/MIT

Mr. Frank Cozza discussed the importance of energy storage for DOD microgrids. He provided case studies that demonstrated the need for Intelligent, Integrated Energy Storage for Renewable Power sources. Mr. Cozza reviewed the safety features of Li-Ion technology along with safety testing results, and the future developments that should be pursued for energy storage.

- Storage benefits to DOD microgrids (see figure 27)—Microgrid Islanded operating mode (outage).

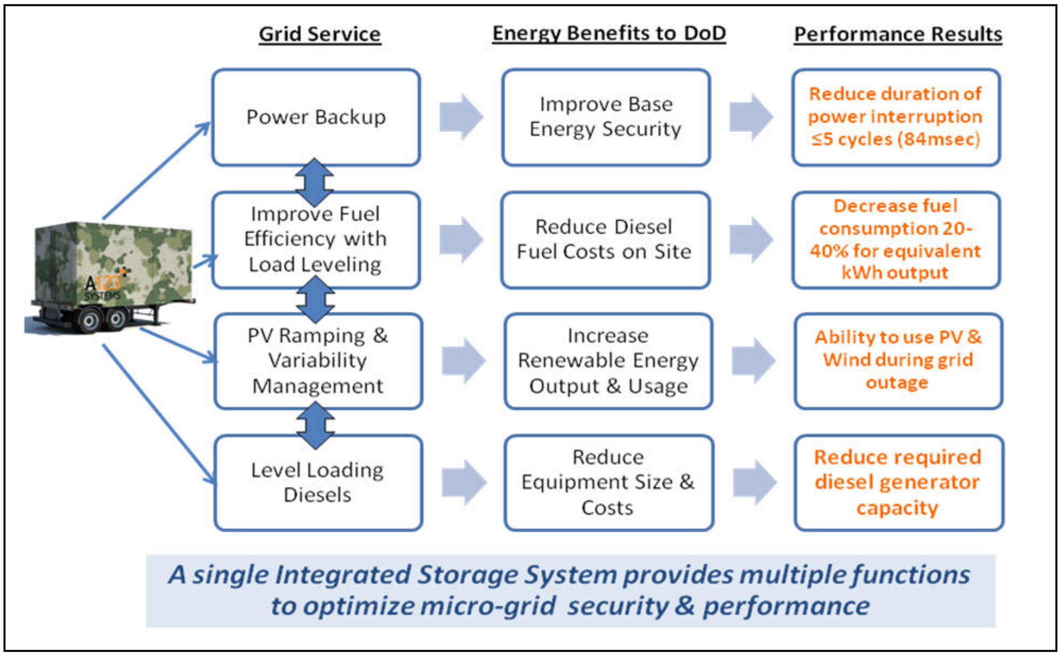


Figure 27. Storage benefits to DOD microgrids.

- State-of-the-art—integrated Li-ion grid energy storage solutions (see figure 28).

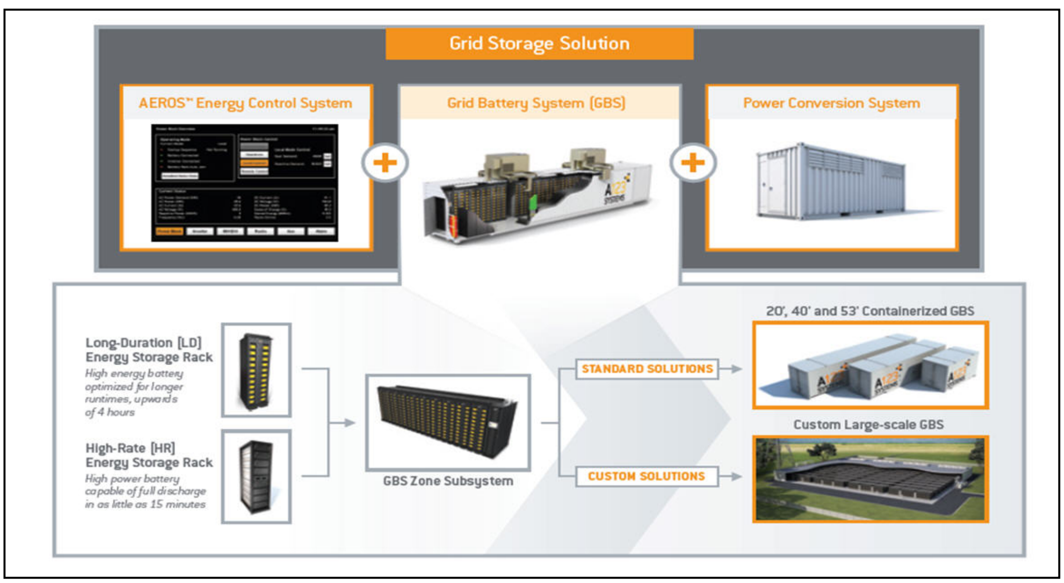


Figure 28. Grid energy storage solutions.

- State-of-the-art—battery technology (see table 3).

Table 3. High-Power Lithium Ion ANR26650 rechargeable cell parameters.

ANR26650	
Voltage (V)	3.3 V
Capacity (Ah) Nominal (Minimum)	2.5 Ah (2.4 Ah)
Energy (Wh)	8.1 Wh
Dimensions (mm)	φ26 x 65 mm
Mass (g)	76 g
Power (W) 10s/90% SOC/1.6V_{min} per USABC HPPC Method	200 W
Specific Power (W/kg) Power Density (W/L)	2,600 W/kg 5,800 W/L
Specific Energy (Wh/kg) Energy Density (Wh/L)	107 Wh/kg 235 Wh/L

- Advanced grid controls—control system will optimize microgrid performance (see figure 29).

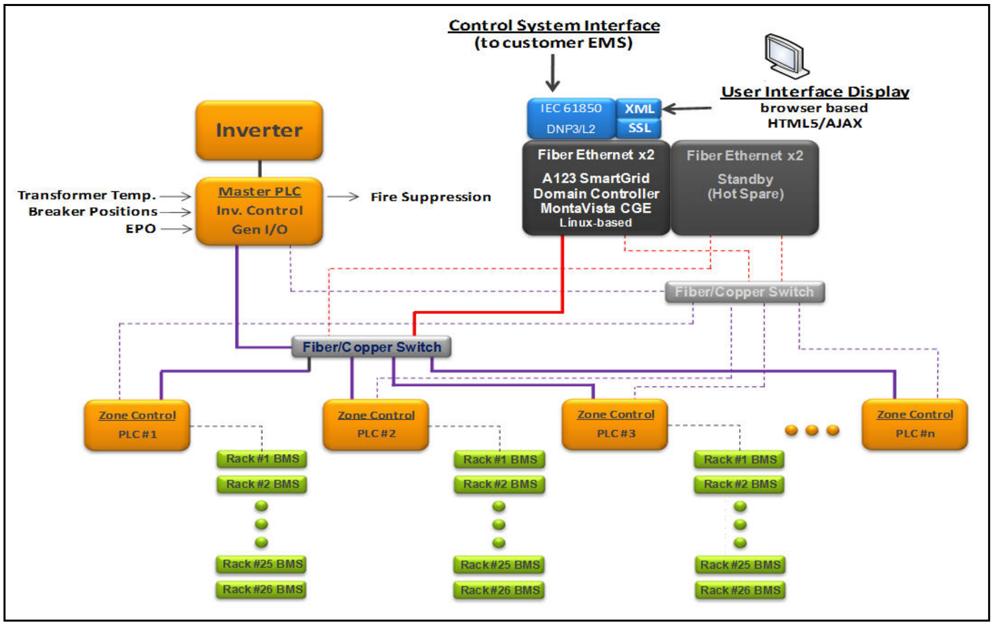


Figure 29. Advanced grid controls (diagram).

2.21 Energy Storage Requirements to Enable Renewable Energy Sources on Deployable Microgrids—Robert Mantz, Army Research Office

Dr. Robert Mantz discussed energy storage requirements and capabilities on deployable microgrids. Dr. Mantz's talk focused on needs for energy storage, energy storage system concept, model to allow use case scenarios to be explored, energy storage metrics, and storage technologies and limitations.

- Vulnerability of fuel supply chain:
  - Fueled generators provide power at forward-deployed bases and camps.
  - Generators account for >70% of fuel usage at camps and bases near the tactical edge.
  - Fuel resupply convoys involve trucks, air, and ground support.
  - Forward locations do not have a reserve energy supply or reliable grid infrastructure.
  - A reliable energy supply from renewables is needed in forward locations.
- Intermittency of renewables spans multiple timescales:
  - Renewable technology is available to generate electrical power for FOBs:
    - Using PV, current power generation is 150 kW on average using one acre of land
    - Wind power varies from 44 kW/acre to 6.5 MW/acre under ideal conditions
    - Inherent fluctuations limit the suitability of renewable energy sources (e.g., wind, solar insolation)
    - Multiple fluctuation timescales
  - Timescale variance necessitates the need for different storage technologies (see figure 30).
  - Energy storage is required to efficiently utilize renewables.

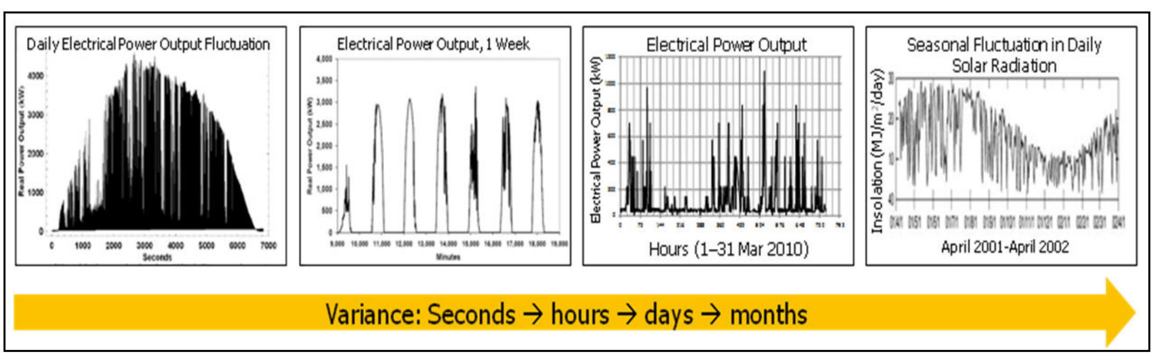


Figure 30. Timescale variance.

- System concept:
  - Current power generation at a FOB:
    - Relies on trucked-in fuel
    - No grid (point-to-point)
  - Future power generation architecture (see figure 31).

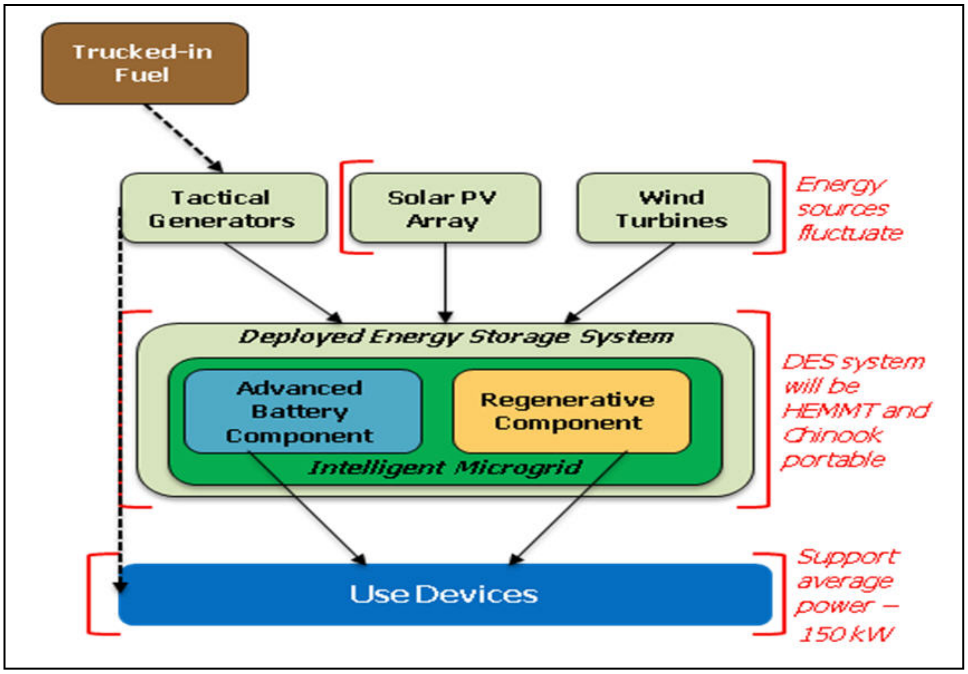


Figure 31. Future power generation architecture.

    - Uninterrupted reserve energy supply for FOB activities
    - Hybrid power storage system:
      - A short-term (for example, battery) component will meet power needs, surges, and disruptions for milliseconds to hours.
      - A long-term (for example, regenerative) component will meet power needs and disruptions for hours to days.
    - Dynamic load sharing between different storage technologies

- Energy storage metrics (see figure 32).

	Final program metrics	Perfomance	Factor
Short-term component	Round trip efficiency	80-90%	**1-2x**
	Specific energy (JP-8 ~12,000 Wh/kg, TNT ~1,300 Wh/kg)	400 Wh/kg	**> 2x**
	Energy density	200 Wh/L	**1.5x**
	Specific power (1x LiIon – 10x Zebra)	200 W/kg	**1-10x**
Long-term component	Round trip efficiency	40%	**> 4x**
	Specific energy	1,000 Wh/kg	**1.25x**
Hybrid system	Uninterrupted average power available	150 kW	–
	Configuration	Less than: 9m L x 2m W x 2m H	–
	Weight	5 x 9,000 kg maximum	

HEMMT and Chinook transportable

Figure 32. Energy storage metrics.

- Model and use case scenario:
  - Model inputs:
    - Average load requirement (150 kW)
    - Available solar and wind power (monthly, site-dependent)
  - Model variables:
    - PV area (1.5 acre) and number of wind turbines (2)
    - Battery charge/discharge rates
    - Max instantaneous load (600 kW)
    - Required duration of energy storage (10-day episode with a 90% loss in renewable energy or a 30% loss of renewable energy over 30 days)
    - Startup time for long-term storage element (1 hour)
  - Model outputs:
    - Size of short- and long-term energy storage components:
      - Short-term/diurnal energy storage requirement (2 MWh)
      - Long-term energy storage requirement (30 MWh)
    - System weight (<45,000 kg)

- Storage technologies and limitations (see figure 33).

	Key characteristics	Energy Storage Challenges	Potential Enabling technologies

Battery technologies  500 kWh Zinc bromide battery container	• Store energy electrochemically (high round trip efficiency, low energy density).
	• Immediate response to power interruptions.
	• Limited duration.
	• Timescale: Milliseconds-hours.
		• Round trip efficiency.
		• Long cycle life at full depth of discharge.
		• High charge/discharge rate.
		• Energy density.
		• Limited reactive material.
			• Novel flow and high temperature chemistries.
			• Flow systems:
			  • Address current battery and energy storage limitations.
			  • Redox materials can be stored externally and flowed into a reactor where energy is generated.

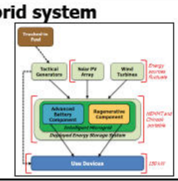
Regenerative technologies  electrolyzer	• Store energy as fuel (high energy density, but lower round trip efficiency). • Fuel sets the theoretical energy density. • Slow (minutes) response to power interruptions. • Timescale: Hours-days.	• Round trip efficiency. • Storage technology. • Carrier liquids.	• Conversion catalysts. • Thermal management technologies. • H_2 storage on hydrocarbon molecules. • Advanced liquefaction technology.
Hybrid system 	• Immediate, continuous response to power interruptions. • Timescale: Milliseconds-hour-days.	• High energy density. • High specific energy. • Integrate with intelligent microgrid technology.	• High efficiency renewable energy sources. • Leveraging Smart Grid technology.

Figure 33. Storage technologies and limitations

2.22 Distribution Fault Anticipation (DFA) Technology—Jeff Wishkaemper, Texas A&M University

Dr. Jeff Wishkaemper discussed the DFA technology providing real-time, online situational awareness not possible with other technologies, and enabling utilities to make informed decisions about system health and operations. The use of high-fidelity current and voltage waveforms, taken from conventional current transformers (CTs) and potential transformers (PTs) enables the diagnostics of the system health. The unique waveform signatures are analyzed using on-line signal-processing and pattern-recognition algorithms for reporting incipient failures and other operational conditions.

- DFA Technology overview:
  - DFA technology is an advanced, multi-purpose monitoring and diagnostic system that alerts users to faults, incipient failures, and other events and conditions on distribution systems.
  - DFA technology has several self-imposed constraints:
    - Standard CTs and PTs as inputs
    - Minimal setup—no requirement for system model
    - No requirement for distributed electronics

    - ➢ No requirement for distributed communications (sub only)
    - ➢ Provide "intelligence," not just data

- Current status of DFA technology:
    - Today DFA hardware and analysis algorithms detect voltage and current signatures indicative of multiple types of incipient failures.
    - The research process revealed that electrical waveforms reflect a broad range of feeder activity, not just incipient failures.
    - Applying on-line signal processing and pattern-matching algorithms to electrical waveforms can provide situational awareness and actionable intelligence for dispatchers, analysts, and repair crews.
    - Need intelligent algorithms for: fault anticipation, diagnosis and protection problems, forensics, operation and maintenance cost reduction, improved safety, reliability, outage management, improved power quality, asset management, and condition-based maintenance.
- Failure types documented in DFA database:
    - Voltage regulator failure
    - Load tap changer (LTC) controller misoperation
    - Repetitive overcurrent faults
    - Lightning arrestor failures
    - Switch and clamp failures
    - Cable failures
    - Tree/vegetation contacts
    - Pole-top transformer bushing failure
    - Pole-top transformer winding failure
    - Bus capacitor bushing failure
    - Capacitor problems

- Data processing by individual DFA devices (see figure 34).

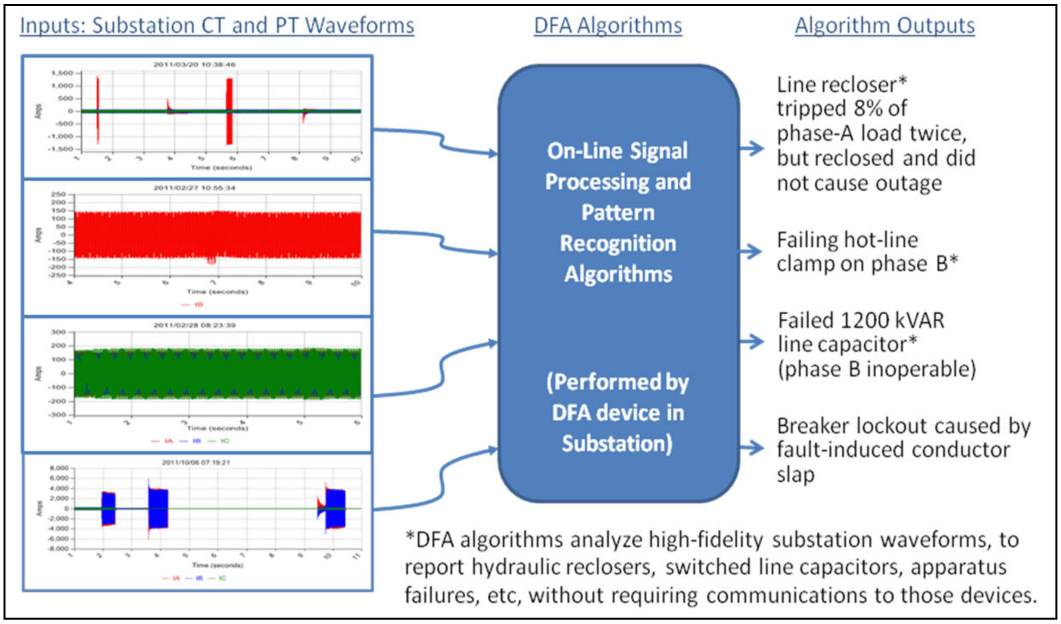


Figure 34. Data processing by individual DFA devices.

- Summary:
  - DFA's fundamental premise is that electrical waveforms reflect feeder activity, and that analysis of these waveforms by sophisticated on-line algorithms can improve the utility's awareness, and therefore operation, of the system.
  - Scope of DFA capabilities and value has expanded greatly beyond original focus on just anticipating failures.
  - Utilities can use the DFA Web site to learn of impending failures, misoperating equipment, protection-system anomalies, etc., and thereby make decisions and take corrective action.
  - Current and anticipated efforts will examine integrating DFA information with other utility information systems and e-mailing alerts to utilities.
  - DFA's implementation anticipates and provides for future enhancements, as new waveform signatures are identified and algorithms are implemented.

2.23 Low-SWaP E-field Sensor and Application for Electric Power Sensing—Maciej Noras, University of North Carolina at Charlotte (UNCC)

Dr. Maciej Noras discussed an effort to develop robust and cost-effective monitoring tools for electric power networks. He presented novel voltage and current measurement sensor, as well as the theoretical and experimental results from its operation:

- Currently used technologies for voltage (potential) measurements:
    - Instrument transformers—voltage transformers (VTs) or PTs are expensive and difficult to install, will not measure well beyond the nominal frequency. The core of the transformer can become saturated, leading to reading errors. If the winding ratio is high, the parasitic capacitance leads to reduction of the measurement bandwidth—cannot measure DC voltages.
    - Resistive divider—directly connected to the live conductor. The resistors need to be of high precision and very high resistance to minimize the current flow. Subject to change of the divider ratio due to resistor material instability over a long period of time. Seldom used in power line measurement and monitoring. They are also relatively large and heavy.
    - Capacitor-coupled transformer—relatively low cost. During the transient conditions the reading error of the capacity-coupled voltage transformers (CCVTs) is very large because the transformers characteristic deteriorate at frequencies other than the fundamental. Influenced by stray capacitances, requires shielding. Parameters of the CCVTs are not stable and shift with time.
    - Electro-optical sensors—the Kerr and Pockel's effects are the electro-optical phenomena that can be used for the DC and AC voltage measurement. The Kerr phenomenon has not been used for power line voltage monitoring. In Pockel's effect the response is directly proportional to the electric field. Pockel's effect devices are expensive and need an external laser beam source and work well up to 20 kHz.
- Other voltage sensing technologies that could (possibly) be used in power industry:
    - Capacitive sensors (inexpensive, will not detect DC voltage, more like an indicator than a meter; company: Fluke)
    - Electrostatic voltmeters (vibrating reed or a high-impedance operational amplifier as a sensor, very good, but very expensive; companies: Trek, Omron, SMC, Plessey Semiconductors, Quasar Federal Systems)
    - Field meters (chopper or rotating vane technology, still relatively expensive and low precision; companies: Monroe, Trek, AlphaLab, Campbell Scientific)
- Why do we need anything beyond what is already available?
    - Growing need for accurate, reliable, inexpensive, easy to mount and small sensors that can provide real-time information about the state of the power lines:
        - Failure detection, including high-impedance faults
        - Essential for avoiding and managing power network events (blackouts, brownouts)

- Increasing use of power electronics (Facts: flow controllers, electronic transformers) and of renewable energy sources requires monitoring of broad spectrum of frequencies (from DC up to 50 kHz)

- Electric field sensing techniques (see figure 35):
    - Induction probe (du/dt)
    - Capacitive coupling probe (du/dt)
    - Kelvin probe (du/dt and dC/dt)

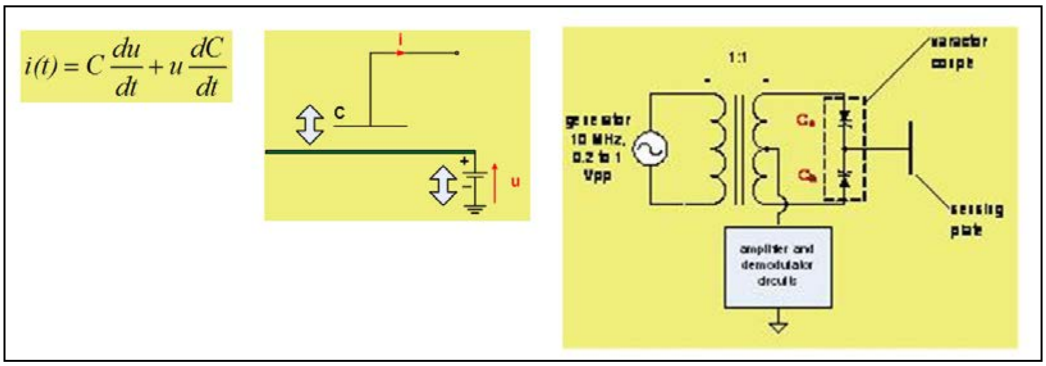


Figure 35. Electric field sensing techniques.

- UNCC's E-field sensor:
    - The sensor can be utilized in detection of the DC and AC electric fields, potentials and charges.
    - Simple construction can be easily miniaturized.
    - Scalable from single V to thousands of kV.
    - Due to a logarithmic character of the varactors' capacitance-voltage dependence, the resolution of the varactor circuit is larger for the small values of the measured electric potentials.
    - Wide frequency range (tested at DC to 5 kHz, 5 MHz possible).
    - It can be used for:
        - Missile detection (funded by the ARL)
        - Power line monitoring and high-impedance fault detection
        - Applications under consideration: EEG monitoring, earthquake prediction

- Summary:
  - New, robust technology—scalable, the characteristics can be changed by manipulating the capacitive couplings (sensor size, distance, varactor characteristics, internal generator frequency tuning).
  - Good frequency response, phase versus frequency needs adjustments.
  - Cheap ($50 for the prototype).
  - Measures DC and AC up to 5 MHz (very broad frequency and voltage range).
  - Can be miniaturized (the current prototype is a combination of through-hole and surface mounted technology, next step can be all surface-mount technology [SMT]).
  - Low-power consumption (1.25 W for the prototype, can be lowered with all SMT components).
  - No need for the solid ground reference.
  - Can be powered from the electric field off the line (work in progress, preliminary stages).
  - Planned for use in the line monitoring (including phasor measurement units) and high-impedance fault detection.

2.24 Remote Sensing Of Hazardous Objects—Peter Zalud, SRI International Sarnoff

Mr. Peter Zalud presented the development of a mobile E-field sensing system integrated on a small pickup truck platform. This system can detect and localize hazardous energized objects in dense urban environments:

- E-field magnitude and vehicle speed are used to detect anomalies, the processor output is converted to acoustic signal in the laptop and overlaid on top of real-time video from the two cameras on the screen. All of this data with global positioning system (GPS) coordinates are logged on the laptop disk. The operator is a key component of the system—key components (see figure 36).

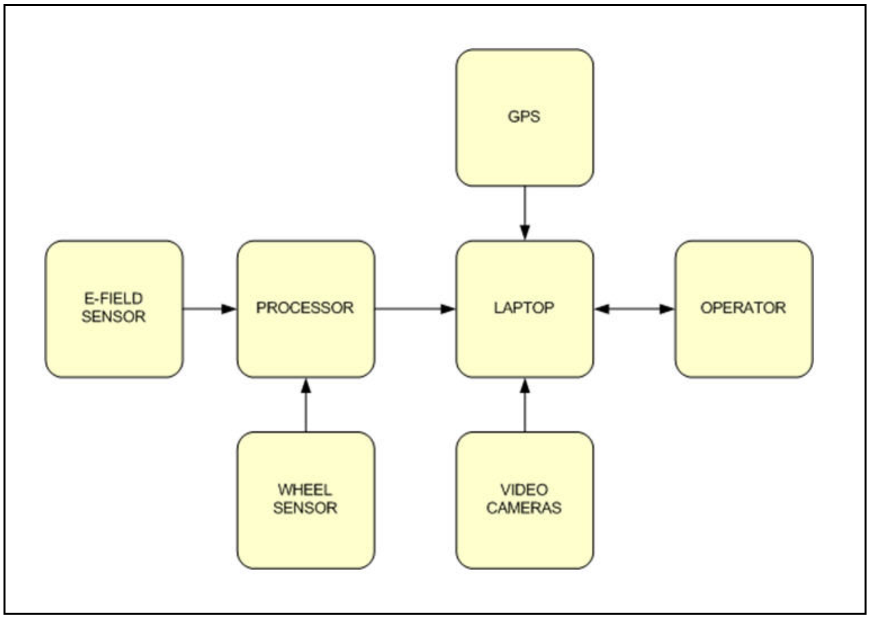


Figure 36. Mobile E-field sensing system—key components.

- Operational and performance capabilities:
  - Senses E-fields (7V/60 Hz) at a distance (15 ft) with sensor mounted on the back of a small pickup truck while moving (15 mph).
  - E-field detection coordinated with standard surveillance cameras and GPS to provide visual information and geo-location of potential targets.
  - Operator in the cabin has acoustic and visual indication of the stray voltage on a laptop computer.
- Deployment experience:
  - Detected over 30,000 voltage hazards during past three years.
  - Reduced public shock instances in New York City, NY, by 80% in less than two years.
- Feasibility study:
  - Analog instrumentation, 60 Hz reference transmitted to receiver, I-Q demodulator, analog-to-digital converter (ADC), laptop.
- Summary:
  - Contactless detection of stray-voltage objects is feasible.
  - Sufficient detection distance to envision detector moving on a sidewalk (or street) sweeping an area of several feet.

2.25 Performance Health Maintenance (PHM) for Vehicle to Grid—A. Dasgupta and M. Pecht, University of Maryland at College Park

Dr. DasGupta presented a system in which plug-in electric vehicles, such as battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate. The presentation discussed the potential advantages of an embedded PHM system, with online anomaly detection and trigger safety mechanisms.

- Center for Advanced Life Cycle Engineering (CALCE) mission (see figure 37).

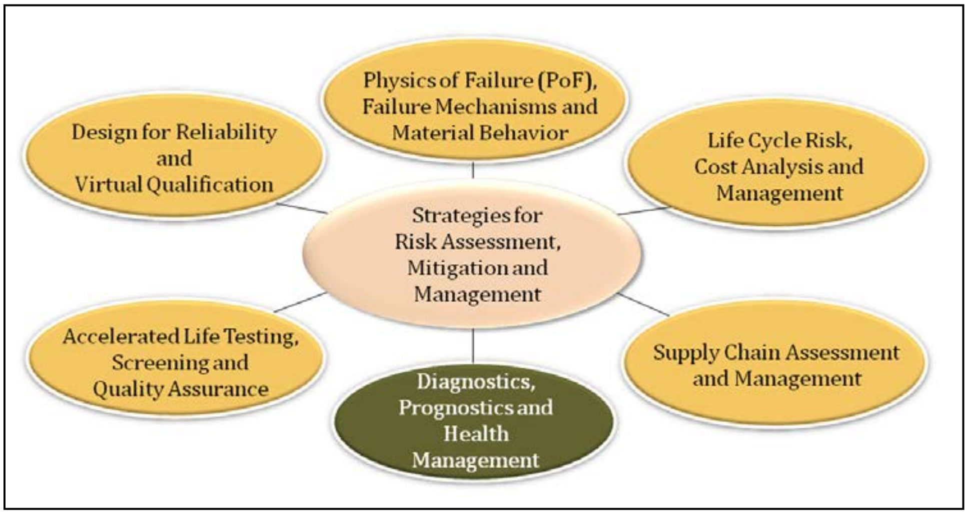


Figure 37. CALCE mission diagram.

- CALCE PHM Consortium Research Program (see figure 38).

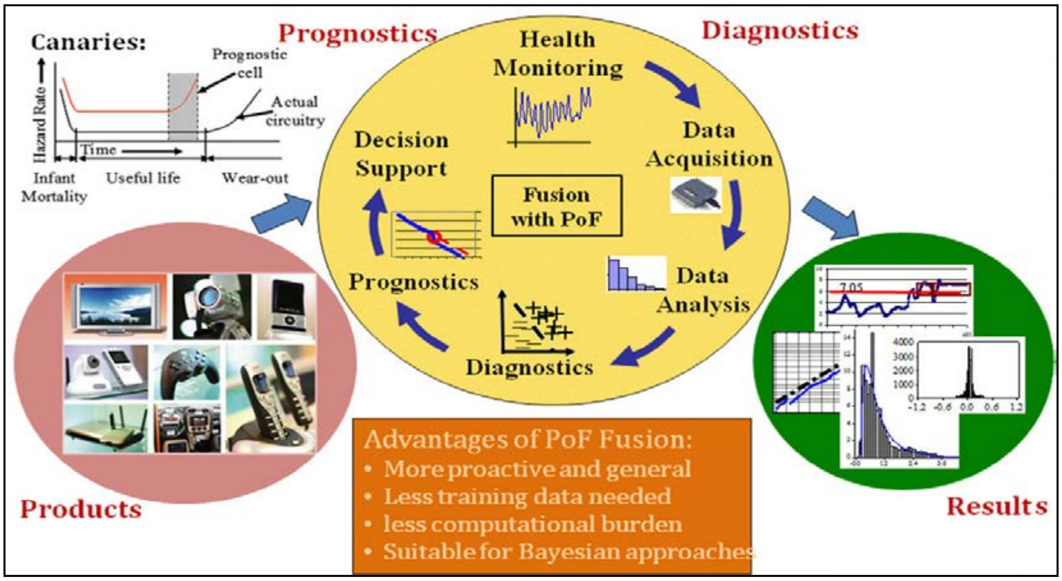


Figure 38. CALCE PHM consortium research program (diagram).

- Vehicle to Grid (V2G) definition—System in which plug-in electric vehicles, such as BEVs and PHEVs, communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate.
- Effect of V2G on battery cycle life:
  - V2G will potentially reduce battery cycle life due to more frequent charging and discharging activities.
  - Battery wear-out is a major concern in V2G applications, because the battery accounts for a significant portion of the total vehicle cost.
  - Battery health prognostic model is needed to develop a strategy to minimize both energy consumption cost and battery degradation.
- Charging safety:
  - Electric vehicle (EV) chargers are high-power devices, can cause safety issues:
    - Level 1: 125 VAC/15 A (or 20 A)
    - Level 2: 240 VAC/40 A–80 A
    - Level 3: 480 V
  - The potential failure modes and mechanisms are not fully investigated.
- PHM for charging stations:
  - Embedded PHM System:
    - Online anomaly detection and trigger safety mechanism
    - Important for family chargers for safety and reliability
  - Remote monitoring network for condition based maintenance (suitable for public charger)
- Data-driven methods for fault detection in batteries and chargers:
  - Sequential Probability Ratio Test (SPRT)—statistical binary hypothesis test based on cross-validation and cost-minimization for optimizing parameter selection.
  - Mahalanobis Distance (MD)—enables dimensional reduction in multi-parameter datasets and supervised classification into severity levels.
  - Projection Pursuit Analysis (PPA)—combines Principal Components Analysis, least squares optimization and Singular Value Decomposition for dimensional reduction, orthogonalization, and unsupervised classification for overcoming masking effects in highly correlated data.

- o Symbolic Time Series Analysis (STSA)—employs combination of wavelet-based noise reduction, MD-based dimensional reduction, time-series discretization, and Markov modeling for classification.
- o Neural Networks (NN)—pattern recognition methods for handling large and complex multivariate datasets with unknown distributions. Self-organizing Maps (SOM) for unsupervised learning, classification, and prediction of remaining life.

- Physics of Failure based fusion methods for prognostics and diagnostics (P&D): Li+ batteries (see figure 39).

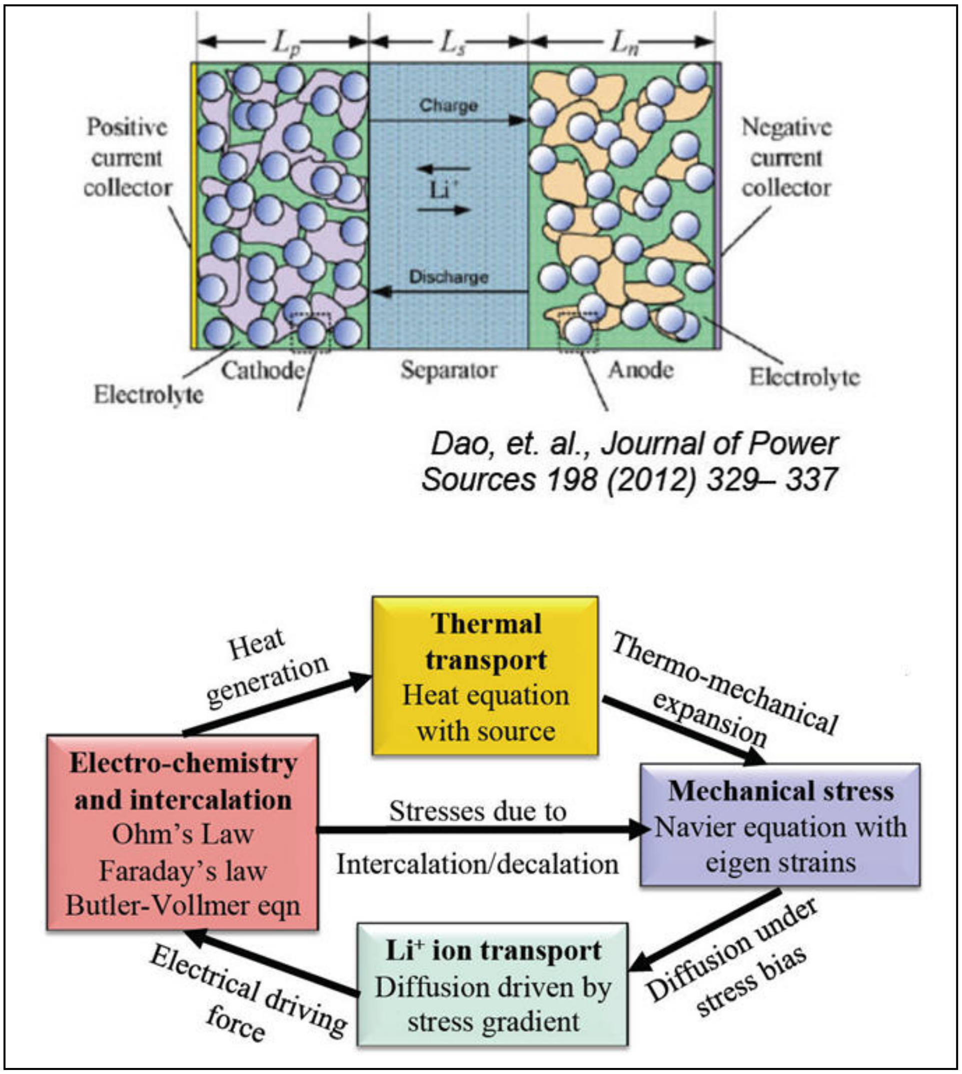


Figure 39. Fusion methods for P&D.

- Battery testing and prognostics should consider V2G effects:
  - o Depth of discharge, temperature, different charging modes and frequencies can impact the battery cycle life.

2.26 Systematic Methodology for P&D—Tools and Case Studies—David Siegel, University of Cincinnati

Dr. David Siegel's presentation focused on review of the methodology and the existing sets of algorithms used in P&D applications. He presented a case study dealing with an intermittent sensor problem, highlighting the data processing steps and the application of such algorithms.

- Common unmet needs in future maintenance and service (see figure 40).

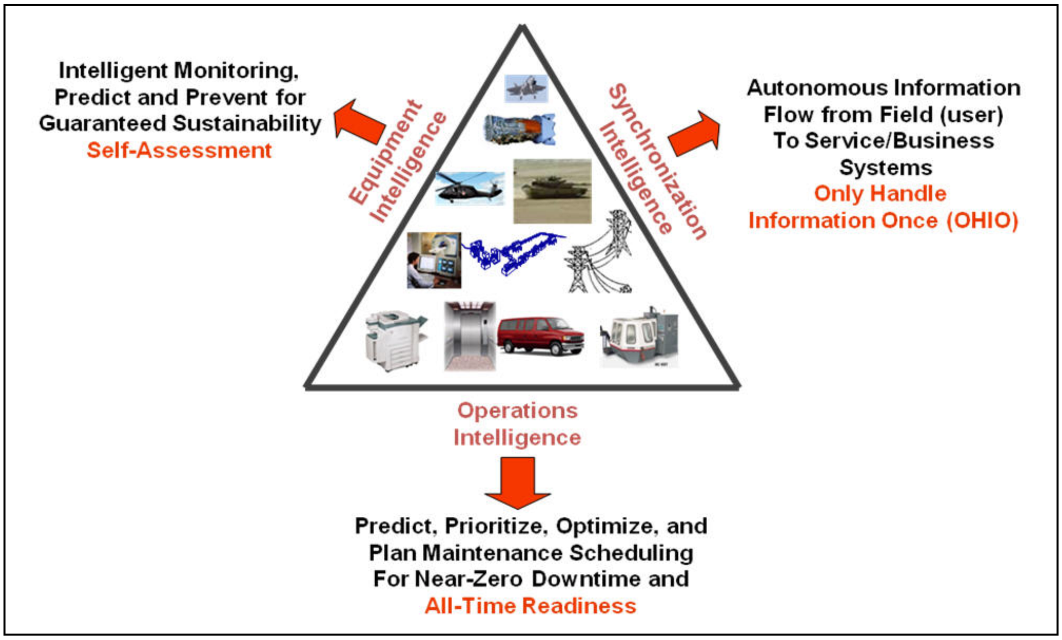


Figure 40. Common unmet needs in future maintenance and service (diagram).

- Intelligent Monitoring System (IMS) data driven Prognostics Health Management approach (see table 4):

Table 4. IMS data driven Prognostics Health Management.

Signal Processing & Feature Extraction	**Health Assessment**
Time Domain Analysis	**Logistic Regression**
Frequency Domain Analysis	**Statistical Pattern Recognition**
Time-frequency Analysis	**Feature Map Pattern Matching (Self-organizing Maps [SOM])**
Wavelet/wavelet Packet Analysis	**Neural Network (NN)**
Principle Component Analysis (PCA)	**Gaussian Mixture Model (GMM)**
Performance Prediction	**Health Diagnosis**
Autoregressive Moving Average (ARMA)	**Support Vector Machine (SVM)**
Elman Recurrent Neural Network (NN)	**Feature Map Pattern Matching (Self-organizing Maps [SOM])**
Fuzzy Logic	**Bayesian Belief Network (BBN)**
Match Matrix	**Hidden Markov Model (HMM)**

- Case study 1—Intermittent sensor health detection using residual clustering algorithm:
  - Algorithm flow chart for shear data set (see figure 41).

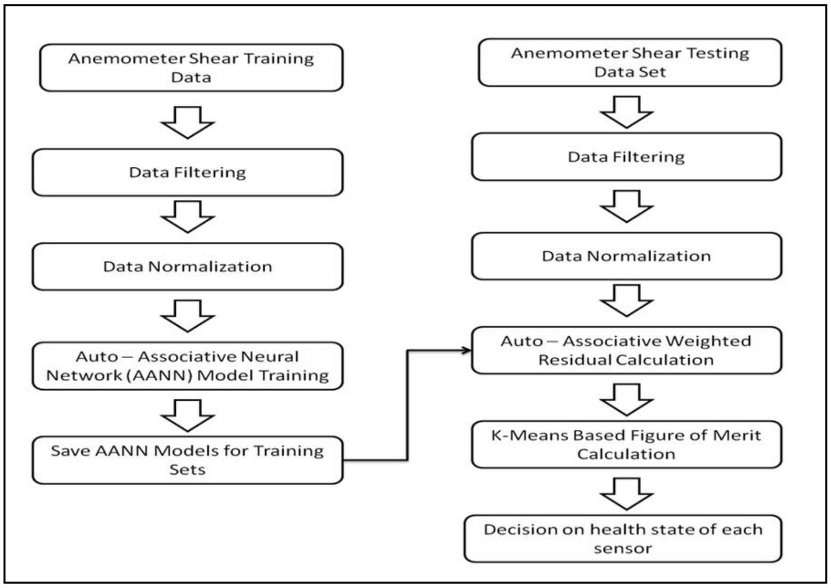


Figure 41. Algorithm flow chart for shear data set.

- Clustering residual value—figure of merit health value:
  - The sensor fault could be intermittent and not present all the time, clustering the residual value could be one way of handling this aspect.
  - The figure of merit health value is the final output and is based on the mean value of the residual value in the more negative cluster.
- Why do Smart/Microgrids need prognostics?
  - Smart Grid design goals:
    - Provide grid observability
    - Accurate control of assets, enhance power system performance and security
    - Reduce costs of operations maintenance and system planning
  - Intermittent energy sources (wind, solar, etc.) along with demand from the move toward electric vehicles will place increased stress on generation, storage, transmission, and management systems.
  - Increased stress leads to increase wear and breakdown.
  - Microgrids are susceptible to unstable transient power signals when they are (dis)connected to the larger gird:
    - Proper system control and prognostics can help manage the effects of these transitions.
  - The overall age of an electrical system is defined by the average age of its components:
    - Replacing old components with new does not necessarily improve the overall health of the system.
    - Managing the repair and replacement of aging components is a key to reduced cost and increased uptime.
- Current work in Diagnostics/Prognostics of Smart Grid/Microgrid:
  - The majority of work has been in identifying and isolating faulty components before they cause instability in the power system as a whole.
  - Fault Diagnosis via Petri-Nets:
    - Transmission lines, transformers, buses, and protective relays are the elements (nodes) of the Petri net.
    - The Petri net transitions are represented by the alarm information generated by the components.

    - The Petri net can identify individual and multiple faults as well as identify faults with uncertain or incomplete alarm information.
  - Fault Diagnosis via Multi-Layered Perceptron:
    - Alarm messages, and tripping commands from protective relays and circuit breakers are used as input vectors.
    - The NN is trained with alarm information from known fault cases.
    - Local Neural Classifiers are used to detect faults in a small number of system components.
  - Fault Diagnosis via Expert Systems:
    - A classification tree was developed based on practical knowledge of the power system and the relationship between its components.
    - Again information about tripped relays and breakers is used to pinpoint faulty components.
- Challenges for microgrid P&D solutions:
  - Most of the current work is just on diagnostics and not early detection or prediction of impending problems.
  - Leveraging existing methods could be one option for components that have developed methods (gearbox, generator, sensors, small gas turbines, or reciprocating engines, etc.)
  - The health information provided by the monitored assets of the microgrid are only one piece, they need to be integrated with an intelligent control and management algorithm.
  - Past implementation of P&D methods have not always been fully integrated with control.

2.27 Prognostics for Microgrid Components—Abhinav Saxena, NASA Ames Research Center

Dr. Abhinav Saxena presented concepts and basics of prognostics from the viewpoint of condition-based systems health management. He discussed differences with other techniques used in systems health management and philosophies of prognostics used in other domains as well. He described the role of constituent elements of prognostics, such as model, prediction algorithms, failure threshold, run-to-failure data, requirements and specifications, and post-prognostic reasoning. He discussed performance metrics and performance evaluation and problems, and challenges in prognostics.

- Goals for prognostics:
    - Contingency management view:
        - Increase safety and mission reliability:
            - Improved mission planning
            - Ability to reassess mission feasibility
        - Decrease collateral damage:
            - Avoid cascading effects onto healthy systems
            - Maintain consumer confidence, product reputation
    - Maintenance management view:
        - Decrease logistics costs:
            - More efficient maintenance planning
            - Reduced spares
        - Decrease unnecessary servicing:
            - Service only specific component that needs servicing
            - Service only when it is needed
- Prognostics for microgrids:
    - Key microgrid components:
        - Power storage—batteries, capacitors and super capacitors
        - Power components and devices—power switches (semiconductor switches and packaging), passive components (inductors, capacitors, high-frequency transformers), controllers and gate drivers
    - Microgrids Prognostics Health Management—potential benefits:*
        - Advanced inverter controls for microgrids
        - Robust operation during fault conditions
        - More informed decision support

(* Key R&D Areas for microgrid reliability as identified in 2011 DOE Microgrid Workshop, San Diego CA)

- Grid Prognostics Health Management Framework—a conceptual notion (see figure 42).

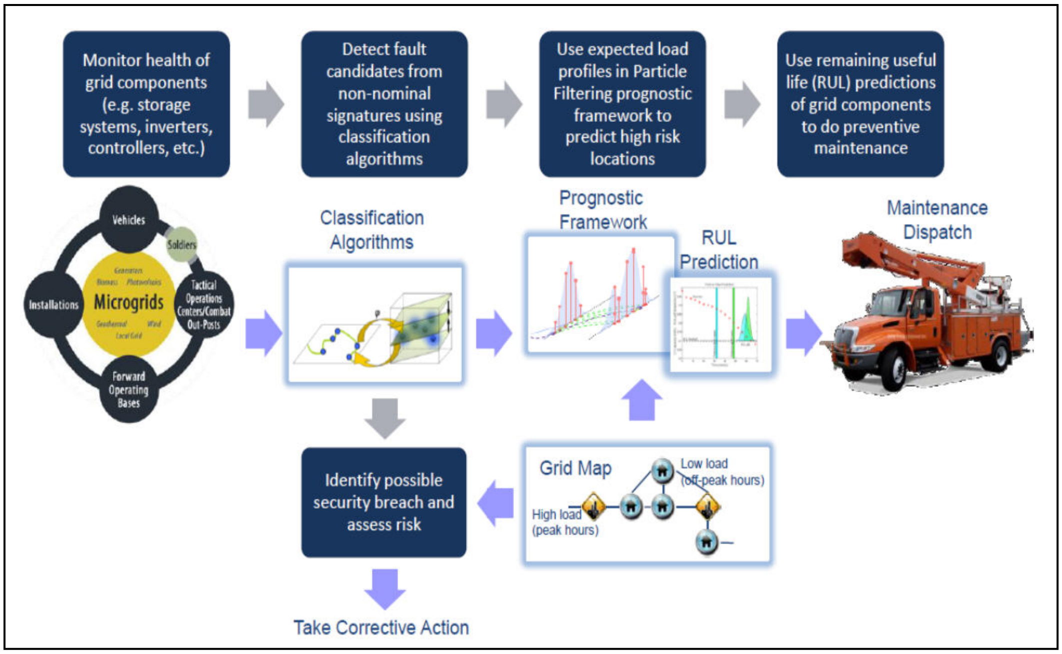


Figure 42. Grid Prognostics Health Management Framework—a conceptual notion (diagram).

- Prognostics categories:
  - Type I—Reliability Data-based:
    - Use population based statistical model.
    - These methods consider historical time to failure data that are used to model the failure distribution. They estimate the life of a typical component under nominal usage conditions.
    - An example: Weibull Analysis
  - Type II—Stress-based:
    - Use population based fault growth model—learnt from accumulated knowledge.
    - These methods also consider the environmental stresses (temperature, load, vibration, etc.) on the component. They estimate the life of an average component under specific usage conditions.
    - An example: Proportional Hazards Model.
  - Type III—Condition-based:
    - An individual component based data-driven model.

➢ These methods also consider the measured or inferred component degradation. They estimate the life of a specific component under specific usage and degradation conditions.

➢ An example: Cumulative Damage Model, Filtering and State Estimation.

- Particle filters (see figure 43).

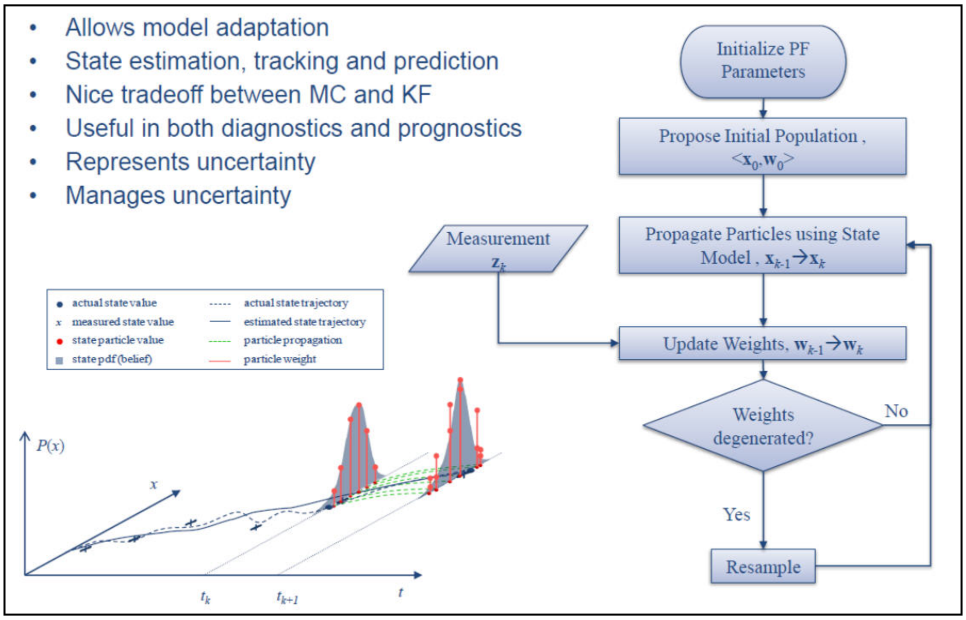


Figure 43. Particle filters (diagram).

- Particle filter-based prognostics (see figure 44).

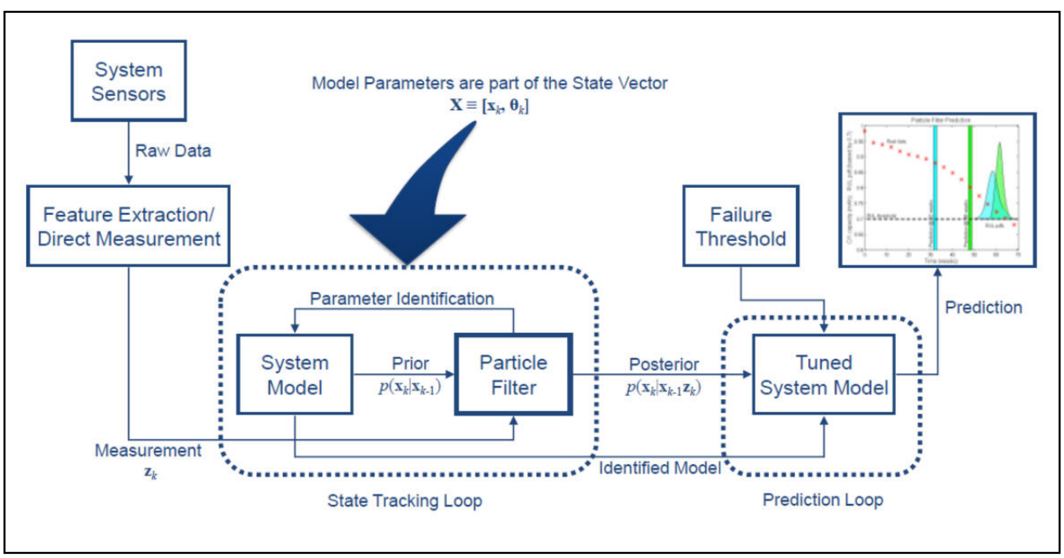


Figure 44. Particle filter-based prognostics (diagram).

- Prognostics applications examples:
  - o Power storage systems—Predicting battery discharge
  - o Power storage systems—Predicting battery capacity
  - o Power electronics failure—MOSFETS
  - o Power component failure—Capacitors
- Metrics hierarchy (see figure 45).

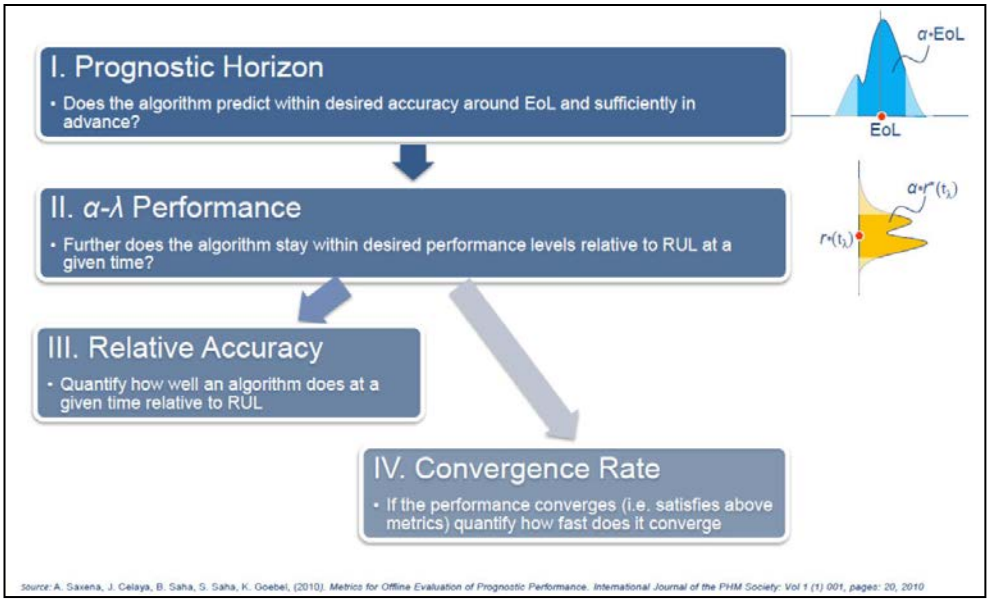


Figure 45. Metrics hierarchy (diagram).

- Prognostic performance metrics (see figure 46).

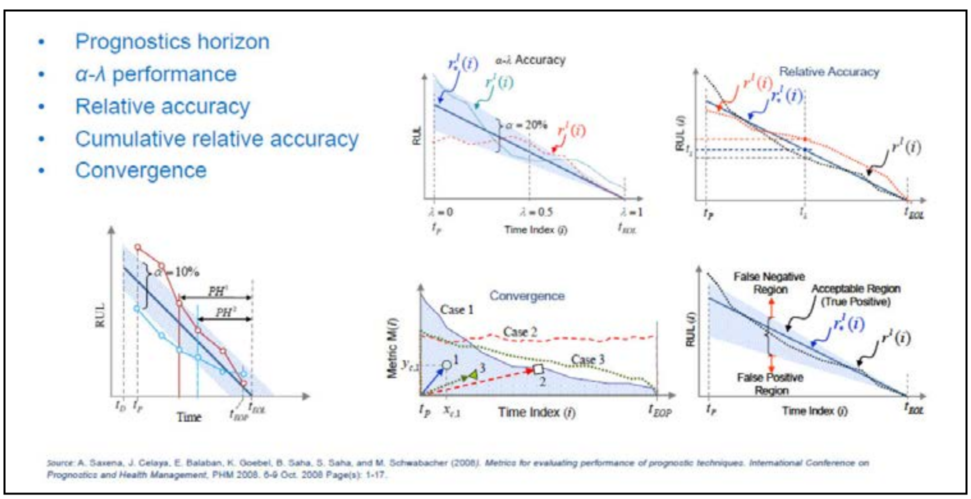


Figure 46. Prognostic performance metrics (diagram).

- Challenges in prognostics:
  - Requirements Specification:
    - How can a requirement be framed for prognostics considering uncertainty?
    - How to define and achieve desired prognostics fidelity?
  - Uncertainty in prognostics:
    - Quantification, representation, propagation and management
    - To what extent the probability distribution of a prediction represent reality?
  - Validation and Verification:
    - How can a system be tested to determine if it satisfies specified requirements?
    - If a prediction is acted upon and an operational component is removed from service, how can its failure prediction be validated since the failure did not happen?
    - Prognostics performance evaluation—offline and online?
    - Verifiability of prognostics algorithms

2.28 Cyber Security for Grids—John James, West Point Military Academy

Dr. John James described a new capability for fast and secure data sharing. The approach is based upon implementation of a recent formal definition and mathematical result derived from the Bell-LaPadula information security result. This approach provides decision makers a means of securely and automatically sharing critical information across security barriers based upon declaration of sharing policies. The declaration and implementation of information sharing policies based upon a need-to-share has been shown to be compatible with information protection policies based upon a need-to-know. Such sharing protected information in real time is necessary for improving distributed control of cyber-physical systems, such as the microgrid.

- Information sharing results:
  - Assumptions:
    - General systems theory applies (updated the Bell-LaPadula discrete models to add continuous system models of current general system theory).
    - Definition of “need-to-share” policy declarations accepted (similar to Bell-LaPadula definition of “need-to-know” policy declarations).
    - Definition of a sharing violation accepted (similar to Bell-LaPadula definition of a security violation).

    - Information owner declares “need-to-share” policies (declares “need-to-share” protected information with selected users and/or groups).
  - Result:
    - FIPS 140-2 protected information is shared in agreement with (IAW) owner policies.
    - Security controls of “need-to-know” information unchanged.
- Implementation overview:
  - Organization (information “owner”) declares a “need-to-share”
  - The Authority Workstation shares Info
  - The Need-to-Share (NTS) cloud receives the shared information
  - Shared content is made available to local nodes
  - Receiving node makes shared content available
- Sharing data in real time:
  - Microgrid implementations should support interfaces to share data with man-in-the-loop control systems such as:
    - Humanitarian assistance/disaster recovery (HADR)
    - Local power grid (Smart grid?)
    - Coalition operations (Air Defense Engagements?)
    - Local Forces C2
  - Initial sharing implementation is multi-cast streaming media:
    - Use current NTS cloud implementation.
    - Begin each multi-cast segment with the encryption key for the following segment using each trusted group’s public key.
    - Only members trusted to receive the content can decrypt the session key for the following segment.
    - At the end of each segment, the sending group’s private key is used to compute a signature for the preceding segment.
    - For each segment, the multicast content can be decrypted quickly and its authenticity evaluated at the end of the segment.

- Disaster response (see figure 47):
  - Sharing data between Military and Government emergency management systems
  - Integrating military command and control systems with the Department of Homeland Security's (DHS) Unified Incident Command Decision Support (UICDS)

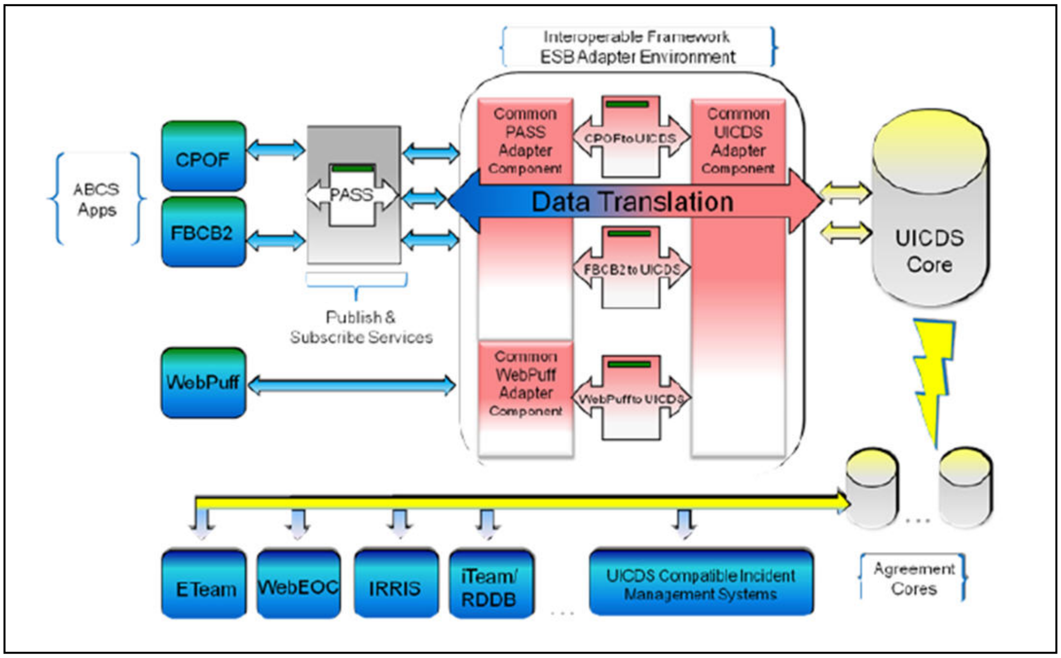


Figure 47. Disaster response (diagram).

- Objectives/concepts/challenges:
  - Microgrid semantics:
    - We do not have the capability to have machine understanding of command intent that matches human understanding of command intent.
  - Microgrid dynamics:
    - We do not understand (cannot predict) dynamics of composed networks (communication, information, and social/cognitive networks).
    - We do not have the capability to achieve cyber-physical situation assessment (state estimation, analysis, and prediction).
  - Microgrid information sharing:
    - We do not provide information system support at the tactical level to share protected information in real time in accordance with command decisions to share.
    - We do not provide belief support for trust and provenance of cyber-physical data.

2.29 Microgrid Situational Awareness for DOD Installations—Steve Fernandez, Oak Ridge National Laboratory

Dr. Steve Fernandez described an analysis framework and computational modules that evaluate the dynamic behavior and impacts due to intermittent generation on grid stability. He showed demonstration results from a visualization system used for real-time status of the electric grid.

- Energy Awareness and Resiliency Standardized Services (EARSS):
    - Pilot to explore open energy (electric grid) status data:
        - Interaction with DOE and community
        - Feasibility based on prior Visualizing Energy Resources Dynamically on Earth (VERDE), expertise and data-availability awareness
    - Geospatial standards for situational energy data:
        - Web-feature service interfaces and representation standards
        - Leading to the National Geospatial-Intelligence Agency (NGA) data brokering (e.g., in Geospatial Intelligence [GEOINT] Online)
    - Enabling geospatial search and streaming-data analysis capability:
        - Spatio-temporal queries relating to energy and infrastructure (including Homeland Infrastructure Foundation Level Data (HIFLD) data sets, etc.)
        - Determine "How does one pose such questions?"
    - Delivered alpha version October 2010.
    - Currently receiving beta test input from potential user community—placed within Homeland Security Information Network (HSIN) Emergency Management (EM) portal.

- EARSS—a description of developed functionality (see figure 48).

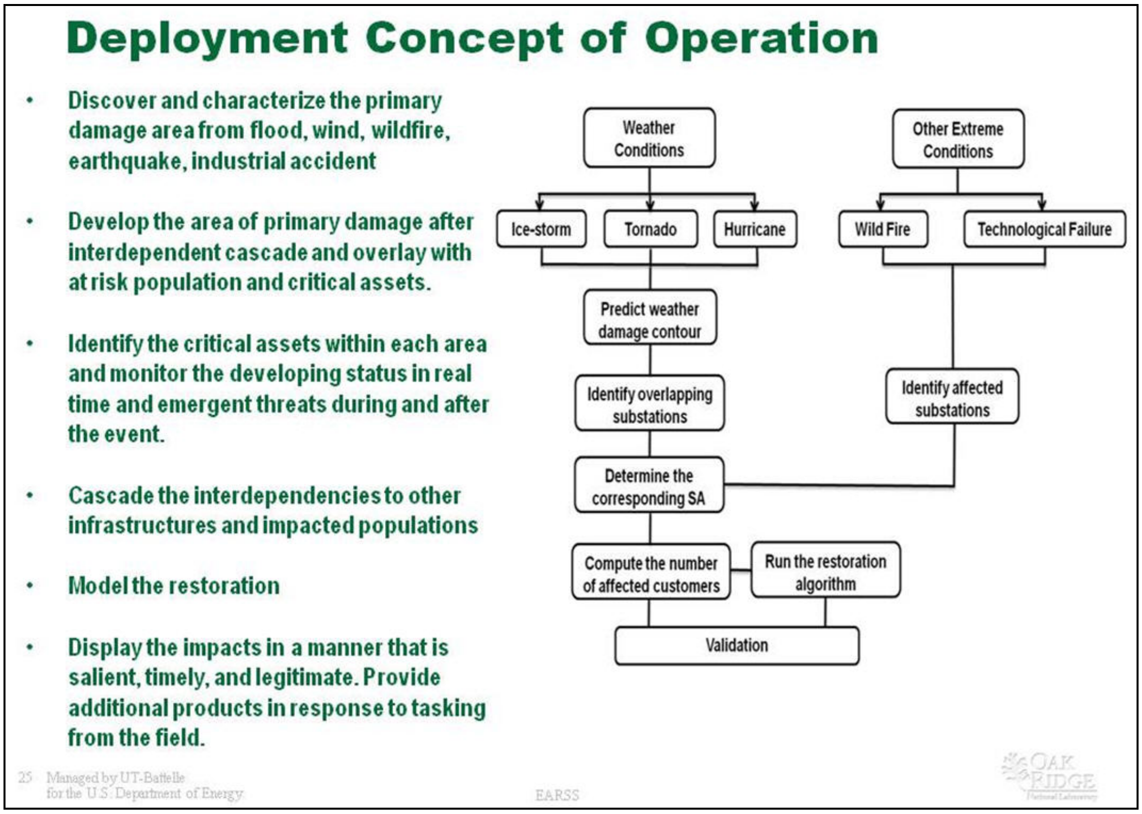


Figure 48. EARSS—a description of developed functionality (diagram).

- Envisioning a class of Web Streaming Services (WSS)—A demonstration of feasibility and steps toward WSS—Sense/Reduce:
    - Stood up GeoServer:
        - Open-Source map software server (GeoTools + Jetty)
        - Multiple input formats (ESRI Shape, PostGIS)
        - Multiple output formats (WMS, WFS, KML)
        - Application-specific logins
        - Web-based administration and map previews
    - Serving grid substations, off, and on lines
    - Scripts to validate and benchmark server
- Summary:
    - Pilot to explore open energy (electric grid) status data

- Geospatial standards for situational energy data:
  - Web-feature service interfaces and representation standards
  - Geospatial search and streaming-data analysis capability through HSIN Platform by
  - Spatio-temporal queries relating to energy and infrastructure (including HIFLD data sets)

2.30 The Needs and Challenges of Adopting Energy Management System for Microgrids—Liang Min, Lawrence Livermore National Laboratory (LLNL)

Dr. Liang Min discussed the evolution of today's EMS for electric transmission and presented the three key functions for microgrid EMS—monitoring, assessment, and control. Specifically, his talk discussed the research needs and challenges for: forecasting technologies for load and renewable energy resources; unit commitment and economic dispatch; and controlled microgrid islanding and re-synchronization.

- The history of EMS in the Electric Grid—(early 1950s until today):
  - SCADA systems and Current EMS systems and applications:
    - Load Frequency Control
    - SCADA, Automatic Generation Control (AGC)
    - Alarm Management System, Network Security Analyses (State Estimator, Load Flow)
    - Load Forecasting, Unit Commitment, optimal power flow (OPF)
    - Real-Time Contingency Analysis (RTCA)

- An example of Real-Time Network Security Analysis (see figure 49).

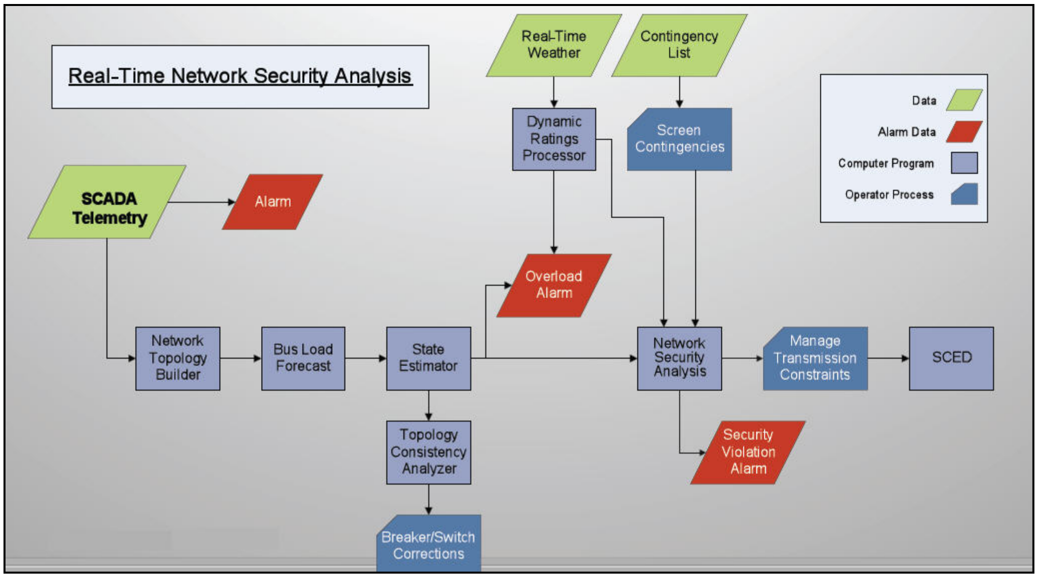


Figure 49. An example of real-time network security analysis diagramed.

- Tomorrow's electric grid (see figure 50).

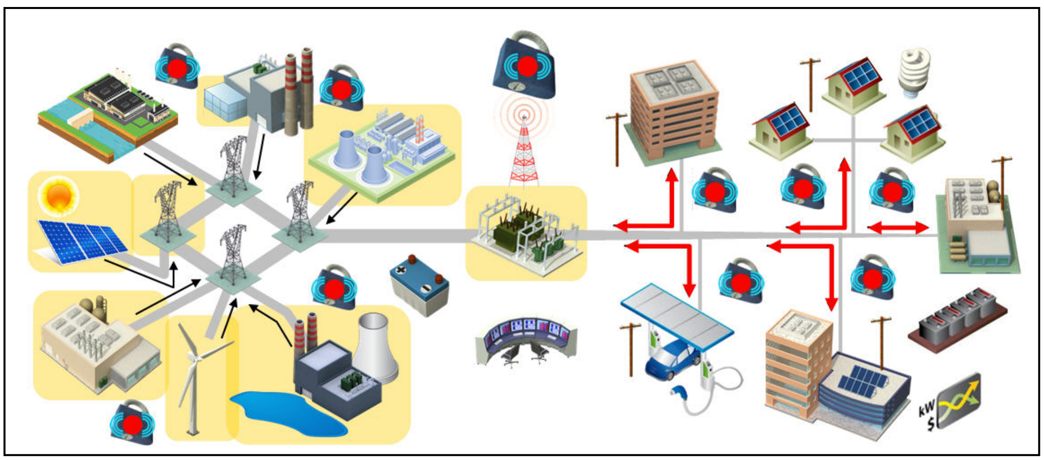


Figure 50. A diagram of tomorrow's electric grid.

- The needs of EMS for microgrids:
  - o Integrate distributed energy resources (especially variable generations, such as solar and wind power) into microgrids.
  - o Dynamically manage energy availability across a larger variety of energy sources, resulting in improved economics, reliability, and efficiency.
  - o Integrate and manage electric vehicle as an alternative ancillary service resource for regulation, as EVs (or PHEVs) begin to proliferate.

- Intelligent islanding and re-synchronization

- The challenges of adopting EMS for microgrids—What we can learn from bulk power system:
  - Forecasting:
    - Challenges on forecasting for high penetration of DER (especially variable generations, such as solar and wind power)
  - Unit commitment and economic dispatch:
    - Challenges on consideration of increasing supply and demand uncertainties into unit commitment and economic dispatch. What are the requirements for load following and regulation under high penetration of variable generation scenarios?
  - Controlled islanding and re-synchronization:
    - Challenges on transition between grid connected and islanded modes on interaction phenomena between distribution generation and high penetration of renewables
- Assess the value of demand response and storage under high-renewable scenarios:
  - Using the Weather Research and Forecasting (WRF)/Data Assimilation Research Testbed (DART) atmospheric modeling system we can reconstruct histories of (a) past actual atmospheric conditions, hour by hour; and (b) the uncertainty the operator would have seen at the start of each day
  - Using Plexos modeling system we reconstruct (1) the stochastic unit commitment given uncertainty each day, and (2) hourly dispatch over the actual conditions that day
  - Statistical model of sub-hourly load and generation variation
  - Load following capacity depends on the state of the generators each hour
  - Regulation is difference between net load and the load following capability
  - Assess the effectiveness of various combinations of technologies in meeting the regulation requirements
- Intelligent islanding and re-synchronization:
  - A real example: Phasor Measurement Units (PMUs) provide direct measurements.
  - Hurricane Gustav on September 1, 2008, SW of New Orleans—there were several transmission lines outages; an electrical island formed in an area including metropolitan New Orleans—formation of island was detected by data from PMUs' rapid diverging oscillations of frequencies that indicated the islanding (see figure 51).

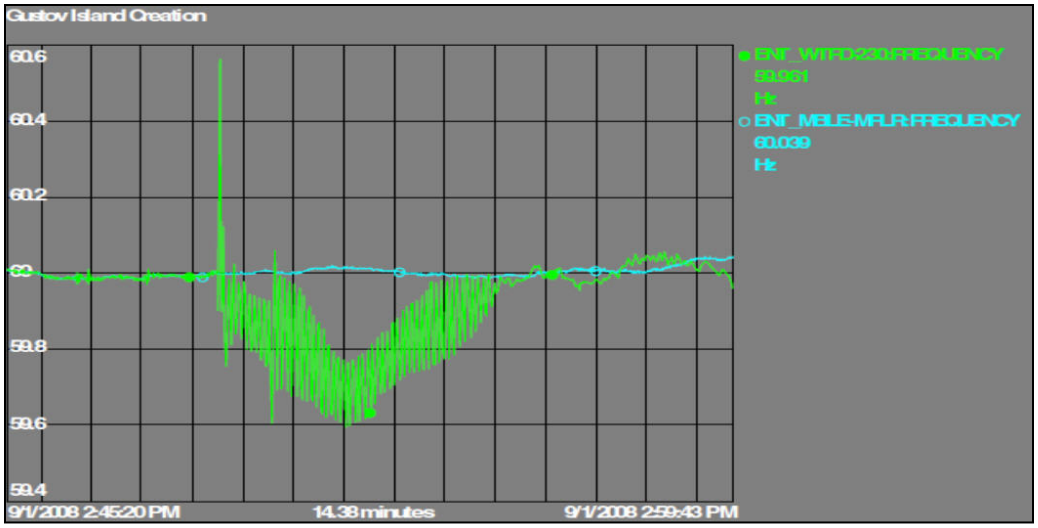


Figure 51. Hurricane Gustav island creation.

- PMU-based intelligent islanding (see figure 52).

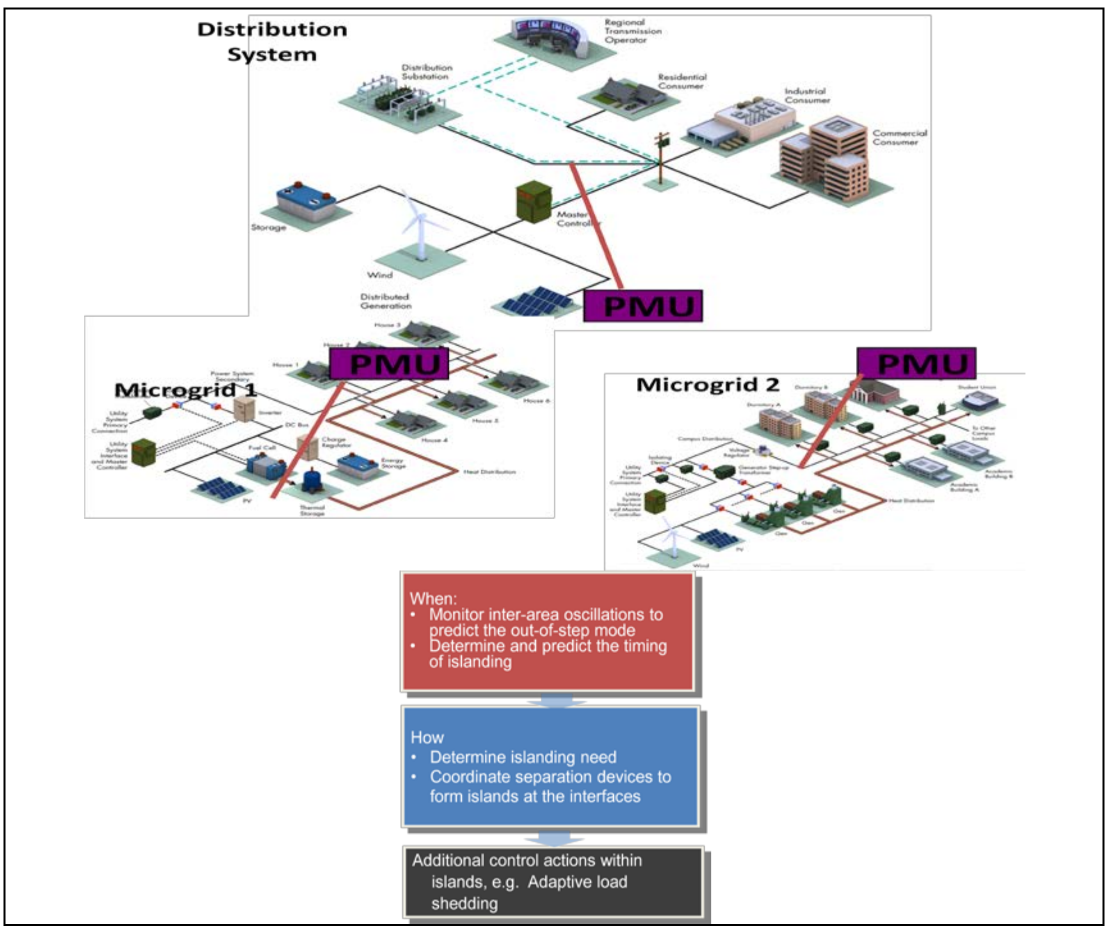


Figure 52. PMU-based intelligent islanding (diagram).

- PMU-based intelligent re-synchronization (see figure 53):
  - With synchrophasors, the phase angles of buses/nodes in different islands can have the same reference.
  - As a result, system dispatchers can compare the phase angles between islands and the distribution system in control center.

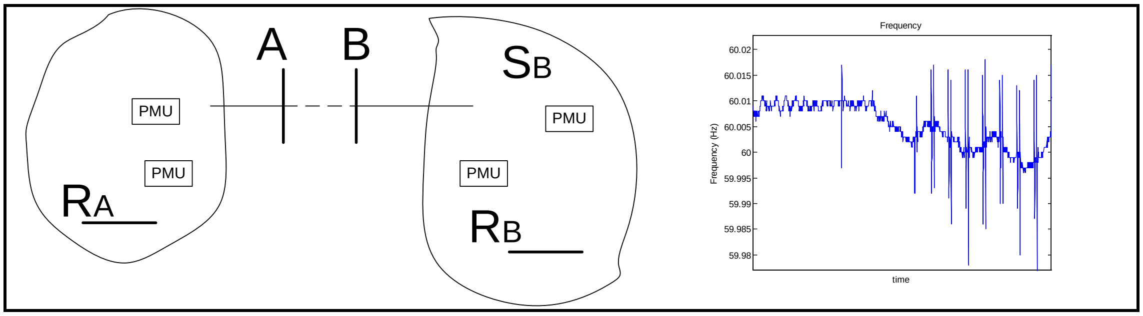


Figure 53. PMU-based intelligent re-synchronization (diagram).

2.31 Integrated, Interconnected and Intelligent Microgrids—Gordon Parker, Wane Weaver, and Steven Goldsmith, Michigan Technology University

Dr. Gordon Parker described the fundamental interactions and influences that all components of a power system have on each other and the overall effect on its performance. His talk showed the framework for a new class of distributed control methods for interconnected energy components based on a game-theoretic and intelligent agent-based model of the power system.

- Integrated, interconnected, and intelligent microgrids—program overview:
  - *Focus*—mobile and interconnected microgrids
  - *Topics*—control, agility, power electronics, Science, Technology, Engineering & Mathematics (STEM) outreach, human factors, business, economy
  - Exploiting tradeoffs between high-power plug-in vehicles, storage and renewable penetration
  - Ensuring optimality, stability, and security during ad hoc scaling and interconnection of multiple microgrids
  - Defining and linking microgrid-relevant STEM topics into new interdisciplinary curriculum threads
  - Developing distributed control strategies at the power electronics level to increase microgrid performance (stability, ad-hoc scaling, cyber security)
  - Modeling and integrating optimal user interaction into microgrid system design

- Energy surety—integrates risk analysis with engineering design so that energy can be delivered with a low probability of failure under expected high-stress scenarios and the impact of unexpected events can be managed:
    - *Safety*—low probability of harm due to non-malicious events—human error, component aging, natural disaster, etc.
    - *Security*—Low probability of harm due to malicious events—terrorism, cyber attacks, theft, etc.
    - *Reliability*—The ability to trust energy delivery under all operating conditions
    - *Recoverability*—The amount of effort required to bring the power back into service after experiencing a disruption of service
    - *Sustainability*—Meeting the needs of the present without compromising the ability of future generations to meet their own needs
- Agile DC bus—a self managed DC power system for the distribution of power from many independent loads from many independent generators in a plug-and-play fashion:
    - Dimensions of agility:
        - Accommodating many heterogeneous voltage levels among sources and sinks
        - Managing the switching of loads and generators on/off the bus at high rates
        - Accommodating generators with time-varying power output capacities
        - Managing in real time the interconnection of multiple DC busses to form microgrids
        - Harmonizing the interests of many principal agents
        - Maintaining cyber security under adverse operating conditions
- Standardized modules:
    - DC-DC converters to mediate generators and loads
    - Agent-based controllers for power planning and coordination
    - Low-power processors and wireless communications
- Base-camp configuration—microgrid approach:
    - Configurable power distribution—multiple microgrids, single microgrid
    - Power directed to where it is needed
    - Utilize all power generation storage assets, i.e., vehicles

- Permits single point, optimal operational energy control in a secure architecture
- Light, rugged, plug-and-play and fuel efficient

- Vehicle microgrid—modern vehicles are microgrids with generation, storage, variable/dispatchable loads, ad hoc interconnection
- Problem space:
  - Vehicle/grid interaction—load shedding; increased renewable penetration; vehicle requirements/duty cycle development
  - Power electronics/control—local versus supervisory control and optimization; control of variable structure systems; modular, intelligent power electronics with on-board control capability for development
- Microgrid programs:
  - HEV mobile laboratory with micro/smart grid
  - AC/DC microgrid power electronics and control test bed (see figure 54):

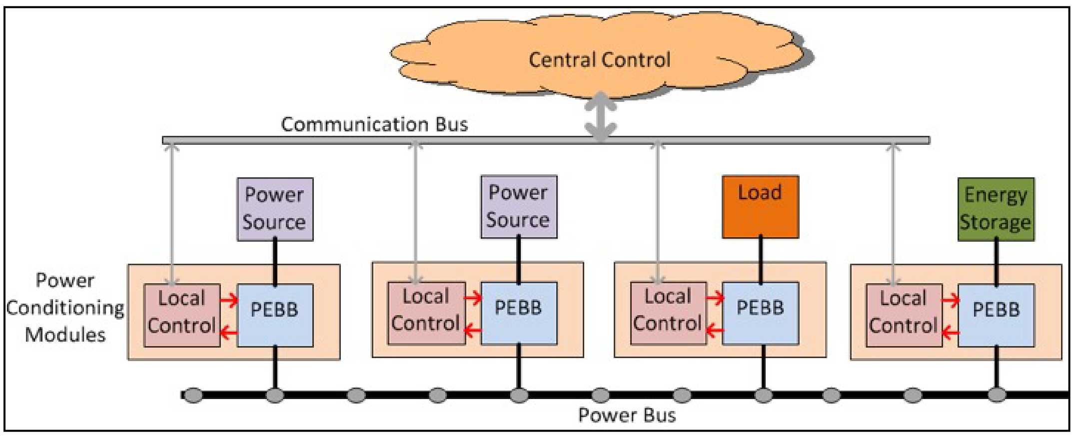


Figure 54. AC/DC microgrid power electronics and control test bed (diagram).

    - Power bus—DC, single or three phase AC up to 600 V
    - Power conditioning modules—Universal Power Electronics Building Blocks (PEBB) with local control up to 1 kW each
    - Power sources—programmable arbitrary profile load
    - Energy storage—NiMH battery pack 48V 13 Ah
    - Data acquisition and control—10 kHz all-signal acquisition and distributed node control
  - Microgrid modeling, control and optimization

- PHEV grid impact
- Storage optimization
- Agent control architecture for agile microgrids:
    - Goals—develop analysis and control methods for DC grids with random load and generation assets-variable structure.
    - Outcomes—Distributed model-predictive control algorithms determine optimal controls that adapt to changing microgrid conditions such as faults, expansion of capacity, and variable generation. Informatics performance models are derived from queuing system analysis.

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Appendix A. Advanced Microgrid Concepts and Technologies Workshop

Agenda

June 7, 2012 (Thursday)

	General Session, Chair: Ed Shaffer
7:30 am	Registration: 60 minutes
8:30 am	Welcome, Army Microgrids Vision Ed Shaffer
9:00 am	DOE prospective on microgrids Stephen Bossart
9:15 am	Advanced microgrid concepts Bob Lasseter , University of Wis
10:00 am	SPIDERS program Jason Stamp, Sandia National Labo
10:30 am	Session Break: 15 minutes
	Power Components, Chair: Paul Barnes
10:45 am	Power electronics for grid applications Alex Huang, NCSU, NSF FREEDM
11:05 am	Power electronics for renewables /storage interface Stan Atcitty, Sandia National Labo
11:25 am	State of the art SMES for grid applications Qiang Li, Brookhaven National Labo
11:45 am	Lunch Break: 60 minutes
	Poster session (during lunch break)
	Power Conditioning, Chair: Bruce Geil
12:45 pm	AC and DC future electronic energy networks Paolo Mattavelli, University of Ten
1:05 pm	Grid emulators and power electronics for utility applications Brad Trento and Fred Wang, Virgini
	Renewable generation, Chair: John Little
1:25pm	Forecasting renewable generation Jan Kleissl, UC-San
1:45 pm	Embedded power converters for renewable energy applications Faisal Khan, University o
2:05 pm	Session break: 10 minutes
	Scalable Energy Networks, Chair: COL Paul Roege
2:15 pm	Scalable energy networks–a new global architecture COL Paul Roege, DA
2:35 pm	Dynamic nanogrid concepts Bruce Nordman,
2:55 pm	Resilient control through distributed intelligent agents Craig Riege
3:15 pm	New electronic design automation tools for efficient, reliable and resilient microgrid Ivan Celanovic, MIT
3:35 pm	Price based energy routing Isaac Faber, U
3:55 pm	Session Break: 15 minutes
4:10 pm	Hybrid energy systems applied to microgrid Mike McKella
4:30 pm	End use loads as active participants in scalable energy network Richard Brown,
4:50 pm	The Perfect Grid Kurt Yeager, Galvin Electricity Ini
5:10 pm	**Discussion Session, Chairs: COL Paul Roege, Ed Shaffer**
5:40 pm	Adjourn

This appendix is presented in its original form without editorial changes.

June 8, 2012 (Friday)

	Energy Storage and Generation, Chair: Cindy Lundgren
8:00 am	Safe Li-ion batteries for Microgrids Karim Zaghib, Institut de Recherche en électricité d'Hydro-Québec
8:20 am	Intelligent integrated energy storage for renewable power sources Frank Cozza, A12
8:40 am	Energy storage requirements to enable renewable energy sources on deployable microgrids Robert Man
	Power Sensing, Chair: David Hull
9:00 am	Distribution Fault Anticipation (DFA) Technology Jeff Wischkaemper, Texas
9:20 am	Low SWaP E-field sensor and application for electric power sensing Maciej Noras,
9:40 am	Remote Sensing of Hazardous Energized Objects Peter Zalud, Sarnoff Lab
10:00 am	Session Break: 20 min
	Prognostics and Diagnostics, Chair: Kwok Tom
10:20 am	PHM for Vehicle to Grid A. Dasgupta and Michael Pecht, UMCP (C
10:40 am	Systematic methodology for P&D David Siegel, Univ. of Cincinnati,
11:00 am	Prognostics for microgrid components Abhinav Saxena, Stinger Ghaffarain Technologies,
11:20 am	Lunch Break, 20 min
	Lunch Session: Communication, Control, and Cyber Security, Chair: Raju Namburu
11:40 pm	Cyber security for grids John James, West Poi
12:00 pm	Microgrid situational awareness for DOD installations Steve Fernandez,
12:20 pm	The needs and challenge of adopting energy management system for microgrid Liang Min,
12:40 pm	Integrated, interconnected and intelligent microgrids G. Parker, W. Weaver and S. Goldsmith,
1:00 pm	Summary Comments Ed S
1:15 pm	Session break: 15 minutes
	Session 11: Government Session–Panel Discussion
1:30 pm	Panel discussion on novel concepts, research priorities, vision for the future Ed S
3:50 pm	Closing remarks Ed S
4:00 pm	Adjourn

Appendix B. Presentations' Abstracts

June 7th, 2012

General Session Chair: Ed Shaffer

0830

Focusing Army S&T for Operational Energy & Microgrid Challenges

Ed Shaffer, Army Research Laboratory

The requirement for power and energy in a modernized, highly digital and network-centric Army is growing exponentially. In addition to the ongoing demand for improved soldier portable power sources, the need for more electric capabilities for combat and unmanned platforms and the requirements of emerging Operational Energy doctrine are driving development of key technologies, including advanced microgrids. "Operational Energy" is defined as the energy and associated systems, information, and processes required to train, move, and sustain forces and systems for military operations. Operational Energy extends the tenets of military energy policy which have been traditionally focused on energy security for large installations and sustaining bases, into the operational and tactical arenas.

The Army is in a unique position to develop a "bottoms up" energy architecture based on aggregating and controlling distributed energy resources. The capability to rapidly integrate and reconfigure local generation, alternative sources, and energy storage on a scalable basis (W-MW) to optimize response to dynamically changing loads, minimize inefficiencies and energy losses, and using mobile or transportable modules is very desirable for military systems. Although a number of emerging technologies are enabling "smartgrid" architectures, many of these efforts assume a fixed grid or installation construct; military environments offer new opportunities toward realizing scalable, reconfigurable energy networks.

The Army S&T community is in the process of shaping its portfolio to address Operational Energy needs. Many of the ongoing underlying material, device and component R&D efforts being done by the Army and others can be adapted toward meeting OE requirements, and many of these will be presented during this workshop. However, our primary goal is to identify key areas where new or additional research focus is needed, and that cannot or will not be met though efforts by others.

This appendix is presented in its original form without editorial change.

Bio: **Dr. Edward C. Shaffer** is the Chief of the Energy and Power Division, U.S. Army Research Laboratory and Lead for the RDECOM Power and Energy Technology Focus Team. Dr. Shaffer received the B.S. degree from the US Military Academy; the M.S. and E.E. degrees from the Massachusetts Institute of Technology, and the Ph.D. degree in Electrical Engineering from Auburn University. He served in a variety of technical and leadership positions as an active duty US Army officer, including Associate Professor of Electrical Engineering at the US Military Academy. Following active duty, Dr. Shaffer was a Senior Design Engineer with Solectria Corporation. He currently serves as Army representative on the DOD Energy and Power Community of Interest (COI) and Chair for the Interagency Advanced Power Group (IAPG) Steering Committee. His awards include the Legion of Merit; he is a Senior Member of IEEE and is a licensed Professional Engineer.

0900

DOE Perspective on Microgrids

Steven Bossart, DOE **-** National Energy Technology Laboratory

Presentation will cover the microgrid program of the Office of Electricity Delivery and Energy Reliability (OE) within the US Department of Energy (DOE). Presentation includes microgrid goals, definitions and concepts; microgrid demonstration projects; microgrid R&D projects; collaboration with military microgrid projects; and microgrid R&D needs. OE's performance target for microgrids is to develop commercial-scale (< 10 MW) microgrid systems capable of reducing outage time for critical loads by 98% at a cost comparable to non-integrated baseline solutions (i.e., UPS plus diesel genset), while reducing emissions by 20% and improving energy efficiency by 20%. Microgrids can be consumer-owned or utility-owned and are a single control point with respect to the primary electric grid. A possible future architecture of a utility distribution system could be distribution control of different types of microgrids including municipal, military, campus, commercial park, industrial, and utility microgrids.

DOE has eight projects within its portfolio that are mainly or exclusively microgrid demonstration projects. Five of these projects were initially funded under the Renewable and Distributed Systems Integration Program and three are funded under the ARRA Smart Grid Demonstration Program. Some key objectives of these projects include demonstration of reducing peak load: ability to integrate variable renewables: ability to operate microgrid in "islanding" and "grid parallel" modes; communication protocols; price-driven demand response; outage management; optimize balance between central and distributed control; and distribution automation. Common technologies include variable renewables and energy storage, various types of communications, smart meters and advanced metering infrastructure, equipment health monitors, electric vehicle chargers, smart appliances, and in-home energy usage displays.

DOE collaboration with DOD on microgrids includes the Energy Surety Microgrid project which attempts to use performance data and lessons learned from military microgrid projects and apply the information to commercial micogrids, and the SPIDERS projects which assist the military in designing reliable and secure microgrids that incorporate variable renewables. High-priority R&D needs for microgrids falls into seven categories including standards, systems design, system integration, switch technologies, control and protection approaches, and inverters/converters.

Bio: **Steven Bossart** is a senior energy analyst at the National Energy Technology Laboratory (NETL). His primary area of study is the electric power sector with an emphasis on Smart Grid. Primary focus is on cost and benefit analysis ARRA Smart Grid Projects. Member of Federal Smart Grid Task Force and Smart Grid Policy Center. He has 27 years of project management and analytical experience at the NETL and its predecessor organizations. He is author of over 70 publications covering a wide range of subjects including coal gasification, waste management, environmental controls, nuclear decommissioning, and Smart Grid. B.S., Chemical Engineering, Pennsylvania State University.

0915
Advanced Microgrid Concepts
Robert Lasseter, University of Wisconsin

Managing significant levels of distributed energy resources with a wide and dynamic set of resources and control points can become overwhelming. The best way to manage such a system is to break the problem down into small clusters of loads and sources. The CERTS (Consortium for Electric Reliability Technology Solutions) concept views clustered generation and associated loads as a grid resource or a “microgrid”. The basic objectives are improved reliability, promote CHP and promote high penetration of renewable sources. The clustered sources and loads can operate in parallel to the grid or as an island. This presentation focuses on the current state of microgrid technology and their application to stationary and forward bases.

Bio: **Robert H. Lasseter** (F’1992) received the Ph.D. in Physics from the University of Pennsylvania, Philadelphia in 1971. He was a Consulting Engineer at General Electric Co. until he joined the University of Wisconsin-Madison in 1980. His research interests focus on the application of power electronics to utility systems. This work includes microgrids, FACTS controllers and the use of power electronics in distribution systems. Professor Lasseter is a Life Fellow of IEEE, past chair of IEEE Working Group on Distributed Resources and IEEE distinguished lecturer in distributed resources.

1000

Smart Power Infrastructure Demonstration for Energy, Reliability and Security (SPIDERS) project

<u>Jason Stamp</u>**,** Sandia National Laboratories

The SPIDERS project (Smart Power Infrastructure Demonstration for Energy, Reliability, and Security) is building three microgrids, each with increasing capability, which will function as permanent energy systems for their sites. The project will promote adoption of microgrid technology for DOD. The resulting microgrids will achieve the following six objectives:

1. Improve reliability for mission-critical loads by connecting generators on a microgrid using existing distribution networks.
2. Reduce reliance on fuel for diesel power by using renewable energy sources during outages.
3. Increase efficiency of generators through coordinated operation on the microgrid and less excess capacity.
4. Reduce operational risk for energy systems through a strong focus on cyber security for the microgrid.
5. Enable flexible electrical energy by building microgrid architectures which can selectively energize loads during extended outages.
6. Develop business cases for microgrid and renewable energy investment for non-islanded operation. This presentation will cover the design methodology and the current status at the three SPIDERS sites.

Bio: **Jason Stamp** is a Distinguished Member of the Technical Staff in the Energy Systems Analysis department at Sandia National Laboratories in Albuquerque, New Mexico. His research areas include cyber security for control systems and the development of energy microgrids for military applications (he is currently the lead engineer of the SPIDERS project for the Department of Defense).

Session Break: 15 min

Session: Power Components
Chair: Paul Barnes

1045

FREEDM System: From Microgrid to Energy Internet

Alex Huang**,** FREEDM Systems ERC

In this talk Dr. Huang will provide an overview of the research conducted at the NSF funded FREEDM Systems Center. The Future Electric Energy Delivery and Management (FREEDM) System is a novel architecture suitable for plug-and-play of distributed renewable energy and distributed energy storage devices. Motivated by the success of the Information Internet, the architecture was put forward by the NSF FREEDM Systems Center as a possible roadmap for an automated and flexible electric power distribution system. In the Information Internet, people share information in a plug and play manner. In the envisioned 'Energy Internet', a vision for sharing of the energy is proposed for ordinary citizen and home owners. Key technologies required to achieve such a vision are discussed. Among many of the key technologies, the development of advanced power semiconductor devices and power electronics systems will be discussed and highlighted.

Bio: **Dr. Alex Huang** received his B.Sc. degree from Zhejiang University, China in 1983 and his M.Sc. degree from Chengdu Institute of Radio Engineering, China in 1986, both in electrical engineering. He received his Ph.D. from Cambridge University, UK in 1992. From 1994 to 2004, he was a professor at Center for Power Electronics System at Virginia Tech. Since 2004, he has been a professor of electrical engineering at North Carolina State University and director of NCSU's Semiconductor Power Electronics Center (SPEC). He is now the Progress Energy Distinguished Professor and the director of the NSF FREEDM Systems ERC. He is also the director of NCSU's Advanced Transportation Energy Center (ATEC). Dr. Huang's research areas are power management, emerging applications of power electronics and power semiconductor devices. He has published more than 250 papers in journals and conference proceedings, and holds 15 US patents. Dr. Huang is a fellow of IEEE and Zhejiang University Qiushi Chair Professor.

1105

Wide-Bandgap Power Switch Reliability for Energy Storage and Grid Applications

Stanley Atcitty[1], Robert Kaplar[1]**,** Sandeepan DasGupta[1], Matthew Marinella[1], Mark Smith[1], Min Sun[2], and Tomas Palacios[2]

[1]Sandia National Laboratories; [2]Massachusetts Institute of Technology

Power semiconductor switches are at the heart of all power electronics systems. While Si-based switches have been effectively utilized for several decades, emerging devices based on the wide-bandgap semiconductors Silicon Carbide (SiC) and Gallium Nitride (GaN) offer potentially disruptive improvements in a number of areas; including, higher efficiency, reduced thermal management, and lower system complexity. Such improvements are especially critical as more renewable energy sources are brought online. Several DOE-sponsored programs at Sandia National Laboratories are currently addressing the issues associated with the implementation of wide-bandgap power electronics in large-scale energy storage and grid transmission systems. This talk will discuss the motivation for moving to wide-bandgap switches from a systems perspective, and will then discuss some of the reliability issues preventing implementation from a materials and device perspective. For SiC Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs), it is demonstrated that gate oxide reliability remains a critical issue, especially at high temperatures, despite the recent commercial availability of these devices. For GaN-based High-Electron-Mobility Transistors (HEMTs), charge trapping in bulk and surface defects is shown to cause current collapse as a result of gate and drain stress, and slow de-trapping transients are analyzed to ascertain the physical nature of these charge traps.

1125

Status and Future Prospect of SMES for Grid Applications

Qiang Li, Brookhaven National Laboratory

Superconductors are capable of carrying electrical current without loss, and hence offer powerful opportunities for increasing capacity, reliability, and efficiency of power grid. The mismatch between variation of renewable energy resources and electricity demand makes it necessary to capture electricity for later use. Developing affordable, large-scale energy storage systems would be a game-changing advance for the grid. Superconducting magnet energy storage (SMES) systems use magnetic fields in superconducting coils to store energy with near zero energy loss, and have instantaneous dynamic response. SMES is currently used to improve power quality around the world. Examples include providing ultra-clean power at some precision manufacturing plants and enhancing stability of the transmission line against uncontrolled voltage fluctuations. Making SMES into a long- term energy storage solution requires the performance of each of the individual subsystems to be propelled far beyond the present state-of-the-art. In this presentation, I will discuss the status and future prospect of grid SMES, as well as major challenges. Highlights from the DOE ARPA-E grid SMES project led by ABB will also be presented.

Bio: **Dr. Qiang Li** is a tenured Physicist and the head of the Advanced Energy Materials Group in Brookhaven National Laboratory. Recently, he has been leading the Lab's effort in several multi-institution projects, including Superconducting Magnet Energy Storage (SMES) System for Grids (DOE ARPA-E), Airborne SMES modeling (U.S. Air Force), superconducting wind turbine generators (DOE ARPA-E), and thermoelectric waste-heat recovery for vehicles (DOE EERE and NSF).

1145 Lunch Break and Poster Session: 60 min

Session: Power Conditioning
Chair: Bruce Geil

1245
AC and DC Future Electronic Energy Networks

***<u>Paolo Mattavelli</u>*,** Virginia Tech

In today's climate of enhanced apprehension about the clash between energy and environment, it is becoming a conventional wisdom to expect that massively increased utilization of electricity in the energy production, transfer, and consumption will provide the necessary means for a sustainable future. Major energy savings will be enabled simultaneously by new electronic energy conversion systems in all energy consuming devices, from home appliances to electric vehicles and industrial waste processing plants. All alternative, sustainable, and distributed energy sources, as well as energy storage systems, will be connected to electric grid through agile and efficient power electronics converters. Starting from the example of a computer power system, the presentation will contemplate possible future ac and dc electronic power distribution system architectures, especially in the presence of renewable energy sources. The proposed nanogrid–microgrid–…–grid structure achieves hierarchical dynamic decoupling of generation, distribution, and consumption by using bidirectional converters as energy control centers. This is illustrated by the description and simulation of static and dynamic operation of a dc nanogrid in a hypothetical future sustainable home. A few concepts for modeling, analysis, and system-level design of such systems, including power flow control, protection, stability, and subsystem interactions, will be presented.

Bio: **Paolo Mattavelli** graduated with honors and received the Ph. D. degree both in electrical engineering from the University of Padova (Italy) in 1992 and 1995 respectively. From 1995 to 2001, he was a researcher at the University of Padova. From 2001 to 2005 he was an associate professor the University of Udine, where he led the Power Electronics Laboratory. In 2005 he joined the University of Padova in Vicenza with the same duties. In 2010 he joined Virginia Tech as professor and member of the Center for Power Electronics Systems (CPES). His major field of interest includes analysis, modeling and analog and digital control of power converters, grid-connected converters for renewable energy systems and microgrids, high temperature, and high-power density power electronics. In these research fields, he has been leading several industrial and government projects. Starting from 2003 he has also served as an associate editor for IEEE Transactions on Power Electronics. From 2005 to 2010 he was the IPCC (Industrial Power Converter Committee) Technical Review Chair for the IEEE Transactions on Industry Applications. For terms 2003-2006 and 2006-2009 he was also a member-at-large of the IEEE

Power Electronics Society's Administrative Committee. He also received in 2005 and 2006 the Prize Paper Award in the IEEE Transactions on Power Electronics and in 2007 the 2^{nd} Prize Paper Award at the IEEE Industry Application Annual Meeting.

Session: Renewable Generation
Chair: John Little

1325
Forecasting Renewable generation
Jan Kleissl, UC–San Diego

Microgrids with a high penetration of variable renewable generation (VRG) sources such as solar and wind require advanced planning to optimize microgrid economics and reliability. Forecasting expected VRG enables such planning minutes, hours, or days ahead. Of particular interest are variability in VRG such as ramp rates and ramp magnitudes that should be counter-balanced by other generators or storage systems. To forecast solar generation, sky imagery is the best tool for intra-hour forecasts, satellite imagery up to several hours ahead, and numerical weather modeling for days ahead. Forecast engines built on artificial intelligence then appropriately select, weight, and correct these data. Advanced solar forecasting tools have been developed and demonstrated at the UC San Diego microgrid and at utility-scale solar power plants throughout California.

Bio: **Jan Kleissl** received a PhD from the Johns Hopkins University in environmental engineering and is an Associate professor in the Dept of Mechanical and Aerospace Engineering at UC San Diego. Kleissl supervises 14 graduate students and numerous undergraduate student who do research on solar power forecasting and solar resource variability to enable grid integration.

1345
Embedded Power Converters for Renewable Energy Applications and Associated Reliability Predictions
***Faisal Khan*,** University of Utah

A solar cell inside a photovoltaic (PV) panel inherently produces dc output which needs to be processed and inverted for ac applications. Unfortunately, power converters used in PV systems are still made of discrete components and are not suitable for mass production. The power engineering and automation research lab (PEARL) team at University of Utah aims to introduce a breakthrough technology to generate 120V/240V ac output directly from the panel. Therefore, the individual PV strings inside the panel would produce ac output rather than dc, and the design is free from failure prone discrete components and interconnections. Interestingly, power converters are complex circuits having both power and mixed signal processing. Like many other electronic circuits, the functionality and performance of a power converter degrades with time, and the amount of degradation depends on several external factors such as any overload, ambient temperature, and connected load types and so on. Converters employed in critical applications are being operated with redundancy and are needed to go through periodic replacements. This periodic maintenance is time and cost intensive, therefore shows promise for optimization. To the knowledge of the PI, there is no known technique to predict the remaining life of an entire power converter. This project aims to find a non-intrusive technique as well a mathematical analysis to quantify the state of health (SOH) of live power converters.

Bio: **Prof. Faisal Khan** received his BSc, MS and PhD degrees from Bangladesh University of Engineering and Technology, Arizona State University, and University of Tennessee, Knoxville in 1999, 2003 and 2007 respectively–all in electrical engineering. From 2007-2009, Dr. Khan has been with Electric Power Research Institute (EPRI) as a senior power electronics engineer. Since 2009, he is with the electrical and computer engineering department of University of Utah as an Assistant Professor. Dr. Khan's major area of interest is high-power capacitor-clamped converters. However, since his appointment at the university, Prof. Khan has extended his research into the field of power converter reliability prediction and cell level power converter design for photovoltaics. Prof. Khan is the founder of the Power Engineering and Automation Research Lab (PEARL) of University of Utah. Under his supervision, PEARL has proposed the revolutionary technique to estimate the remaining life of a live power converter without interrupting the normal operation. In addition, the "AC solar cells" design proposed by his group is which is presently under fabrication. In addition, Prof. Khan is also involved with renewable energy research including wind energy harvesting using split-phase induction generators and grid-tied energy storage. Prof. Khan is a member of the IEEE power electronics society, industry applications society and industrial electronics society. He is the recipient of the 2007 IEEE IAS first prize paper award for his contribution to high-power modular multilevel dc-dc converters. He is the award chair of IEEE ECCE 2012 and the general chair of IEEE COMPEL 2013 in Salt Lake City.

1405 Session Break: 10 min

Session: Scalable Energy Networks
Chair: COL Paul Roege

1415

Scalable Energy Networks–a New Global Energy Architecture

***COL Paul Roege*,** Army Operational Energy Office

Since prehistoric times, mankind has used energy in useful and flexible ways. However, as we have developed more complex systems, application-centric design approaches have tended to limit that flexibility and, in the process, reduced resiliency. The US power grid, a remarkably extensive and coordinated system, provides a significant level of integration among diverse sources and use cases; however, it requires proactive, centralized management to respond to changing loads and to prevent extensive service disruption. Moreover, emergent trends to integrate renewable sources and more electric vehicles will certainly exacerbate the challenges of system control stability.

The concept of scalable energy networks suggests that we emulate the information domain by defining overarching energy architecture with separately defined layers, such as system, control, and transport–reminiscent of the Open System Interconnect (OSI) model. The proposed schema would coordinate all forms of energy through development of new taxonomies, control algorithms, protocols and standards. Fully manifested, scalable energy networks would enable coordinated interchange and management of energy among different forms and at different levels to support diverse applications through "plug and play" connectivity. Stored thermal energy within "smart buildings," electrical vehicle batteries plugged into charging stations, and distributed natural gas sources would interact seamlessly to contribute to, rather than detracting from, stability of local, regional and national energy networks in an interactive manner. This behavior would emulate the Internet, with real-time localized control decisions being made based upon application needs and composite pricing information. Resilient, decentralized control would implement behaviors and priorities informed by respective applications, while networks form and reform in a dynamic manner. Finally, energy conversion, storage and distribution components would be systematically arranged to optimize their respective characteristics such as entropy and time constant.

Development of this new architecture requires collaboration among a number of distinct technical and non-technical communities, including network theory, distributed control, economics, cyber protection, process engineering, and representatives of various use cases. This workshop session is intended to expose relevance of ongoing and emergent research areas, explore use cases to advance our understanding, and identify research or analysis which could advance the concept.

Bio: **Colonel Paul Roege** manages the Army's new Operational Energy Office, where he coordinates service-wide efforts to strengthen military capabilities and performance through effective use of energy.   His goal is to weave energy into system design, business processes and individual behaviors in order to achieve a holistic concept of “energy-informed operations.” In recent assignments, he developed the Army’s Operational Energy concepts and strategies as a special assistant to the Director, Army Capabilities Integration Center, then served as a program manager at the Defense Advanced Research Programs Agency. A registered mechanical engineer, COL Roege has led military and civilian projects to design, build, operate and decommission nuclear, petrochemical and various military facilities in North America, Africa, Southwest and Eastern Asia. He graduated from the United States Military Academy in 1979, received his Masters’ degree in Business Administration from Boston University in 1982 and the degree of Nuclear Engineer from the Massachusetts Institute of Technology in 1985.

1435

Dynamic Nanogrid Concepts

Bruce Nordman**,** Lawrence Berkeley National Laboratory

The Internet upended many assumptions from traditional telecom technologies, enabling applications not previously possible. Similarly, a bottom-up network model of power distribution based on new principles can enable capabilities the traditional grid model cannot deliver. This talk describes local power distribution in which loads are connected to and communicate with a “nanogrid” which sets a local price for electricity and may have local storage. Nanogrids in turn can be connected to each other, local generation, microgrids, or to the backbone grid–scaling to any size. Exchanges of power are all price-mediated, and connections among grids can be of any topology and be changed dynamically. Nanogrids enable better matching of electricity needs (e.g. reliability, cost) to supply and storage, better integration with local renewables, easier use of low-voltage DC, and more flexible and resilient operation. Technologies which digitally manage power distribution exist today as USB and PoE, but lack a local price. Local power distribution is a generally useful technology, not only for all uses of electricity in the military context, but also for general use globally, particularly for people who today lack any access to electricity. By putting quality and reliability at the edge of the network, local power distribution enables a less reliable central grid to reduce costs of the entire network.

Bio**: Bruce Nordman** (bnordman@lbl.gov) is a research scientist with the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory. He has degrees in Architecture and Energy & Resources, both from the University of California, Berkeley. His work includes topics such as energy use of electronics, low power mode energy use, network technologies and energy, user interfaces, and local power distribution. He works with many technology standards organizations.

1455

Resilient Control Through Distributed Intelligent Agents

__Craig Rieger__**,** Idaho National Laboratory

A timely understanding of critical infrastructure interdependencies can alleviate the impact of unrecognized failures that jeopardize mission success. The human aspect is perhaps one of the most complex attributes to characterize, as quantitative results are far from definitive. Even within highly automated facilities, a complex chain of management, engineering and regulatory individuals affect the philosophy of operation for a facility and its associated industrial control system(s) (ICS). Multi-agent analysis provides a worthy approach to decompose these complex relationships, which can then be optimized for mission assurance. The concept of multi-agent analysis originates from the computer science artificial intelligence movement of 20 years ago, but is now being discussed in the context of ICS. However, the complexities of ICS are much different, as the control system design is tied to plant assets, such as valves and transmitters, and therefore is not as amenable to concepts such as platform independence. Within the control system literature, specifically for power systems, a number of papers and texts have been written that discuss the idea of how to codify the dynamics within a multi-agent design. However, a conceptual breakdown of the human and control/cyber elements must be performed on real world examples to demonstrate how these designs can applied. This research takes a propose framework for hierarchical design, using researchers in complex systems, control systems and human systems, and applies it to a Microgrid example for codification of design elements.

Bio**: Craig Rieger**, PhD, PE, is the lead for the Instrumentation, Control and Intelligent Systems distinctive signature area, a research and development program at the Idaho National Laboratory (INL) with specific focus on next generation resilient control systems. In addition, he has organized and chaired four IEEE technically co-sponsored symposia in this new research area. He received B.S. and M.S. degrees in Chemical Engineering from Montana State University in 1983 and 1985, respectively, and a PhD in Engineering and Applied Science from Idaho State University. Craig's PhD coursework and dissertation focused on measurements and control, with specific application to intelligent, supervisory ventilation controls for critical infrastructure. Craig has 20 years of software and hardware design experience for process control system upgrades and new installations. Craig has been a supervisor and technical lead for control systems engineering groups having design, configuration management, and security responsibilities for several INL nuclear facilities and various control system architectures.

1515

New Electronic Design Automation (EDA) tools for efficient, reliable, and resilient microgrid: towards energy informed plug and play power systems

Ivan Celanovic**,** Massachusetts Institute of Technology

Micro-grid is the key towards efficient, resilient, reliable, and flexible power delivery solution—beyond just electrical grid—for many military applications. Indeed, the US military is in a position to lead the way and catalyze the transformative technologies that will enable the transition from "old" grid to the "new" grid. However, there are major challenges to be overcome, in terms of how we design, build, control, test, and configure microgrids. In this talk we present a new approach to EDA based on ultrahigh-fidelity real-time Hardware-in-the-Loop (HIL) emulation platform for power electronics, renewables, and microgrids in general, that enable completely realistic, large-signal modeling of all the dynamical processes (from micro seconds to minutes and hours). Since all the control algorithms are running on real controller platforms (that can be deployed in final converter/system) directly controlling the HIL real-time emulator (via real, unaltered, physical interfaces) rapid system design, testing, QA, and deployment is becoming a reality. In addition, real-time emulation in HIL configuration opens the doors for wider engineering and research community to engage in critical component, subsystem, and system level controls design, testing, and integration without the need for large investment into the high-power test beds.

Bio**: Dr. Ivan Celanovic** received the Diploma Engineer degree from the University of Novi Sad, Republic of Serbia, in 1998; the M.Sc. degree from Virginia Polytechnic Institute and State University in 2000, and the Sc.D. degree from the Massachusetts Institute of Technology (MIT), Cambridge in 2006, all in electrical engineering and computer science. In 2006, he joined the MIT Laboratory for Electromagnetic and Electronic Systems as a Postdoctoral Associate; in 2008, as a Research Scientist he joined the MIT Institute for Soldier Nanotechnologies. His work spans ultrahigh-fidelity real-time emulation of power electronics, smart grid, applied controls and modeling, design and fabrication of photonic crystals, on-chip solid-state energy conversion systems, thermophotovoltaics, and thermoelectric power generation technologies. In 2009 he co-founded the *Typhoon HIL Inc.*, a *Power Electronics Design and Test Automation* company that successfully developed and commercialized an ultrahigh-fidelity real-time emulation platform for the design, testing, and quality assurance (QA) of power electronics. Dr. Celanovic has published over 45 papers, two book chapters, and is leading numerous DOE, NASA, DOD, and industry sponsored projects.

1535
Price Based Energy Routing
***<u>Major Isaac J. Faber</u>*, **United States Military Academy

In recent years energy infrastructure has gained increasing concern. The motivation of cost, environmental impact, and a growing population has increased the scrutiny of the electrical power system in the United States, and by extension the Army. A reengineering of the electrical system along the lines of the Internet could yield potentially significant benefits. The important differences between information and energy transmission would necessarily yield a significantly different architecture. However, many of the concepts and approaches would be similar. *The key difference is the replacement of bandwidth with a price based energy routing scheme.* The fundamental concept is that price can guide energy production and consumption efficiently in distributed networks. In a world of ever increasing security threats and complexity a contribution to the discussion about the Army's future energy issues is needed more than ever. Our proposal is that many of the problems that the future of energy security holds can be addressed though the development of an updated architecture based on pricing information. The significant requirement of this proposal is to develop, at a system level, a method for communicating pricing in order to dictate the flow energy through the network.

Bio: **Major Isaac J. Faber** is an instructor at the United States Military Academy at West Point in the Department of Systems Engineering. He has education and experience in the areas of industrial and systems engineering and operations research. He has research experience in the areas of manufacturing design, financial derivatives, and efficient portfolios. His main area of research is focused on financial engineering and engineering economy. He has taught courses in model based systems engineering, project management, and fundamentals of systems engineering. Major Faber has degrees in Computer Information systems (BS, Arizona State University), and Industrial Engineering (MS, University of Washington). He is a member of the Institute of Industrial Engineers (IIE), the American Society for Engineering Management (ASEM), and Military Operations Research Society (MORS).

Session Break: 15 min

1610
Hybrid Energy Systems Applied to Microgrid
***<u>Mike McKellar</u>*, **Idaho National Laboratory

Hybrid energy systems take advantage of the complementary characteristics of different energy sources-such as renewable, conventional and unconventional fossil, and nuclear sources-to gain efficiencies through advanced integrated system controls and engineering technologies that improve a given system's or process' environmental and energy performance. Examples of hybrid energy systems merge and optimally control units such as bio-mass sources, renewable energies, and nuclear systems to provide stable power production and chemical products such as fuels to provide stability, independence, and security for microgrid systems.

Bio: **Dr. Michael McKellar** received PhD. and Master of Science Degrees in Mechanical Engineering at Purdue University and received a Bachelor of Science Degree in Mechanical Engineering from Brigham Young University. From 1991 to present he has worked at the Idaho National Laboratory. He has worked in the areas of biomass to liquid fuel production, high-temperature electrolysis, natural gas liquefaction, refrigeration systems, nuclear power conversion systems, integration of heat and electricity from nuclear reactor to chemical processes, and carbon dioxide sequestration. His primary expertise is process modeling of thermal systems and testing of refrigeration and liquefaction systems. He currently has 13 patents and many publications in the areas of high-temperature electrolysis, liquefaction, enhanced two-stroke engines, carbon dioxide sequestration, and intelligent valve systems. He is part of a team which received the R&D 100 Award for small-scale natural gas liquefaction.

1630

End-use Loads as Active Participants in the Scalable Energy Network

***Rich Brown*,** Lawrence Berkeley National Laboratory

Traditional power systems are designed on the premise that end-use loads must be equally served at all times, regardless of their varying importance and need for power reliability and quality. Scalable energy networks, on the other hand, can take advantage of the fact that end-use devices (e.g., cooling equipment, appliances, etc.) can increasingly adapt their energy use to local conditions (including power system state, user needs, weather, etc.). This talk reviews the buildings sector as an example of how intelligent devices and buildings can work interactively with the power grid (and building occupants) to manage peak loads, reduce costs, and ease the integration of intermittent renewable power sources. From the power system's perspective, end-use devices in buildings can be categorized by several factors, such as their power reliability requirements, and their ability to shift load. These factors are used as a basis to review the current state of intelligence in buildings and devices, and to define a vision for the role of smart devices in scalable energy networks. Military contingency basing is another use case with energy end-uses that are similar to buildings, and an even greater need to manage power demands. To realize this vision, more development is needed on enabling technologies such as standardized communication protocols and user interfaces.

Bio: **Rich Brown** (rebrown@lbl.gov) is a research scientist with the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory. His degrees are in Operations Research and Energy & Resources. He leads a team at LBNL that is developing solutions to address the growing energy use of electronics and miscellaneous equipment in buildings.

1650
The Perfect Grid
***Kurt Yeager*,** Galvin Electricity Initiative

Electricity is the lifeblood of our nation's economy, security and quality of life. A truly intelligent electricity grid creates and maintains a fully integrated electricity network that instantaneously diagnoses and resolves service problems as they arise, and enables the real-time exchange of energy and information between utilities and all their customers. In order to most expeditiously realize this Perfect Grid transformation, the Galvin Electricity Initiative has developed and is demonstrating with universities and communities an open electricity service system design architecture, customized to local needs, that achieves maximum consumer value. These Perfect Power Microgrids, which can remain linked to the bulk power supply, enable the essential hallmarks of service quality perfection: Maximum reliability and efficiency, entrepreneurial electricity innovation leadership in competitive free markets, plus local new job and enterprise creation. This includes providing an instantaneously accurate, reliable and secure two-way flow of electricity and information giving all customers an unprecedented level of control over their energy use while eliminating the quality and cost barriers inherent in today's obsolete electricity infrastructure. These Perfect Power Microgrids also enable the integration of local clean distributed electricity resources as practical electricity generation assets.

Bio: **Kurt E. Yeager**, former President and CEO of the Electric Power Research Institute (EPRI), created the non-profit Galvin Electricity Initiative, an Initiative focused on transforming the reliability and value of U.S. electricity service, with Robert Galvin in 2005. They also co-authored the book, "Perfect Power." A Fellow of the American Society of Mechanical Engineers, Yeager has served on the Energy Research Advisory Board to the Secretary of Energy, and on National Academy of Engineering and World Energy Council Leadership Committees.

1710 Discussion Session
Chairs: COL Paul Roege and Dr. Ed Shaffer

June 8th, 2012

Session: Energy Storage and Generation Chair: Cindy Lundgren

0800

Safe Li-ion batteries for Microgrid

***Karim Zaghib*, **Institut de Recherche en électricité d'Hydro-Québec (IREQ)

The carbon-coated $LiFePO_4$ Li-ion oxide cathode was studied for its electrochemical, thermal, and safety performance. This electrode exhibited a reversible capacity corresponding to more than 89% of the theoretical capacity when cycled between 2.5 and 4.0 V. Cylindrical 18650 cells with carbon-coated $LiFePO_4$ also showed good capacity retention at higher-discharge rates up to 5C rate with 99.3% couloumbic efficiency, implying that the carbon coating improves the electronic conductivity. Hybrid Pulse Power Characterization (HPPC) test performed on $LiFePO_4$ 18650 cell indicated the suitability of this carbon-coated $LiFePO_4$ for high-power HEV applications. The heat generation during charge and discharge at 0.5C rate, studied using an Isothermal Microcalorimeter (IMC), indicated cell temperature is maintained in near ambient conditions in the absence of external cooling. Thermal studies were also investigated by Differential Scanning Calorimeter (DSC) and Accelerating Rate Calorimeter (ARC), which showed that $LiFePO_4$ is safer, upon thermal and electrochemical abuse, than the commonly used lithium metal oxide cathodes with layered and spinel structures. Safety tests, such as nail penetration and crush test, were performed on $LiFePO_4$ and $LiCoO_2$ cathode based cells, to investigate on the safety hazards of the cells upon severe physical abuse and damage.

Bio: Karim Zaghib Dr. Zaghib is currently Director of Energy Storage and Conversion Department of the CSE (Conversion and Storage of Energy Department) Group at the Institute de research d'Hydro-Québec in Varennes, Quebec, Canada. He obtained his MS in 1987 and his PhD in 1990, both in electrochemistry from the Institut National Polytechnique de Grenoble, France under the direction of Prof. Bernadette Nguyen. In 2002, he received the HDR (Habilitation à Diriger la Recherche) in materials science from the Université de Pierre et Marie Curie, Paris, France. Dr. Zaghib has published 240 refereed papers and 164 patents and served as editor or co-editor of 13 books. He was organiser or co-organiser of 41 symposiums, meetings, workshops. In June 2010, he was the General Chairman for the International Meeting on Lithium Batteries (IMLB) in Montreal, Quebec. He is very active in the Electrochemical Society, and recently completed his term as the Chairman of the Energy Technology Division. Dr. Zaghib is the recipient of the International Electric Research Exchange (IERE) Research Award (2008) in Iguaçu, Brazil, the International Battery Association (IBA) Research Award in January 2010 and Electrochemical Society Energy Division Research award, April 2010. In 2011 Dr. Zaghib has been elected as ECS Fellow.

0820
Intelligent, Integrated Energy Storage for Renewable Power sources
Frank Cozza**,** A123/MIT

This presentation will discuss why energy storage is important for DOD Microgrids. Case studies will be examined that will demonstrate the need for Intelligent, Integrated Energy Storage for Renewable Power sources. A quick review of the safety features of Li-Ion technology will be presented along with safety testing results. Finally, there will be a discussion of what future developments should be pursued for Energy Storage.

Bio: **Mr. Franck Cozza** is the Senior Program Manager for Energy Storage applications for the Department of Defense Micro-grids. He has over 20 years experience in working for and with the DOD to develop solutions involving energy efficiency, facility system optimization, and soldier protection. Most recently, he was the Program Manager at Siemens Government Technologies for the Utility Monitoring and Control System IDIQ contract with the US Army Corps of Engineers, Huntsville Center of Excellence. Mr. Cozza is a graduate of the United States Military Academy and holds advanced degrees in Physics from the University of New Mexico and International Relations from Boston University. He served 21 years in the US Army and retired as a Lieutenant Colonel. He served overseas for 4 years and also was an Assistant Professor of Physics at USMA for 3 years. He is LEED certified.

0840

Energy Storage Requirements to Enable Renewable Energy Sources on

Deployable Microgrids

Robert Mantz, Army Research Office

To maximize the use to renewable energy sources in microgrids used at forward operation bases they need energy storage capabilities. This is due to the intermittent nature of many renewable energy sources, such as photovolatics and wind turbines. A model to quantify both short term and long term energy storage requirements was developed and the characteristics and trade space of the energy storage element determined for an example forward operating base.

Bio: Dr. Robert Mantz is the Electrochemistry program manager and the Army Research Office. He has a broad background including: energetic materials, fuels chemistry, paints and coatings, synthesis is silsesquioxane containing polymers, and electrochemistry and characterization of ionic liquids. He has recently returned to ARO after being detailed to DARPA as the program manager of the Biofuels Program.

Session: Power Sensing

Chair: David Hull

0900
Distribution Fault Anticipation (DFA) Technology
Jeff Wishkaemper**,** Texas A&M University

The past decade has witnessed mainstream application of “smart” control and monitoring technologies to electric power distribution systems. From AMI systems to power-quality meters, technologies create an exponential increase in the volume of electrical data reflective of system conditions. The data contains incredible inherent value, but the sheer volume of data makes it impractical for human analysis to extract much of the value. For more than a decade, researchers at Texas A&M University have focused on the use of high-fidelity current and voltage waveforms, taken from conventional current and potential transformers (CTs and PTS) to diagnose system health. They have discovered unique waveform signatures that represent incipient failure of various line apparatus, and they have created on-line signal-processing and pattern-recognition algorithms for examining waveforms and reporting incipient failures and other operational conditions. In addition, researchers have found serendipitous value in analyzing electrical waveforms to monitor the performance of other “smart grid” technologies, such as self-healing systems. Known as Distribution Fault Anticipation (DFA), this technology monitors dozens of distribution feeders across the North America, providing real-time, online situational awareness not possible with other technologies, and enabling utilities to make informed decisions about system health and operations.

Microgrids face the conventional challenges associated with apparatus failure. In addition, microgrids incorporate unique loads, weak sources, distributed resources, and advanced control and protection systems. These features of a microgrid, and particularly the complex interaction between its constituent components, make the process of engineering, operations, troubleshooting, and refinement difficult. Systematic acquisition and analysis of high-fidelity electrical-waveform data may provide a valuable tool for understanding, and thereby overcoming, operational and engineering challenges in the microgrid environment.

Bio: **Jeff Wischkaemper** (M’2006) received his B.S. and Ph.D. degrees from Texas A&M University in Electrical Engineering in 2003 and 2011 respectively. Dr. Wischkaemper is a member of the Power System Automation Laboratory and has worked on a variety of research projects including investigating arcing on low-voltage networks, characterization of non-traditional sensing technologies, and electrically characterizing vegetation contacts with conductors

0920

Integrated Clamp-On Voltage and Current Measurement Sensor

***Maciej Noras*,** University of North Carolina at Charlotte

This work is an effort to develop robust and cost effective monitoring tools for electric power networks, as part of a smart grid initiative. The paper presents a novel voltage and current measurement sensor that can be easily deployed at a desired location in the live power transmission system. The sensor does not require galvanic contact with the energized conductor, allowing for measurements on bare and insulated wires and unshielded cables. The theoretical background of the sensor operation as well as experimental results are presented and discussed.

Bio: **Maciej A. Noras** received the M.S. degree in electrical engineering from Wroclaw University of Technology, Wroclaw, Poland, in 1994, and the Ph.D. degree in engineering science from Southern Illinois University, Carbondale, in 2000. He is an Assistant Professor at the University of North Carolina at Charlotte, Dept. of Engineering Technology. His research focuses on electric field sensors (electric fields and charge detection), power electronics (high-voltage amplifiers and power supplies), and materials science (high-T_c superconductors, piezoelectrics, electrorheological fluids).

0940

Remote Sensing of Hazardous Energized Objects

***Peter Zalud*,** SRI International Sarnoff

Aging power distribution infrastructure in major North American cities results in increasing number of objects being unintentionally energized. Such objects present health hazard to the public. SRI International Sarnoff in close collaboration with major electrical utility company developed mobile e-field sensing system integrated on a small pickup truck platform. The system detects and aids in localization of hazardous energized objects in dense urban environment. It has been in routine daily use for over 7 years. This presentation is focused on the development of this system, the hurdles encountered and the solutions implemented with the intent to trigger discussion/thinking of new applications for this technology.

Bio: **Peter Zalud** is a Senior Member Technical Staff of the Products and Services Group at SRI International Sarnoff. His specialized expertise is in: System level design of hardware and hardware/software solutions for customer defined problems; System level analysis, proof of concept validation; Design and modeling of algorithms; FPGA-based prototyping; and DSP-based solutions. Representative research assignments at Sarnoff Corporation include Timing and control circuitry for Sarnoff's first CMOS imager; Light-powered CMOS monolithic micro-transponders for DNA assays; Miniature surveillance camera with real-time histogram equalization; Battery-less RFID Tag; Long range RFID Tag for mobile applications; Non-invasive medical diagnostic instrumentation; Fingerprint-based biometric RFID Tag; and Stray electric field detection system. He holds MSEE from the Czech Technical University, 1973. He holds four US patents.

Session Break: 20 minutes

Session: Prognostics and Diagnostics
Chair: Kwok Tom

1020
PHM for Vehicle to Grid
***A. Dasgupta*, M. Pecht**, University of Maryland, College Park

Vehicle-to-Grid (V2G) describes a system in which plug-in electric vehicles, such as electric cars (BEVs) and plug-in hybrids (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate. V2G are expected to potentially reduce battery cycle life due to more frequent charging and discharging activates. Battery wear out is a major concern in V2G application, because the battery account for about 50% of the total vehicle cost. Battery health prognostic model is needed to develop a strategy to minimize both energy consumption cost and battery degradation. Furthermore, electric vehicle chargers are high-power devices, can cause safety issues. The potential failure modes and mechanisms have not been fully investigated. For example, Volt owners have reported the overheating and melting problem of the power cord, and also there is a risk of the system getting wet in the rain since chargers are often located outdoors. This causes a potential safety risk for electric shocks. This presentation discusses the potential advantages of an embedded PHM system, with online anomaly detection and trigger safety mechanisms. Such capabilities will be important for family chargers for safety and reliability and also for remote monitoring network for condition based maintenance (suitable for owners of fleets of public chargers).

1040
Systematic Methodology for Prognostics and Diagnostics–Tools and Case Studies
David Siegel, University of Cincinnati

Implementation of diagnostic and prognostic tools for microgrid components and systems can leverage similar research and development efforts in other domains, such as aerospace, automotive, manufacturing, among other areas. This presentation reviews the methodology and existing set of algorithms that have been used in other prognostic and diagnostic applications. A case study dealing with an intermittent sensor problem is presented to highlight the data processing steps and how the algorithms can be applied. A residual processing method and a k-means clustering based health metric is used to determine the health condition of the anemometer sensor used to measure wind speed. The presented algorithm from the case study resulted in the most accurate method compared to other techniques. Some further discussion on how the current state of the art methods can be applied to microgrid applications is presented. An additional set of remarks about the potential challenges in developing and implementing prognostic and diagnostic methods for microgrid applications are also discussed.

Bio: **David Siegel** is currently a Ph.D. student at the University of Cincinnati and a research assistant at the Center for Intelligent Maintenance Systems. He has experience in developing health monitoring and failure prediction methods for a diverse set of applications including machine tools, wind turbines, helicopter drive-trains, and ground vehicles. David is also a previous winner of the 2009 and 2011 Prognostics and Health Management Data Challenge.

100
Prognostics for Microgrid Components
***Abhinav Saxena*,** Stinger Technologies/NASA

Prognostics is the science of predicting future performance and potential failures based on targeted condition monitoring. Moving away from the traditional reliability, centric view, prognostics aims at detecting and quantifying the time to impending failures. This advance warning provides the opportunity to take actions that can preserve uptime, reduce cost of damage, or extend the life of the component. The talk will focus on the concepts and basics of prognostics from the viewpoint of condition-based systems health management. Differences with other techniques used in systems health management and philosophies of prognostics used in other domains will be shown. Examples relevant to microgrid systems and subsystems will be used to illustrate various types of prediction scenarios and the resources it take to set up a desired prognostic system. Specifically, the implementation results for power storage and power semiconductor components will demonstrate specific solution approaches of prognostics. The role of constituent elements of prognostics, such as model, prediction algorithms, failure threshold, run-to-failure data, requirements and specifications, and post-prognostic reasoning will be explained. A discussion on performance evaluation and performance metrics will conclude the technical discussion followed by general comments on open research problems and challenges in prognostics.

Bio**:** **Dr. Abhinav Saxena** is a Research Scientist with SGT Inc. at the Prognostics Center of Excellence of NASA Ames Research Center, Moffett Field, CA. His research involves developing prognostic algorithms and methodologies to standardize prognostics that include performance evaluation and requirement specification for prognostics of engineering systems. He is leading the prognostics development on battery systems and is also involved in prognostics for power electronics components. He has been involved in PHM research for the last nine years and has published several papers on these topics. He is currently the chief editor for the International Journal of the PHM Society. He is a PhD in Electrical and Computer Engineering from Georgia Institute of Technology, Atlanta and earned his B.Tech. in 2001 from Indian Institute of Technology (IIT) Delhi.

Lunch Break: 20 minutes

Lunch Session: Communication, Control and Cyber Security
Chair: Raju Namburu

1140
Cyber security for grids
***John James*, USMA**

We describe a new capability for "owners" of protected data to quickly and securely share real-time data among networked decision-support and real-time control devices with whom the "owners" of the data have explicitly decided to "share the data. The service is based upon implementation of a recent formal definition and mathematical result derived from the decades-old Bell-LaPadula information security result. The service provides decision makers a means of securely and automatically sharing critical information across security barriers based upon declaration of sharing policies. The declaration and implementation of information sharing policies based upon a need-to-share has been shown to be compatible with information protection policies based upon a need-to- know. Indeed, the implementation of the need-to- share service is based upon extending the mathematical foundations of need-to-know information security systems (the Bell-LaPadula result of 1973). We claim that sharing protected information in real-time is necessary for improving distributed control of cyber-physical systems, such as the microgrid.

Bio: **John James** is a faculty member in the Department of Electrical Engineering and Computer Science at West Point. His research interests are in knowledge-based systems for control, decision support systems, and network science. He is a former Director of the Artificial Intelligence Center at the US Army Training and Doctrine Command and the founding Director of the Network Science Center at West Point.

1200

Microgrid Situational Awareness for DOD Installations

Steve Fernandez, Oak Ridge National Laboratory

Key advances in the concept of operations for the operation of microgrids for DOD have driven new technologies for situational awareness of the surrounding civilian grid and the internal microgrid. An example will be presented and future directions will be discussed. We will describe an analysis framework and computational modules that evaluate the dynamic behavior and impacts due to intermittent generation on grid stability. Demonstration results from a visualization system used for real-time status of the electric grid will be shown. The data to display environmental factors that will impact power demand from the microgrid such as storm runoff, temperature, and precipitation will be shown. In this example for Joint Base Pearl Hickam, each military installation can be geographically overlaid with any data set the commander chooses showing critical facilities. By interfacing the system with base Energy Management System (EMS) frequency, voltage and phase angle at critical facilities can be displayed and compared with the situation in the civilian grid.

Bio: **Dr. Steven Fernandez** is a Senior R&D Staff Member at Oak Ridge National Laboratory. Before joining Oak Ridge National Laboratory in April, 2007, he directed NISAC efforts in the Electric Grid and Economic analysis at Los Alamos National Laboratory. Current interests at Oak Ridge National Laboratory include the modeling of the interdependent consequences of disrupted infrastructures.

1220

The Needs and Challenges of Adopting Energy Management System for Microgrid

***Liang Min*, LLNL,**

Energy management systems (EMS) are computer-based systems used today to operate the complex electric power systems around the world. These systems assure that the power system or "grid" operates properly and that consumers enjoy reliable electricity supply at the lowest possible cost. These systems operate by balancing the demand for electricity with generation resources. A microgrid is a semiautonomous grouping of generating sources and end-use sinks that are placed and operated for the benefit of its members, which may be a single utility "customer," a grouping of several sites, or a set of dispersed sites that nonetheless operate in a coordinated fashion. The energy balance between energy production and consumption of a microgrid must be maintained by dispatch too.

There is no standard functional specification for microgrid EMS although several commercially Energy Management Systems are available and they hold promise for the control and management of microgrid operation. This talk examines the evolution of today's EMS for electric transmission and presents the three key functions for microgrid EMS–monitoring, assessment and control. Specifically, this talk discusses the research needs and challenges for: Forecasting technologies for load and renewable energy resources; Unit commitment and economic dispatch; and Controlled microgrid islanding and re-synchronization.

1240

Integrated, Interconnected and Intelligent Microgrids

***<u>Gordon Parker</u>*, Wane Weaver and Steven Goldsmith,** Michigan Technological University

In the bulk utility grid, local actions taken by a single component have an insignificant effect on the overall system. However, in small-scale power systems, the actions of each load or source component can have a considerable impact on the operation and stability of the entire system. Small-scale power systems include telecommunication, naval, aerospace, automotive power networks, and microgrids. Microgrids have been applied to stationary and fixed hardware platforms, like residential neighborhoods, corporate campuses and military instillations. These systems have been built to improve reliability and to help foster an increase in renewable energy like solar and wind. Traditionally, the individual sources and loads in these types of systems are designed to meet only a local objective, but the lack of a holistic view has led to integration, performance, and stability issues. It is only when the overall system is viewed as a collection of mutually dependent, individual modules that a proper control can be designed. Researchers at Michigan Technological University are studying the fundamental interactions and influences that all components of a power system have on each other and the overall effect on performance. This talk will show the framework for a new class of distributed control methods for interconnected energy components based on a game-theoretic and intelligent agent-based model of the power system

Bio: **Gordon G. Parker** is a John and Cathi Drake Professor of Mechanical Engineering, Michigan Tech. Dr. Parker has been developing control strategies for electro-mechanical systems for the past 24 years. He and his graduate students recently developed a mobile microgrid research and education laboratory through a grant sponsored by the U.S. DOE. Prior to taking his current position at Michigan Tech he spent four years at Sandia National Laboratories in Albuquerque developing a variety of structural vibration control solutions including large-angle spacecraft reorientation.

Bio: **Wayne Weaver** is Assistant Professor, Electrical and Computer Engineering, Michigan Tech. Dr. Weaver's area of expertise is in the areas of power electronics and microgrids. His research focus is in distributed control methodologies in microgrids that enable robust and efficient distribution of energy resources. Prior to his current position he worked as a control system development engineer in the electric power generation group at Caterpillar Inc, and as a research associate at the U.S. Army Corp of Engineers - Construction Engineering Research Lab in the area of military microgrids.

1300
Summary Comments
***Ed Shaffer*,** Army Research Laboratory

Session Break: 15 minutes

Government Session:
Chair: Ed Shaffer

1330 Panel Discussion on Novel Concepts, Research Priorities, Vision for the Future

1350
Ed Shaffer, Closing Remarks
1600
Adjourn

Appendix C. ARL Poster Session—Abstracts

ARL-PLUMS: Power-line M&S tool
Ross Adelman–Army Research Lab

The U.S. Army Research Laboratory's Power-Line unmanned aerial vehicle (UAV) Modeling and Simulation (ARL-PLUMS) is a tool for estimating and analyzing quasi-static electric and magnetic fields due to power lines. This tool consists of an interactive 2-D graphical user interface (GUI) and a compute engine that can be used to calculate and visualize the E-Field and H-Field due to as many as seven conductors (two 3-phase circuits and a ground wire). ARL-PLUMS allows the user to set the geometry of the lines and the load conditions on those lines, and then calculate Ey, Ez, Hy, or Hz along a linear path or cutting plane, or in the form of a movie. The path can be along the ground or in the air to simulate the fields that might be observed, for example, by a robotic vehicle or a UAV. ARL-PLUMS makes several simplifying assumptions in order to allow simulations to be completed on a laptop PC interactively. In most cases, the results are excellent, providing a "90% solution" in just a few minutes of total modeling and simulation time. This paper describes the physics used by ARL-PLUMS, including the simplifying assumptions and the 2-D Method of Moments solver. Examples of electric and magnetic fields for different wire configurations, including typical 3-phase distribution and transmissions lines, are provided. Comparisons to similar results using a full 3-D model are also shown, and a discussion of errors that may be expected from the 2-D simulations is provided.

Bio: **Ross Adelman** is a graduate of the Carnegie-Mellon University (BS, ECE), and is currently a PhD student at the University of Maryland. Ross has worked at ARL for seven summers in the area of power-line field modeling and simulation, electric- and magnetic-field sensor calibration, and related technology.

Simulations of Bulk and Interfacial Properties of Electrolytes for Li Ion Batteries
Oleg Borodin–Army Research Lab

High-voltage electrolytes are needed to cycle battery with novel 5-V class cathodes resulting in improved energy density (lower weight). Optimization of electrolytes and passivation layers or SEI formed at electrodes is also required to increase power density of batteries, and cycling. Fundamental understanding of electrolyte electrochemical and transport properties in bulk and at interfaces is needed for rational electrolyte design and development of computational screening

This appendix is presented in its original form without editorial change.

novel electrolytes. Quantum chemistry calculations are utilized to predict oxidation potential of electrolytes and oxidation induced decomposition of electrolytes at non-active electrodes. Molecular dynamics simulations with developed in-house polarizable force fields are utilized to predict transport and structural properties of electrolytes, SEI components such as dilithium ethylenene dicarbonate (Li_2EDC) and validate predictions via comparison with experimental data. Goals: (a) development of validated methodology for prediction of electrochemical and thermophysical properties of electrolytes; (b) computational screening of novel materials.

Ultra-energetic Materials for Compact Power Sources
Dr. James J. Carroll–ARL

Nuclear isomers are metastable excited states of atomic nuclei and can store on the order of 10^8 Wh/kg, far beyond the most "extreme" chemicals, for durations of days to millennia. The ability to switch a population of isomers to shorter-lived states would provide control over these ultra-energetic materials and increase their power output upon demand. This type of control has already been demonstrated for a few isomers, most recently in on-site tests at ARL, one achievement of a new basic research program. Begun in 2011, the program builds on 25 years experience in nuclear structure and nuclear reaction experiments. The program encompasses direct tests of switching mechanisms, spectroscopic studies of relevant nuclei, investigations of production reactions and searches for new long-lived isomers. Research occurs at ARL's own radiation "Test Cell" and at national resources in the United States and elsewhere, leveraged at modest cost as part of an extensive network of collaborations. On-site tests utilize two electron linear accelerators and over $1M in state-of-the-art radiation detectors and instrumentation, from which customized experimental systems are constructed as-needed.

Electric-field sensor characterization in the ARL "Cage"
Simon Ghionea, ARL

An accurate calibration of an electric-field sensor is difficult to carry out due to challenges involved in generating a uniform electric field over the sensor volume. Additionally, capacitive coupling between the field source and the sensors and related instrumentation tend to distort this field further. Sensor characterization includes not only calibration, but also determination of the frequency response (both magnitude and phase), noise power spectral density, dynamic range, and linearity. The use of oppositely charged square plates at a spacing of half the plate width is advised by the IEEE 1308-1994 standard for generation of a uniform electric field. Previously, the U.S. Army Research Laboratory has shown that by employing guard tubes in the construction of an electric field generating chamber, the fringing fields can be controlled, and the spacing between the endplates can be increased while maintaining a uniform field. The considerations and techniques for minimizing error due to fringing and distortion from metal conductors will be presented, along with the techniques and laboratory equipment used for characterizing the sensor.

Bio: **Simon Ghionea** is a graduate of Oregon State University (BSEE and MSEE). He has worked at ARL for approximately three years, and has designed and tested various custom and prototype electric-field sensors for different applications

Investigation of SiC MOSFET Device Physics for Reliability Testing
Dr. Aivars Lelis, ARL

The research on device reliability physics of Silicon Carbide (SiC) supports the development of SiC Power MOSFETs, which has been identified as an enabling technology for the Army. PM Ground Combat Vehicle (GCV) wants to replace existing Si Insulated Gate Bipolar Transistor (IGBT) power switches with SiC MOSFETs to allow high-temperature operation and increased efficiency to meet the significantly increased requirements for electrical power generation, distribution, and control to enable enhanced lethality, survivability, and mobility. The Device Reliability Team is focused on identifying the key reliability issues regarding SiC power MOSFETs and determining the device physics of potential failure mechanisms. Key accomplishments include the identification of HTRB (high-temperature reverse bias) induced leakage current in the *OFF*-state as a potential failure mode, caused by a significant negative shift of the threshold voltage (V_T). This V_T instability in turn is likely caused by the high-temperature activation of additional near-interfacial oxide traps charged by a direct tunneling mechanism. Key remaining reliability issues include the development of reliability test standards appropriate for SiC-based power switches, to ensure that recent device improvements by ARL's industrial partners are in fact sound. This in turn requires a better understanding of the underlying device physics, including the development of better models for the complex response of the various types of interfacial charge to bias, temperature, and time. Additional issues include identifying the causes of extrinsic gate-oxide breakdown and the correlation of epitaxial defects in the SiC and high-voltage breakdown in the semiconductor. Also of great interest is determining the cause of low channel mobility, since improved device performance can be traded off for improved device reliability.

Long-Lived Isotope Energy Source
Dr. Marc Litz, Dr. James Carroll, ARL

We must be prepared to deploy rapidly, sustain indefinitely, and re-supply rarely.
Our goal is to develop a compact, long-lived, high-energy-density nuclear battery for unattended sensors, communications and ultimately UAV power levels. The logistics tail is dominated by fossil fuel support. Safety and maneuverability are constrained. Alternative energy sources must be planned for the future. A nuclear battery consists of a) the energy source, b) the energy converter, and c) energy management. The isotopic energy source required for mW output is typically pico-grams of material; far below background radiation levels. The scientific investigations continues into semiconductor materials and configurations that limit the radiation damage (increasing lifetime) and increasing phosphor efficiency (increasing energy output). The physics and engineering issues surrounding the most efficient coupling of isotope with energy converter is masked by the nontechnical issues of isotope cost, availability and total radiation activity. Numerical calculations addressing concept designs and configuration are providing encouraging results. The predictive modeling underway includes nuclear scattering modeling, solid state electron/hole flow modeling and circuit modeling to verify experimental results, gain physical insight and identify the engineering difficulties. It is expected that 100μW power supplies lasting for 15 years will be field tested by spring 2013.

Solid-State Circuit Breaker
Damian Urciuoli, ARL

In addition to AC systems, several DC power systems have bidirectional current flow. Such is the case in many renewable and distributed energy systems, as well as in hybrid electric vehicle systems. Despite system trends of increasing power density, and faster system response times through the integration of power electronic components, conventional mechanical fault protection devices are still being implemented in these applications. Mechanical fault protection components cannot provide the actuation speed and reliability required to adequately protect many systems. Solid-state fault protection devices have important advantages over mechanical ones. Solid-state devices, even coupled with transient voltage suppression components, can achieve actuation that is orders of magnitude faster. Solid-state circuit breakers can provide dramatic improvements in reliability and operating life, resulting in superior system protection and reduced maintenance. Solid-state circuit breakers can be better suited to withstand high temperatures and higher shock and vibration. ARL has developed bidirectional scalable solid-state circuit breaker (BDSSCB) technology. ARL's BDSSCB is extremely versatile and applicable to a wide variety of systems. The design can conduct current and block voltage in both directions like a mechanical switch, but can actuate up to three orders of magnitude faster. Unlike other solid-state circuit breakers, the ARL BDSSCB can protect systems operating on AC power, DC power, and bidirectional DC power. This capability can improve the operation of modern Army vehicles and modular ground based power systems such as microgrids. Unlike mechanical fault protection devices which can have reduced reliability and short operating life at maximum current, ARL's BDSSCB topology has ultralow degradation resulting in high reliability, longevity, and is highly tolerant of shock and vibration. These features especially benefit Army systems critical for mobility and survivability.

Bio: **Damian Urciuoli** earned a master's degree in Electrical Engineering from Virginia Tech and joined the Army Research Lab in 2003. His interests lie in the area of power electronic components and systems in support of ground vehicles. Presently, his work focuses on the development of DC-DC converters, silicon-carbide switch modules, and solid-state high-speed bidirectional fault protection devices and control techniques. He has authored or co-authored more than 20 papers in this area.

Substituted Li7La3Zr2O12 as a Solid State Electrolyte for Li/S, Li/Air and Li Batteries, Dr. Jeff Wolfenstine, ARL

The objective of this research is to develop dense high-Li-ion conductivity (>10-4 S/cm) solid state electrolytes for use in Li/S, Aqueous Li-Air and Li batteries. The development of these batteries would be lighter, longer-lasting, and higher-performance batteries for the Army than are presently available. Our approach is to investigate solid state electrolytes based on the garnet structure (Li7La3Zr2O12) [LLZO]. There are two major problems with LLZO: 1] stabilizing the cubic structure at room temperature and 2] obtaining a material with a high-relative density (>95%). To solve the first problem we have investigated doping LLZO with Al or Ta. To solve the second problem we are consolidating the material using hot-pressing. It was determined that at least 0.204 moles of Al is required to stabilize the cubic phase at room temperature. Below this Al content the tetragonal phase is the stable phase. This experimental result is in agreement with results of density functional theory modeling. TEM analysis revealed grain boundaries and triple junctions free of amorphous and second phases. Hot-pressing of cubic LLZO powders (Al ~ 0.77 wt %) lead to a highly dense material (relative density ~98%). The room temperature AC conductivity results for the hot-pressed cubic LLZO sample yielded a total ionic conductivity value of 4 x 10-4 S/cm with an activation energy of 0.26 eV/atom. For the case of Ta doping a room temperature total conductivity of 8.9 x 10-4 S/cm was obtained. This value is getting close to values for liquid electrolytes. Thus, Ta doping is very promising. Future work will focus on chemical stability, mechanical properties and making test cells of the Ta-doped material.

Bio: **Dr. Jeffrey Wolfenstine**: Electrochemistry Branch, Energy and Power Division, U.S. Army Research Laboratory. Dr. Wolfenstine received his Ph. D. from Cornell University in Materials Science. He is currently a senior research scientist at the U. S. Army Research Laboratory working on new materials for Li-ion rechargeable and Li primary batteries. He is an internationally recognized scientist in the field of materials science with main emphasis on processing, characterization and properties of structural and energy storage materials. He has published over refereed 150 journal papers (> 1,500 citations), research referenced in textbooks, many of these papers are cited in review articles. Presented invited talks at international and national technical meetings, universities and DOD briefings. He was received 3 Army R&D awards, one best paper at an Army science conference, 3 patents and 5 patent disclosures. One of his papers was voted top paper of the year for the Journal of Thermal Sprays. He is currently on the editorial board of the Journal of Power Sources and reviews papers from over 15 journals and proposals from many federal agencies. His current research interest is in solid state conductors for use in Li, Na and Mg batteries.

1000 Hour SiC Reliability Study
Robert Wood, ARL

The commercial availability of Silicon-Carbide (SiC) power devices began over a decade ago with the introduction of SiC diodes and has expanded in complexity the past few years to include the offering of SiC transistors and power modules. Research efforts continue to develop the manufacturability and performance to extend the capabilities of this burgeoning technology. SiC MOSFETs have a multitude of applications in army vehicles and can provide significant benefits over the current state of the art silicon (Si) IGBTs currently being utilized in vehicle power converters. SiC MOSFETs can provide higher efficiencies, and operate at higher-junction temperatures and frequencies. This allows designers to construct smaller and more efficient power converters for vehicles while provide additional capabilities not accessible through Si technology. Reliability is one of the unknowns and an area of concern about SiC technology and little research has been done to show the stability and capabilities of SiC MOSFETs in power modules with enough current capacity for Army hybrid vehicles. Four 1200-V, 880-A all-SiC modules were built to test the feasibility of SiC technology at a current capability substantial enough for hybrid vehicle applications. Two modules were fully characterized to document the substantial benefits that can be obtained with SiC, and the other two modules were destined for long-term testing in a power converter emulating a hybrid vehicle inverter. A profile from a hardware in the loop vehicle navigating the NATC Churchville B course was utilized so that the module would be vetted in a circuit emulating a possible end application for these modules. The module tested exhibited little change in device characteristics after successfully completing 1,012 hours of operation in the experimental circuit, operating at a switching frequency of 10 kHz and using a coolant temperature of 80˚C. The 1,012 hours of circuit operation represents

11,783 miles on the test course or over half of the expected lifecycle in a vehicle traction inverter. Another 1000 hours of operation at a higher current and coolant temperature will stress the devices to their thermal limit of 150 °C and should be completed FY 2012. With this reliability demonstrated, the substantial benefits of large all-SiC power modules over state of the art Si can be utilized by design engineers in future systems.

Bio: **Mr. Robert Wood** is a member of the Power Conditioning branch in the Energy and Power Division at the U. S. Army Research Laboratory where he is currently the principle investigator for DC to AC inverter systems for vehicle traction drives and grid applications. Mr. Wood has worked at the U. S. Army Research Lab for over 7 years and his primary areas of focus has been DC to AC inverters, DC to DC converters, high-power wide-bandgap device testing, anti-IED systems, advanced controller designs and programming. Mr. Wood deployed to Iraq in 2006 in support of an anti-IED system designed, built and deployed by ARL and then again in 2011 in support of an OSD survey on operational energy. Mr. Wood received his B.S.E.E. and M.S.E.E degrees from the Colorado School of Mines, Golden, Colorado in 2002 and 2004 respectively.

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List of Symbols, Abbreviations, and Acronyms

AANN	Associative Neural Network
AC	alternating current
ADC	analog-to-digital converter
AEP	American Electric Power
AGC	Automatic Generation Control
AMI	Advanced Metering Infrastructure
AMMPS	Advanced Medium Mobile Power Sources
ANN	Artificial Neural Networks
ARC	Accelerating Rate Calorimeter
ARL	U.S. Army Research Laboratory
ARMA	Autoregressive Moving Average
ARPA-E	Advanced Research Projects Agency-Energy
BAA	Broad Agency Announcement
BBN	Bayesian Belief Network
BDSSCB	bidirectional solid-state circuit breaker
BEV	battery electric vehicle
C2	command and control
CALCE	Center for Advanced Life Cycle Engineering
CCVT	capacity-coupled voltage transformer
CERDEC	Communication Electronics Research and Development Engineering Command
CERL	Sandia-Cyber Engineering Research Laboratory
CERTS	Consortium for Electric Reliability Technology Solutions
CHP	combined heat and power
CISD	Computer and Information Sciences Directorate

CM	Consequence model
CNDA	Components and network design analysis
COI	Community of Interest
COTS	commercial-off-the-shelf
CPDA	Controls and protection design analysis
CSDA	Cyber security design analysis
CT	current transformer
DA	Department of the Army
DART	Data Assimilation Research Testbed
DC	direct current
DER	distributed energy resources
DFA	Distribution Fault Anticipation
DG	Distributed generation
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	U.S. Department of Energy
DR	Distributed resources
DRGS	Distributed Renewables, Generators and Storage
DSC	Differential Scanning Calorimeter
E&P	Energy and Power
EARSS	Energy Awareness and Resiliency Standardized Services
ECS	Energy Control System
EDA	Electronic Design Automation
EEG	Electroencephalogram
EM	Emergency Management
EMI	Electromagnetic Interference
EMS	Energy Management System

EPS	electric power system
ERC	Engineering Research Center
ESR	equivalent series resistance
EV	electric vehicle
FOB	forward operating base
FREEDM	Future Renewable Electrical Energy Delivery and Management
GA	Genetic Algorithms
GaN	Gallium Nitride
GDM	Grid dynamics model
GEOINT	Geospatial Intelligence
GMM	Gaussian Mixture Model
GPS	global positioning system
GTO	gate turn-off
GWAC	Government Wide Acquisition Contracts
HADR	Humanitarian assistance/disaster recovery
HES	Hybrid Energy Systems
HEV	hybrid electric vehicle
HIFLD	Homeland Infrastructure Foundation Level Data
HIL	hardware-in-the-loop
HMM	Hidden Markov Model
HP	Hydro-thermal Pyrolisis
HPPC	Hybrid Pulse Power Characterization
HSIN	Homeland Security Information Network
HTRB	high-temperature reverse bias
HTS	high-temperature superconductor
HVDC	High-voltage direct current
IA	Information Assurance

IAW	in agreement with
ICE	Internal Combustion Engine
ICS	Industrial Control System(s)
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IMC	Isothermal Microcalorimeter
IMS	Intelligent Monitoring System
INL	Idaho National Laboratory
IP	Internet Protocol
IPM	Intelligent Power Management
IREQ	Institut de Recherche en électricité d'Hydro-Québec
IT	Information Technology
JCTD	Joint Capability Technology Demonstration
JFET	Junction Field Effect Transistor
JFQ	Joint Force Quarterly
LBNL	Lawrence Berkeley National Laboratory
LFM	Load flow model
LL	Lincoln Laboratory
LLNL	Lawrence Livermore National Laboratory
LTC	load tap changer
LTS	low-temperature superconducting
M&S	Modeling and Simulation
MD	Mahalanobis Distance
MIT	Massachusetts Institute of Technology
MIT-LL	MIT Lincoln Laboratory
MOSFET	Metal Oxide Field Effect Transistor
MPPT	maximum power point tracking

NCSU	North Carolina State University
NEMA	National Electrical Manufacturers Association
NGA	National Geospatial-Intelligence Agency
NIST	National Institute of Science and Technologies
NN	Neural Network
NSF	National Science Foundation
NTS	Need-to-Share cloud
O&M	Operations and Maintenance
OASIES	Optimization Analysis of Strategic Integrated Energy Systems
OE	Operational Energy
OGA	other government agency(ies)
OHIO	Only Handle Information Once
OPF	optimal power flow
OSD	Office of Secretary of Defense
OSI	Open System Interconnect
P&D	Prognostics and Diagnostics
P&E TFT	Power and Energy Technology Focus Team
PC&PC	Power components and power conditioning
PCA	Principle Component Analysis
PCS	power conversion system
PEARL	Power Engineering and Automation Research Laboratory
PEBB	Power Electronics Building Blocks
PHEV	plug-in hybrid electric vehicle
PHM	Performance Health Maintenance
PLC	Power Line Communication
PMU	Phasor Measurement Units
POC	Point(s) of Contact

PoE	Power over Ethernet
PoF	Physics of Failure
PPA	Projection Pursuit Analysis
PQR	Power quality and reliability
PRM	Performance/reliability model
PS	power sensing
PT	potential transformer
PV	photovoltaic
R&D	research and development
RDECOM	Research, Development and Engineering Command
RTCA	Real-Time Contingency Analysis
S&T	science and technology
SBAD	SmartBED Automation Devices
SBIR	Small Business Innovation Research
SCADA	Supervisory Control and Data Acquisition
SCED	Security Constrained Economic Dispatch
SCR	Short Circuit Ratio
SEDD	Sensors and Electron Devices Directorate
SiC	Silicon Carbide
SmartBed	Smart Battlefield Energy on-Demand
SMES	superconducting magnet energy storage
SMT	surface-mount technology
SMUD	Sacramento Municipal Utility District
SOH	state of health
SOM	Self-organizing Maps
SPIDERS	Smart Power Infrastructure Demonstration for Energy, Reliability, and Security
SPRT	Sequential Probability Radio Test

SST	Solid-state transformer
SSTDR	Spread Spectrum Time Domain Reflectometry
STEM	Science, Technology, Engineering & Mathematics
STSA	Symbolic Time Series Analysis
SVM	Support Vector Machine
SWaP	size, weight and power
TARDEC	Tank Automotive Research and Development Engineering Center
TDR	Time Domain Reflectometry
TFT	Technology Focus Team
TPA	Technology Program Annex
TQG	Tactical Quiet Generator
UC	University of California
UICDS	Unified Incident Command Decision Support
UNCC	University of North Carolina at Charlotte
UPAMD	Universal Power Adapter for Mobile Devices
UPS	uninterruptible power supply
USB	Universal Serial Bus
USMA	United States Military Academy
V2G	Vehicle to Grid
VAR	volt-ampere reactive
VERDE	Visualizing Energy Resources Dynamically on Earth
VRG	variable renewable generation
VT	voltage transformer
WRF	Weather Research and Forecasting
WSS	Web Streaming Services

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