System Operations, Power Flow, and Control

Jeff Dagle, PE (SM)
Chief Electrical Engineer / Team Leader
Electricity Infrastructure / Resilience Team
Pacific Northwest National Laboratory
Richland, Washington USA
+1(509)375-3629
jeff.dagle@pnnl.gov
Vision

Advanced control technologies to enhance the reliability and asset utilization of transmission and distribution systems

Expected Outcomes

• By 2020 deliver an architecture, framework, and algorithms for controlling a clean, resilient and secure power grid
  – leveraging advanced concepts, high performance computing, and more real-time data than existing control paradigms
  – Involving distributed energy resources as additional control elements
• Develop software platforms for decision support, predictive operations & real-time adaptive control
• Deploy through demonstration projects new classes of power flow control device hardware and concepts
• Advance fundamental knowledge for new control paradigms (e.g., robustness uncompromised by uncertainty)

Conventional controls

Distributed controls
<table>
<thead>
<tr>
<th>Key Element</th>
<th>Key Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Architecture and Control Theory Development</strong></td>
<td>Develop comprehensive architectural model, associated control theory, and control algorithms to support a variety of applications. Target improving grid flexibility, future adaptability, and resilience while not compromising operational reliability or security.</td>
</tr>
<tr>
<td><strong>Coordinated Control (EMS/DMS)</strong></td>
<td>Create, test, and demonstrate new control grid operating system designs reflecting emerging system control methodologies. Develop framework(s) for the next generation EMS/DMS systems.</td>
</tr>
<tr>
<td><strong>Advanced Analytics and Computation for Grid Operations and Control</strong></td>
<td>Reliably evaluate future and real-time operating conditions with short decision time frames and a high degree of uncertainty in system inputs. Enhanced automation using predictive capabilities, advanced computational solvers, and parallel computing. Provide better decision support to operators in control rooms through pinpoint visualization and cognitive technologies.</td>
</tr>
<tr>
<td><strong>Power Electronics Device Hardware Development</strong></td>
<td>Improved controllability and greater flexibility of the electrical grid with low-cost power flow control devices. Enhanced efficiency, reliability, and flexibility resulting from optimal power flow control. More reliable and more efficient power electronics and power flow controllers. Wide-area control strategies to improve reliability, resilience, and asset utilization.</td>
</tr>
</tbody>
</table>
Key Focus: Updated System Architecture

System Qualities, Legacy Constraints

Architecture development process

Specify system goals/aspirations
- qualities and properties

Build mappings
- Sys properties x sys qualities
- Structures x sys properties
- Components x sys properties

Specify architectural elements
- Structural views and details,
- components,
- Properties of components and structures (qual. and quant.)
- Analyze and validate

Component Set
- Text documents
- Lists
- Diagrams
- Modeling files
- Simulations
- Presentation slide decks

Visible Properties
- Structure/Component

Structural Views
- Component/connector
- Module
- Allocation
- Industry design patterns
- Connectivity/topology
- Entity-relationship diagrams
- Design Structure Matrix

Architecture Principles and Basis

Backward look
Existing Model
Present state

Forward look
Emerging Trends
End state

Top down
Systemic Issues
Cross-cutting

Bottom up
Use Cases
Siloed
Planning and Design Tools

John Grosh
Deputy Associate Director
Computation Directorate
Lawrence Livermore National Laboratory
Livermore, California  USA
925 424 6520
grosh1@llnl.gov
LLNL-PRES-667315
Vision

Drive next generation of tools to accurately perform cost-benefit trade-offs and improve reliability of design for deployment new smart grid and renewables

Expected Outcomes by FY20

• Coupling grid transmission, distribution, and communications models to understand cross-domain effects
• Computational tools, methods and libraries that enable 1000X improvements in performance for electric production cost simulation
• Incorporate uncertainty and system dynamics into reliability planning tools to accurately capture effects of renewable generations
<table>
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<tr>
<td><strong>Tools for Economic Assessment</strong></td>
<td>• Scalable production cost models coupling transmission and distribution (T&amp;D) with uncertainty, markets, communications, and generation</td>
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<td>• Methodologies for assessing new grid technologies (DR, storage)</td>
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<td>• Modeling tools for externalities impacting grid (e.g., NG supply)</td>
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<tr>
<td><strong>Tools for Reliability and Resilience</strong></td>
<td>• Mod sim codes for coupled T&amp;D and communications</td>
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<td></td>
<td>• Tools for analyzing impact of extreme events (e.g., cascading blackouts)</td>
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<td>• Data-driven approaches to automating model development and validation</td>
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<td>• Develop approaches to connect HWIL devices across networks and broaden the scope of simulation using HPC and virtual simulation</td>
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<tr>
<td><strong>Computational Infrastructure and Technologies</strong></td>
<td>• Computing resources (HPC systems, data archives, access controls) to institutional analysis and grid tools development</td>
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<td>• Benchmarks validated by stakeholders (e.g., utilities) that can be used to drive R&amp;D in tools</td>
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<td></td>
<td>• Scalable libraries and tools to perform complex math operations (e.g., nonlinear solvers, optimization, uncertainty quantification)</td>
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<td>• Deploy “technology to practice” programs to work with vendors, utilities, and ISOs to transition PDT technologies into industry tools and usage</td>
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Grid Modernization Laboratory Consortium

Grid Sensing & Measurement

Thomas King
Program Director
Sustainable Electricity
Oak Ridge National Laboratory
Oak Ridge, TN
865-241-5756
kingtjjr@ornl.gov
Vision: Grid Sensing & Measurement

System Visibility for Enhanced Resiliency and Control

- **Expected Outcomes**
  - Demonstrate novel, low-cost sensors (e.g. under $10/sensor in buildings) to provide nearly 100% observability across the entire electric delivery system by 2020
  - Develop real-time data management and data exchange framework that enables analytics to improve prediction and reduce uncertainty by 2020
  - Develop next generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resiliency by 2020

- **Federal Role**
  - Accelerate the development and deployment of low-cost sensors and a data analytics framework for the next generation grid
  - Ability to transfer data inter-operably, securely including frequency coordination with the FCC
# Grid Sensing & Measurement Program Elements

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<tbody>
<tr>
<td>**Buildings/Customer Sensors &amp;</td>
<td>• Develop low cost sensors to enhance controls for buildings and distributed generation systems to be “grid friendly” in provision of ancillary services such as regulation and spinning reserve.</td>
</tr>
<tr>
<td>Communications**</td>
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<tr>
<td>**Tools to Provide Visibility on the **</td>
<td>• Develop low cost sensors and ability to efficiently and effectively deploy these technologies</td>
</tr>
<tr>
<td><strong>Distribution System</strong></td>
<td>• Develop tools for observability strategy including sensor type, number, location, and data management optimization</td>
</tr>
<tr>
<td>**Transmission Sensors &amp; Asset</td>
<td>• Develop advanced synchrophasor technology that is reliable during transient events as well as steady state measurement.</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
<td>• Develop low cost sensors to monitor electric delivery equipment condition.</td>
</tr>
<tr>
<td><strong>Data Analytics &amp; Visualization</strong></td>
<td>• Enable 100% visibility of generation, loads and system dynamics across the electric system. Validate improvements in the ability to measure, analyze, and model grid operations</td>
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<td>• Develop measurement and modeling techniques for estimating and forecasting renewable generation both for centralized and distributed generation for optimizing buildings, transmission, storage and distribution systems</td>
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<td>• Develop real-time data management for ultra-high velocities and volumes of grid data from T&amp;D systems.</td>
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<td>• Establish National Test-bed to assist in interoperable sensors and communication systems.</td>
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Low Cost Sensors & Controls – Technology Platform

Material Processing and Device Integration

- Thin Film Deposition
  - Inkjet Printing
  - Ultrasonic Spray
  - Sputtering
  - E-beam Evaporation

- Low Temperature Photonic Curing
  - PulseForge 3300
  - Vortek-300
  - Vortek-500

- Materials and Device Characterization
  - CNMS
  - CATS Lab
  - NSTL
  - EMC2
  - RF-Clean Room
  - RF Test Setups

TFT Development
- PTP Curing
- Multilayer Structure
- Characterization

Development Target
Flexible Sensor

Target Technologies
- Sensors
  (Chem-Bio, Temperature, Environment, Mechanical)
- Optoelectronics
  (Phosphor, OLED, Display)
- Batteries
  (CNT, Nanoparticles, C-fiber)
- RF Electronics
  (Energy Harvesting, RF Tags)
- Photovoltaics
  (a-Si, CIGS, CZTS, Polymer)
- Organic Electronics
  (PV, Sensor, TFTs, RF)

Plastic Integrated Thin Films
- Metal
- Semiconductor
- Dielectric
Turning Data to Wisdom

- Data needs to inform and must have context
- Information is data within context
- Knowledge includes experiences; difficult to transfer
- Wisdom is ultimate level of understanding

Courtesy Infovis.net and Shedyoff
Data Cross-Sector Comparison

- Data issues assessed with other sectors
- Opportunities to pull in best practices from other sectors
- Unique solutions still needed for the utility sector in certain areas

<table>
<thead>
<tr>
<th>Comparison Category</th>
<th>Healthcare</th>
<th>Finance</th>
<th>Military</th>
<th>Internet Technology</th>
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</thead>
<tbody>
<tr>
<td>Volume: amount of data</td>
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<tr>
<td>Velocity: moving of data</td>
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<tr>
<td>Latency: delay of data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variety: different data formats</td>
<td>Yellow</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Veracity: data uncertainty</td>
<td>Yellow</td>
<td>Green</td>
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<tr>
<td>Cyber-Physical Control</td>
<td></td>
<td></td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>Distributed Data Processing</td>
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<td></td>
<td>Green</td>
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Solutions Needed for the Electric Grid Sector

- Some Data Issues Solved
- Most Data Issues Solved and Solutions Available
Device and Integrated System Testing

Ben Kroposki, PhD, PE, FIEEE
Director – Power Systems Engineering Center
National Renewable Energy Laboratory
Golden, CO, USA
Device and Integrated Systems Testing

High level outcomes

By 2017:

• Identify energy services* and develop use cases for DERs and other devices** and integrated systems and analyze value for providing these services

• Develop federated lab testing capability and model library of devices for use in simulations

By 2020:

• Develop & enable a wide range of grid-connected devices to provide energy services

• Coordinate & support validated test procedures & standards development for devices and systems to provide energy services

• Validate range of devices integrated systems that support high variable generation, increased reliability & improved operational efficiency levels at several easily replicated scales

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* Energy Services include both energy services to owners/customers (power) and grid ancillary services (e.g. frequency and voltage support, spinning reserves, etc.)

** Devices are individual EERE and OE technologies that connect to the grid including: PV, CSP, wind, EVs, electricity and thermal storage, building loads, appliances, HVAC systems, lighting, fuel cells, electrolyzers, CHP/BCHP, engines, microturbines, wires, cables, switches, transformers, etc. Sensors are part of the Sensing and Measurement area. Power flow controllers are part of the System Operations, Power Flow, and Control area.
### Device and Integrated Systems Testing - Program Elements

<table>
<thead>
<tr>
<th>Program Element</th>
<th>Program Outputs by 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device Development</strong></td>
<td>• Revolutionary improvements in downstream grid devices enable 25% reduction in reserve margins, double the benefit-cost ratio of DERs, and reduce the cost of integrating renewables by 50% by 2020.</td>
</tr>
</tbody>
</table>
| **Standards and Test Procedure Development** | • Formalize standards & procedures for characterizing the ability of technology devices to provide a full range of grid energy & ancillary services by 2017  
• Accelerate completion of standardized requirements & test procedures for interconnection & interoperability by 2020 |
| **Device Testing and Validation**       | • Identify & develop a comprehensive device testing capability at the national labs: test facility integration & optimization, testing frameworks, and a component model library, by 2018  
• Complete the measurement, characterization and validation of device grid service performance by 2020                                                                                   |
| **Multi-scale Systems Integration and Testing** | • Validated a range of scalable, integrated energy systems that can operate at 50% variable generation capacity penetrations at campus and distribution scales by 2018 & at 100% by 2020 & ensure that the systems can be replicated.  
• Develop approach for operating integrated energy systems at 35% variable generation penetration by energy at a regional scale demonstrated using hardware-in-the-loop simulations by 2018 & 50% by 2020 and ensure that the systems can be replicated.  
• Validate transaction-based control constructs coordinating distributed generation, storage, and controllable loads at levels representing 10% of system load by 2018 and 25% by 2020  
• Validate microgrids are capable of providing improved reliable local electricity service (10% reduction in customer outages), increased use of renewable energy (up to 75% variable generation), and coordinating with grid operations by 2020.  
• Validate fault location, isolation, & service restoration (FLISR) systems to meet 10% reduction in distribution system outages to customers  |
Device and Integrated Systems – Near Term Plans

• Form the National Laboratory Grid Testing Network (NLGTN) – consortium of national lab testing facilities
  ▪ Develop federated testing capability list & inter-lab connection
  ▪ Develop library framework for device models

• **Accelerate** interconnection, interoperability requirements & test procedures development through coordinated expertise

• **Validate** connected & responsive energy technologies that provide grid services & integrated systems that are affordable, highly reliable & integrate high variable generation levels at several scales (microgrid, distribution, transmission, etc.)
  ▪ Formalize tests process for individual technologies & integrated systems
DOE Grid Modernization Initiative

February 2015

Dan Ton
Acting Deputy Assistant Secretary
Power Systems Engineering Research and Development
Office of Electricity Delivery and Energy Reliability
Why Grid Modernization?

The existing U.S. power system has served us well... 
*but our 21st Century economy needs a 21st Century grid.*

Emerging Threats

Renewables

Extreme Events

New Services
Grid Modernization Vision

The future grid provides a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It must deliver **reliable, affordable, and clean electricity** to consumers where they want it, when they want it, how they want it.

### Achieve Public Policy Objectives
- 80% clean electricity by 2035
- State RPS and EEPS mandates
- Access to reliable, affordable electricity
- Climate adaptation and resilience

### Sustain Economic Growth and Innovation
- New energy products and services
- Efficient markets
- Reduce barriers for new technologies
- Clean energy jobs

### Mitigate Risks and Secure the Nation
- Extreme weather
- Cyber threats
- Physical attacks
- Natural disasters
- Fuel and supply diversity
- Aging infrastructure
Key Attributes of a Modernized Grid

- Reliable
- Affordable
- Clean
- Flexible
- Innovative

How do we encourage new technologies, products, services, and business models?

How do we better absorb rapid changes in supply, delivery or demand conditions?

How do we keep the lights on and protect against threats?

How do we reduce our environmental impact?

How do we keep costs reasonable for consumers?
Grid Modernization Initiative

An aggressive five-year grid modernization strategy for the Department of Energy that includes:

- Alignment of the existing base activities among the Offices
- An integrated Multi-Year Program Plan (MYPP)
- New activities to fill major gaps in existing base
- Development of a laboratory consortium with core scientific abilities and regional outreach
Technical Areas

- **Sensing and Measurements**
  - Visualization tools that enable complete visibility of generation, loads and grid dynamics across the electric system

- **Devices and Integrated Systems**
  - Establish common test procedures and interoperability standards for devices that can provide valuable grid services alone and/or in combination

- **System Operations and Power Flow**
  - Develop advanced real-time control technologies to enhance the reliability and asset utilization of T&D systems

- **Design and Planning Tools**
  - Create grid planning tools that integrate transmission and distribution and system dynamics over a variety of time and spatial scales

- **Security and Resilience**
  - Develop advanced security (cyber and physical) solutions and real-time incident response capabilities for emerging technologies and systems

- **Institutional Support**
  - Provide tools and data that enable more informed decisions and reduce risks on key issues that influence the future of the electric grid/power sector
Goals and Outcomes

• This new crosscutting effort will build on past successes and current activities to help the nation achieve at least three key outcomes within the next ten years:
  > 10% reduction in the societal costs of power outages
  > 33% decrease in cost of reserve margins while maintaining reliability
  > 50% cut in the costs of wind and solar and other DG integration

• If achieved, these three key outcomes would yield more than $7 billion in annual benefit to the U.S. economy

• In addition, our efforts will ensure the future modernized grid is a flexible platform for innovation by entrepreneurs and others who can develop tools and services to empower consumers and help them make informed energy decisions.
Outputs to Deliver Outcomes

> 10% reduction in the societal costs of power outages

- Deliver new grid architecture that enable controllability across emerging fleet of microgrids and end use devices
- Deliver next gen sensing and data management platforms that enable full system visibility for adaptive wide area control
- Deliver new control theory and algorithms to enable adaptive measurement based control and faster restoration
- Deliver real-time N-K contingency tools to inform and predict outages in the face of threats
Outputs to Deliver Outcomes

> 33% decrease in cost of reserve margins while maintaining reliability

- Deliver a next gen EMS/DMS platform with attributes enabling HPC implementation, algorithms that handle uncertainty, and co-coordination across transmission and distribution
- New grid architecture that enables real-time wide area controls NOT dependent on traditional contingency analysis
- Ultra-fast state estimation (< 1sec) and state measurement to arm real-time controls
- Sensing and data management to enable real-time model validation of distribution circuits under high penetrations of microgrids and distributed resources
- Demos at LSE and balancing area levels to validate concepts
Outputs to Deliver Outcomes

> 50% cut in the costs of wind and solar and other DG integration

- Deliver next gen EMS/DMS platform with controllability to engage responsive loads in balancing variable gen (HPC, full system transparency for model validation and restoration)
- Planning tool platform with HPC and capacity to handle uncertainty to enable fast, risk-based planning at industry and state levels
- Deliver power flow devices (power electronics) to enable flow management at T and D levels to mitigate need for system transmission expansion
- Define and evaluate alternate market-based control concepts that enhance efficiency of variable gen integration
Implementation

We will accomplish this by

• Coordinating grid related research across the DOE, better leveraging the $300 million DOE funding (FY2015 request, actuals being assessed)

• Using the Grid Modernization Laboratory Consortium to coordinate the existing $100M+ in activities of the National Labs associated with grid research into a single, efficient and well coordinated portfolio

• Prudently applying DOE investment in Grid Modernization over the next five years and directing these new resources into gaps identified as part of a new Grid Modernization Multi-Year Program Plan (MYPP); and

• Supporting regional, state, and local groups of stakeholders from industry, academia, communities, and local regulators, that will help translate the tools and knowledge from Grid Modernization R&D into actual deployments of modernized grids.
Security and Resilience

Juan Torres
Senior Manager, Renewable Energy Technologies
Deputy Program Area Director, Renewable Systems and Energy Infrastructure
Sandia National Laboratories
Security and Resilience

Providing a pathway to holistic and comprehensive security and resilience for the nation’s power grid

Expected Outcomes

- Holistic grid security and resilience, from devices to systems
- Inherent security designed into components and systems vs security as an afterthought
- Security and resilience addressed throughout system lifecycle and covering the spectrum of legacy and emerging technologies

Federal Role

- Lead and establish security and resilience research programs to develop technology solutions and best practice guidance
- Improve adoption of security and resiliency practices, and provide technology-neutral guidance
- Inform stakeholders of emerging threats and help address threats appropriate for government response
Security and Resilience
Program Elements

• **Identify**
  – Develop understanding of threats, vulnerabilities, and consequences to all hazards
  – Outcome: Improved risk management and streamlined information sharing

• **Protect**:
  – Inherent system-of-systems grid resilience
  – Outcome: Increase the grid’s ability to withstand malicious or natural events

• **Detect**:
  – Real-time system characterization of events and system failures
  – Outcome: Accelerated state awareness and enhanced event detection

• **Respond**:
  – Maintain critical functionality during events and hazards
  – Outcome: Advanced system adaptability and graceful degradation

• **Recover**:
  – Real-time device management and transformer mobilization
  – Outcome: Timely post-event recovery of grid and community operations
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| Identify    | • Enhance All Hazards aspects of cybersecurity capability maturity models and risk management process.  
• Develop streamlined information sharing capabilities.  
• Conduct an annual R&D Gap Analysis. |
| Protect     | • Develop interdependency and network optimization model application for studying technology integration and response of integrated communication, control, and energy systems in response to all-hazards events.  
• Develop and demonstrate model-driven, logistical optimization planning tools that minimize outage durations. |
| Detect      | • Develop a baseline description and capture framework of grid operations from a cyber-physical standpoint for the full lifecycle to enable anomaly detection.  
• Design and institute a data exchange protocol and data-store capable of working with input from all devices on the cyber-physical electric grid lifecycle.  
• Develop advanced analytics to detect cyber-physical threats and attacks spanning multiple time scales, across the system lifecycle, with emphasis on early detection of abnormal system behavior. |
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</table>
| **Respond** | • Develop an infrastructure degradation assessment and proactive control framework that maintain critical operations in spite of threat.  
• Develop a role-based, cyber-physical state awareness framework and visualization for power grid contextual understanding.  
• Develop intelligent, diverse cyber detection and feedback mechanisms for recognition and autonomous response to attack.  
• Develop an adaptive and agile architecture for optimizing efficiencies of operation, autonomous and human response in an all-hazards environment. |
| **Recover** | • Advance the portability of EHV transformers by defining standards that guide physical requirements.  
• Develop flexible methods using common impedance matching devices to couple standardized and other surplus EHV transformers into a “customized” grid application.  
• Perform multi-physics modeling and engage in reduced- and full-scale physical equipment testing to advance the state of the art in hardening from impacts of GMD and EMP events.  
• Develop fail-safe mode and wireless capabilities for essential SCADA, communications and sensor elements that bypass components that could be vulnerable to a cyber-attack. |