RESEARCH PRIORITIES FOR THE FUTURE GRID

RJT Workshop
Cornell University

Gil Bindewald
August 9, 2012

Disclaimer: Views expressed are solely those of presenter, and do not necessarily reflect those of U.S. Department of Energy.
One cannot consider development of any particular piece of the modern world in isolation.

The history of science and invention has demonstrated how various discoveries, scientific achievements, and historical world events were built from one another successfully in an interconnected way to bring about particular aspects of modern technology.
Interregional connections brought additional reliability
- Back-up in times of equipment failure, unexpected demand, or routine maintenance.
- Economics through reserve sharing and access to diverse energy resources.
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<tr>
<th>Likelihood</th>
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<tr>
<td>High</td>
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</table>

- **Electricity & gas interdependency**
- **Data analytics**
- **Transitioning workforce**
- **Customer engagement**
- **State RPS**
- **Energy efficiency expansion**
- **International Influences**
- **Mergers and acquisitions**
- **Emerging economies**
- **Changing energy supply mix**
- **Transmission planning and cost allocation**
- **Aging infrastructure**
- **Reactive Power**
- **Constrained water resources**
- **Variability of renewable resources**
- **Distributed energy implementation**
- **Weather and climate**
- **Device supply chain**
- **Electric vehicle integration**
- **Microgrid development**

- **Low price of natural gas**
- **Cyber threat capabilities**
- **Generator retirements** *(e.g. impacted by EPA regulations)*
- **Electricity demand**

*Source: Energetics*
Achieving a Clean Energy Future

- Will pose operational challenges to the grid…
  - The future generation resource mix is unknown
  - The variability and uncertainty of wind and solar power require new ways to operate the power system (including the use of storage, natural gas, demand response, inter-hour scheduling)
  - Load profiles are uncertain as on-site renewable energy resources, demand response technologies, and EVs/PEVs are introduced to distribution systems
  - Valuation of ancillary services is evolving
  - Changing technologies and policies, e.g. environmental legislation, will have a significant effect on future generation and transmission
  - Boundary seams (planning, modeling, and operations) are critical for effective integration with legacy systems

- ... And Drives Need to …
  - Dynamically optimize grid operations and resources (over a variety of temporal-spatial scales)
    - Multidirectional power and communication flow
    - Adaptability of controls and protection to changing conditions
    - Fully integrate demand response and consumer participation into grid resource planning and operations
## Technology Options to create a more flexible, reliable & higher capacity energy infrastructure

### Reliability Areas

- **Transmission Congestion**
  - Control power flow & grid stability
  - Increase power flow within existing corridors
  - Real-time control and responsive loads
  - Wide area monitoring & visualization

- **Major Disruptions**
  - Power conditioning
  - Rapid fault response
  - Monitoring & visualization
  - Real-time controls & distributed resources

- **Power Quality & Momentary Outages**

- **Security**

### System Needs

- **Near Term**
  - Power Flow control:
    - FACTs devices ($$)
    - HVDC ($$)
    - SuperVar
  - Advanced conductors
  - Next-gen transformers
  - Advanced components
  - Distributed resources
  - Ancillary services
  - Real-time controls
  - Phasor Measurement Units
  - Real time visualization
  - FACTs devices ($$)
  - HVDC ($$)
  - SuperVar
  - Energy storage ($$$)
  - Sensing & Detection
  - Real-time controls

- **Long Term**
  - Power electronic devices
  - Solid state switch
  - Superconducting cable
  - Energy Storage
  - Model complex system
  - Advanced control concepts
  - Model Complex System
  - State Estimation & Extreme Contingency
  - Low cost storage
  - High-power electronics
  - Fault current limiters
  - Real-time prediction tools

### Science & Technologies

Source: Laboratory Working Group (2007)
Grid Activities

Understanding (Knowledge)

Societal Factors (Markets, Institutions, Policies, Standards)

Flexibility (Physical)

Visibility (Informational)

1. Databases
2. Planning Tools
3. Models and Simulators
4. Analyses and Assessments
5. Technology Integration
6. Technology Demonstrations
7. Test Beds
8. Real Time Operator Tools
9. Automation and Grid Management Systems
10. Electricity Systems Hub
11. IT/Control Architectures
12. Cyber-Physical Security
13. Smart Devices
14. Power Flow Controllers
15. Cables and Conductors
16. Protection Devices
17. Transformers
18. HVDC
19. Energy Storage
20. Communications Hardware and Protocols
21. End-Use Energy Management Systems
22. AMI’s
23. PMU’s
24. Other Sensors and Relays
25. Forecasting
26. Large Data Processing and Management
27. Visualization
28. AMI’s
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30. Other Sensors and Relays
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58. Visualization
Evolution of Transmission Reliability Program

Assumption
Prior to mid-1990s:
Industry will make investment in transmission-related strategic research to ensure reliability

1996, 1999:
Transmission Reliability Program initiated; CERTS formed; Issue papers published

2001:
Transmission Reliability Program Multi-Year Plan released

Blackout 2003:
Lack of wide-area visibility & situational awareness impacting grid reliability

2006:
Phasor Roadmap developed; Workforce Trends Report issued (aging workforce & skills shortages)

2007, 2009:
Workshops with Office of Science on advanced computational needs for power systems

2012:
Phasor Network

2015:
Wide-Area Situational Awareness

2020:
Capability to model, interpret, and react to dynamic power system conditions

2025:
Automatic Switchable Network

Data Structures/ Data Management: Addressing the “Data Overwhelm” Problem
Algorithms & Advanced Controls (Data ➤ Information): Building a flexible, adaptive grid
Informed Decision-Making (Information ➤ Decisions): Developing robust, reliable models, scenarios, & simulations

Blackouts 1996, 1999:
Dwindling industry investment in strategic research; recognition that DOE should engage in grid technology development to mitigate reliability impact
Synchrophasor Technology

- Synchrophasors are precise grid measurements from monitors called phasor measurement units (PMUs)
- Improve power system reliability and visibility through wide area measurement and control, based on GPS time synchronized high resolution data
- **TODAY**: Important applications today include wide-area monitoring, control strategies for outages, and forensic analysis of grid disturbances.
- **FUTURE**: Phasor technology is expected to offer great benefit for real-time operations and power system planning, including integrating renewable and variable resources, automated controls for transmission and demand response, increasing transmission system throughput, and improving system modeling.

August 14, 2003

- Grid Stress – phase angle measurements
- Grid Robustness – damping status and trend
- Dangerous Oscillations – low damping
- Frequency Instability – Frequency variation across interconnection
- Voltage Instability – Low Voltage Zones
- Reliability Margin – “How far are we from the edge” – Sensitivity metrics

Source: PNNL
Synchrophasor Deployment

Phasor Measurement Units in North American Power Grid

- ATC: 48 PMUs
- NYISO: 39 PMUs
- ISO-NE: 30 PMUs
- WECC: 250 PMUs
- MISO: 150 PMUs
- PJM: 81 PMUs
- Entergy: 38 PMUs
- Midwest Energy: 21 PMUs
- FPL: 45 PMUs
- Duke Energy Carolinas: 102 PMUs

ARRA Total: 804 PMUs

Source: Map from North American Synchrophasor Initiative, 2009
# Emerging Real-Time Tools

## Subcategory Readiness

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Algorithm</th>
<th>Hardware</th>
<th>Data</th>
<th>Decision Support</th>
<th>Demo</th>
<th>Pilot Study</th>
<th>Utility Application</th>
<th>Standards</th>
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## Monitoring vs. Controls

- **Near-Term (Requires Development and Pilots):** Needs Moderate Development
- **2-5 years:** Available Now or Soon
- **>5 years:** Requires Development and Pilots

- **Algorithm**
- **Hardware**
- **Data**
- **Decision Support**
- **Demo**
- **Pilot Study**
- **Utility Application**
- **Standards**
**10 SGIG Synchrophasor Projects**

Benefits:
- Improved reliability and resiliency
- Improved asset utilization
- Reduced transmission congestion
- Integration of distributed generation and renewables
Today's Power Grid Planning and Operation Paradigm

From Reactive to Predictive

Long-Term Vision for Power Grid Planning and Operations

TODAY:
- Reliance on off-line analysis to set operating limits
- Operator trying to make control decisions, especially fast decisions during a disturbance, on incomplete data
- High reliance on local protection technologies to protect the grid if all else fails
Accelerate existing functions (faster)
- Fast state Estimation
- N-k Contingency Analysis
- Look ahead dynamic sim
- Financial trans right

Develop new functions (better)
- Dynamic State Estimation
- Stochastics and UQ
- Multi-scale Modeling

Integrated functions
- Operation + Planning
- Trans + Distribution
- Grid + Data

- **Basic Research**
  - multi-scale modeling, optimization, stochastic simulations, uncertainty quantification, large-scale data analysis and data management, and visualization

- **Transformational energy research**
  - innovative control software and control architectures

- **Applied research**
  - accelerate performance and enhance predictability of power systems operational tools; development of new software platforms and capabilities using time-synchronized data, e.g. phasors; reliability modeling in support of regional and interconnection planning
  - development of non-proprietary models of wind generators and inverter technologies for use in transmission planning/interconnection studies
  - use of stochastic simulations for generation dispatch
Coordinated Examples

- **Improved Power System Operations Using Advanced Stochastic Optimization**
  - Parallel algorithms and software for solving stochastic optimization problems (SC)
  - New commitment/dispatch/pricing formulation and models that uses probabilistic inputs to account for uncertainty (ARPA-E, SC, OE)
  - Real-time tools and platforms for balancing demand-side flexibility and supply-side variability (OE, EERE, ARPA-E)
  - Renewable integration model (RIM) for multi-timescale power-flow analysis (OE, EERE)

- **Fusing Models and Data for a Dynamic Paradigm of Power Grid Operations**
  - Calibrated real-time dynamic model (SC)
  - Look-ahead dynamic simulation (OE)
  - Dynamic contingency analysis (OE, ARPA-E)

- **Exploring Power Systems Models using Nonlinear Optimization Techniques**
  - New toolkit for solving nonlinear optimization problems (SC)
  - Modular suite of test problems using either DC or AC (linear or nonlinear) transmission models (OE)
  - Explore effect of AC & DC models for transmission switching (OE, ARPA-E)

Power Grid Planning and Operation: From Reactive to Predictive

- Data collection cycle
- Look-ahead dynamic simulation
- Calibrated real-time dynamic model
- Dynamic contingency analysis

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<thead>
<tr>
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Fast computation supports non-wire solution to congestion management

Fast Dynamic Simulation:
New simulation improving system efficiency

- 6x faster-than-real-time for interconnection-scale systems.
- Supports real-time rating for key assets and dramatically improves asset utilization: from off-line (weeks) to real-time (minutes):

Real-time path rating: demonstration on an IEEE 39-bus power system model

- 26% more capacity without building new transmission lines

Transfer limit of a critical path, MW

- 25.74% more energy transfer using real-time path rating

Graph showing transfer limit over time compared to offline path rating.
**GENI Program**
Green Electricity Network Integration

**Objectives**
- Enable 40% intermittent non-dispatchable generation penetration
- Mitigate challenges for implementation of “real-time” electricity markets
- Greater than 10x reduction in power flow control hardware (target < $0.04/W)
- Greater than 4x reduction in HVDC terminal/line cost relative to state-of-the-art

**Motivation**
- The intermittency of wind and solar stresses existing transmission resources and is a significant obstacle to expanded integration
- Blackouts resulted in an estimated $79B in lost revenue annually
- Nearly 1/3 of the electricity infrastructure in the USA is approaching or has passed end-of-life

**Approach 1: Control Architectures (scalability demonstrated with > 10,000 node simulations)**
- Develop control architectures that are resilient, reliable, cost-optimizing and are capable of managing distributed intermittent resources

**Approach 2: Transmission Controllers (> 3 controllers/terminals connected with > than 5 nodes)**
- Hardware demonstration of resilient, reliable power flow control

Program Dir.: Tim Heidel
Kick-off: 12/15/2011
No. Projects: 15
Investment: $39.4M
GENI TOOLKIT

SCUC/SCED

10k bus test case
DC-OPF
Transient stability

Convex Relaxation

AC-OPF

GENI

Scalable Computing
Parallellism

Wind integration test cases
Renewables Integration

Stochastic optimization

‘real-time’ dispatch of alt. hardware
Distributed control
Transmission Topology Optimization

Estimates indicate that implementation of TC in the entire US electrical grid would save of $1-2 billion in generation costs and would reduce the needs for transmission investments.
Highly Dispatchable and Distributed Demand Response for Integration of Distributed Generation

- OpenADR, IP-based telemetry solutions, and intelligent forecasting and optimization techniques to provide “personalized” dynamic price signals to millions of customers in timeframes suitable for providing ancillary services to the grid.
The DOE Applied Mathematics program supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and Office of Science missions; analysis and development of robust mathematical models, algorithms and software for enabling predictive scientific simulations of DOE-relevant complex systems.

FY12: $40M/year, ~110 projects

Future: Modeling, analysis, and algorithms for simulation of DOE complex systems:

- Increase fidelity: develop new multi-scale, multi-physics models, analysis of coupled systems
- Uncertainty Quantification and V&V
- Approaches for systems that are inherently stochastic
- Methods that integrate data and simulation
- Novel analysis of algorithms for large data / streaming data
- Solvers and optimization methods with reduced global communication
- Higher-order methods; accuracy, stability of methods that move away from bulk synchronous programming models
- Algorithms resilient to machine errors
- Analysis of algorithms for emerging architectures

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<tr>
<td>PDE methods (35%)</td>
<td>Optimization (15%)</td>
<td>UQ &amp; Stochastic Systems (15%)</td>
<td>Linear Algebra (10%)</td>
<td>Analysis of Large Data (10%)</td>
<td>Discrete Systems (10%)</td>
<td>Other (5%)</td>
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Applied Mathematics research has broad impact

Methods and algorithms impacting DOE applications

Foundational models, analysis, and techniques

Methods and algorithms impacting SciDAC

Broad Impact to DOE Mission

Models, algorithms and software impacting exascale and Co-Design

Methods, algorithms and software impacting exascale and Co-Design

Software

Applications

U.S. DEPARTMENT OF
Office of
ENERGY

Office of Science

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Applied Math across ASCR - October 25, 2011
New DOE Applied Mathematics paradigm

Support the research and development of applied mathematical models, methods and algorithms for understanding natural and engineered systems related to DOE’s mission.

Long-term goals:

• Mathematics research that 5-10+ years out will impact DOE mission efforts: DOE Applications, SciDAC Partnerships, and Exascale Co-Design

• New Mathematical Multifaceted Integrated Capability Centers (MMICCs) directly enhances impact of applied math on DOE mission

• Cross-cutting mathematics projects: addresses foundational, algorithmic and extreme-scale mathematical challenges

• High-risk, high-payoff: new mechanism to bring in highly innovative research
Mathematical Multifaceted Integrated Capability Centers (MMICCs)

**Background**

- 2005 Multiscale Mathematics solicitation
- 15 projects awarded under Multiscale Mathematics and Optimization of Complex Systems (ending 8/2012)
- 7 projects awarded under Mathematics for Complex Distributed Interconnected Systems (ending 8/2012)
- 7 projects awarded under ARRA Multiscale Mathematics and Optimization of Complex Systems (ending 8/2012)
- Applied Math Summit 3/7/2012.

**New Paradigm**

- Holistically address mathematics for increasingly complex DOE-relevant systems for scientific discovery, design, optimization and risk assessment.
- Broader view of the problem as a whole, and devise solution strategies that attack the problem in “its entirety” by building fundamental, multidisciplinary mathematical capabilities
- Enable applied mathematics researchers to work together in large, collaborative teams to more effectively address science problems earlier in the problem solving process.
M2ACS: Multifaceted Mathematics for Complex Energy Systems

AN ASCR MMICCS project, PI Anitescu (ANL), 3.5M/yr FY12-FY16
Participants: ANL, PNNL, SNL, U Wisconsin, U Chicago

- Focuses on the grand challenges of analysis, design, planning, maintenance, and operation of electrical energy systems and related infrastructure in the presence of rapidly increasing complexity of the systems.
- Four mathematical areas identified:
  - Predictive modeling that accounts for uncertainty and errors
  - Mathematics of decisions that allow hierarchical, data-driven and real-time decision making
  - Scalable solution algorithms for optimization and dynamic simulation
  - Integrative frameworks leveraging model reduction and multiscale analysis
- Mathematical aspects include: discrete and continuous optimization, dynamical systems, multi-level techniques, data-driven methods, graph-theoretical methods, and stochastic and probabilistic approaches for uncertainty and error.
- Mathematics addresses a broad class of complex energy systems challenges including planning for power grid and related infrastructure; analysis and design for renewable energy integration; real-time broad-scale system monitoring and prediction; and predictive control of cascading blackouts.
<table>
<thead>
<tr>
<th>Topic Structure</th>
<th>Dynamics and stochasticity</th>
<th>Hamiltonian &amp; Lyapunov structure</th>
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<tbody>
<tr>
<td>Predictive modeling</td>
<td>Constantinescu, Huang, Lin, Tartakovsky</td>
<td>DeMarco</td>
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<tr>
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<td>Stability</td>
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<td>DeMarco, Lee</td>
<td>Halappanavar, Hovland, Huang</td>
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<tr>
<th>Math. of decision</th>
<th>Hierarchical Decision Making</th>
<th>Data-driven decisions</th>
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<td>Wright/Leyffer</td>
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Integrating Model Platforms

Simulation Horizon

1 decade
1 year
1 hour
1 min
1 sec
Real-time

Time Step Increment

1 msec
1 sec
1 min
1 hour
1 year
1 decade

Bulk power operational planning models
Long-term infrastructure planning models
Distribution system planning models
Stability models
Real-time diagnostic models

Source: M. Kintner-Meyer, PNNL
Emerging Areas of Model Research

Develop and test new approaches for operations and planning that incorporate...

- Uncertainty
  - Wind, other generation
  - Load
  - Contingencies (discrete, low probability/high consequence)

- Spatiotemporal dimension
  - Storage, load shifting
  - Ramping constraints and costs
  - Unit commitment; economic dispatch
  - New generation and transmission infrastructure – dynamic effects

- Environmental costs/drivers

- Infrastructure Inter-dependencies

- Pricing
  - Co-optimize, avoiding sequential optimization
    (avoid proxy contraints)
  - Capture consumer behavior
    (as enhanced by smart grid technologies)

- Operator Interface

- Framework for Data Integration
Need for National Reliability Center?
NASA’s Aeronautics Mission Directorate (ARMD)

- Works to solve the challenges that still exist in our nation’s air transportation system: air traffic congestion, safety, and environmental impacts
- Requires innovative technical concepts, and dedicated research and development
- Pursues development of new flight operation concepts, and new tools and technologies that can transition smoothly to industry to become products
- Conducts fundamental, cutting-edge research into the new aircraft technologies, as well as system-level research into the integration of new operations concepts and technologies into the Next Generation Air Transportation System
SGIG Deployment Status

Total Investments in 99 SGIG Projects
as of March 19, 2012

9.3 of 15.5 million residential and commercial smart meters

Distribution automation equipment on 4,200 out of 6,500 circuits

195 out of over 800 networked phasor measurement units

AMI and Customer System Assets
$2,767

Distribution Assets
~$2,500

Transmission Assets
~$1,000

Reported to date
Estimated at completion
### Analytical Focus

<table>
<thead>
<tr>
<th>Advanced Metering Infrastructure</th>
<th>Peak and Overall Demand Reduction (62 projects)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operational Efficiency Improvements (60 projects)</td>
</tr>
<tr>
<td>Distribution Automation</td>
<td>Reliability Improvements (48 projects)</td>
</tr>
<tr>
<td></td>
<td>Efficiency Improvements (47 projects)</td>
</tr>
<tr>
<td>Transmission System Applications</td>
<td>Reliability and Efficiency Improvements (10 projects)</td>
</tr>
</tbody>
</table>

Eleven (11) statistically rigorous consumer behavior studies are being conducted to:

- Identify factors influencing customer acceptance of dynamic electricity rates and AMI technology
- Quantify the effect of dynamic rates on electricity consumption (peak and overall load reduction)
- Understand the relative and combined contributions of pricing, information feedback, and control technology on consumer behavior
- Provide statistically-relevant data with analysis to researchers and decision-makers
Investments in AMI are being made by 75% of the SGIG projects

<table>
<thead>
<tr>
<th>Peak and Overall Demand Reduction</th>
<th>Operational Efficiency Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>62 projects are pursuing ......</strong></td>
<td><strong>60 projects are pursuing ......</strong></td>
</tr>
<tr>
<td>• 40 w/ pricing programs</td>
<td>• 60 w/ automated meter reading</td>
</tr>
<tr>
<td>• 25 w/ customer systems</td>
<td>• 44 w/ voltage and power quality monitoring</td>
</tr>
<tr>
<td>• 21 w/ direct load control devices</td>
<td>• 51 w/ outage detection and notification</td>
</tr>
<tr>
<td>• Reducing requirements for generation capacity and energy (less fuel)</td>
<td>• Operations and maintenance (O&amp;M) cost reductions</td>
</tr>
<tr>
<td>• Improved asset utilization</td>
<td>• Greater responsiveness to customer</td>
</tr>
<tr>
<td>• Lower emissions (CO₂, NOx, SOx)</td>
<td>• Lower outage duration</td>
</tr>
<tr>
<td>• Lower bills</td>
<td>• Improved energy efficiency</td>
</tr>
</tbody>
</table>

Office of Electricity Delivery and Energy Reliability
Distribution Automation

DA investments are being made by over 50% of the SGIG projects

### Distribution Reliability

- 48 projects are pursuing distribution system reliability improvements
  - 42 w/ automated feeder switches
  - >6 w/ equipment monitoring
  - 27 w/ DMS integration
  - 21 w/ AMI integrated with OMS

- SAIDI, SAIFI and CAIDI improvements
- O&M cost reductions

### Volt/VAR Control

- 47 projects are pursuing voltage/VAR control and optimization
  - 35 w/ automated capacitor banks
  - 32 w/ automated voltage regulators
  - 22 w/ DMS integration

- Energy efficiency improvements
- O&M cost reductions
Measuring Line Losses

Real and Reactive Power on One Circuit

Energy Savings: Apr 1 – Sept 30

<table>
<thead>
<tr>
<th></th>
<th>Losses (MWh)</th>
<th>Diff. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Caps</td>
<td>355.3</td>
<td>---</td>
</tr>
<tr>
<td>W/ Caps</td>
<td>340.3</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

Observations (17 feeders):
1. Automated capacitors reduced losses by about 3%
2. Feeders with high reactive loads showed the greatest improvements in losses
3. Sometimes the capacitor bank(s) overcompensated
# Consumer Behavior Studies

<table>
<thead>
<tr>
<th>Rate Treatments</th>
<th>Sierra Pacific</th>
<th>Nevada Power</th>
<th>OG&amp;E</th>
<th>MMLD</th>
<th>CVPS</th>
<th>VEC</th>
<th>MN Power*</th>
<th>CEIC</th>
<th>SMUD</th>
<th>DECo</th>
<th>Lake land</th>
<th>Total</th>
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<td>CPR</td>
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<tr>
<td>Non-Rate Treatments</td>
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<tr>
<td>Education</td>
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<td>Cust. Service</td>
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<td>Within</td>
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</tr>
<tr>
<td>Number of Participants</td>
<td>9,509</td>
<td>6,853</td>
<td>3,196</td>
<td>500</td>
<td>3,735</td>
<td>6,440</td>
<td>4,025</td>
<td>5,000</td>
<td>97,480</td>
<td>5,400</td>
<td>3,000</td>
<td>145,138</td>
</tr>
</tbody>
</table>

Sierra Pacific and Nevada Power are testing the effect of a technology package, including an IHD and a PCT.

MN Power is also testing the difference between hourly energy feedback and daily energy feedback.
OGE deployed TOU-CP and VPP-CP programs in Summer 2011, VPP-CP is highlighted here.

<table>
<thead>
<tr>
<th>Price Level</th>
<th>Residential VPP-CP Price</th>
<th>Number of days in summer 2011 at each price level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low and off-peak</td>
<td>4.5¢ per kWh</td>
<td>63</td>
</tr>
<tr>
<td>Standard</td>
<td>11.3¢ per kWh</td>
<td>25</td>
</tr>
<tr>
<td>High</td>
<td>23.0¢ per kWh</td>
<td>28</td>
</tr>
<tr>
<td>Critical</td>
<td>46.0¢ per kWh</td>
<td>6</td>
</tr>
<tr>
<td>Critical Event</td>
<td>46.0¢ per kWh</td>
<td>7 (included in the above)</td>
</tr>
</tbody>
</table>

**Potentially Avoid Future Generation:**

- Study results show a 1.3 kW reduction per customer is possible (max reduction: 1.97 KW)
- Hoping for 20% participation by Dec 2014
- Targets: Enroll ~ 40K customers in 2012 with 72MW peak reduction; 150K customers by Dec 2014 with 210 MW peak reduction (offsets a natural-gas fired peaking plant)
- Discontinue roll out of IHD in 2012
Background:

- For over 70 years, members submitted their own meter readings (highly inaccurate)
- Rolling trucks 6,000 times/year for routine service connection/reconnection and 9,000 times/year for non-payment problems ($40-$50/truck roll)
- Outage locations based on pattern of customer phone calls

TEC’s SmartGrid Program:

- Deployed AMI to about 56,000 customers and upgraded 46 of 86 circuits with advanced capacitors for voltage control and outage management.
- With AMI, TEC avoided 8,800 truck rolls in 2011 for non-payment problems saving more than $350,000
- Expecting to avoid additional 5,500 truck rolls for routine service connections (savings of $200,000/year)
- Expecting to reduce outage durations from more precise pinpointing of faults and dispatching of repair crews to exact locations without guesswork.

Facts & Figures

Total Project Budget: $16,200,000
Federal Share: $ 8,100,000
Customers Served: 57,000
Service Area: 2,600 square miles spanning 4 counties in northern Florida
One utility has installed 230 automated feeder switches on 75 circuits in an urban area. From Apr 1 – Sep 30 2011:

SAIDI improved 24%; average outage duration decreased from 72.3 minutes to 54.6 minutes (or by 17.7 minutes).

| Estimated Avg. Customer Interruption Costs US 2008$ by Customer Type and Duration |
|-----------------------------------------------|---------------------------------|-----------------|--------|--------|--------|
| Customer Type                  | Interruption Cost Summer Weekday | Interruption Duration |     |       |       |
|                               |                                 | Momentary | 30 mins | 1 hr  | 4 hr  | 8 hr  |
| Large C&I                     | Cost Per Average kWh             | $173      | $38     | $25   | $18   | $14   |
| Small C&I                     | Cost Per Average kWh             | $2,401    | $556    | $373  | $307  | $2,173 |
| Residential                   | Cost Per Average kWh             | $21.6     | $4.4    | $2.6  | $1.3  | $0.9  |

Sullivan J, Michael, 2009 Estimated Value of Service Reliability for Electric Utility Customers in the US, xxi

VOS Improvement $\Delta = \Delta \text{SAIDI} \times \text{Customers Served} \times \text{Avg Load} \times \text{VOS Coefficient}$

| VOS Estimate for SAIDI Improvement on 75 feeders from Apr 1 to Sep 30 2011 |
|-----------------------------------------------|-----------------|--------|--------|--------|
| Customer Class       | $\Delta \text{SAIDI}$ | Customers Served within a Class | Average Load (kW) Not Served | VOS Coefficient ($/kWh) | $\Delta \text{VOS}$ |
| Residential          | 17.7 mins (0.295 hrs) | 107,390 | 2      | $2.60  | $164,736 |
| Commercial           |                  | 8,261   | 20     | $373.00 | $18,179,477 |
| Industrial           |                  | 2,360   | 200    | $25.00  | $3,481,325 |
| Total                |                  | 118,011 |        |        | $21,825,537 |

Office of Electricity Delivery and Energy Reliability
Conservation Voltage Reduction

Objective: Reduce energy consumption and peak load via operating at the low end of the ANSI C84.1 Range A Band (114V – 126V)

- Load Tap Changer
- Voltage Regulators
- Capacitors
- Line Sensors
- DMS

Near-real-time feedback loop enables optimized operation of these components. However, deployment strategies differ with respect to objectives and levels of sophistication.

Results Averaged across 11 Circuits

<table>
<thead>
<tr>
<th></th>
<th>Initial Results</th>
<th>Potential Customer Savings (estimated for a 7 MW peak circuit with 53% load factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Energy Reduction</td>
<td>2.9%</td>
<td>943 MWh/year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$75,440 (at $.08/kWh)</td>
</tr>
<tr>
<td>Peak Demand Reduction</td>
<td>3%</td>
<td>210 kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defer construction of peaking plants</td>
</tr>
</tbody>
</table>

NOTE: Utilities and regulatory commissions will need to work together to establish appropriate recovery of fixed costs as consumption is reduced
What and Why is ISGAN?

A mechanism for bringing high-level government attention and action to accelerate the development and deployment of smarter electricity grids around the world.

ISGAN...

- Sponsors activities that build a **global understanding** of smart grids, **address gaps** in knowledge and tools, and **accelerate** Smart Grid deployment
- Builds on the momentum of and knowledge created by the **substantial global investments** being made in smart grids
- Is organized as a task-shared **IEA Implementing Agreement** (2011)
- Was launched as an initiative of the **Clean Energy Ministerial** (2010)
- Fulfills a key recommendation in the **Smart Grids Technology Action Plan** (released by Major Economies Forum Global Partnership, 2009)
- **Leverages cooperation** with other initiatives and Implementing Agreements
Current ISGAN Work Portfolio

**Foundational Projects**
- Annex 1: Global Smart Grid Inventory
- Annex 2: Smart Grid Case Studies
- Annex 3: Benefit-Cost Analyses and Toolkits
- Annex 4: Synthesis of Insights for Decision Makers

**New Projects**
- Annex 5: Smart Grid International Research Facility Network (SIRFN)
- Annex 6: Power T&D Systems

*ANNEX* = Major Project

**Approved March 2012**

25 May 2012
ISGAN is one of 12 Initiatives under the Clean Energy Ministerial (CEM)
The CEM & Its Strategy

Goal: Accelerating the Transition to Clean Energy Technologies

1. High-Level Policy Dialogue  
2. Technical Cooperation  
3. Engagement with the Private Sector and Other Stakeholders

Fourth Annual CEM meeting (CEM4) will take place in Delhi, India in 2013

<table>
<thead>
<tr>
<th>Country</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>🇦🇺</td>
</tr>
<tr>
<td>European Commission</td>
<td>🇪🇺</td>
</tr>
<tr>
<td>Brazil</td>
<td>🇧🇷</td>
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<tr>
<td>Canada</td>
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<td>Denmark</td>
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<td>United Kingdom</td>
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<td>United States</td>
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<tr>
<td>China</td>
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</tbody>
</table>

>90% of Global Clean Energy Investment  > 80% of Global GHG Emissions
Enhancing Security and Reliability Through the Use of Microgrids

DOE’s Goal: lead national efforts to modernize the electric grid, enhance security and reliability of the energy infrastructure, and facilitate recovery from disruptions to energy supply.

<table>
<thead>
<tr>
<th>Grid Modernization</th>
<th>DOE Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Efficiency</strong></td>
<td>Increase efficiency of the electric delivery system through reduced energy losses.</td>
</tr>
<tr>
<td><strong>System Efficiency</strong></td>
<td>Reduce peak price and price volatility of electricity, increased asset utilization and provide accessibility to a variety of fuel sources.</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Strengthen grid stability and reduce the frequency and duration of operational disturbances.</td>
</tr>
<tr>
<td><strong>Security</strong></td>
<td>The energy infrastructure is hardened to detect, prevent and mitigate external disruptions to the energy sector.</td>
</tr>
</tbody>
</table>

**Microgrid Enhanced Distribution**

- Ease of CHP application
- Supports increase of renewables—firms intermittent resources
- Arbitrage of energy price differentials
- Enhance G&T by use of plug-and-play DER for peak shaving
- Enhance reliability with international islanding
- High local reliability
- Energy during outages
## Defining Microgrids

### Microgrid Definition

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

### Key Attributes

1. Grouping interconnected loads and distributed energy resources
2. Can operate in both island mode or grid-connected
3. Can connect and disconnect from the grid
4. Acts as a single controllable entity to the grid
## Microgrid Related Funding

To date, the bulk of our work has been on microgrid demonstrations.

### FY 2012 and prior
- Renewable and Distributed Systems Integration
- Consortium for Electric Reliability Technology Solutions (CERTS)
- The Distributed Energy Resources Customer Adoption Model (DER-CAM)
- Energy Surety Microgrids
- Smart Power Infrastructure Demonstration for Energy, Reliability, and Security (SPIDERS)
- Standards Development – Interconnection and Interoperability

### FY 2012-and beyond
- Microgrid Development
  RD&D to reach 2020 microgrid performance targets * on costs, reliability, system energy efficiencies, and emissions
  Industry workshop held August 30-31, 2011, to define needed research areas and activities – Follow on July 2012

*Develop microgrid systems capable of reducing outage time of required loads by >98%; cost comparable to non-integrated baseline solutions (UPS + diesel genset); reduce emissions by >20%; improve system energy efficiencies by >20%*
Federal programs, institutions, and the private sector are increasing microgrid development and deployment. The number of successfully deployed microgrids will verify the benefits and decrease implementation risks further expanding the market for microgrids.
Need for Electric Systems Hub?
Technologies, Markets, and Policies are Intricately Linked

- Policies and regulations drive markets which drives technology
- When finding solutions to challenges, all aspects need to be considered simultaneously

**Policies**
- state RPS, federal CES, FERC, PUC’s, environmental regulations, siting, etc.

**Markets**
- business models, cost allocation, wholesale power trading, utilities, vendors, etc.

**Technologies**
- generation, infrastructure, smart grid, electric vehicles, storage, etc.
Where will the next-generation of research occur?
Centers 1: Engineering Research Centers Program

- Program initiated in 1985
- ~ $4M/year up to 10 years
- 17 Centers funded—two joint with DOE

Goals:
- Create and sustain an integrated, interdisciplinary research environment to advance fundamental engineering knowledge and engineered systems
- Educate a globally competitive and diverse engineering workforce from K-12 on
- Join academe and industry in partnership to achieve goals
Future Renewable Electric Energy Delivery and Management (FREEDM) System Engineering Research Center (ERC)

- “Energy Internet” concept to enable every citizen to participate in energy production, conservation and utilization
- Develop plug-and-play infrastructure to enable the use of distributed renewable energy resources

FID: Fault Isolation Device
SST: Solid State Transformer
DRER: Distributed Renewable Energy Resource
DESD: Distributed Energy Storage Device
Center for Ultra-wide-area Resilient electric Energy Transmission networks (CURENT)

• A nation-wide transmission grid that is fully monitored and dynamically controlled for high efficiency, high reliability, low cost, better accommodation of renewable sources, full utilization of storage, and responsive load.

• A new generation of electric power and energy systems engineering leaders with a global perspective coming from diverse backgrounds.

• University of Tennessee
• Northeastern University

RTO
Regional Transmission Organization
credit: NPR & UTK
Proposal 1041877

EXISTING LINES
- 345-499 kV
- 500-699 kV
- 700-799 kV
- 1,000 kV (DC)

PROPOSED LINES
- New 765 kV
- AC-DC-AC Links

- Eastern
- Western
- Texas (ERCOT)

• Tuskegee University
• Rensselaer Polytechnic Institute
Centers 2: Industry/University Cooperative Research Centers (I/UCRC)

- Initiated in 1973:
- Catalyzed by a small investment from NSF; primarily supported by industry center members
  - Planning Grants ($10K/year, 1 year)
  - Full Center awards ($55-$80K/year, 5-15 years)
- Goals:
  - To contribute to the nation’s research infrastructure base by developing long-term partnerships among industry, academe and government
  - To leverage NSF funds with industry to support graduate students performing industrially relevant research
- ~60 centers currently NSF funded
Power Systems Engineering Research Center

Empowering minds to engineer the future electric energy system

Power Systems

Transmission & Distribution

Organization in Brief

- NSF I/UCRC
- 37 Industry Members
- 13 Universities
- 14 on-going industry projects
- Supporting ~50 grad students
- U.S. DOE projects (Future Grid Initiative, CERTS)
The mission of GRAPES is to accelerate the adoption and insertion of power electronics into the electric grid in order to improve system stability, flexibility, robustness and economy.

Research Areas:
- Distributed Energy Resources
- Demand Side Management
- Power Flow Control
- Power Electronic Modules
- Power Electronic Systems

Founded in 2009
18 Industrial Members
Supporting ~20 grad students
Grid Activities

Understanding (Knowledge)

Societal Factors (Markets, Institutions, Policies, Standards)

Visibility (Informational)

Flexibility (Physical)

- Understanding (Knowledge)
  - Databases
  - Planning Tools
  - Models and Simulators
  - Analyses and Assessments

- Visibility (Informational)
  - Large Data Processing and Management
  - Forecasting
  - AMI’s
  - PMU’s
  - Other Sensors and Relays
  - End-Use Energy Management Systems
  - Communications Hardware and Protocols

- Flexibility (Physical)
  - HVDC
  - Power Flow Controllers
  - Energy Storage
  - Cables and Conductors
  - Protection Devices
  - Transformers
  - Cyber-Physical Security
  - IT/Control Architectures
  - Smart Devices
  - Electricity Systems Hub
  - Automation and Grid Management Systems
  - Real Time Operator Tools
  - Test Beds
  - Integration

- Societal Factors (Markets, Institutions, Policies, Standards)
  - AMI’s
  - Large Data Processing and Management
  - Forecasting
  - AMI’s
  - Other Sensors and Relays
  - End-Use Energy Management Systems
  - Communications Hardware and Protocols

End-Use Energy Management Systems

- Technology Demonstrations
- Technology Integration
- Test Beds

- AMI’s
- IT/Control Architectures
- Smart Devices
- Cyber-Physical Security
- Computers and Conductors
- Protection Devices
- Transformers

- HVDC
- Power Flow Controllers
- Energy Storage
- IT/Control Architectures
Thanks!