Advanced Modeling and Computation for the Electric Grid

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The Electric Grid: A Complex System

Physically

• Not holistically designed, evolved incrementally in response to local load growth. Today:
  – Over 180,000 miles of transmission line
  – 15,000 Transmission substations
  – Distribution grid connects these substations with over 100 million loads - residential, industrial, and commercial customers

• Diverse industry
  – 3,170 traditional electric utilities
  – 239 investor-owned, 2,009 publicly owned, 912 consumer-owned rural cooperatives, and 10 Federal electric utilities

Technically

• Electricity flows within three major interconnections along paths of lowest impedance (at the speed of light); yet grid is operated in a decentralized manner by over 140 control areas

• Demand is semi-uncontrolled – smart grid technologies provide opportunity for dynamic, real-time balancing of demand and supply (demand response)

• Ultimate “just-in-time” production process
Operational Challenges

• 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; market impacts)

• 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

• Vulnerabilities (workforce; cybersecurity; manufacturing) are continually emerging

• Boundary seams (planning, modeling, and operations) are critical for effective integration with legacy systems
Through 2015, the Recovery Act funds will result in the deployment of:

- An additional 15.5 million smart meters on homes and commercial buildings,
- Sensors, smart switches and control devices that will help automate approximately 6,500 distribution circuits, and
- Over 800 networked phasor measurement units distributed throughout the transmission system.
Addressing the Challenges...

• “Smart Grid” data sources enable real-time precision in operations and control to dynamically optimize grid operations to adapt to changing conditions
  – Real-time data from distribution automation and smart meter systems will significantly advance real-time operations of distribution systems and enable customer engagement through demand response, efficiency etc.
  – Time-synchronous phasor data, linked with advanced computation and visualization, enable advances in state estimation, real-time contingency analysis, and real-time monitoring of dynamic (oscillatory) behaviors in the system.
GOAL: Develop the computational, mathematical, and scientific understanding needed to transform the tools and techniques (e.g. mathematical formulations) that underpin the planning and operation of the electric system.

STRATEGY: Support mathematically-based power systems research to:

- **Accelerate Performance** – improving grid resilience to fast time scale phenomena that drive cascading network failures and blackouts

- **Enable Predictive Capability** – relying on real-time measurements and improved models to represent with more fidelity the operational attributes of the electric system, enabling better prediction of system behavior and thus reducing margins and equipment redundancies needed to cover uncertainties

- **Integrate Modeling Platforms (across the system)** – capturing the interactions and interdependencies that will allow development (and validation) of new control techniques and technologies
Computational, mathematical, and scientific understanding is needed to transform the tools and techniques (e.g. mathematical formulations) that underpin the planning and operation of the electric system:

**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

**Long-Term Vision for Power Grid Planning and Operations**
**Question:** How well can the system withstand disturbances?

Damping (in %) is a measure of the grid's resilience to system events.

**Desirable Condition**

- Well Damped Oscillations
  - Decay Rate (i.e., Damping)

**Dangerous**

- Poorly Damped Oscillations

**Bad Situation**

- Negatively Damped Oscillations

**Source:** CERTS
**Question:** How far are we from the edge?

With PMUs, we can directly measure Voltage Sensitivities (kV/100MW) at critical interfaces or load pockets.

When voltages drop too far, the entire power system can collapse.

Large power flows over long distances increase the risk of voltage collapse.

Source: CERTS
What is needed?

- New algorithms that are scalable and robust for solving large nonlinear mixed-integer optimization problems and methods for efficiently (real-time) solving large sets of ordinary differential equations with algebraic constraints, that include delays, parameter uncertainties, and data as input.

- A new mathematics for characterizing uncertainty in information created from large volumes of data and for characterizing the uncertainty in models used for prediction.

- New methods to enable efficient use of high bandwidth networks by dynamically identifying only the data relevant to the current information need and discarding the rest. This would be especially useful for wide area dynamic control where data volume and latency are barriers.

- New software architectures and new rapid development tools for merging legacy and new code without disrupting operation. Software should be open source, modular, and transparent. Security is a high priority.
Smart Grid Workforce Training Projects:
Developing the Capacity and Capability
to Address Our Nation’s Future Energy Challenges

Helping modernize the nation’s electrical grid and implement smart grid technologies in communities across the country.
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