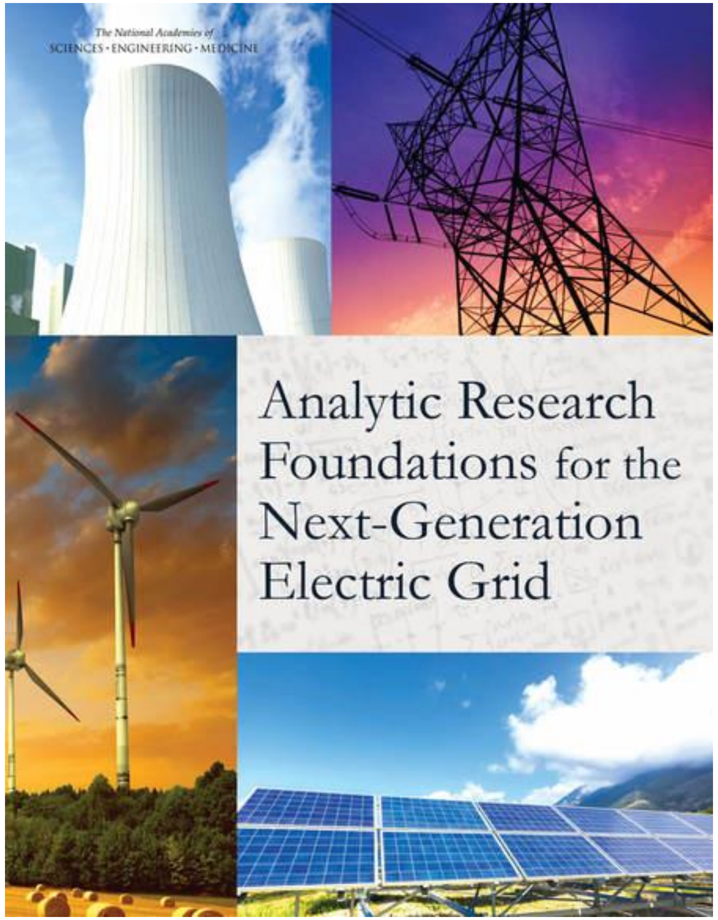
National Research Council Committee Report



http://www.nap.edu/catalog/21919/analytic-research-foundations-for-the-next-generation-electric-grid

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DOE Charge

- What are the critical areas of mathematical and computational research that must be addressed for the next-generation electric transmission and distribution (grid) system? Identify future needs. In what ways, if any, do current research efforts in these areas (including non-U.S. efforts) need to be adjusted or augmented
- Because this research frontier is best approached by a community that is truly multidisciplinary – including not only a cutting-edge knowledge of mathematics, statistics, and computation, but also a deep understanding of the emerging electric grid and of the questions that need answering to realize its potential:
    - How can DOE help to effectively build this community?
    - What mix of backgrounds is needed and how can the community be developed?
    - How can DOE extend its reach beyond its existing ties?

Report Context

- Changing physical infrastructure
  - New power sources: wind, solar
  - More real time data: PMUs
  - New devices: electronic controls, storage
  - Load management: smart meters
- Organizational issues
  - Reliability is essential
  - Control architecture is central
  - Regulations and standards matter
- Key areas of mathematics
  - dynamics
  - optimization
  - control

Report Outline

- Background
  - Physical structure of the grid
  - Organization and markets
  - Existing tools and methods
  - Important mathematics research areas
- The future grid
  - Uncertainty, challenges and technologies
  - Mathematical priorities
  - Case studies
- Building a multidisciplinary community

Recommendations

- 10. The Department of Energy and National Science Foundation should sponsor the development new open-source software for the next-generation electric grid research community.
- 4. Given the critical infrastructure nature of the electric grid and the critical need for developing advanced mathematical and computational tools and techniques that rely on realistic data for testing and validating those tools and techniques, the power research community, with government and industry support, should vigorously address ways to create, validate, and adopt synthetic data and make them freely available to the broader research community.

Recommendations

- 9. The Department of Energy should sponsor additional efforts to create synthetic data libraries to facilitate studies of, and tool building for, the reliability and control of the future electric grid.
- 2. The Federal Energy Regulatory Commission (FERC) should require that all text file formats used for the exchange of FERC715 power flow cases be fully publicly available.
- 3. The Federal Energy Regulatory Commission should require that descriptions of all models used in system-wide transient stability studies be fully public, including descriptions of any associated text file formats.

Recommendations

- 1. The Department of Energy should develop and test a full ac optimal power flow(ACOPF) model with an optimization algorithm using all nodes in the market area, taking advantage of supercomputers and parallel processing and respecting all thermal and voltage constraints.
- 8. Order-of-magnitude improvements in nonlinear, nonconvex optimization algorithms are needed to enable their use in wholesale electricity market analysis and design for solving the ac optimal power flow problem. Such algorithms are essential to determine voltage magnitudes. Therefore the Department of Energy should provide enhanced support for fundamental research on nonlinear, nonconvex optimization algorithms.

Recommendations

- 7. The Department of Energy should support research on data-driven approaches applied to the operations, planning, and maintenance of power systems. This would include better machine-learning models for reliability, comprehensible classification and regression, low-dimensional projections, visualization tools, clustering, and data assimilation. A partial goal of this research would be to quantify the value of the associated data.
- 5. Integration of theory and computational methods from machine learning, dynamical systems, and control theory should be a high-priority research area}. The Department of Energy should support such research, encouraging the use of real and synthetic phasor measurement unit data to facilitate applications to the power grid. Establishment of test-beds for physical experiments would provide valuable additional sources of data.

Recommendations

- 6. The Department of Energy should support research to extend dynamical systems theory and associated numerical methods to encompass classes of systems that include electric grids. In addition to simulation of realistic grid models, one goal of this research should be to identify problems that exemplify in their simplest forms the mathematical issues encountered in simulating nonlinear, discontinuous, and stochastic time-dependent dynamics of the power system. The problems should be implemented in computer models and archived in a freely available database, accompanied by thorough documentation written for both mathematicians and engineers. Large grid-sized problems that exemplify the difficulty in scaling the methods should be presented as well.

Recommendations

- 12. The Department of Energy should establish a National Electric Power Systems Research Center to address fundamental research challenges associated with analysis for the future electric system. The center would act as an interface between the power industry, government, and universities in developing new computational and mathematical solutions for data and modeling issues and in sharing valuable data.
- 11. In view of the importance of its efforts to coordinate power grid research at the national laboratories, the Department of Energy should broaden this coordination to include academic and industry researchers.

Challenges to Analytical Development - Foundational

- IEEE Common Data Format has not kept up to date
  - Commercial Tools can read / exchange data but only if user has licensed them
  - Expanding the research community requires ease of data access and exchange
- Today much power system data is privileged and secure
  - DHS critical infrastructure security
  - Commercial data security
  - Researchers need “realistic” data sets and problems representative of scale/complexity in real world that are readily available and can be used to compare/validate results
  - IEEE small scale models of the past not sufficient
- Detailed models of power system components – especially dynamic components in transient stability, EMTP, harmonics – control systems, inverters, etc. – are frequently proprietary in commercial tools and not fully disclosed or open source
  - Creates issues for researchers in validating new models and controls, and in exchanging data
- The commercial market for some analytics is small and may not support R&D needs
  - If the only users are RTO / ISO level and NERC – insufficient user base to support competitive development

Challenges – the Electric Power Environment

- 000,000 of Distributed Energy Resources Appearing
  - Many will have/want direct market access
  - High penetrations will require planning, real time and market coordination across the Transmission – Distribution divide
- High renewable penetration and smart loads add to uncertainty
- Inverter Based Resources add to Voltage Issues, add faster dynamics to system behavior
- The “Internet of Things” may link end use loads to market signals
- “Big Data” explosion in data available to utilities and grid operators
- Climate Change threatens assets, changes loads, threatens resources

Specific Examples

- MISO reports that the SCUC is close to limits on performance
  - Difficulty in solving reliably in market closure time window; and FERC requesting a shorter window!
  - Modeling CCGT in full detail and modeling storage can run up the # of integer variables – challenges the MIP engine
  - Current MIP engines do not parallelize well
- ALL market operators use DC OPF Today
  - Integrating VAR support / voltage constraints into the SCUC will require an AC OPF with speed and reliability
- Moving to Risk Based Contingency Analysis and Risk Based SCUC – How?
- Integrating transmission OPF and distribution resources for volt/var optimization

The R&D Challenges

- All our Chips are on MIP and DC OPF
  - What other optimization mathematics are out there?
- Power Engineering R&D and Mathematics R&D not connected
- Power Engineering has not focused on advances in computing nor control systems and dynamic systems research