Electricity Transmission System Research and Development: Grid Operations and Planning

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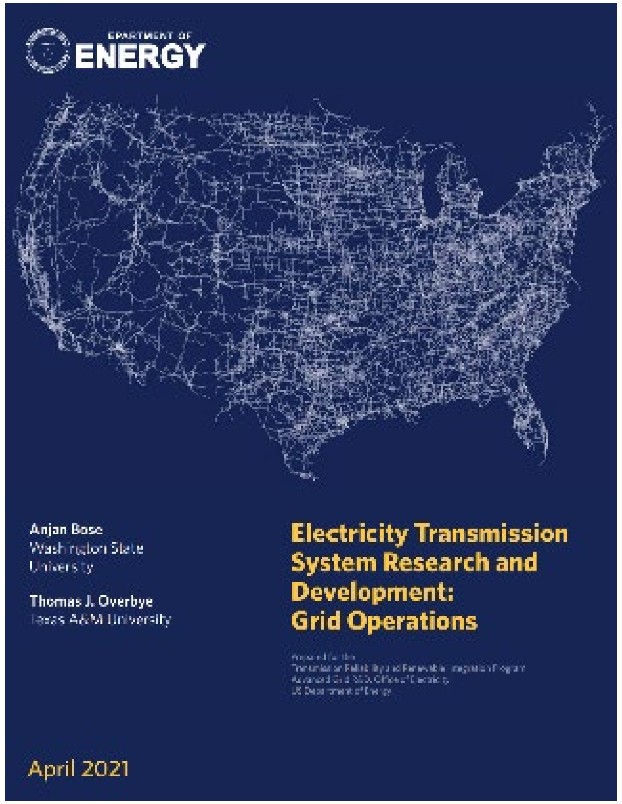
Overview

Presentation is based on one of five white papers looking at areas in which DOE can take leadership in catalyzing the transition to the future grid over the next 10 to 20 years

– **Transmission Grid Operations and Planning (This Presentation)**
– Distribution Integrated with Transmission Operations
– Automatic Control Systems
– Hardware and Components
– Economic Analysis and Planning Tools



Grid Operations and Planning Paper Structure

The paper has eleven chapters

- Introduction
- Electricity Transmission Grid Operations: Past and Present
- Likely Future Scenarios
- Technologies to Support Operators' Management of Real-Time Operations
- Engineering Tools to Support Real-Time Operations
- Technologies to Enhance the Use of Historical Real-Time Data
- Technologies for Engineering Tools to Support Transmission Planning
- Training Simulators
- High-Impact, Low-Frequency Events; Restoration; Other Infrastructures
- Research Infrastructure
- Recommendations

A Few Starting Quotes

"For at least the next two decades, most customers will continue to depend on the functioning of the large-scale, interconnected, tightly organized, and hierarchically structured electric grid for resilient electric service."

- *Enhancing the Resilience of the Nation's Electricity System*, The National Academies Press (NAP), Washington, DC, 2017)

"All models are wrong but some are useful"

- George Box, *Empirical Model-Building and Response Surfaces*, (1987, p. 424)
- The math itself is correct

"If I have seen further it is by standing on the shoulders of Giants"

- Isaac Newton (1675 in letter to Robert Hooke)

"It is always wise to look ahead, but difficult to look further than you can see"

- Winston Churchill

"It is a mistake to think that the future is just some extrapolated view of the present"

- *Analytic Research Foundations for the Next-Generation Electric Grid*, NAP, 2016

Where We've Been Over the Last 140 Years

Chapter 2 covers the history of electric grid operations

- The grid has been in a continual state of change and electric utilities have often been leaders in new technology and analytics
- Many of the grid changes have been driven by rare events
  - 1965 blackout, WECC 1996 blackout, Sept 11, 8/14/03 blackout, others
- The operation of the grid has gotten much more complex over the last several decades, and one size definitely does not fit all!
- Concepts can take decades to fully develop
  - EMSs, state estimation, optimal power flow, simulators
- Understanding the different operating modes is crucial
  - normal, alert, emergency, in extremis, restoration

Transmission Operations & Planning In Four Words

Impressive

- Electrification including operations is an engineering marvel!!

Diverse or **Complex**

- Recent changes have made the US grid much more diverse

Vital

- We're more dependent than ever, and blackouts can rapidly move from annoying to catastrophic

Opaque (at least some)

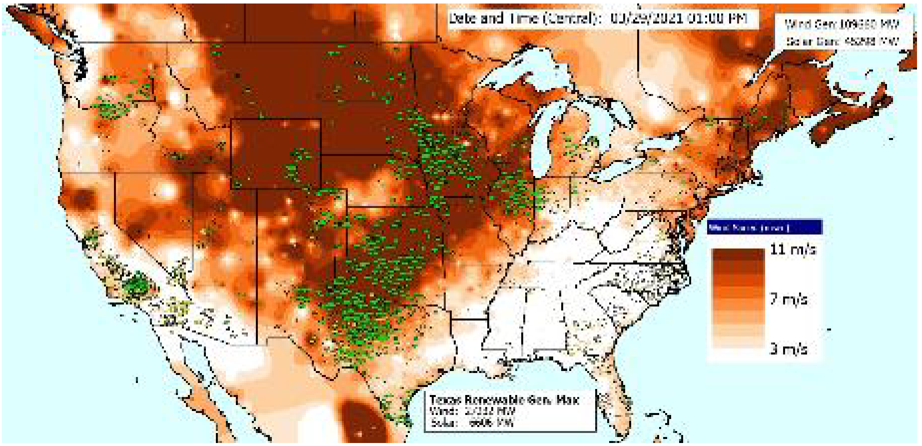
- While information is shared within the operations community, much of this information is not shared outside of this community

Image Source: why.org from 3/17/20 of PJM control room

Where We’re Going in the Next Two Decades

Chapter 3 presents our thoughts on future directions

- We’re optimistic for the future! This is an exciting time to be in the power field, with rapid changes occurring in all areas of the grid.
  - These rapid changes mean that we’re sailing into uncharted waters with lots of opportunities but also potential perils
- A key take away is since the future is inherently uncertain, research needs to prepare for a range of scenarios
  - A goal should be to future-proof the grid so regardless of how the grid evolves the US is prepared [a]



[a] *Analytic Research Foundations for the Next-Generation Electric Grid*, The National Academies Press (NAP), Washington, DC, 2016

Where We're Going in the Two Decades, cont.

- There is likely to be a continued growth in wind and solar generation with much more storage and perhaps a large increase in load with electrified transportation
  - Some of these changes will be at the transmission level (our scope) and some in the distribution system (out of our direct scope yet certainly impacting the transmission grid)
- The essence of the transmission grid is unlikely to change
  - Most electricity will flow through the transmission system and most customers will depend upon it for at least part of their electricity needs
- Large increase in observability and controllability of the grid
- Rare events are likely and are likely to have a paramount impact

Background on Recommended Focus Areas

The next sections present some specifics, but it is important to understand the scope of this paper

- This is one of five papers focused on the research and development targets for DOE's Office of Electricity
- Hence paper does not present an overall research agenda for the electric power industry
- Many of the research needs are better handled be others: NSF, EPRI, vendors, utilities, other parts of DOE, other agencies

Overall research focus should be on the complexities of large-scale grids, with a focus on better mitigating high impact events

Operators' Management of Real-Time Operations

- Two types of control centers (ISOs/RTOs/RCs and TOPs) and two types of technical staff (operators and engineers)
  - Humans will be very much in the loop next two decades
- Top research focus areas include
  - Data management
    - There will be much more data including from PMUs and other sources
  - User interface (including visualizations) especially for rare events
    - Displays tend to work well in normal operations; focus on emergencies
  - Intelligent applications
    - This will become more crucial as the grid becomes more automated
  - Transmission-distribution data exchange

Engineering Tools to Support Real-Time Operations

Enhanced engineering support tools are needed, driven both by more data and the need for better decisions

- State estimator (SE) including linear state estimators
  - The SE should be more robust, particularly for stressed system conditions
- Contingency analysis including dynamics
  - Faster algorithms and more complete system representation
- Power flow and optimal power flow, SCOPF
  - There are still convergence issues, and a need for faster algorithms
- Corrective/preventative actions
  - Better decisions support for humans, and automated control support

Technologies for Use of Historical Real-Time Data

Transmission operations generate and consume vast amounts of data; there is a need to better utilize this data for future decision making and for planning

- Forecasting
  - Focus on electrical applications, with weather forecasting out of scope
- Machine learning
  - Research is needed to develop the knowledge required for operators to take action. Deep learning from long periods of historical data can predict what actions are needed
- Model tuning
  - More effective and automated use of historical data is needed to create better models

Engineering Tools for Transmission Planning

The goal of planning is to ensure that the transmission system is adequate during normal and likely contingent situations, and that it is resilient to high impact events

- Transmission planning is more difficult in the absence of integrated generation planning; lack of generation adequacy in the future is a major threat to grid reliability/resiliency
- Better stochastic methods for planning and long-term forecasting
- Better representation of grid dynamic behavior including more representation of the protection system and RASs
- Machine learning applications including the use of historical data
- Improved situational awareness with planning models, which are ever growing in complexity

Training Simulators

Training simulators are widely used in operations, but they can also be used for broader training and education; newer ones now incorporate faster dynamics

- Power system module
  - Improved integration of faster dynamics
- Control center module
  - There is a need for broader access and for incorporation of coupled infrastructures
- Instruction module
  - Primitive compared to other industries, needs much development
- Power system simulation access
  - For people other than operators

Image Source: A. Bose, R. Podmore, J. Spanel, "Challenges in Operator Training," IEEE Power and Energy Magazine, 2023

High-Impact, Low-Frequency Events; Restoration

Blackouts cannot be totally eliminated, but their frequency and duration can be decreased.

The societal impact of blackouts is not a linear function of their size or duration

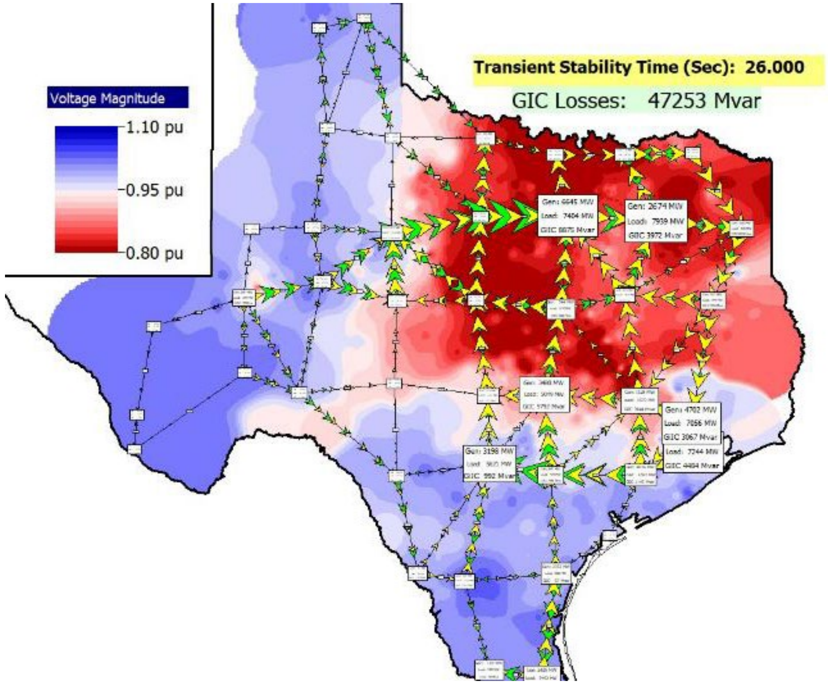
- The industry also has a long and mostly successful track record of quickly restoring service following many disruptions

However, there are some events are of such magnitude that their impact on the electricity grid and on society as a whole could be catastrophic

- “High-Impact, Low-Frequency” (HILF) or “Black Sky” events

High-Impact, Low-Frequency Events; Restoration

- Mitigating the impact of HILF events needs to be a high (or highest) priority
  - A broad portfolio of research is needed to understand, simulate and develop mitigation strategies for HILF events. Recent events have demonstrated that such events could be devastating
  - Researching these issues can help with normal operations as well
- HILF Simulation
  - Currently there is a lack of HILF event simulations



Research Infrastructure (Transmission Perspective)

- Research is not done in a vacuum and a complete discussion of priorities needs to consider the capabilities of researchers to provide useful results. The three main research providers are
  – Industry, universities, national labs
- While historically many of the top publications came from industry, now a comparatively insignificant portion of papers is contributed by industry or people conducting practice oriented research
  – There is a desperate need for more practice oriented research
  – Much information about current industry practice is not published

Research Infrastructure

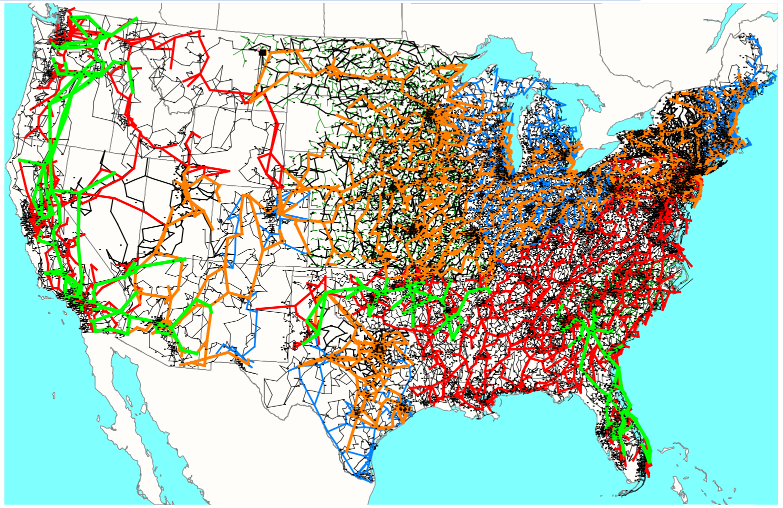
A common research practice is to

- Simplify the problem to make it relative easy to express mathematically (putting all the “wrongness” here)
- Provide an elegant mathematical solution, which impresses paper and proposal reviewers; scalability is often ignored
- Real complexities are left to “future work” that never gets done!

A key issue in transmission operations and planning is actual electric grids are quite complex and don’t fit this paradigm

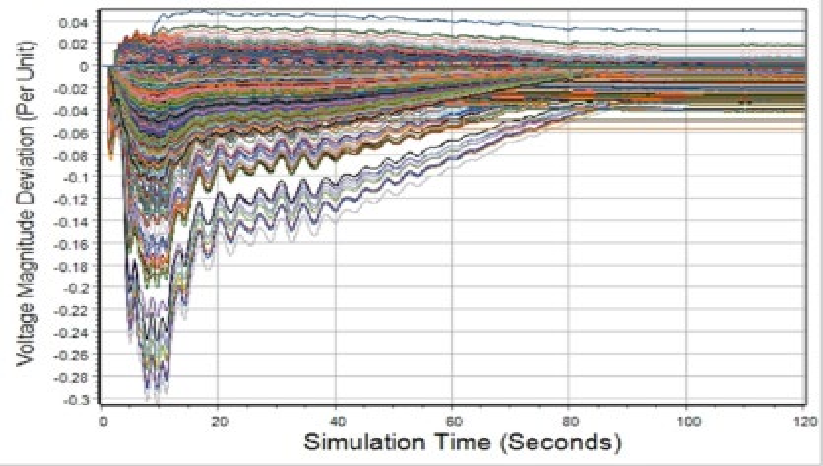
We need more research publications focused on engineering practice!!

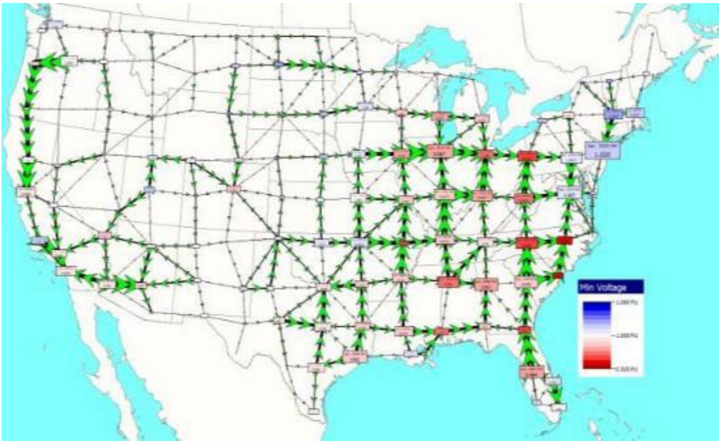
Research Infrastructure: Some Recommendations



Improved access to large-scale, complete electric grid models and data sets; due to CEII issues much of this would be synthetic

- ARPAE has done a lot to help make these available, but there is a crucial need for synthetic grids that include dynamics
- Ability to conduct large-scale studies to research changes in grid architecture is hampered by balkanization of data and tools





Questions?

Email: bose@wsu.edu, overbye@tamu.edu

Full report is at https://www.energy.gov/sites/default/files/2021-05/Grid%20Operations%20Bose%20Overbye_0.pdf