Transient Stability Aspects of Renewable Generation Integration

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September 13, 2016

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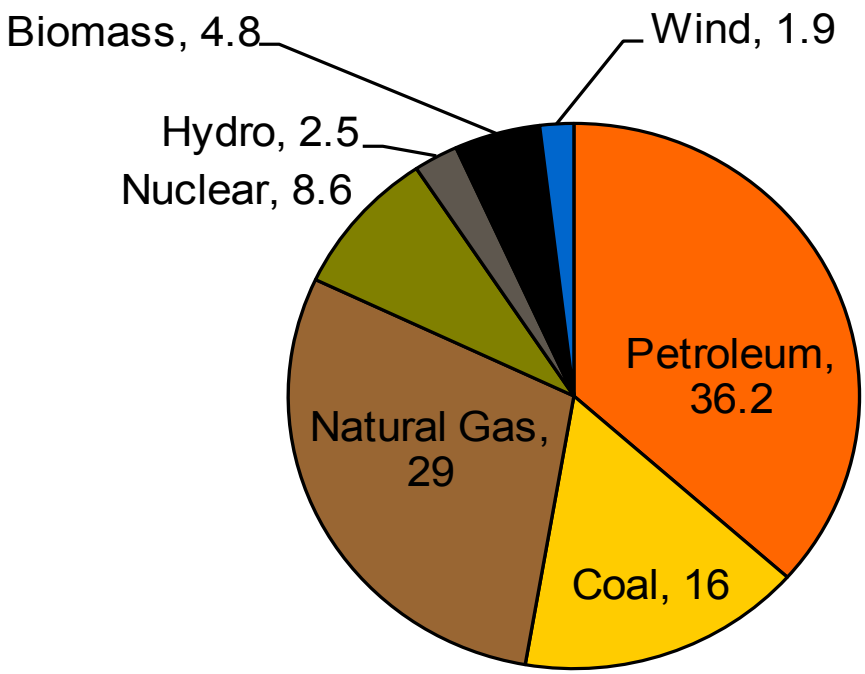
PSERC

Overview

- Interconnected electric grids are going to play a key role in the development of our sustainable energy future
  - In the US about 40% of our energy transported as electricity, a value that should be increasing as transportation becomes more electrified
  - Most non-carbon energy is first converted into electricity
  - Off-grid options are unlikely to supply a significant percent of our energy needs
- Presentation covers implications of large-scale renewable integration on electric grid dynamics

Where We Got Our Energy in 2015

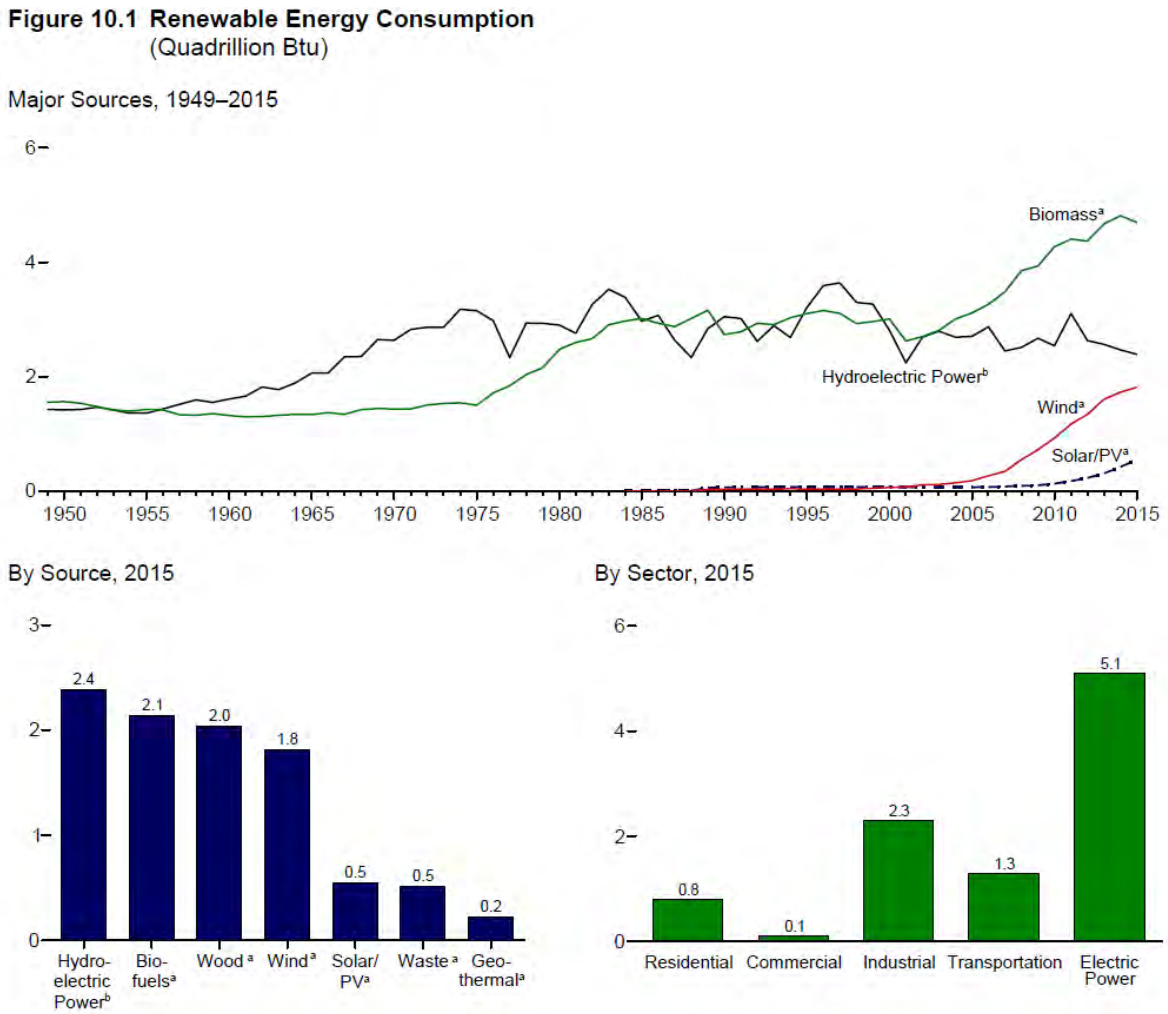


In 2015 we got about 1.9% of our energy from wind and 0.6% from solar (PV and solar thermal), 0.2% from geothermal

About 81% Fossil Fuels (86% in 1990 and 2000)

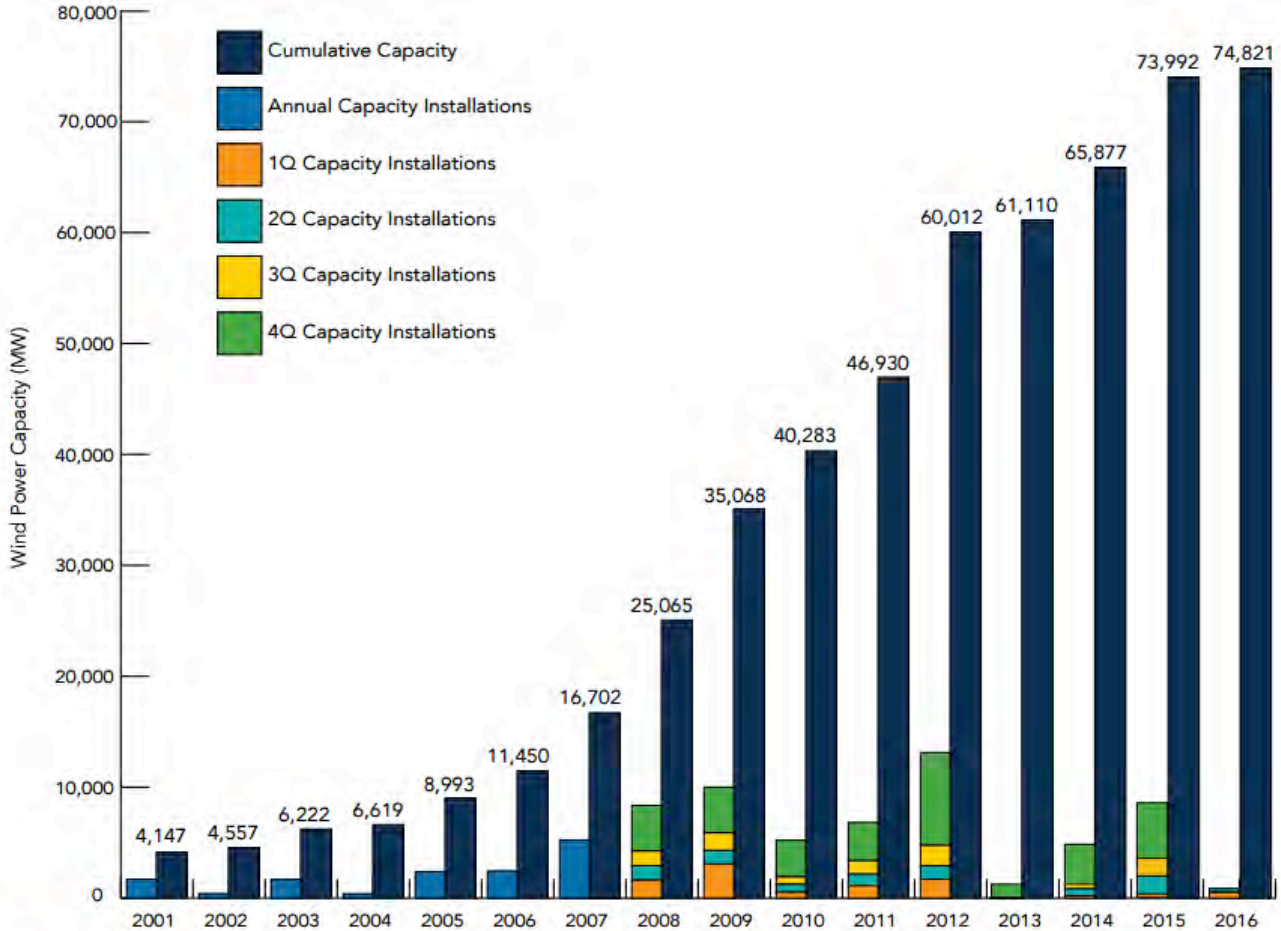
Source: EIA Monthly Energy Review, July 2016

Renewable Energy Consumption



Source: EIA Monthly Energy Review, July 2016

Growth in US Wind Power Capacity

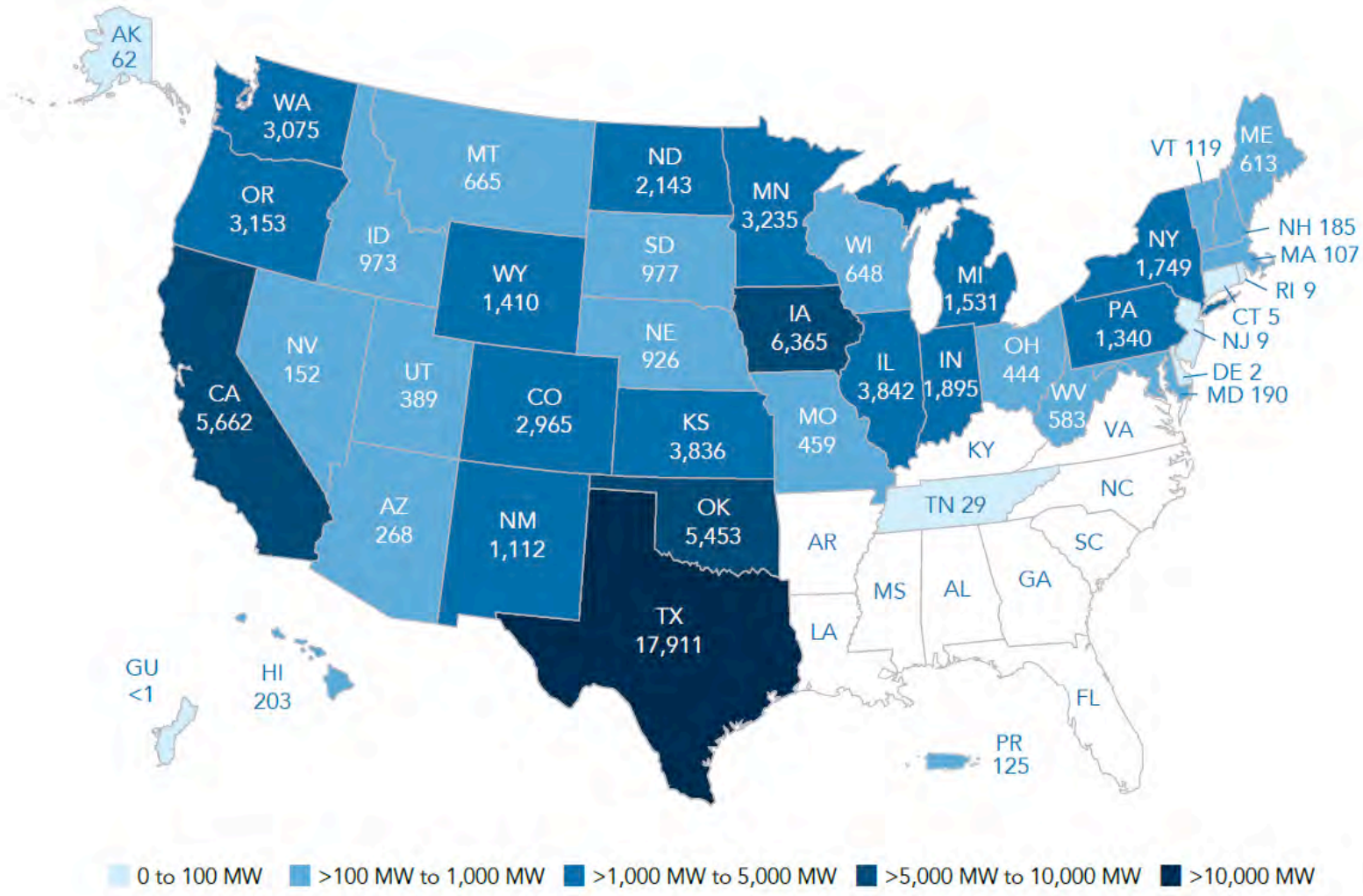


Note: Utility-scale wind capacity includes installations of wind turbines larger than 100-kW for the purpose of the AWEA U.S. Wind Industry Quarterly Market Reports. Annual capacity additions and cumulative capacity may not always add up due to decommissioned, uprated and repowered wind turbines. Wind capacity data for each year is continuously updated as information changes.

American Wind Energy Association | **U.S. Wind Industry Second Quarter 2016 Market Report** | AWEA Public Version 4

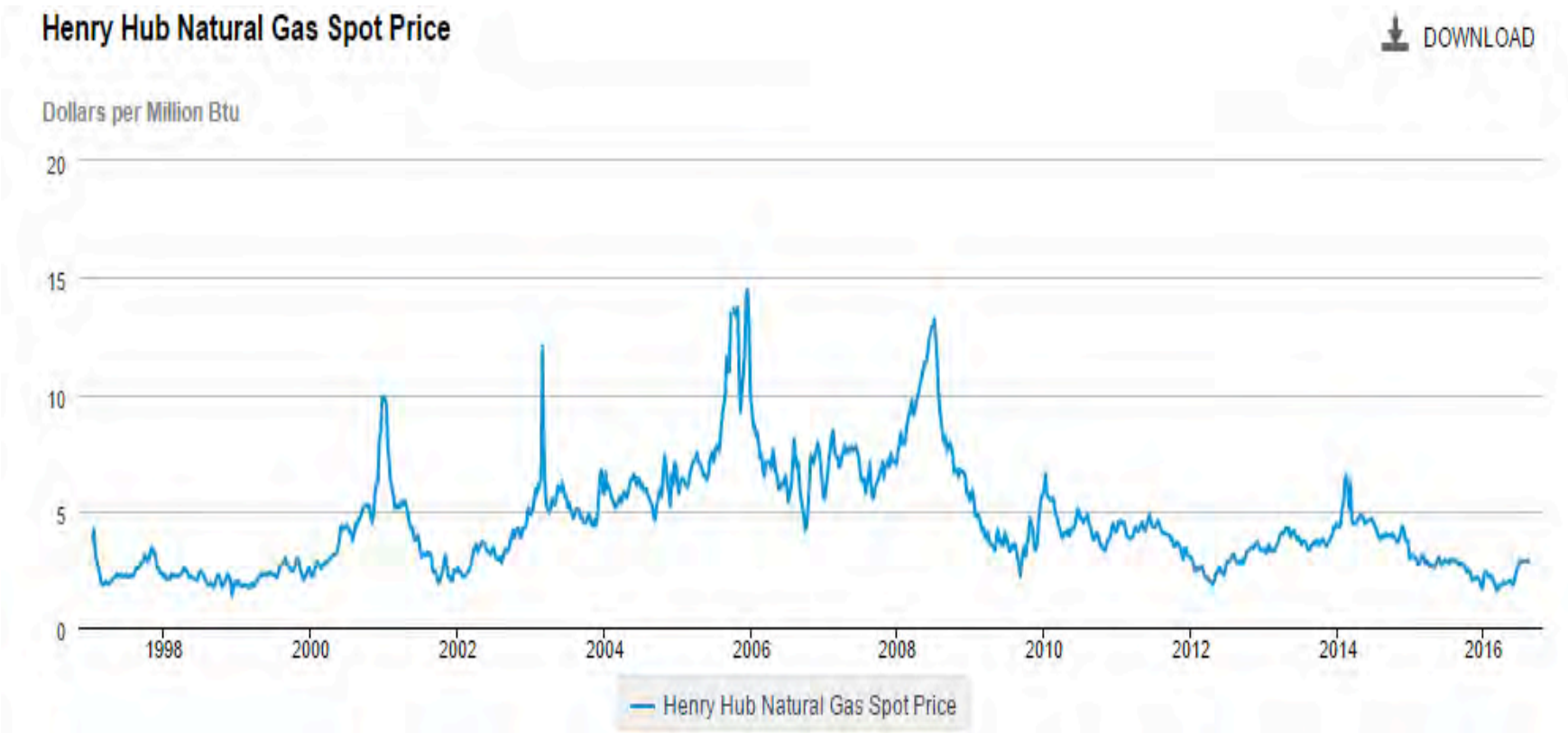
Source: AWEA Wind Power Outlook 2 Qtr, 2016

Wind Capacity Installations by State



Source: AWEA Wind Power Outlook 2 Qtr, 2016

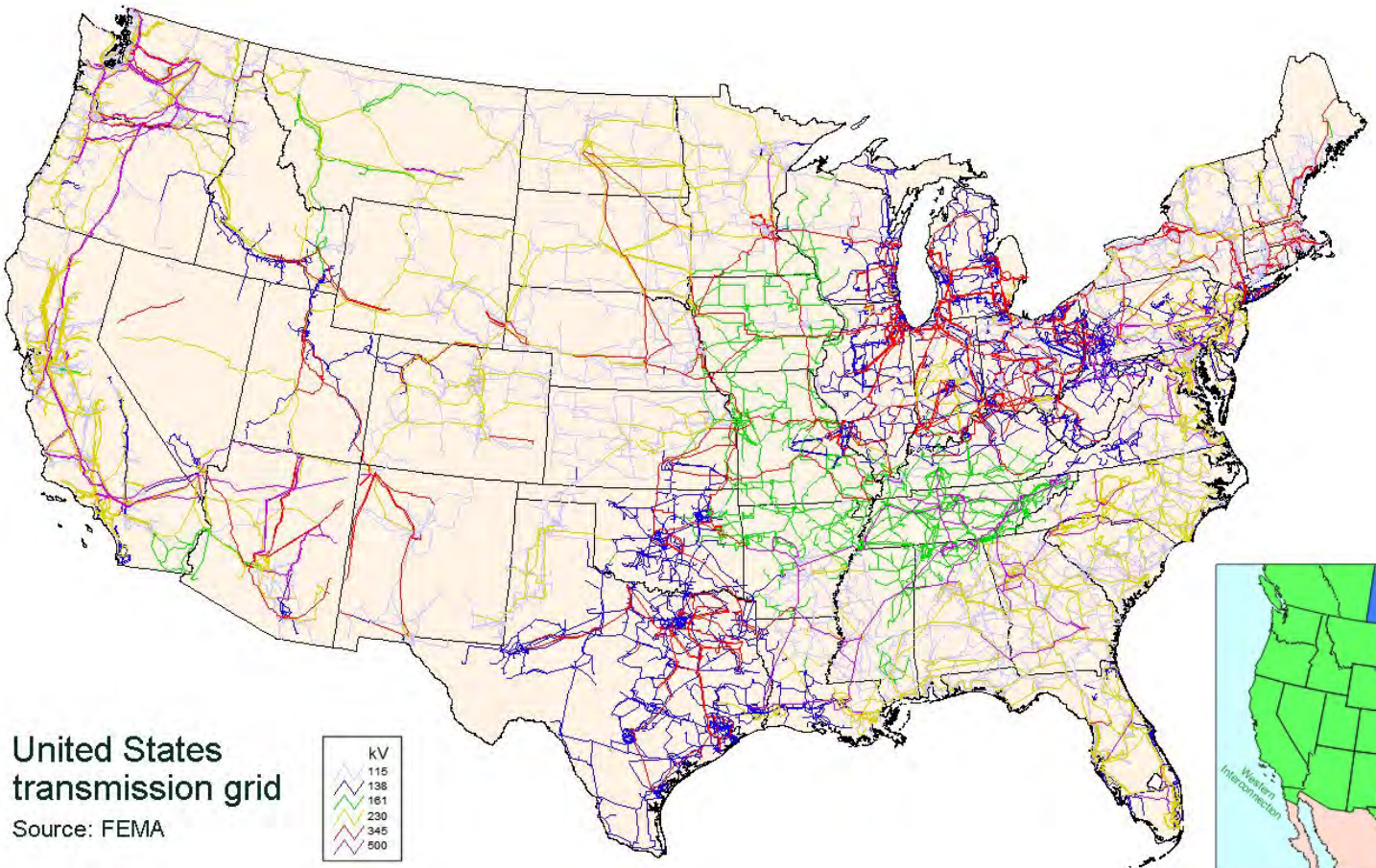
Natural Gas and Electricity



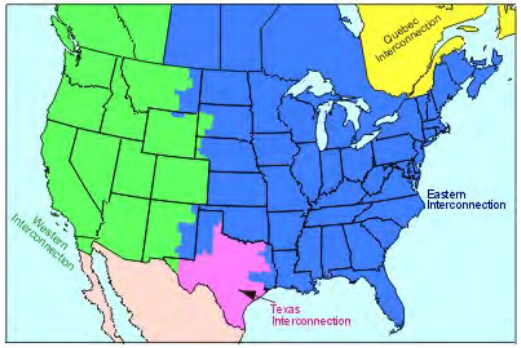
Marginal cost for natural gas fired electricity price in $/MWh is about 7-10 times gas price

Source: http://www.eia.gov/dnav/ng/hist/rngwhhdW.htm

US Transmission Grid



Voltages up to 765 kV; Highly inter-connected but with some what limited long distance power transfer capabilities



What Makes the Grid Unique

- Each electric interconnect is one large circuit
- Fast system propagation of disturbances throughout an interconnect.
- There is no mechanism to efficiently store electric energy: generation must equal load
  - only several seconds of kinetic energy stored
  - no equivalent of busy signal, or holding pattern
- With few exceptions, there is mechanism to directly control power flow in grid
  - flow is dictated by impedance of lines; “loop flow” is a significant problem on some systems

Power System Time Frames

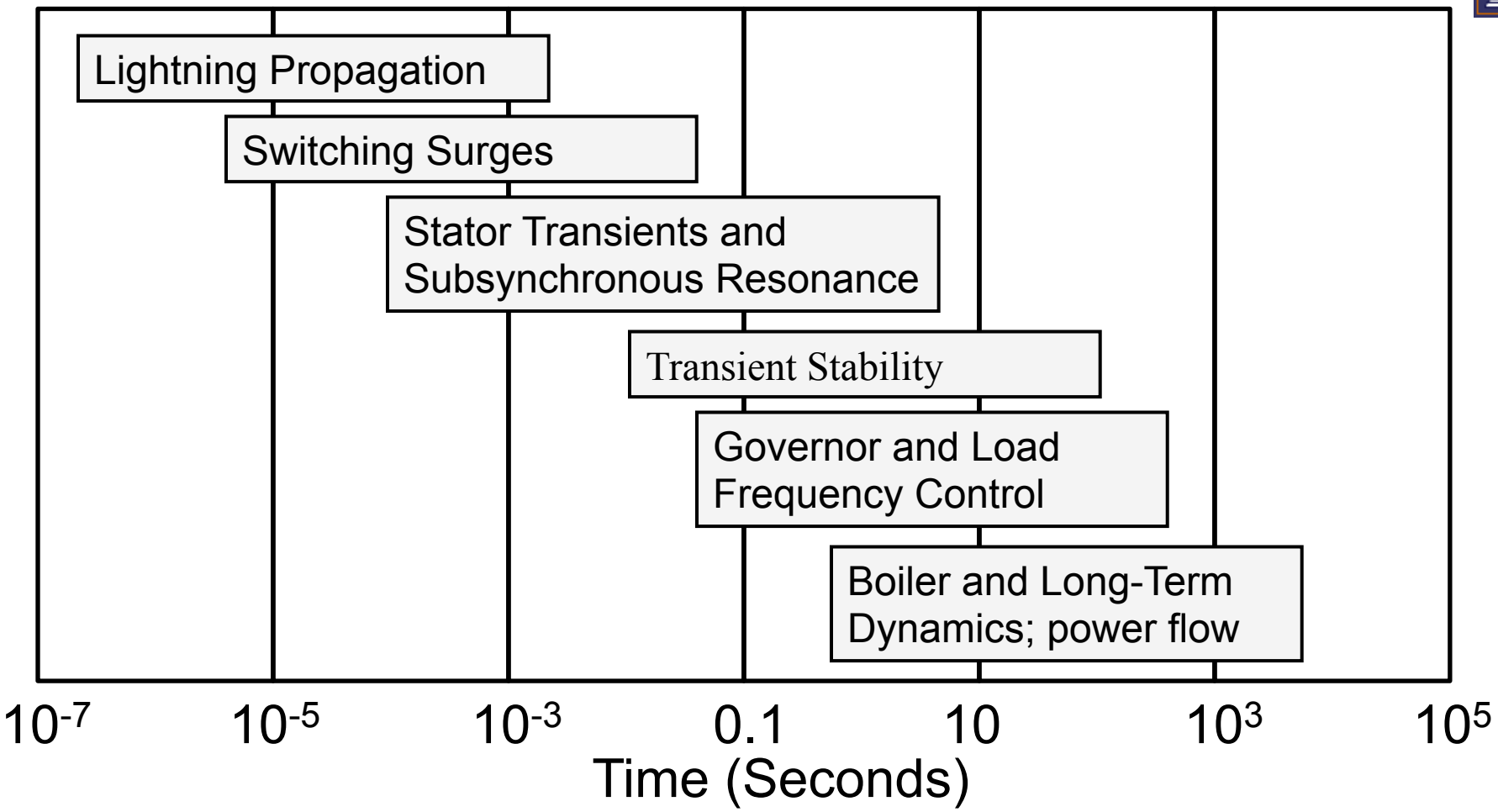
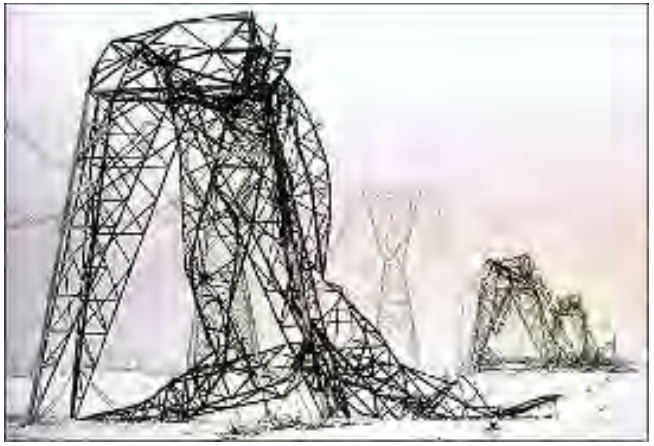


Image: Sauer, P.W., M. A. Pai, *Power System Dynamics and Stability*, Stripes Publishing, 2007

The Grid Needs to Be Resilient to Lots of Disturbances

- Lightning strike sequence of events: 1) lightning strikes line causing a fault, 2) circuit breakers deenergize line in a few cycles, clearing fault, 3) circuit breakers reclose within several seconds restoring line.
- But ice, tornados and hurricanes can bring large-scale damage.



Frequency Response for Generation Loss

- In response to rapid loss of generation, in the initial seconds the system frequency will decrease as energy stored in the rotating masses is transformed into electric energy
  - Solar PV has no inertia, and for most new wind turbines the inertia is not seen by the system
- Within seconds governors respond, increasing power output of controllable generation
  - Solar PV and wind are usually operated at maximum power so they have no reserves to contribute

But It Can Fail Dramatically

Blackout misery

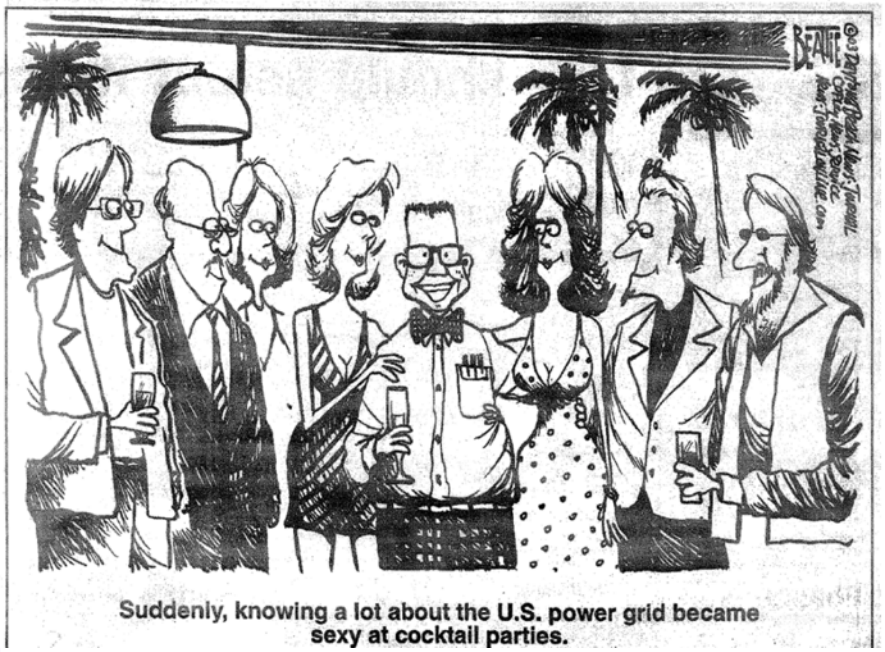
50 million affected in Northeast and beyond as power grid fails

Transportation Many 'wait it out,' by air and land ■ 4A | **Scenes** Moms in labor, cars stuck in car washes ■ 5A | **Impact** Offices close, ATMs idle, cellphones jam ■ 1B

By Chad Rachman, New Brisbet, via AP

Brooklyn Bridge: Thousands of commuters in New York took to their feet Thursday evening after a major power outage hit the city and much of the Northeast.

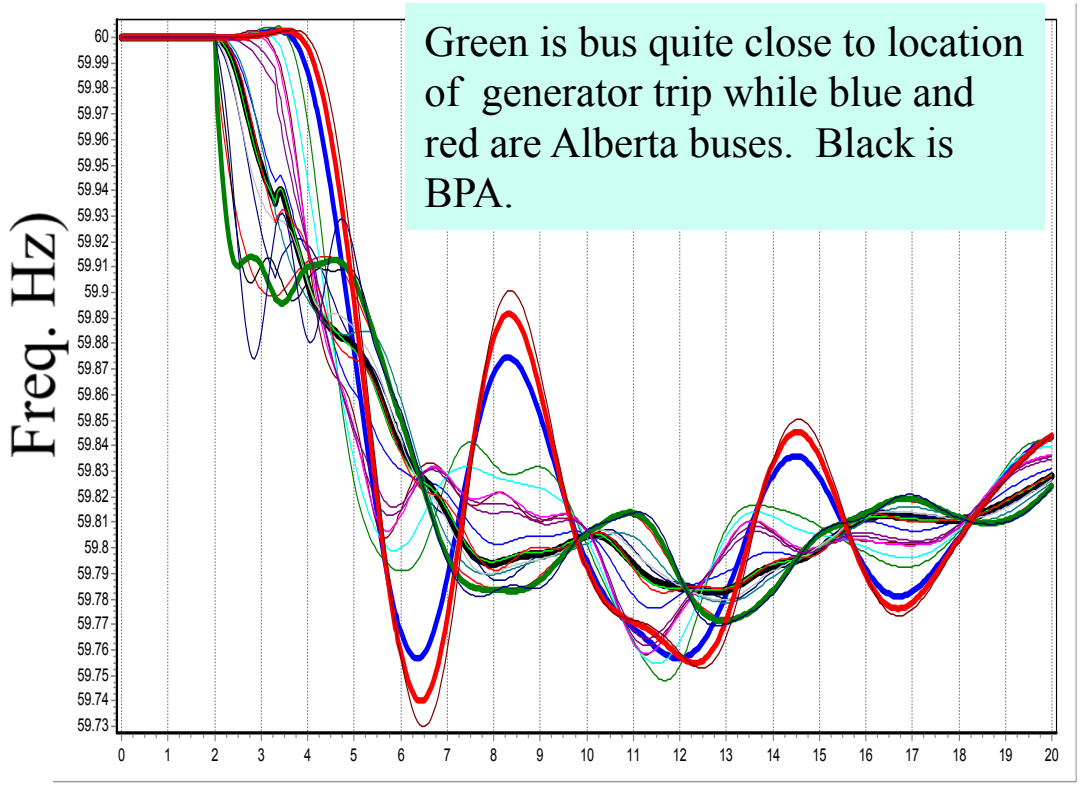
August 14, 2003
Blackout



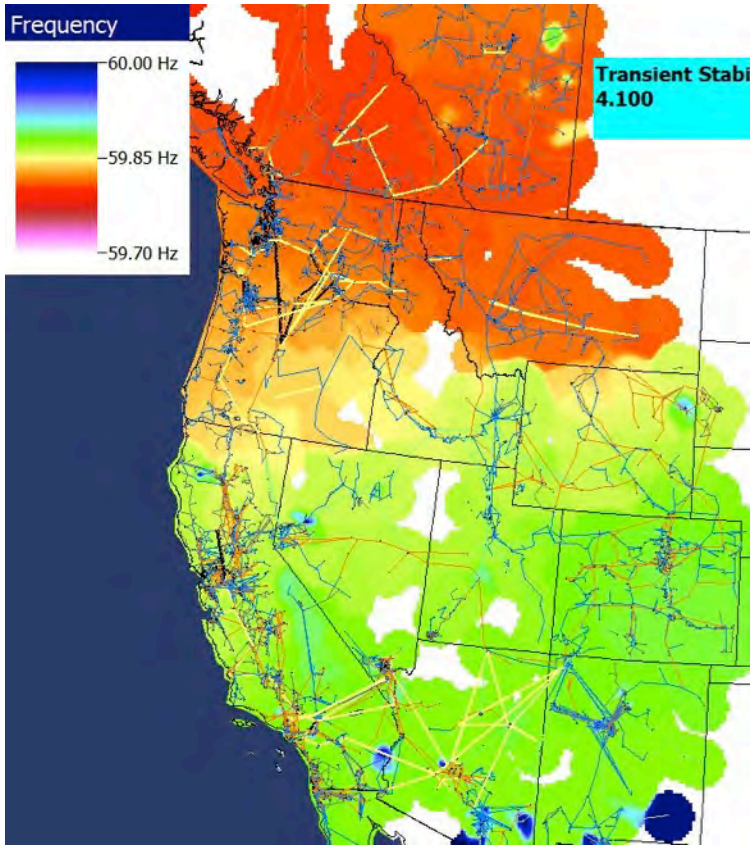
Suddenly, knowing a lot about the U.S. power grid became sexy at cocktail parties.

Power Grid Disturbance Example

Figures show the frequency change as a result of the sudden loss of a large amount of generation in the Southern WECC



Time in Seconds



Frequency Contour

Disturbance Animation

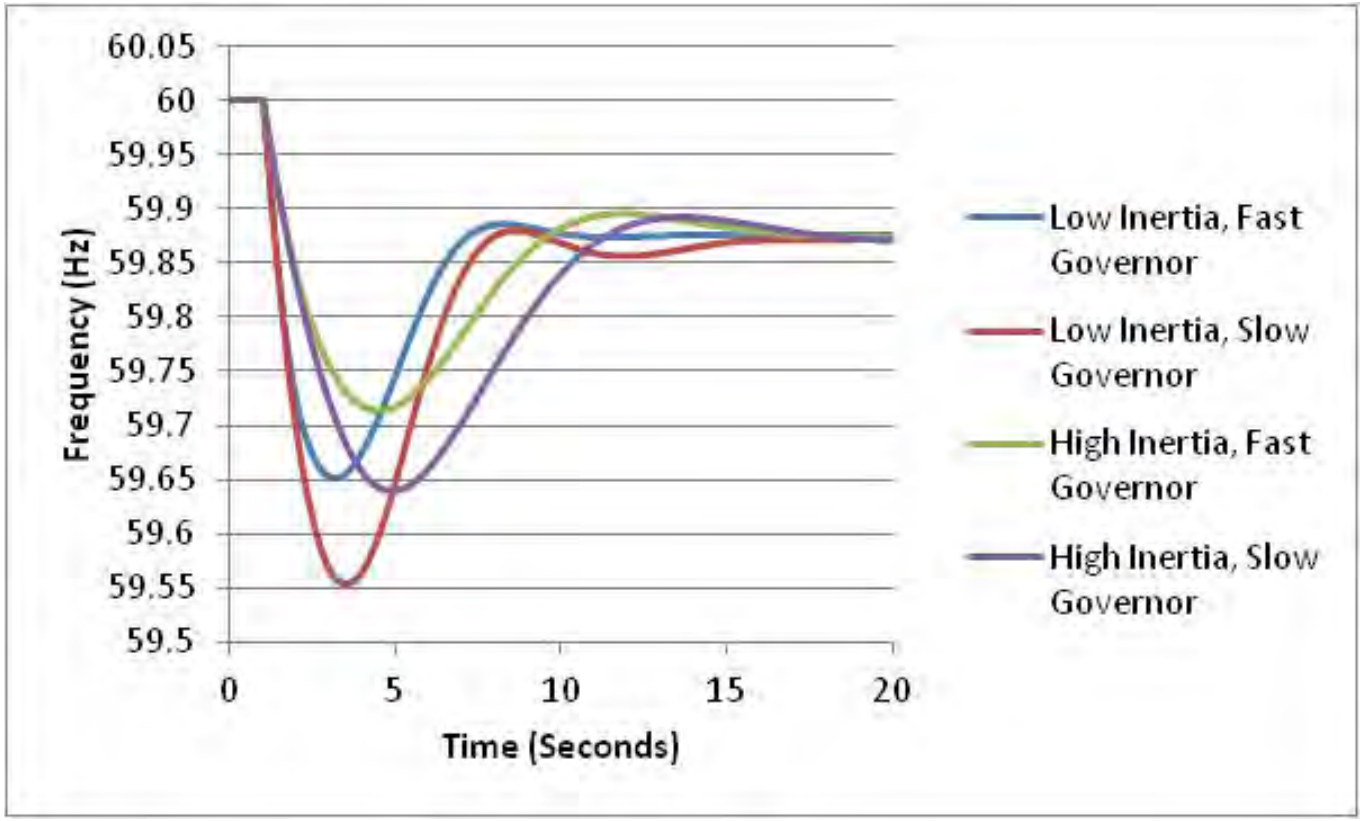
WECC Large Generation Drop Simulation Using PowerWorld version 16 (1/3 real-time playback)

Renewable Generation Implications

- Over last several decades the grid has been stabilized by the inertia provide by large generators, mostly coal and nuclear
- The integration of large amounts (e.g., 50%) of wind and solar PV requires enhanced controls to handle the potential for larger frequency excursions
- More dispersed renewable resources are less likely to suddenly fail, but can be subject to more prolonged, correlated changes
  - Cloud bank moving in over a region that contains lots of solar PV
  - Rapid decrease in wind over large region

Impact of Generator Inertia and Governor Response for Small Case

- Figure shows inertia determines initial frequency drop rate, and governor speed the recovery



The least frequency deviation occurs with high inertia and fast governors

Power System Dynamics Motivation: August 14th 2003 Blackout

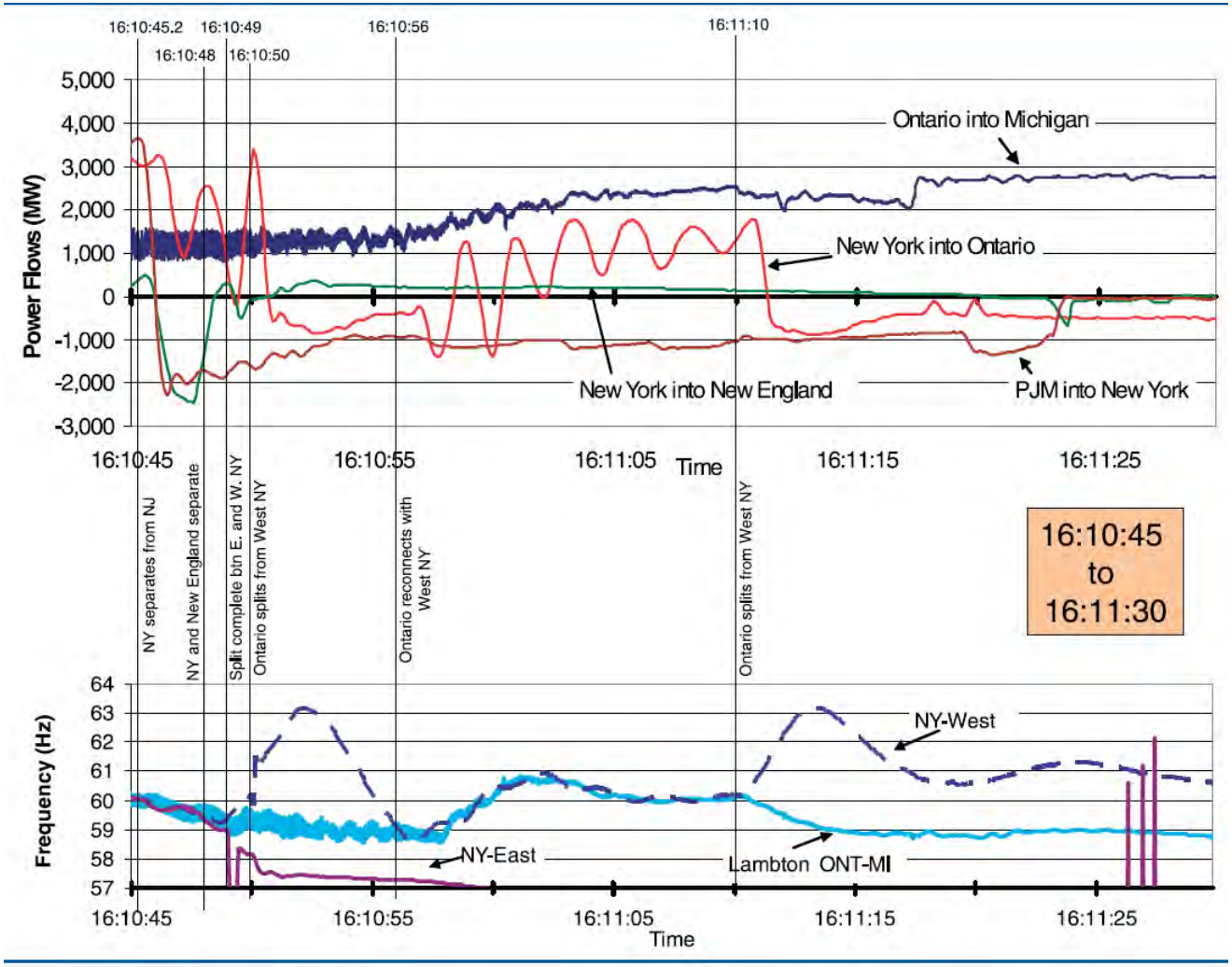


Image source: August 14 2003 Blackout Final Report, Figure 6.26

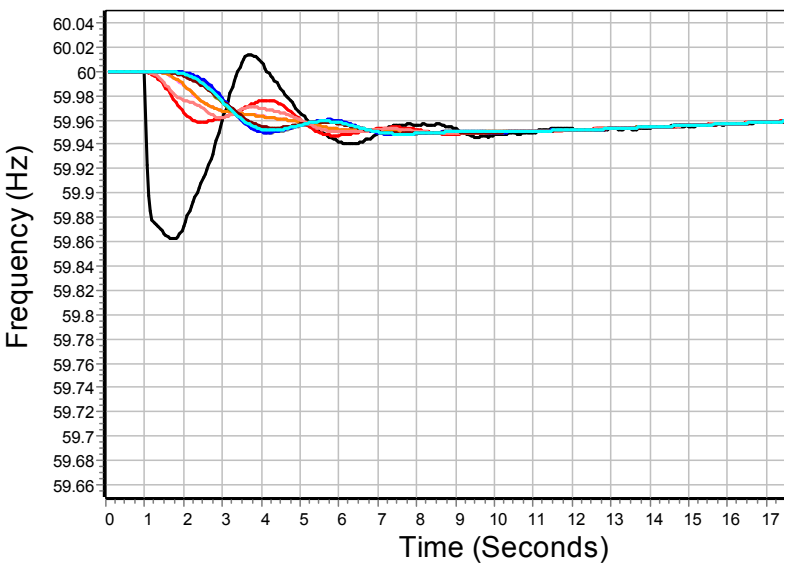
Control Implications

- Possible solutions include
  - Operating renewable generation at values below maximum power output to provide reserves; this helps with governor response but not inertia
  - More controllable load; if response is fast (less than about 2 seconds) this can help with inertia response
  - Modified wind controls to mimic inertia
  - Markets that correctly price value provided by inertia
- Frequency provides a useful control signal
  - Universally available; because of propagation delays communication based control may be faster

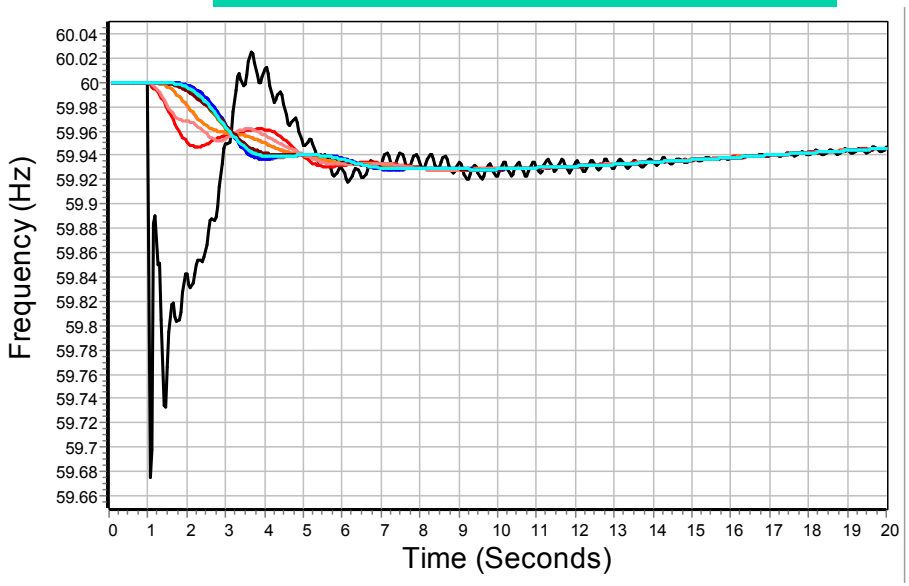
Valuing Inertia and Locational Impacts

- Electric grids need inertia to withstand disturbances
- An open research issue is how to correctly value this inertia
- Another related issue is how much location matters

100% in Subregion

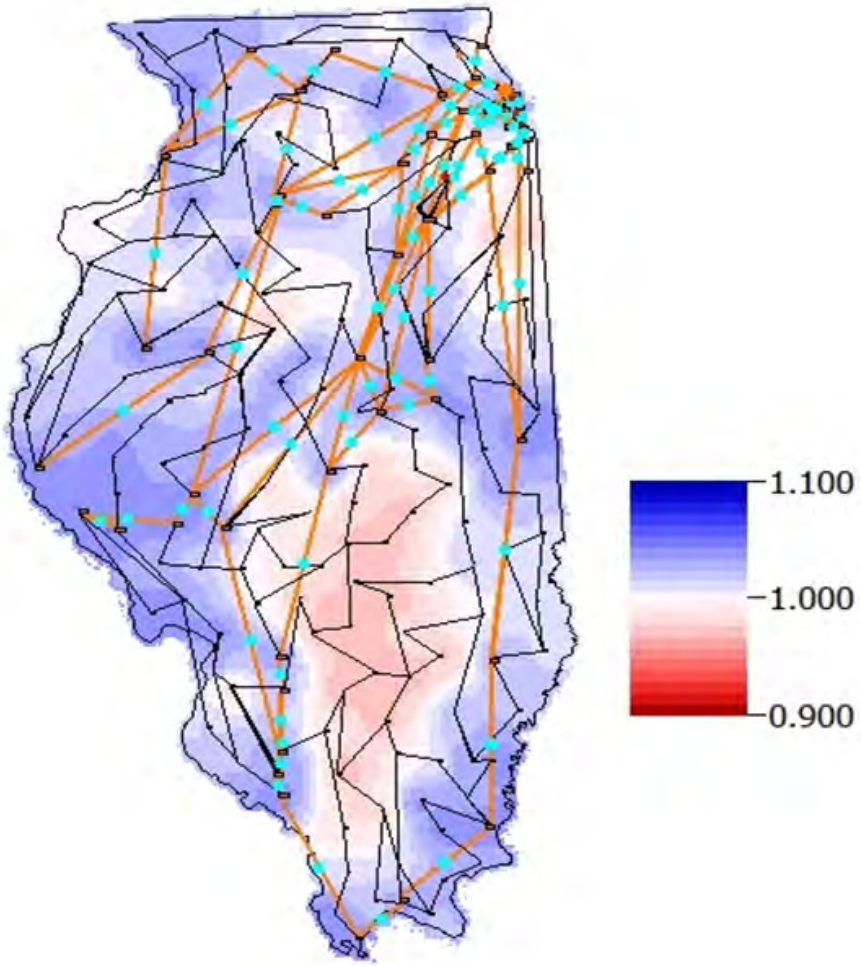


10% in Subregion



A Driver of Research: Synthetic Models

- Access to actual grid models is limited because of confidentiality concerns
- New research is ongoing in the development of synthetic models
  - Mimic actual grid
- Being used in ISEE for coupled infrastructure research



Thank You!

Questions?