Enhancing Electric Grid Innovation Through the Use of Highly Detailed Synthetic Grids

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Acknowledgments

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- Slides also include contributions from many of my students, postdocs, staff and colleagues at both TAMU and UIUC

The Need for Synthetic Electric Grids

- Prior to 9/11/01, a lot of electric grid information was publically available
- Now access to data and models about the actual power grid in the US is quite restricted (e.g., critical energy/electricity infrastructure [CEII])
  - What is available is often partial, and can't be shared
- To do effective research, and to drive innovation, researchers need access to common, realistic grid models and data sets
  - Scientific principle of reproducibility of results

The Need for Synthetic Grids, cont.

- Synthetic grids and datasets are, of course, designed to augment, not replace actual grids
- But the synthetic grids offer some significant advantages, both to industry and researchers
  – Since there are no CEII or privacy concerns, full models and their associated datasets can be freely shared; this is particularly helpful for interdisciplinary research
  – Synthetic grids can allow future grid scenarios to be considered in-depth (i.e., high renewables or high impact, low frequency events) yet still be potentially public

Talk Overview: Synthetic Electric Grids

- The talk covers the development and application of high quality, geographically-based synthetic electric grids
  - What are they?
  - How are they created?
  - What is the current state-of-the-art?
  - How are they being applied?
  - How can they help to drive innovation?
  - What's next?

Synthetic Electric Grids

- Synthetic electric grids are models of electric grids that were not created to represent any actual electric grid
- The below image shows the five bus synthetic grid I used as an undergraduate

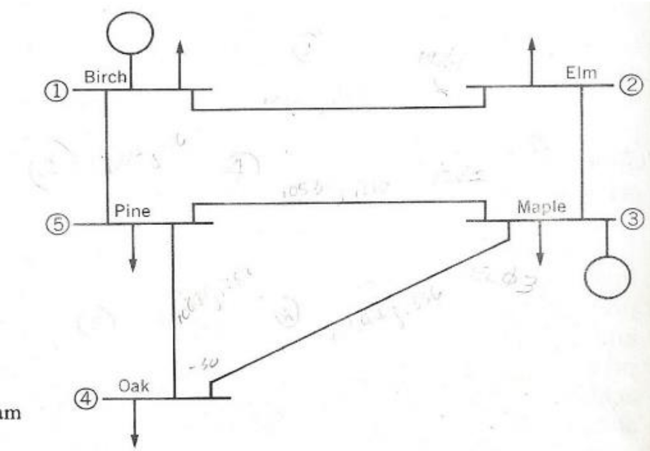


Figure 8.1 One-line diagram for Example 8.1.

Image Source: W.D. Stevenson, *Elements of Power Systems*, Fourth Edition, McGraw-Hill Book Company New York, 1982 (the first edition was in 1955)

Geographically-Based Synthetic Electric Grids

- Synthetic electric grids can be created with or without reference to actual geography
- The image shows an early geographically-based synthetic electric grid
- This grid was designed to show concepts to regulators

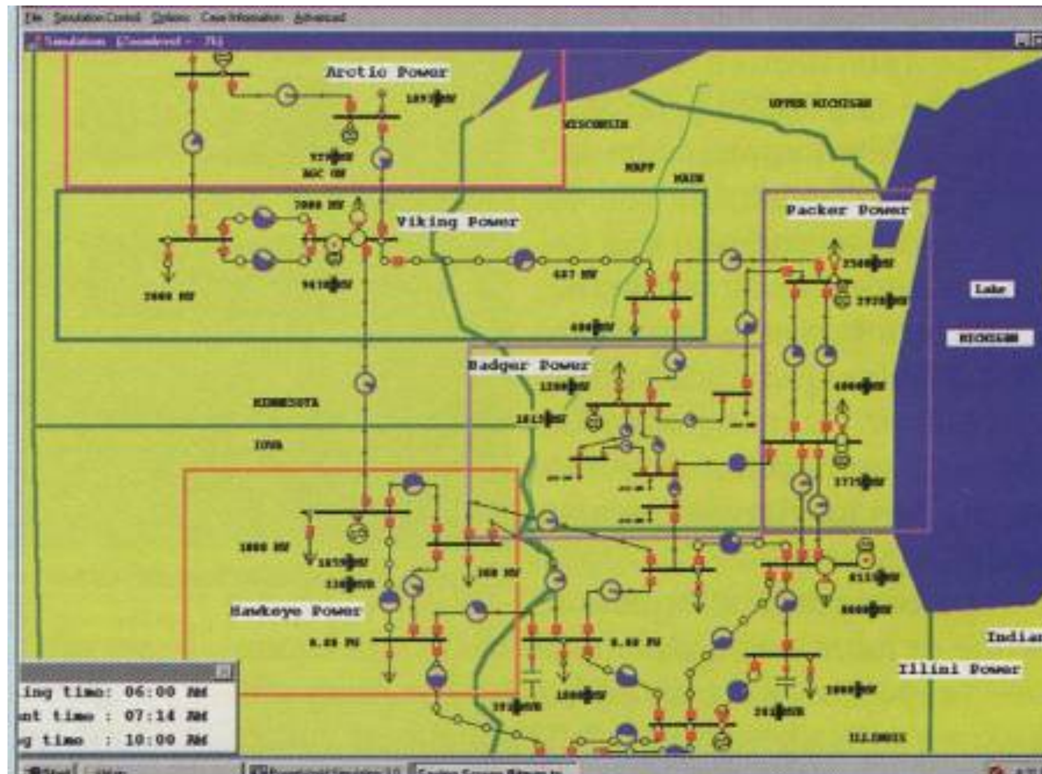


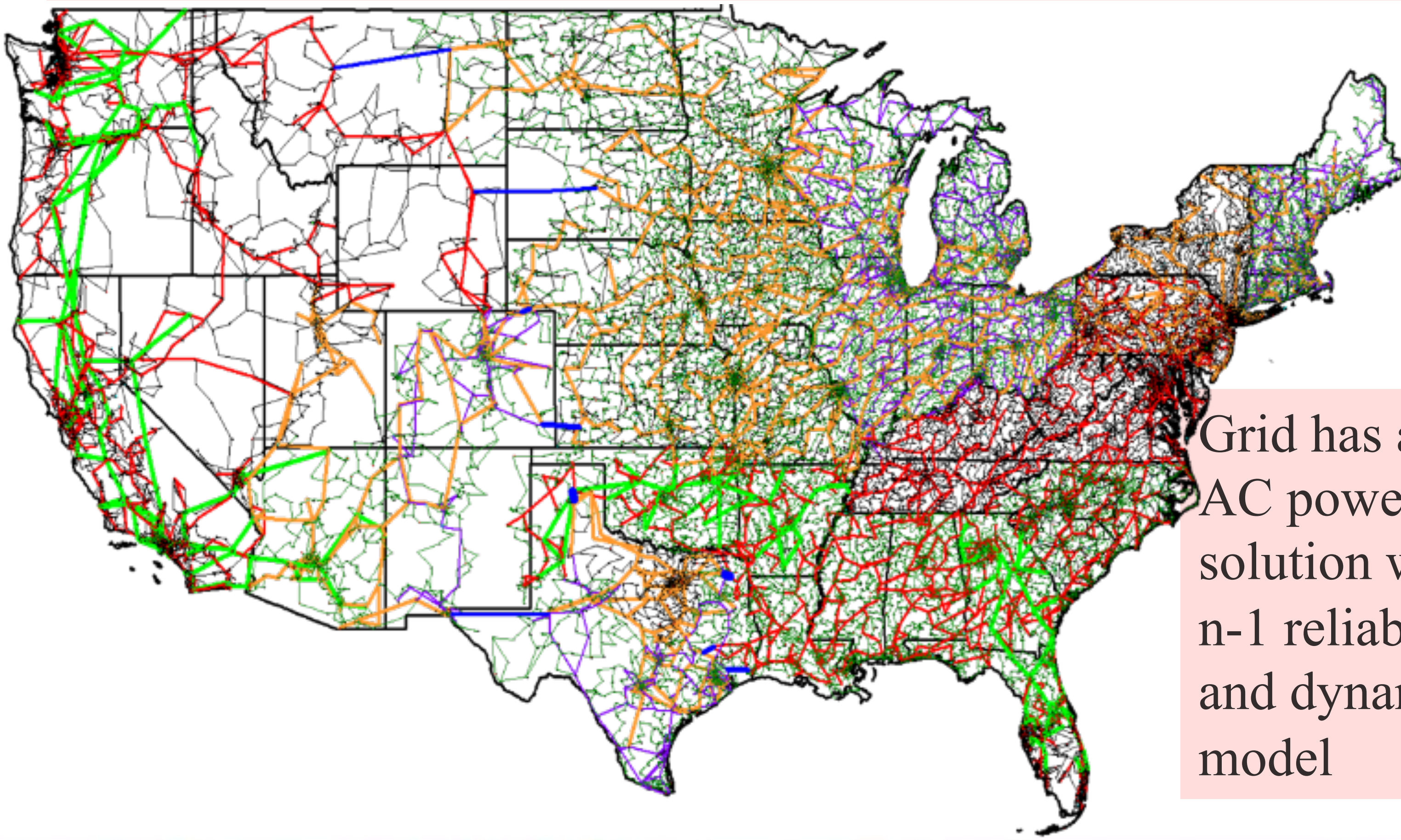
Image Source: PowerWorld Corporation, 1995

High-Quality, Geographically-Based Synthetic Electric Grids

- High-quality synthetic electric grids are designed to have a wide range of characteristics that are similar to those found in actual electric grids
  - "Realistic but not real" to quote Wisconsin colleagues
  - Fictional, but hopefully good fiction
  - **Developed techniques can be applied to real grids**
- However, importantly these grids are not designed to try to duplicate any actual grid
- Over the last four years tremendous progress has been made, much supported by ARPA-E, at both the transmission and distribution levels

Current Status: Large-Scale Grids are Now Available

This is an 82,000 bus synthetic model that we publicly released in summer 2018 at **electricgrids.engr.tamu.edu**

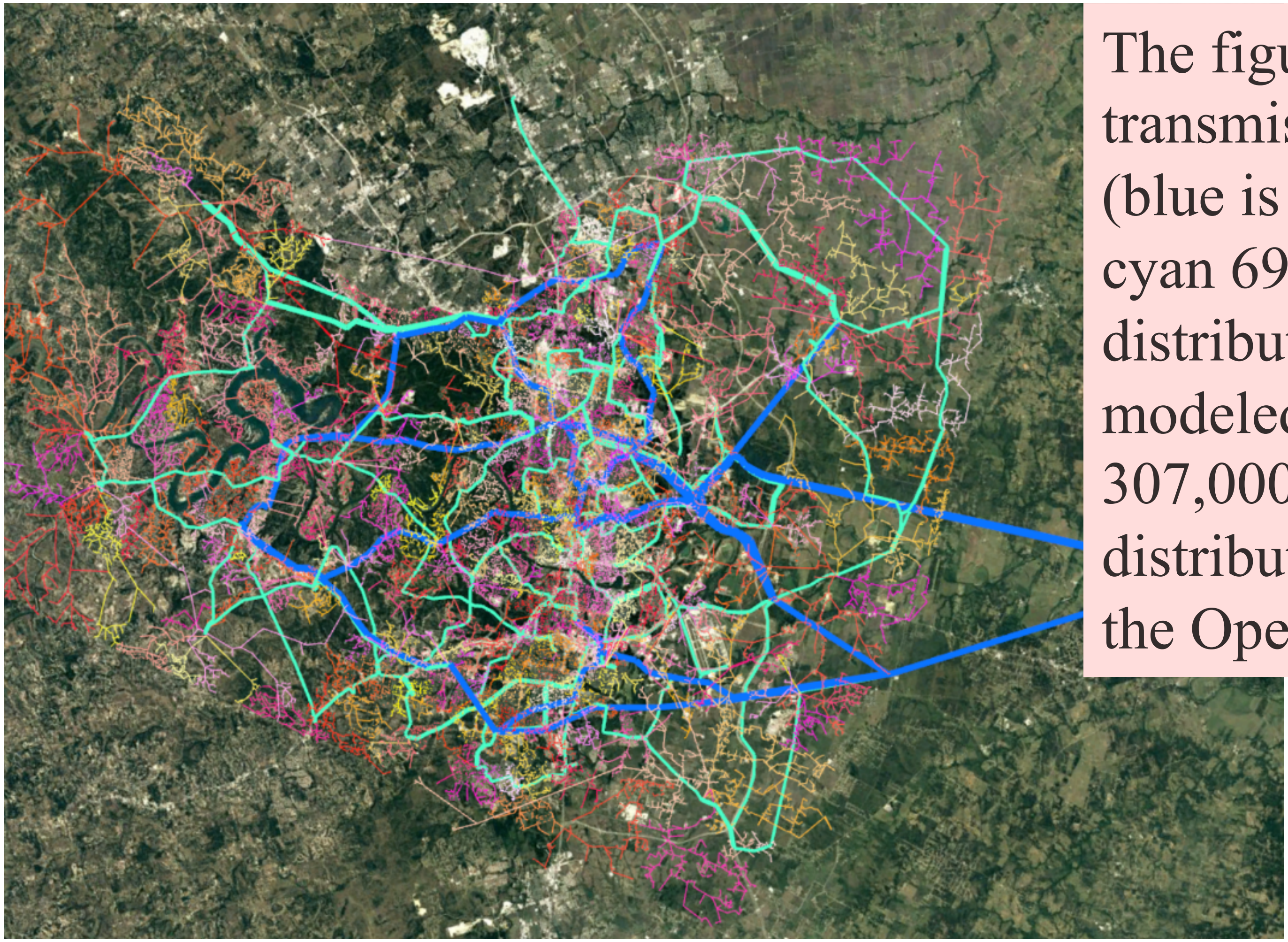


Grid has an AC power flow solution with n-1 reliability and dynamic model

Highly Detailed Combined Transmission and Distribution Grids

- Previous transmission grids were geographic to the zip code level
- On a current ARPA-E project we (with NREL and other universities) are developing "down to the meter" synthetic grids
- Actual parcel data is used to determine location of the electric meters. The parcels are connected by a distribution system, and the distribution system by a transmission grid
- Currently bout 50% of the Texas load is done

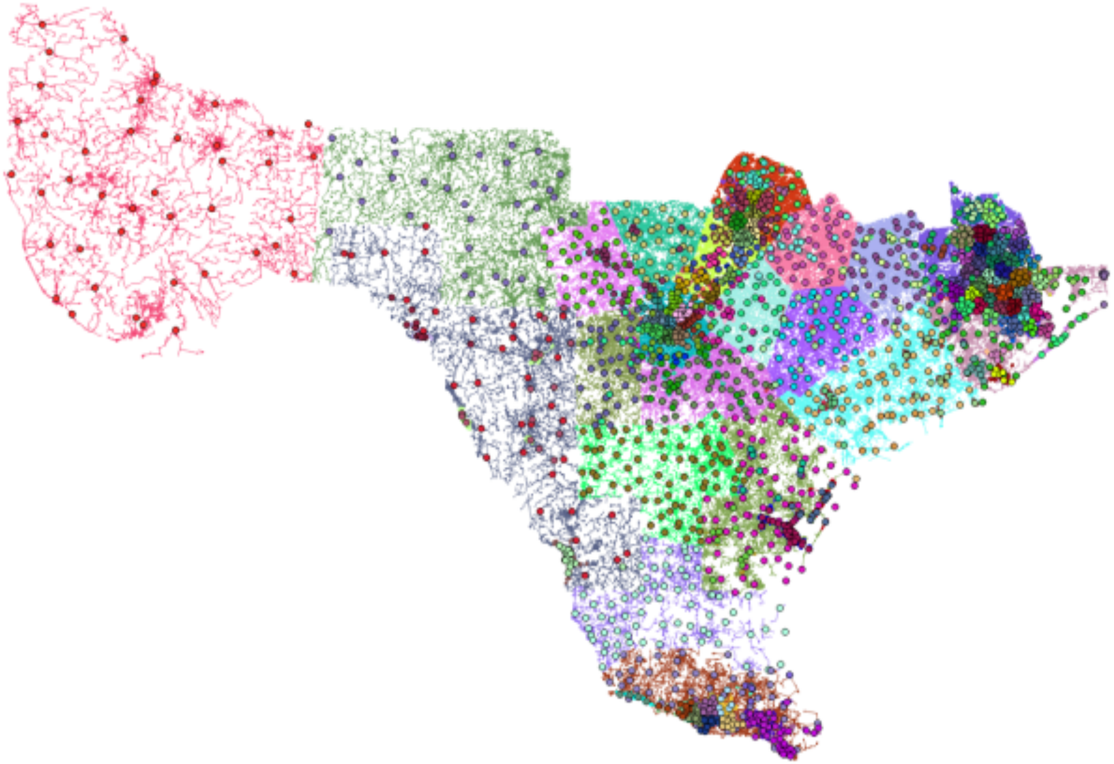
Travis County, Texas (location of Austin, TX)



The figure shows the transmission system (blue is 230 kV and cyan 69 kV) and the distribution system modeled down to 307,000 meters. The distribution data is in the OpenDSS format.

Current Texas Synthetic Grid

- The finished grid will have about 50 million electric nodes; the current grid covers the southern portion of Texas

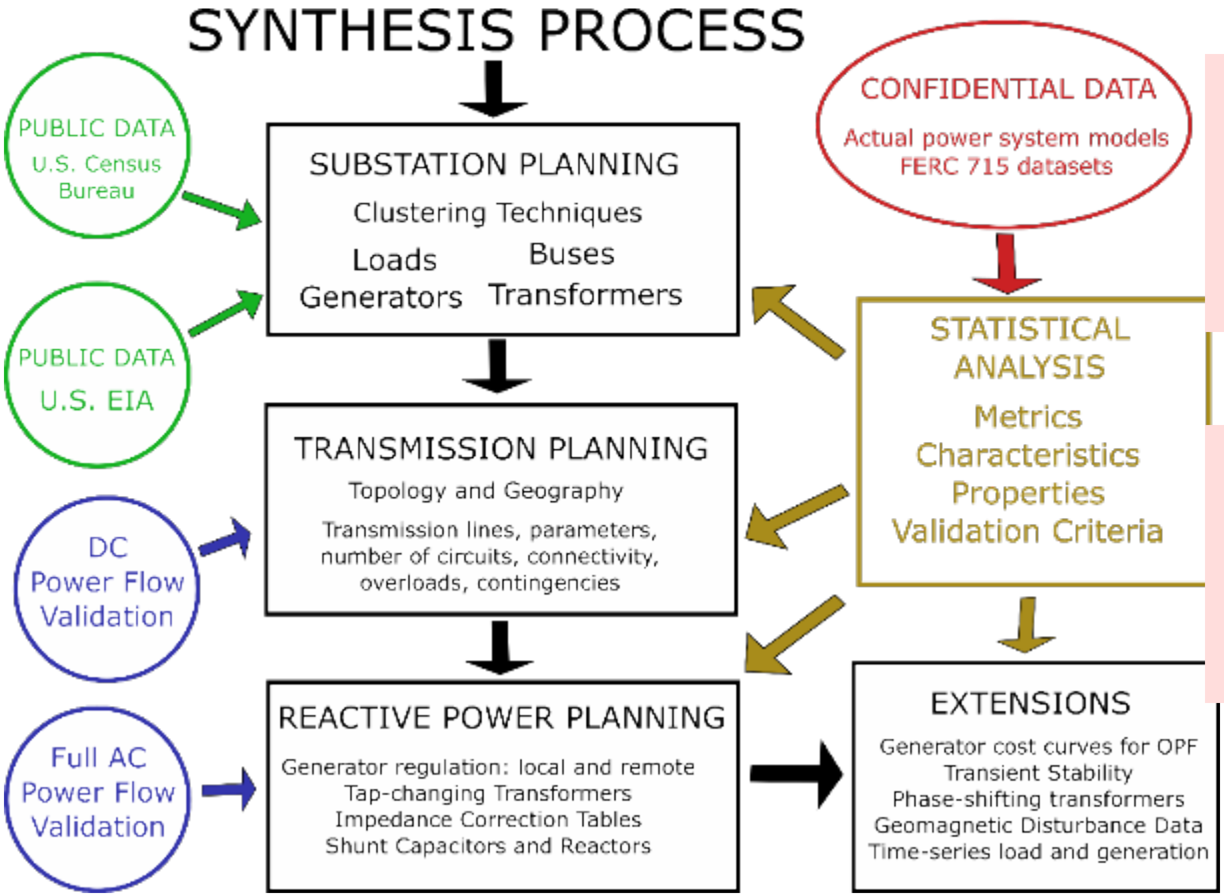


This partially completed grid has 8.4 million customers and 21.7 million electric nodes

Our Synthetic Grid Approach

- Make grids that look real and familiar by siting them geographically (North America for us) and serving a population density the mimics actual
- Goal is to leverage widely available public data
  - Geography
  - Population density (easily available by post office)
  - Load by utility (US FERC 714), state-wide averages
  - Existing and planned generation (Form US EIA-860, which contains lots of generator information)
- Substation locations and transmission system is entirely fictional (but hopefully good fiction!)

Synthetic Model Design Process



The assumed peak load is based on population, scaled by geographic values

Much of this is automated, but there is still some manual adjustment

This process can be augmented to couple with detailed distribution grids

More Details on Design Process

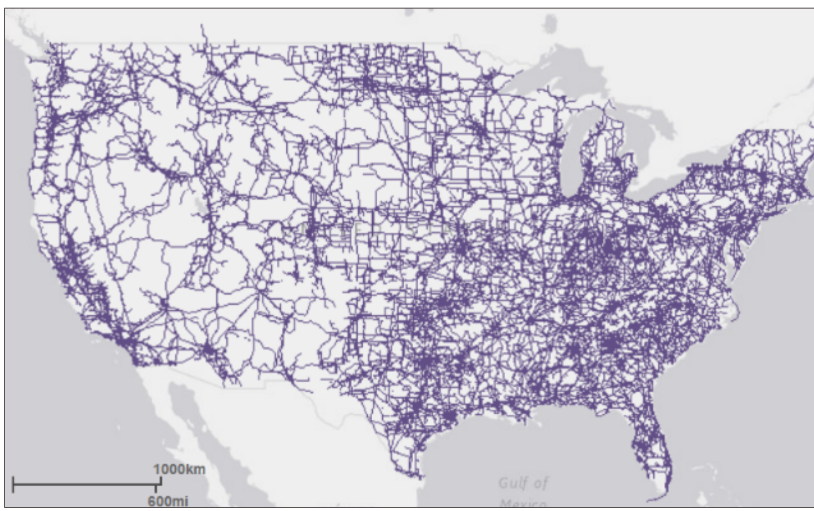
- Substation planning: cluster actual population and energy data into correctly-sized substations and assign load, generation, bus voltage levels, and internal branches, along with parameters.
- Transmission planning: use iterative penalty-based dc power flow algorithm to place transmission lines, with the Delaunay triangulation neighbor statistics
- Reactive power planning: iterative ac power flow starting from known solution to place capacitors and adjust generator set points.

Validation: Insuring High Quality

- Based upon data from actual grids we've developed a large number of metrics that cover many aspects of both transmission and distribution grids
- For example:
  - Buses/substation, Voltage levels, Load at each bus
  - Generator commitment, dispatch
  - Transformer reactance, MVA limit, X/R ratio
  - Percent of lines on minimum spanning tree and various neighbors of the Delaunay triangulation
  - Bus phase angle differences, flow distribution

Intersections (Transmission Line Crossings)

- We've found it is important to match properties of electric grids that depend on their physical layout; for example transmission line crossings
  - Transmission line right-of-ways are available in EIA datasets; hence line crossings can be analyzed



GEOGRAPHIC CROSSINGS FOR EIA DATASET VOLTAGE NETWORKS

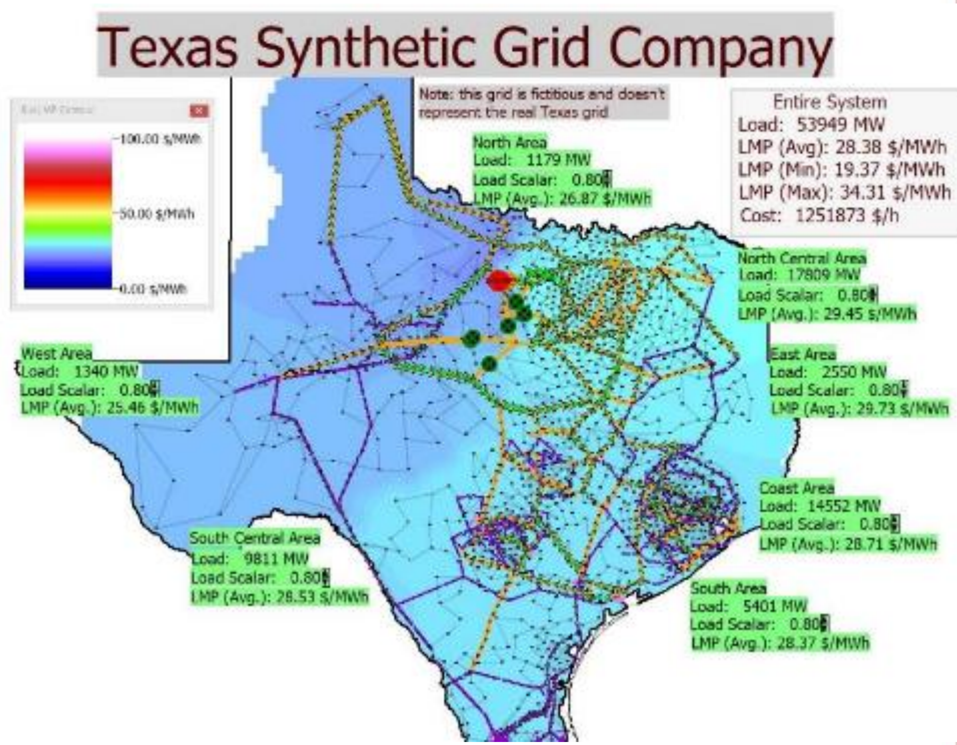
Voltage class	Number of substations	Number of lines	Crossings, straight-line: Number	Crossings, straight-line: % of lines
765kV	40	42	1	2.4
500kV	529	732	67	9.2
345kV	1526	2171	297	13.7
230kV	4648	6233	935	15.1
161kV	2633	3172	405	13.0
138kV	8611	10684	1617	15.3
115kV	12826	15031	1485	10.2
100kV	894	1595	118	7.5
69kV	8022	8022	289	3.7

Synthetic Grid Applications: Different Levels of Modeling

- Just because we have detailed grids, doesn't mean we always simulate the coupled transmission and distribution models. Other options are
  - Transmission only
  - Distribution only
  - Full transmission with distribution topology; this can be quite useful for doing multi-infrastructure simulation in which we just need to know what parts of the distribution system are out-of-service

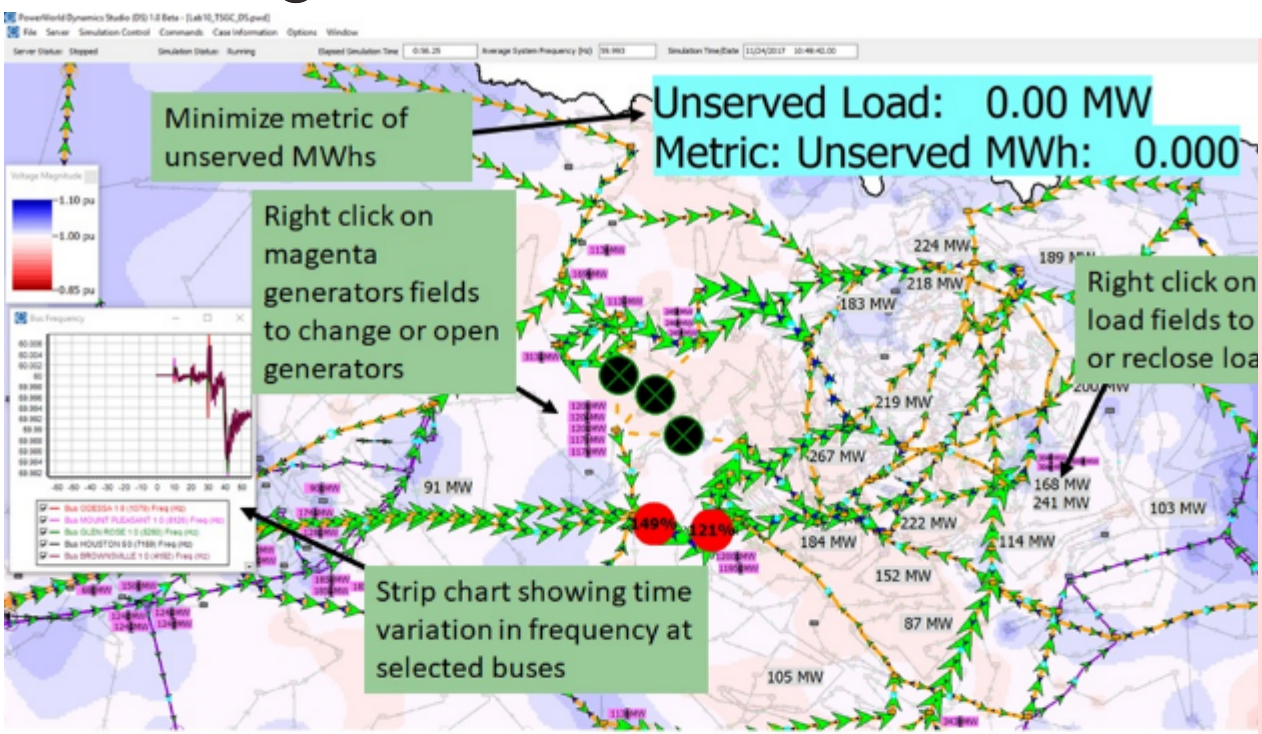
Synthetic Grid Applications: Innovative Electric Power Education

- Lab assignments involving a 2000 bus case have been integrated into Texas A&M's power classes
- Class includes large-system exercises for power flow, economic dispatch, contingency analysis, SCOPF, and transient stability



Innovative Electric Power Education

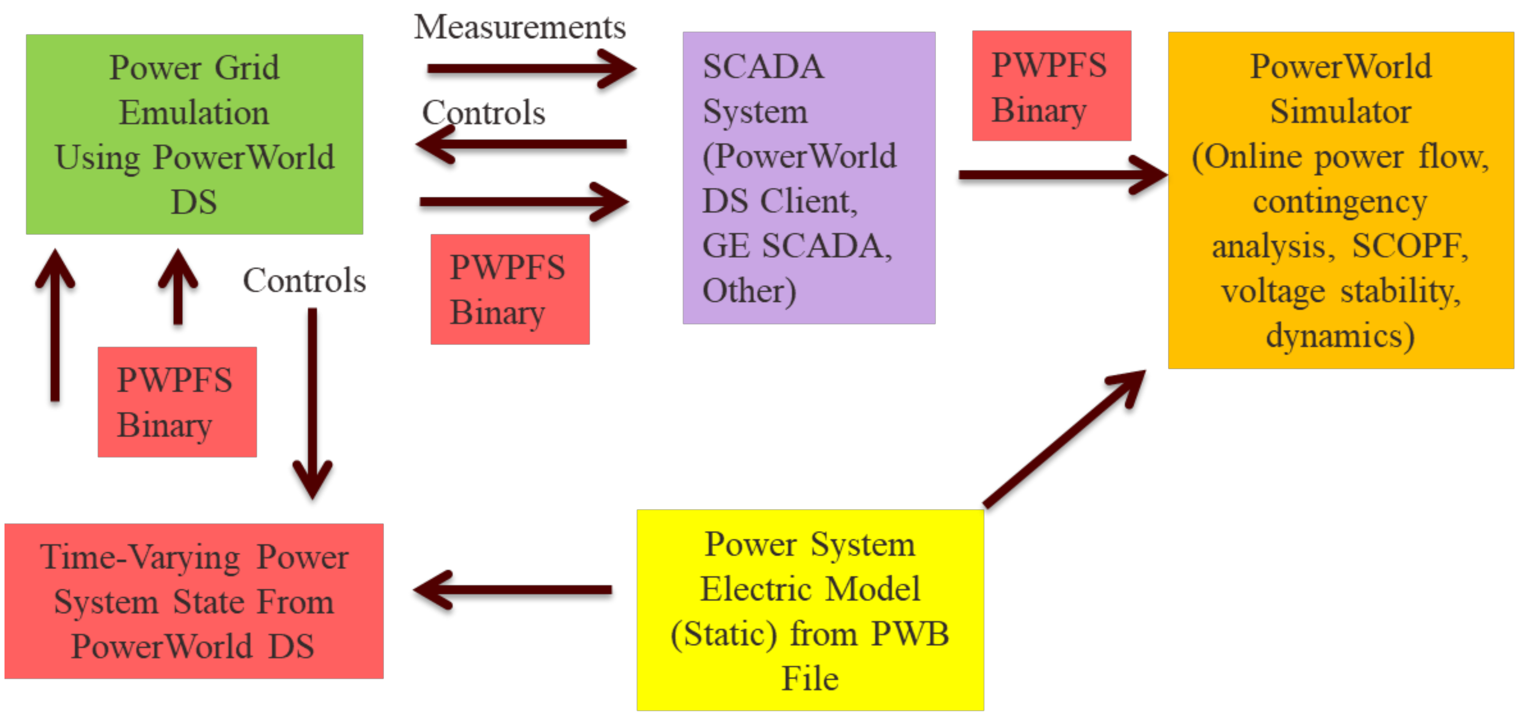
- One lab challenges students to save the synthetic Texas grid from voltage collapse following a simulated tornado in real-time!



The lab was introduced in Fall 2017; in Fall 2018 it was expanded to be a multi-user simulation. However it did not involve integrated analysis.

A Challenge: Adding Analytics to Simulations

- We've recently augmented the simulation to allow power flow analysis support, but this requires initializing a power flow from a dynamic solution



Giving Students (and Others) Experience In Grid Operations

- Most electric power students have little or no experience in actually operating an electric grid (real or simulated)
- One of our goals is to provide such an experience both in an individually and as part of a team
- Developing this involves a combination of the electric grid, the scenario, and the associated simulation environment, and the path to give the users experience with the environment
- This also generates data

The Simulation Environment

Synthetic Grid Applications: Visualization Research

- With the now wide spread availability of large-scale, geographically based public synthetic grids, there has been increased need for better wide-area visualizations
- I.e., with a large system study, **What Happened?**
- Visualizations involve many trade-offs, with the best approach ultimately application dependent
- Recent research using the synthetic grids is focused on how to maximize display space, while retaining some geographic context

Pseudo-Geographic Mosaic Displays Can Maximize Screen Usage

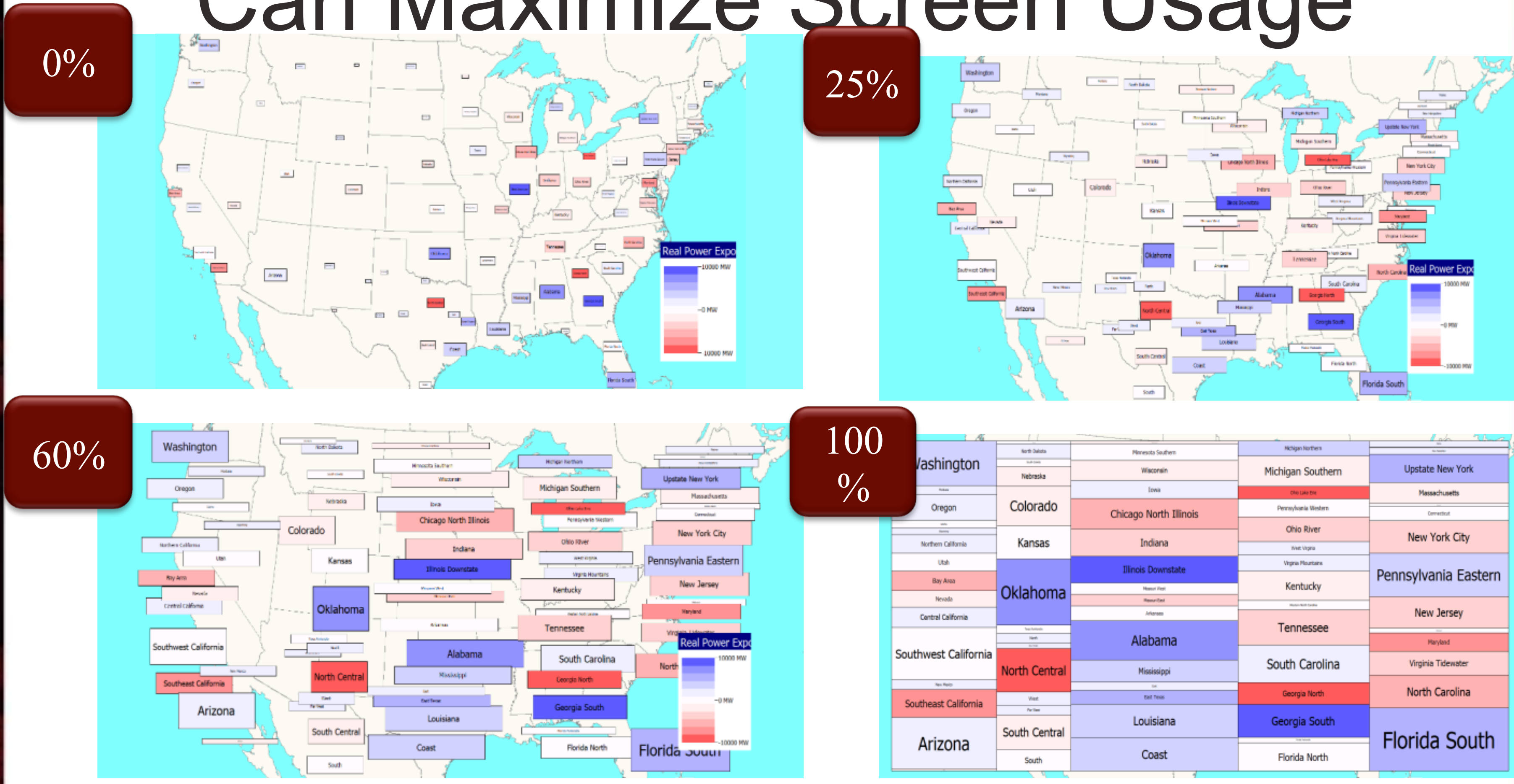
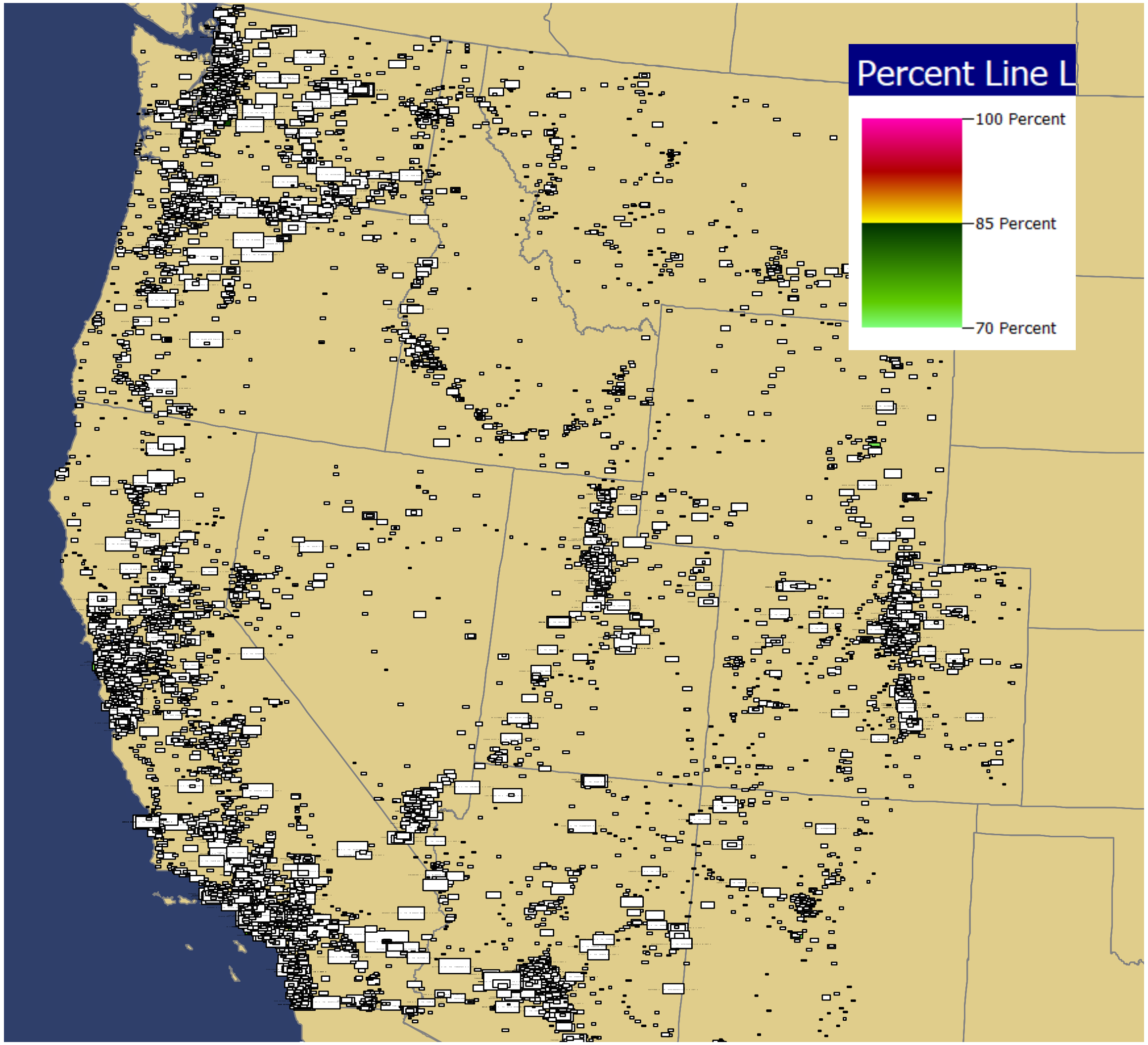


Image source: Overbye, Wert, Birchfield, Weber, “Wide-Area Electric Grid Visualization Using Pseudo-Geographic Mosaic Displays,” Proc. 2019 North American Power Symposium (NAPS), Wichita, KS, Oct 2019

Visualizing 12,700 Line Flows:



Large-scale synthetic grids can help guide new visualization solutions. This image attempts to show 12,700 line flows, with object size based on the line's MVA flow and its coloring based on percentage loading.

Visualizing 12,700 Line Flows:

Visualization using a pseudo-geographic mosaic approach with all rectangles linked to provide drill-down details

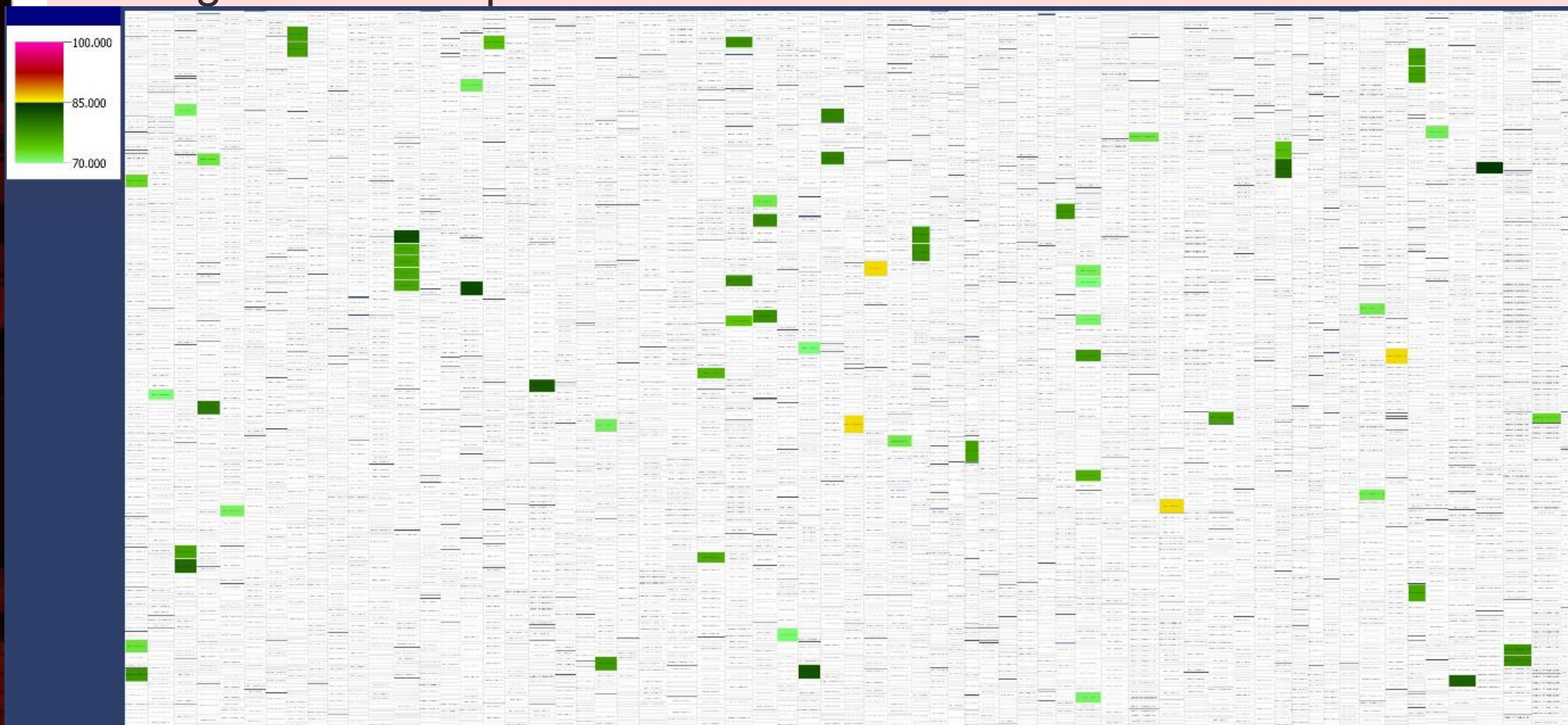


Image source: Overbye, Wert, Birchfield, Weber, “Wide-Area Electric Grid Visualization Using Pseudo-Geographic Mosaic Displays,” Proc. 2019 North American Power Symposium (NAPS), Wichita, KS, Oct 2019

Auto Screen Layout Designed to Percentage Screen Fill

Images show generation by capacity and fuel type using different percentages of the available screen space

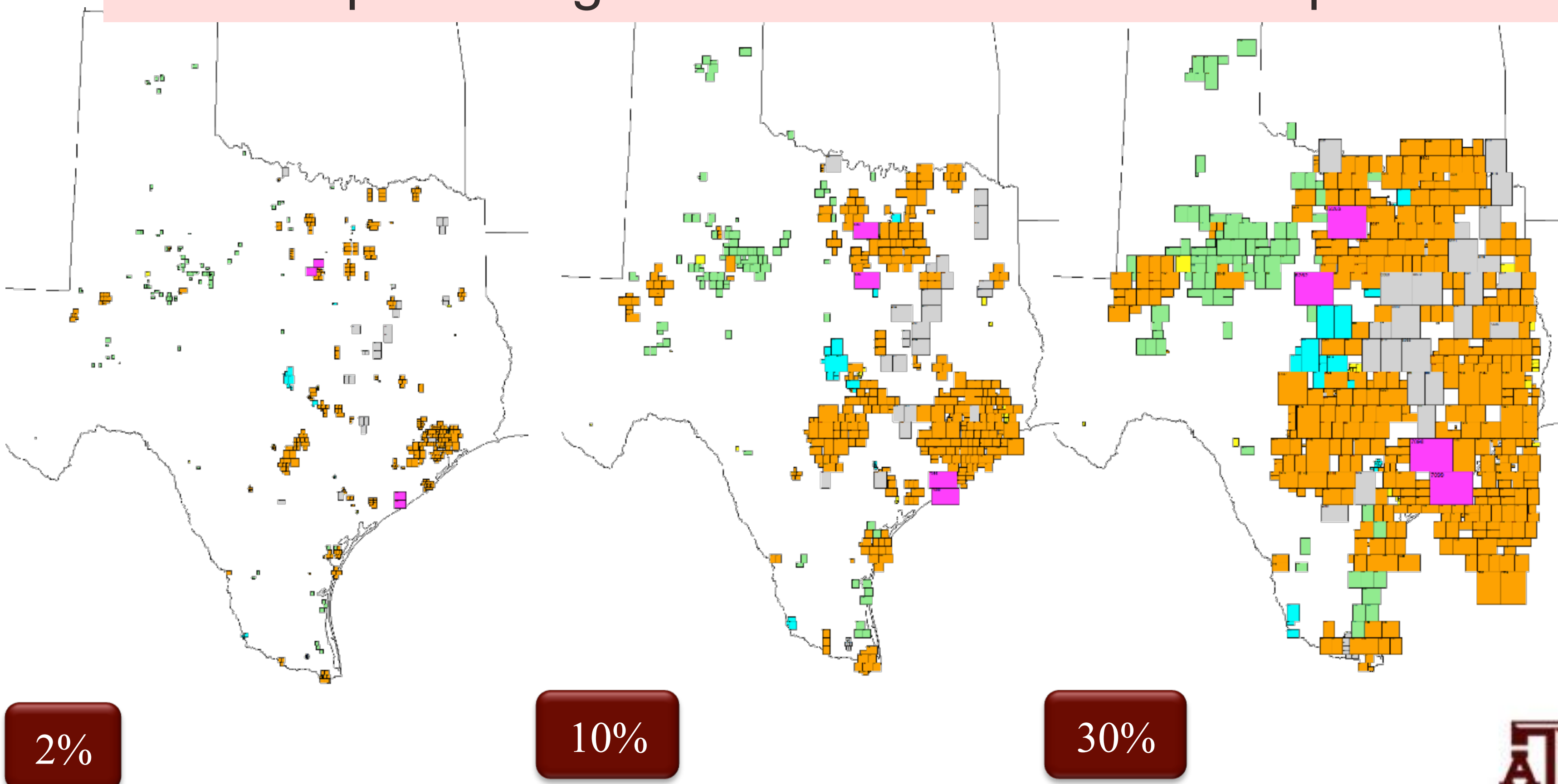


Image source: Adam Birchfield, “Mosaic Packing to Visualize Large-Scale Electric Grid Data,” accepted in IEEE Open Access Journal of Power and Energy

Applications: Coupled Infrastructures and Extreme Events

- Since the highly detail synthetic grids are linked to actual parcels, they can be used in coupled infrastructure simulation
  - Metadata is used to indicate the number of people at a meter and other attributions
- By partnering with the Texas Transportation Institute we're moving forward with coupled electric grid/transportation studies
  - Blackouts affect people, and large blackouts can affect a lot of people, causing transportation impacts

Summary

- Thanks to investment primarily by ARPA-E, large-scale, highly detailed synthetic grids are a reality
  - Ongoing research on enhancements and applications
- These can be used to generate large amounts of context-aware data, helping to enable a large amount of power system research
- Coupled infrastructure research is now potentially available to a much broader audience
- Lots of opportunities for university and industry involvement in this exciting and impactful area!!

Thank You!

Questions?