TEXAS A&M UNIVERSITY
Engineering

Creating Realistic Synthetic Electric Grids to Promote Open Science in Power Engineering

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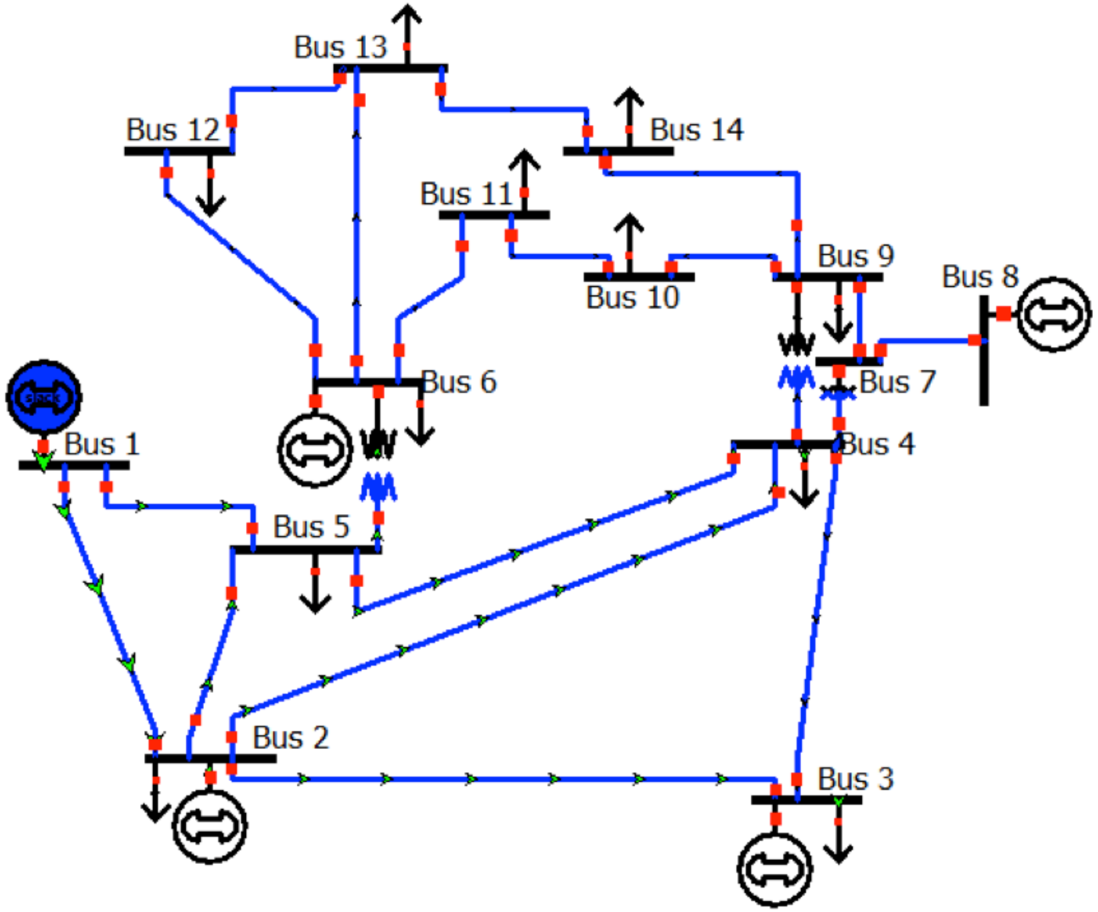
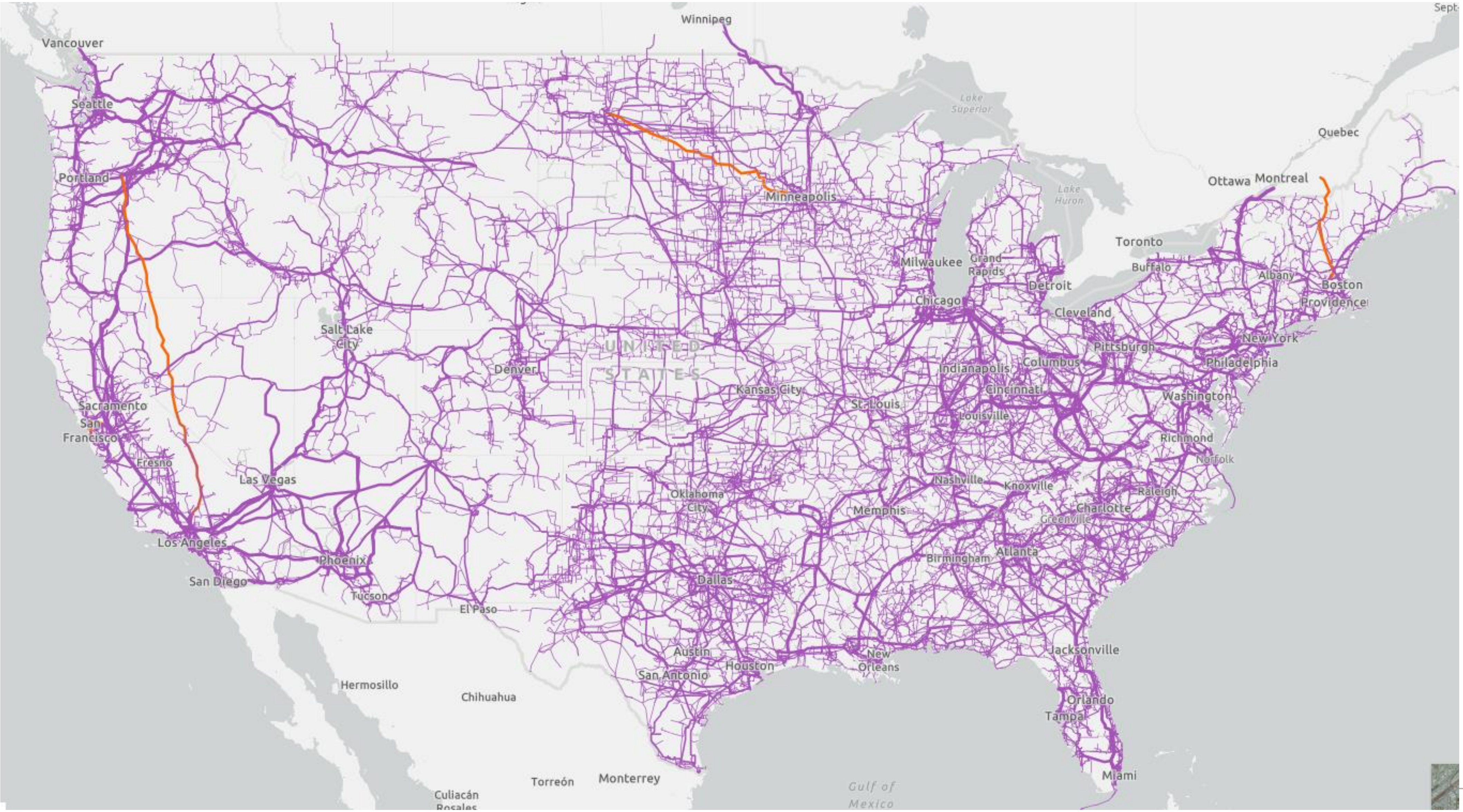
Test Cases for Power Systems Research

- Power grid data is critical energy infrastructure information (CEII)
- Existing test cases—prior to synthetic grids—are small, simple, and outdated
- Goal of building synthetic power grids is to drive innovation by providing test cases that are large, complex, realistic, and fully public.
- Applications include research, innovation, education, cross-validation and demonstration



Some existing test cases, such as the IEEE 14-bus (pictured) and 118-bus case, despite their popularity, are known to vary significantly from actual grids.

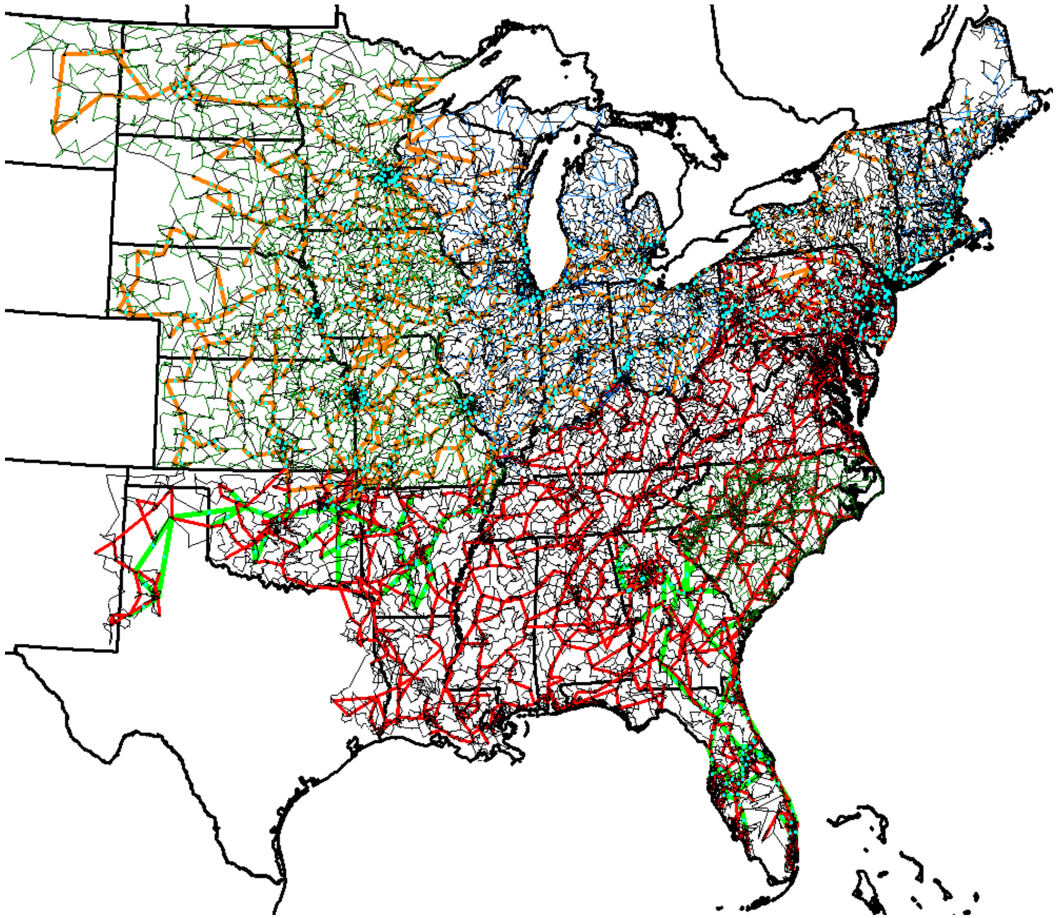
The U.S. Electric Grid Network



Source: US EIA Energy Atlas

Synthetic Power Grids

- **Large**: This case is 70,000 buses, similar to the actual Eastern Interconnect
- **Complex**: Multiple interacting voltage levels, remote regulation, capacitors, taps
- **Realistic**: Matching a large suite of validation metrics against actual systems
- **Fully public**: It does not correspond to any actual grid or contain any confidential information



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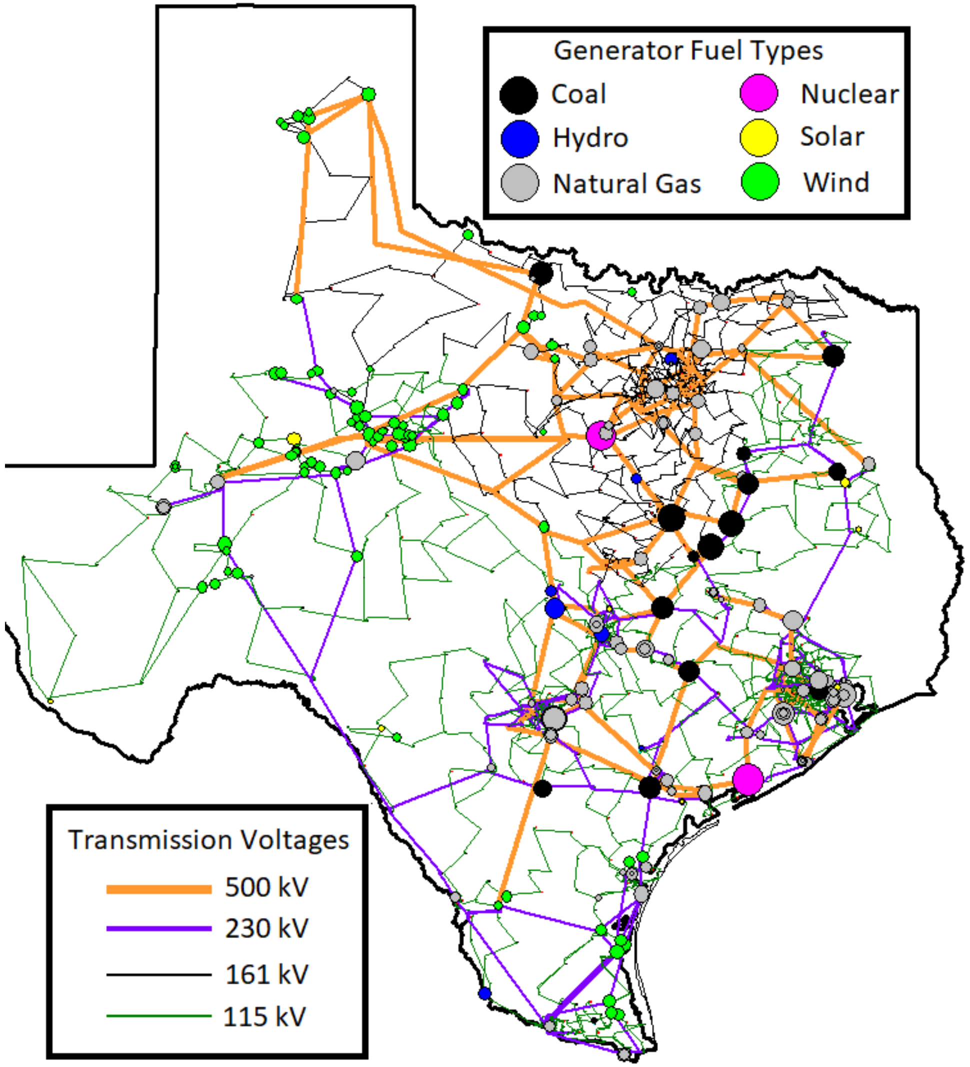
How Do We Build Synthetic Grids?

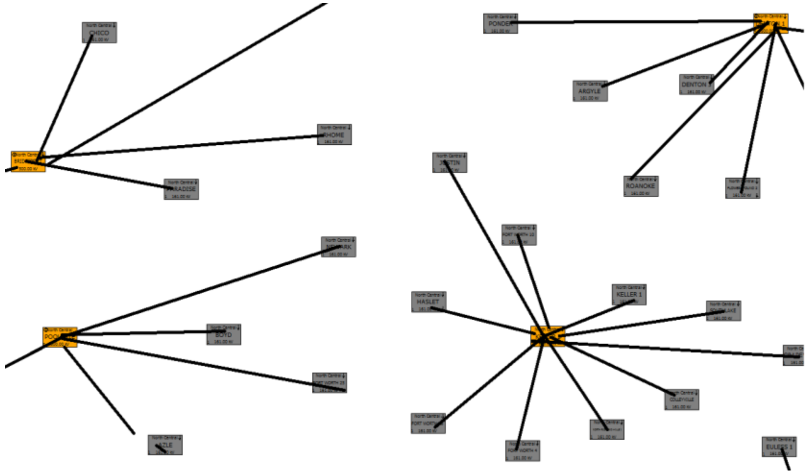
- Substation Planning
  - Start with public data for generation and load
  - Cluster substations, add buses, transformers
- Transmission Planning
  - Place lines and transformers
  - Iterative dc power flow algorithm
  - Match topological, geographic metrics
  - Contingency overload sensitivity
- Reactive Power Planning: Power flow solution (ac), Voltage control devices
- Extensions: Transient stability, geomagnetic disturbances, single-line diagrams, optimal power flow (OPF), time series scenarios, interactive simulations, …



2000-bus synthetic grid on the Texas footprint

Synthetic Substation Planning

- Substation planning is seeded by public Energy and Census data
- For large systems, decouple by area
- Modified hierarchical clustering technique combines zip code fragments and generators into substations
  - Use the same technique to assign higher voltage to about 20% of substations
  - Higher load/generation more likely to have higher voltage buses
  - Need cross-area connections for neighboring areas that do not share kV levels
- Economic generation dispatch assuming peak planning load

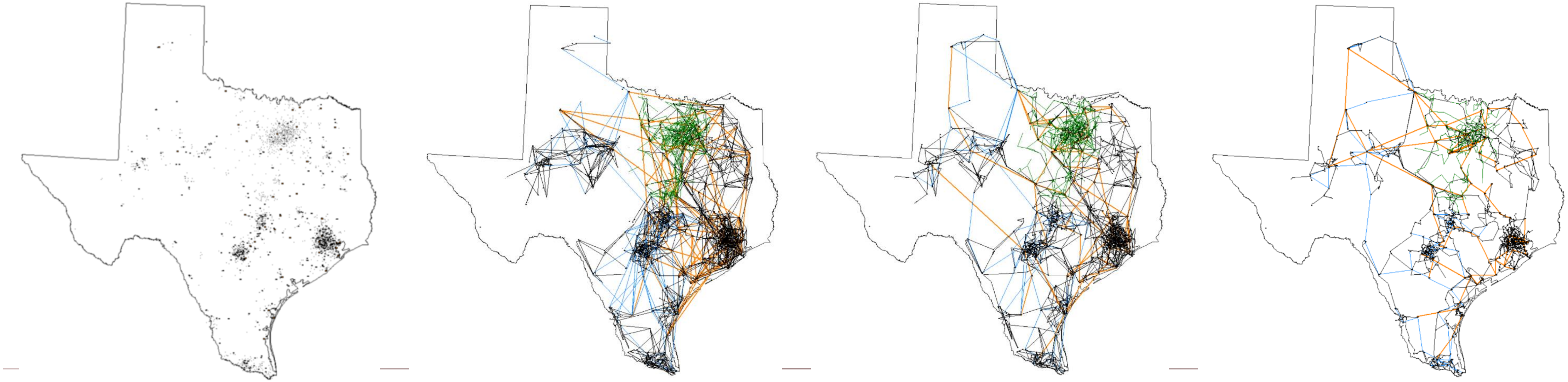


Synthetic Transmission Planning

- Geography drives transmission planning, and is central to the approach
- Network topology parameters: Graph metrics considering both individual voltage level networks and combined bus-branch topology
- Power flow feasibility: Avoid line limit violations in base and N-1 contingency conditions
- Difficulties for large grids
  - Possible branches is n^2, possible combinations of branches is intractable
  - Many competing metrics to meet
  - Large grids have many overlapping voltage networks that connect at substations
  - Consideration of contingency conditions increases computation even more
  - Manual adjustments grow with system size

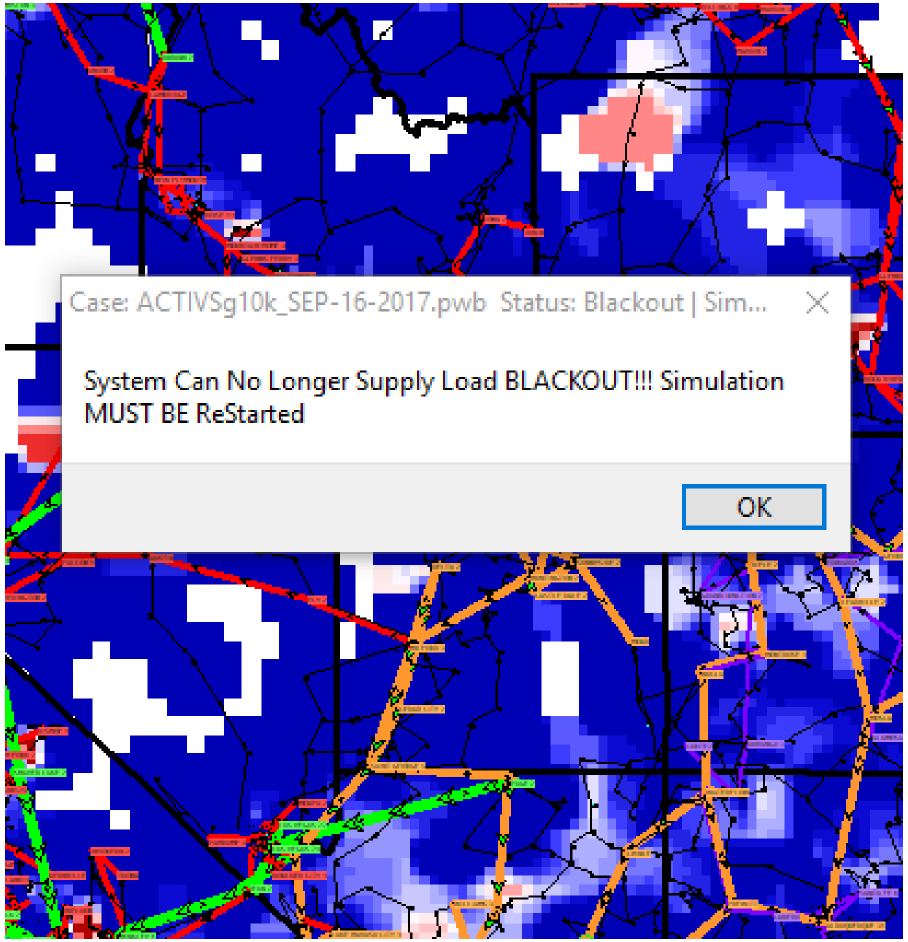
Synthetic Transmission Planning, Cont.

- Our solution
  - Reduce search space from n^2 to $21n$ with Delaunay triangulation (99% of lines < 3 dist.)
  - Begin with randomized graph and iterate toward high-quality network
  - Consider N-1 contingency analysis with DC power flow and overloading sensitivity metric
    - Line “innage” sensitivities rapid to calculate for 100k+ candidate lines
  - Parameterize to get the right balance of fixed cost and network/simulation performance
  - Validate metrics against metrics collected from actual grids



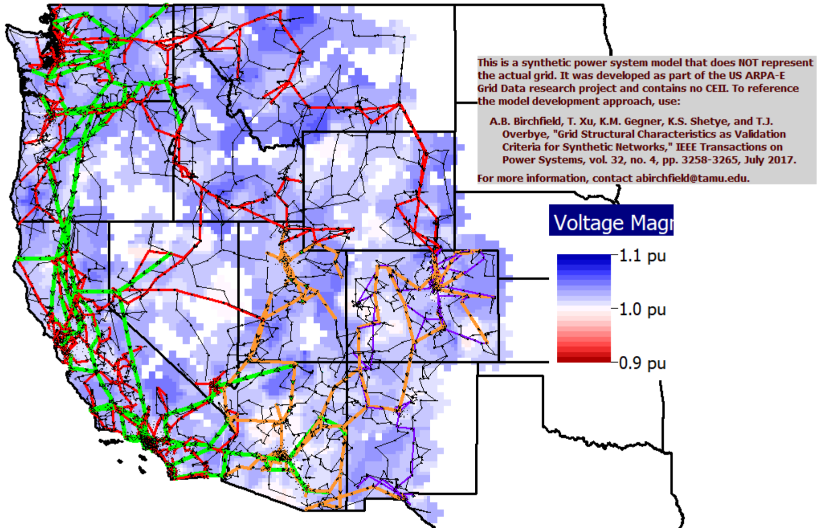
Synthetic Reactive Power Planning

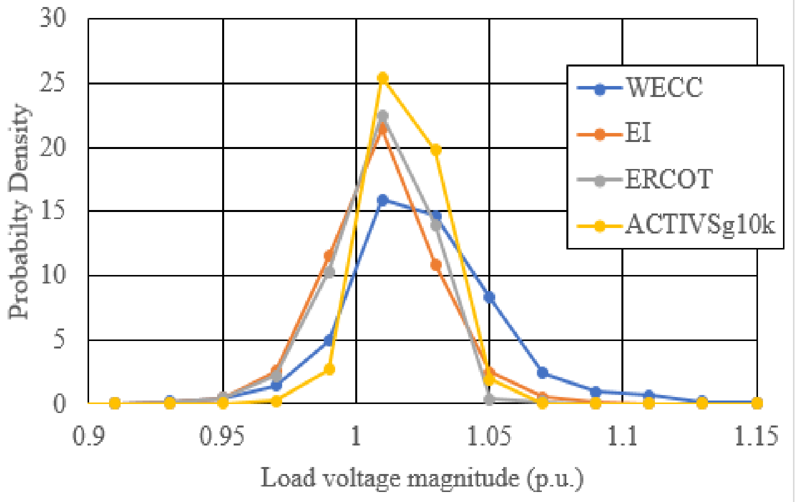
- Flat start often does not converge!
- For real interconnects, start with a prior solution
  - Doesn't work for new synthetic grids
  - Also synthetic grids, without reactive compensation, might not even have a solution
- So what do we do?
  - Since we have a good dc solution, iteratively move from that to a realistic ac solution
  - Add a temporary generator to the highest voltage bus of every substation with 0 MW, controlling the bus voltage
  - Solve the ac power flow solution with this large number of PV buses
  - Iterate over 100 groups, removing most temporary generators and adjusting the others, until the remaining ones become shunt capacitors and reactors.



Synthetic Reactive Power Planning, Example

- 10,000 bus case representing WECC
- Initial power flow solution diverges!
- Algorithm previously described was applied
- 387 shunt capacitors remained for 4762 substations
  - This is 8%, actual grid has 10-20% (good)
- Voltage profile matches actual interconnect observations



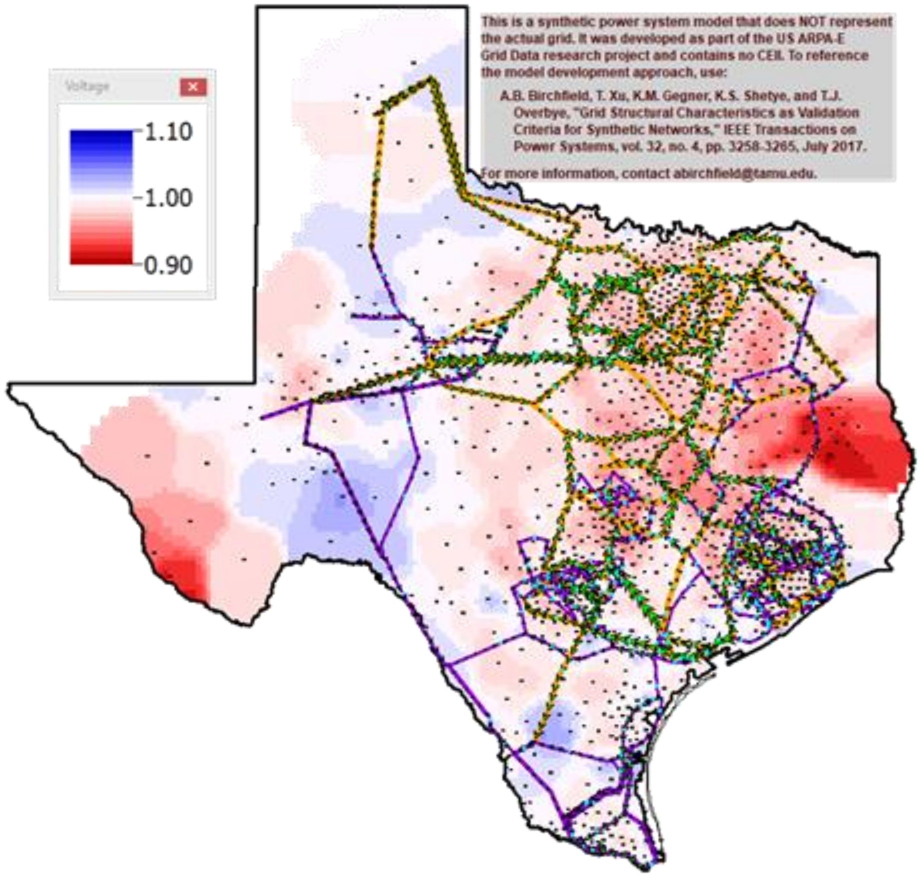


Results and Validation

- The results are large, solved power flow cases that do not contain CEII! They are also highly realistic…
- …how can we show they are highly realistic?
- Complex problem: our validation metrics collected from many actual US electric grid cases help to provide a check on case quality. Because of the variety in engineering design and practice, actual grids are quite diverse. Some metrics:
  - Overall size and structure (ratios of loads/generators/shunts/buses, dispatch, capacity)
  - Device parameters (XFMR reactance, X/R ratio, t-line limits and per-distance Z and B)
  - Network topology (degree distribution, cycle basis, SIL, clustering coefficient, average shortest path length)
  - Technical performance (static N-1 contingencies, voltage profile, loss levels, reactive power balance)

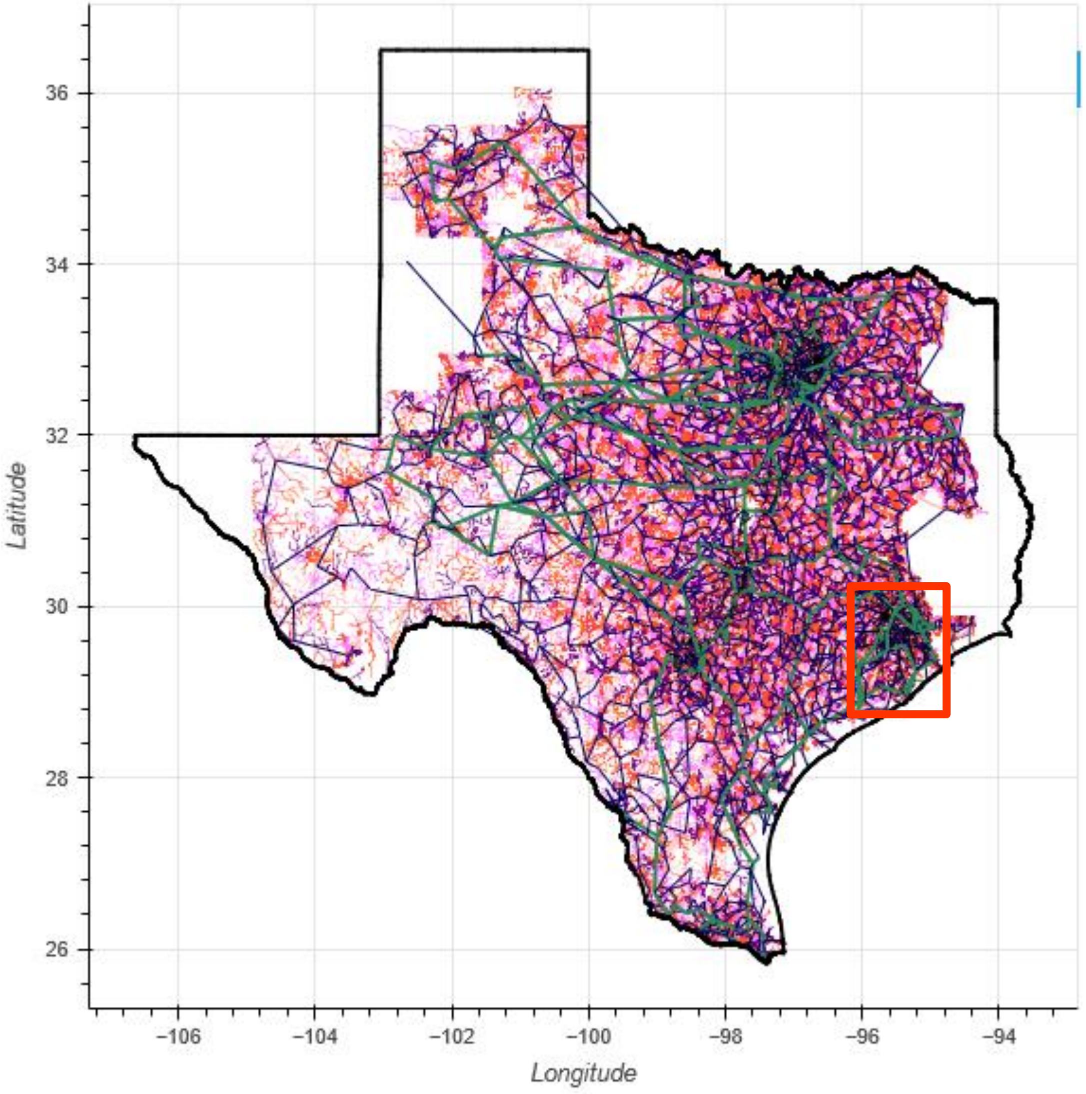
Impact of Synthetic Grids – R&D

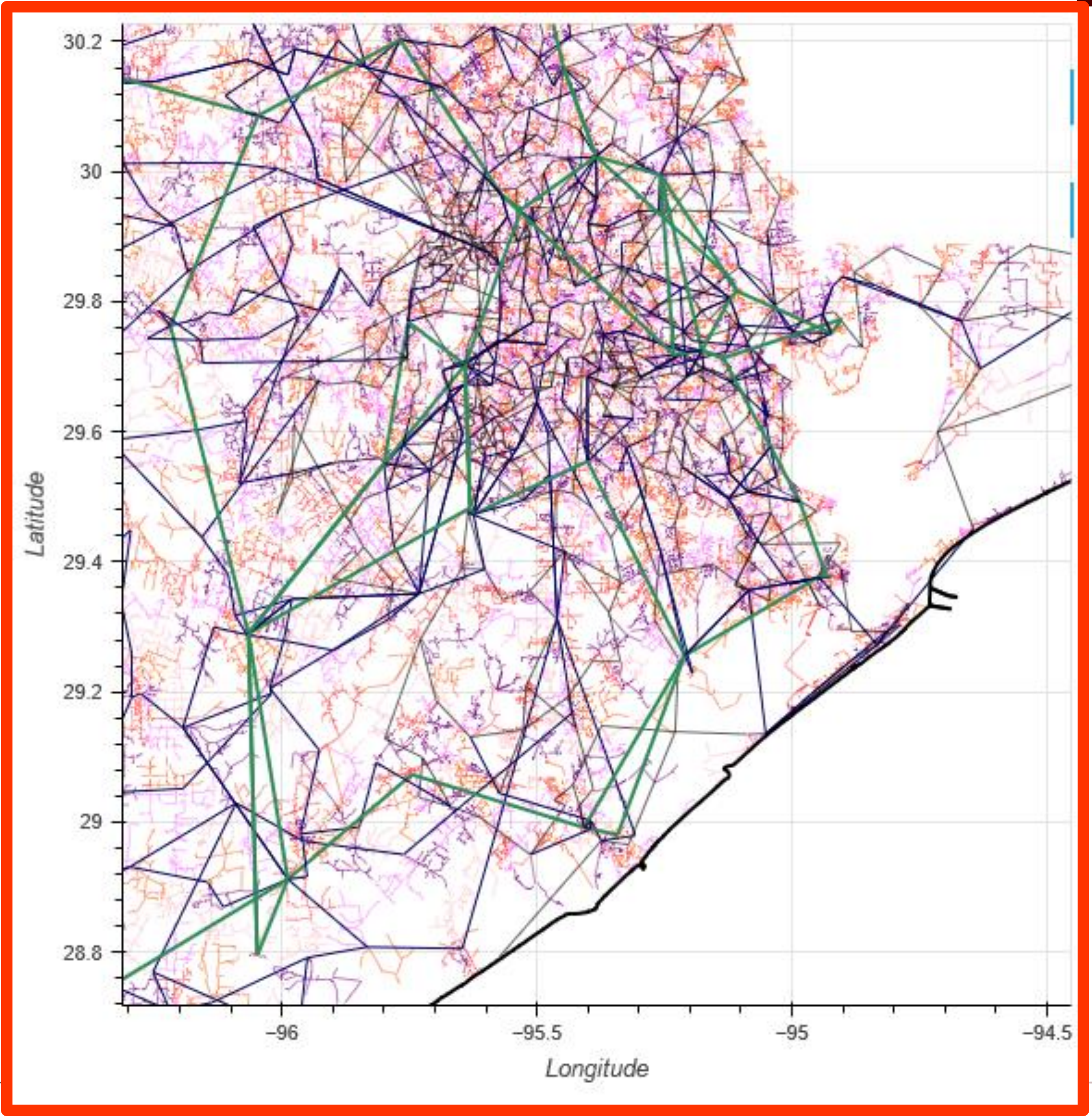
- Higher quality, larger, more complex, and more realistic than existing test cases
- Improved ability to cross-validate published research results in power systems literature
- For industry, ability to demonstrate new capabilities for analysis without compromising sensitive data
- Geographic embedding allows connection with other geographically-oriented datasets
- Our more recent work has developed higher quality dynamic models for transient stability and EMT analysis



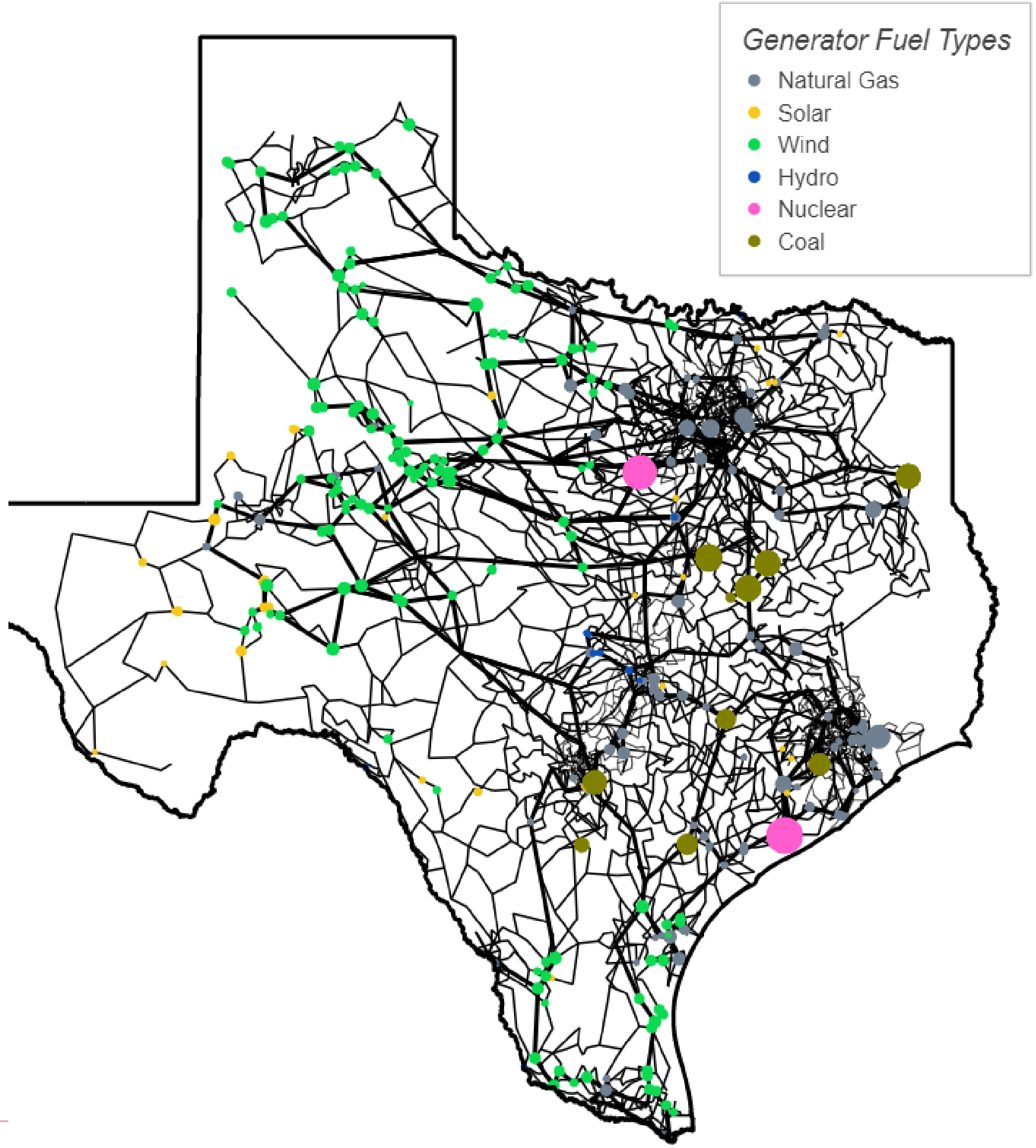
GMD-induced voltage sag n

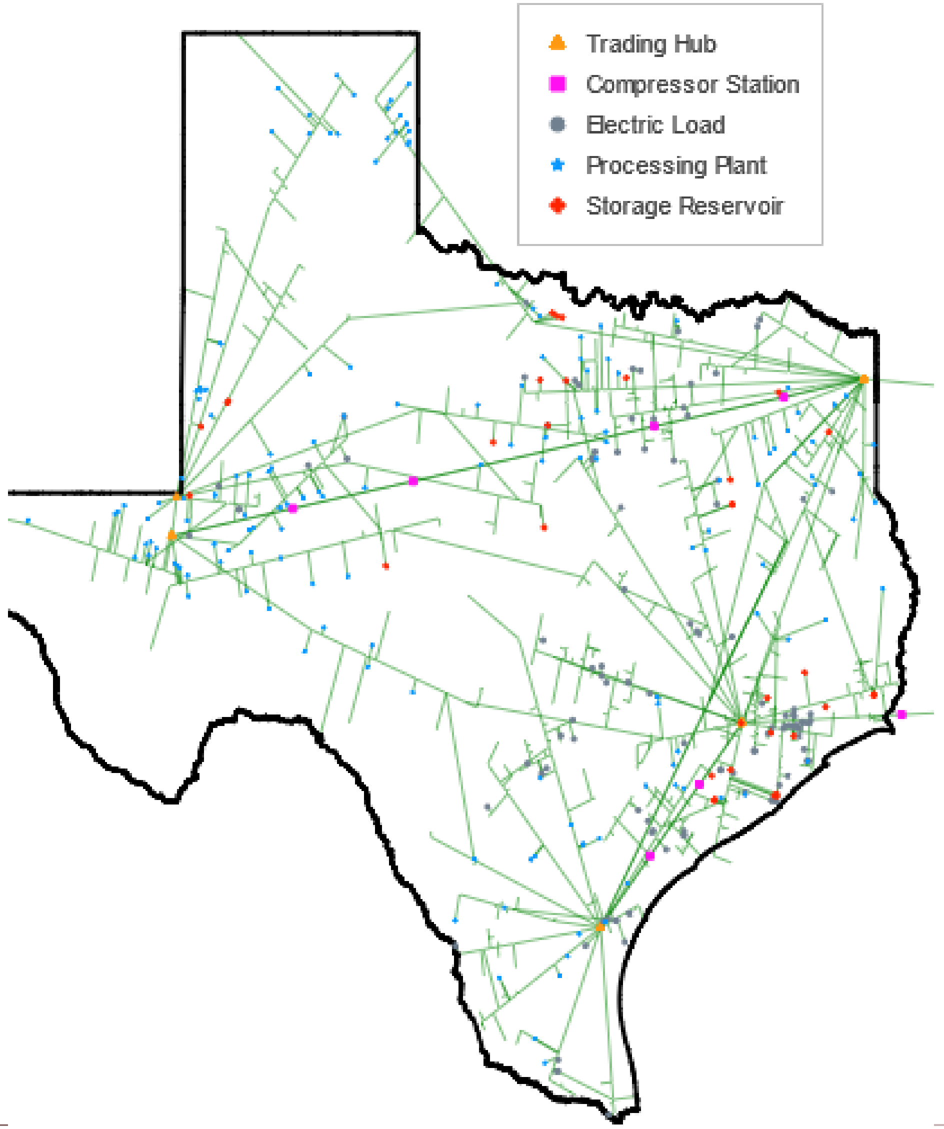
Combined T&D Synthetic Grids



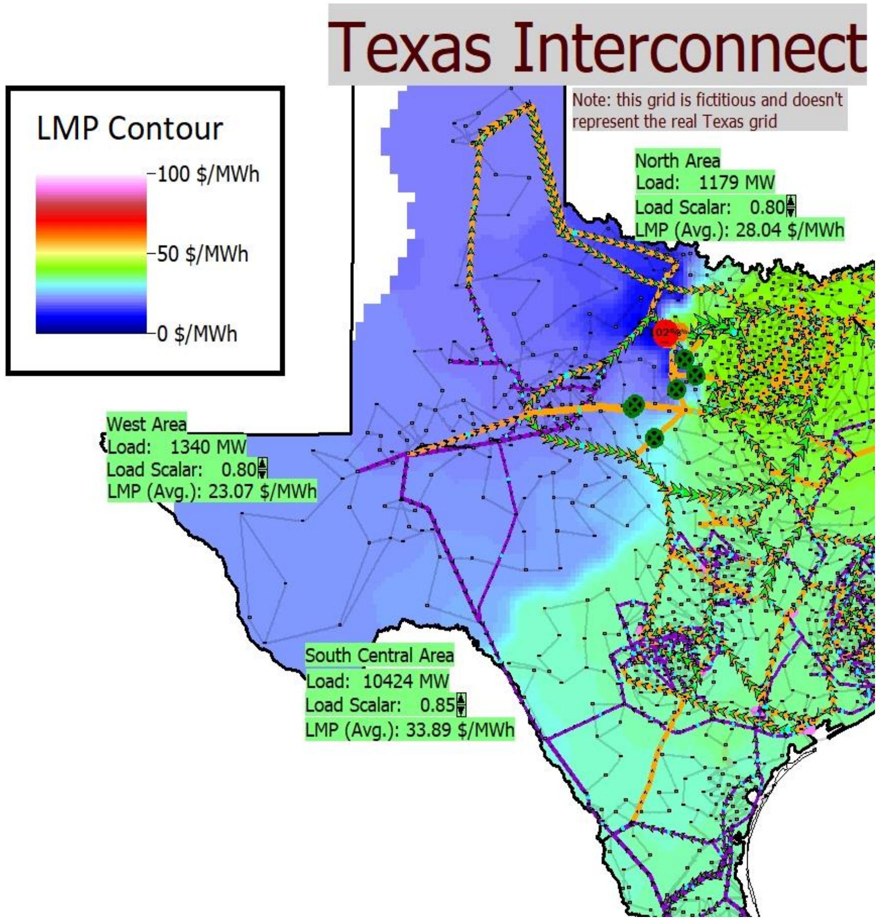


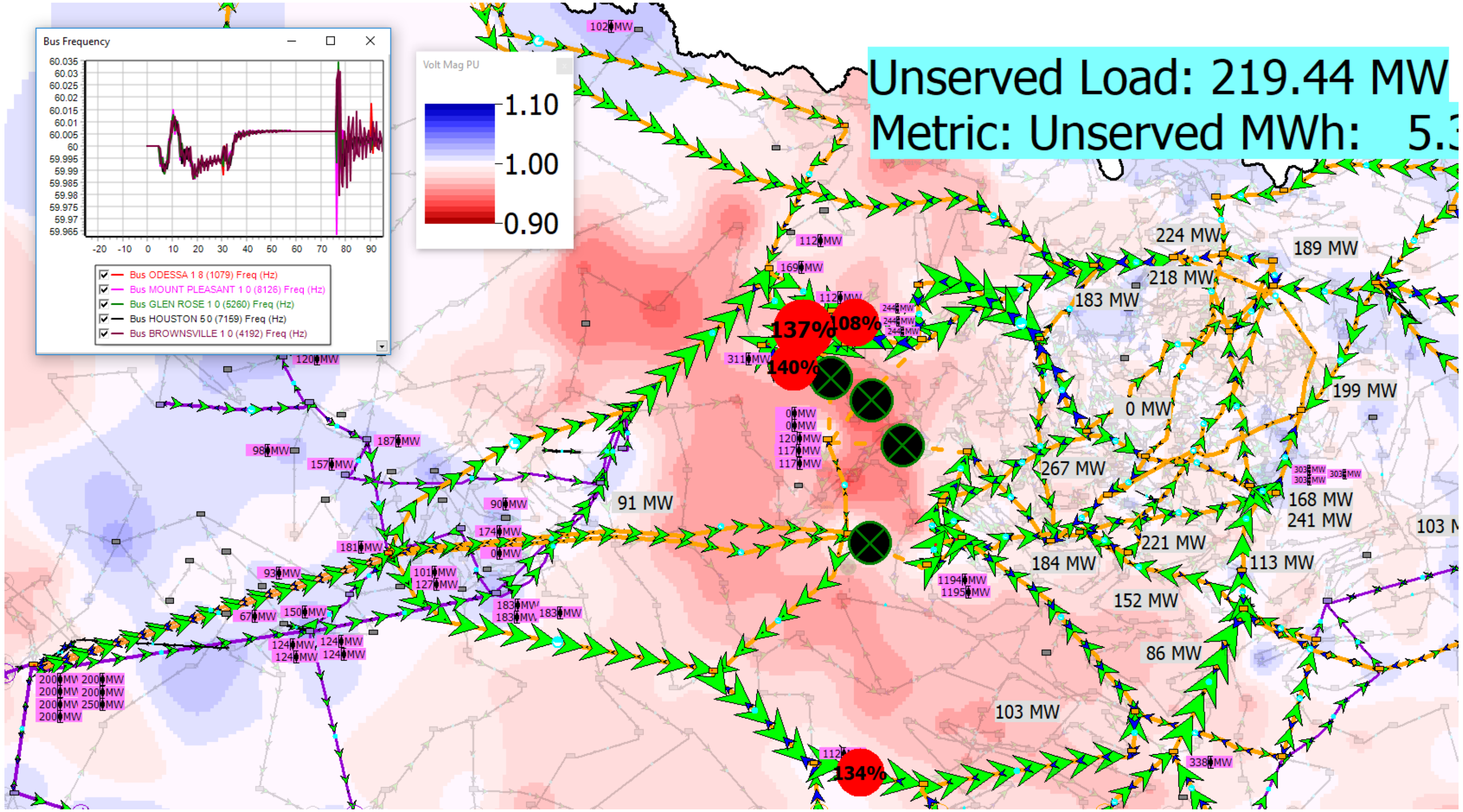
Combined Electric & Gas Grids





Transforming Education and Training





ARPA-E GO Competition

- Our cases were used in the ARPA-E Grid Optimization (GO) Competition
- Goal was for participants to develop scalable, high-quality SCOPF solvers.
- Our work involved creating difficult, realistic problem scenarios to enable evaluation of competitors
- Much of the data is available on our website

Summary Thoughts

- There is no substitute for running studies on the actual grid!
- Synthetic grids are designed to complement real-grid studies and spur innovation with modern, public, high-quality, scalable test cases for power systems R&D and education
- Our synthetic grids are available for your research—and we are always looking for feedback to improve them

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