Grid Optimization (GO) Competition Challenge 2 Case Studies

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Acknowledgements

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- Their support and the contributions of our collaborators on that project are gratefully acknowledged.
- Since then, additional support from ARPA-E, NSF, DOE, and others has helped to expand and improve this research.
- This work is a collaborative effort among researchers in the energy and power group at Texas A&M ECE.

Contents

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GRID OPTIMIZATION (GO) COMPETITION

A Multi-Round Challenge to Revolutionize the American Grid

Introduction

- Optimization problems are frequently solved for power systems operation, expansion planning, and analysis of electricity markets.
- The size and complexity of the optimization problems are constantly increasing.
- It is crucial to solve these optimization problems in a timely manner and to find a feasible near-optimal solution.
- This is one of the most fundamental concerns in electrical power system operation, control and management.
- The most common optimization problems that need to be solved frequently for power system operation are to minimize the operation cost or maximize the overall efficiency from the electric grids, >> finding the optimal solution of these problems will save huge amounts of money.

Motivation

- US power flow cases and structural information of the grid are critical energy/electricity infrastructure information
- There is a strong need for access to diverse, large and complicated power systems for research
- Limited work focusing on the creation of complicated and realistic synthetic large-scale power system that can mimic the full complexity of modern electricity grids

Main Benefits of Using Synthetic Electric Grids

- Large: Up to 82,000 buses, similar to the actual grids
- 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

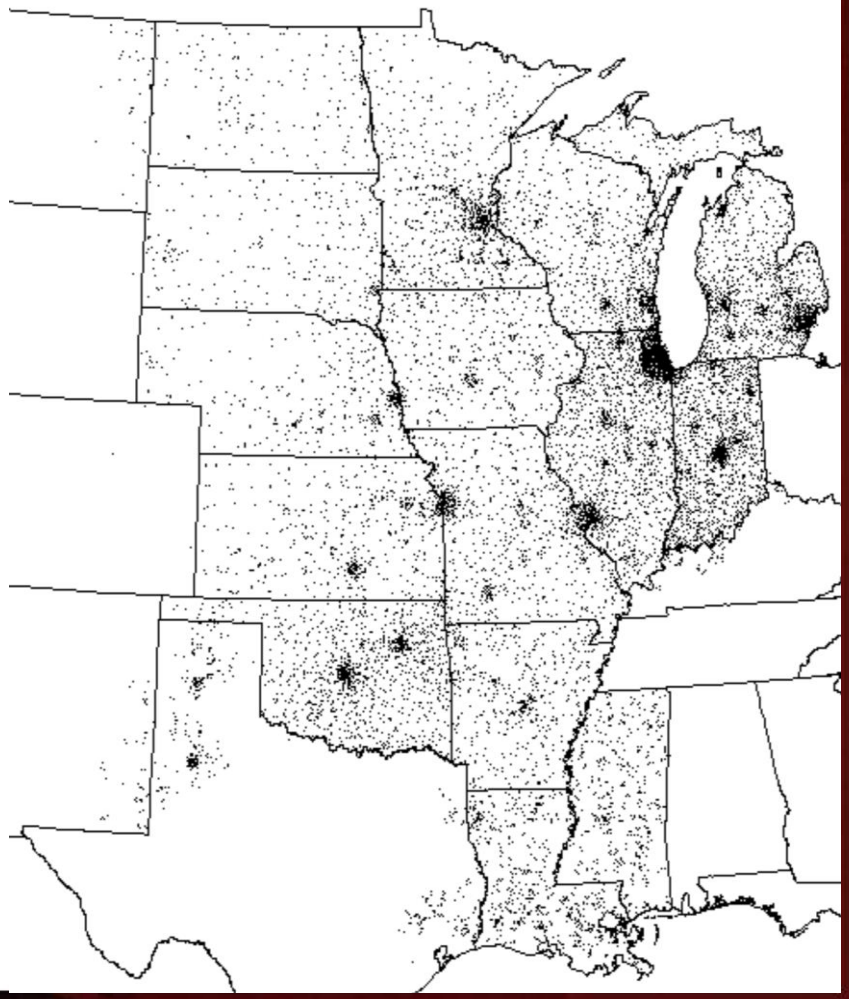
GO competition challenges 1 and 2

- GO competition challenge 1 SCOPF
- GO competition challenge 2 with improvements to have a more realistic model by adding topology optimization, component participation, demand response, and reactive power control under different load and weather scenarios
- The case study includes 6 actual industry grids as well as 16 realistic synthetic grids with up to 32,000 buses.

Synthetic Grid Creation

The overall approach for building these networks

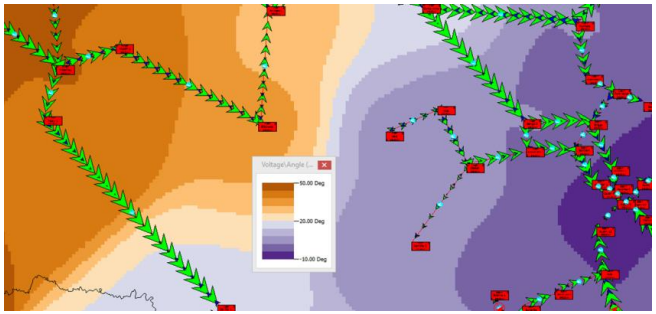
- Substation Planning
  - Start with public data for generation, load
  - Cluster substations, add buses, transformers
- Transmission Planning
  - Place lines and transformers
  - Iterative dc power flow algorithm
  - Match topological, geographic metrics
  - Contingency overload sensitivity
- Reactive Power Planning
  - Power flow solution (ac)
  - Voltage control devices



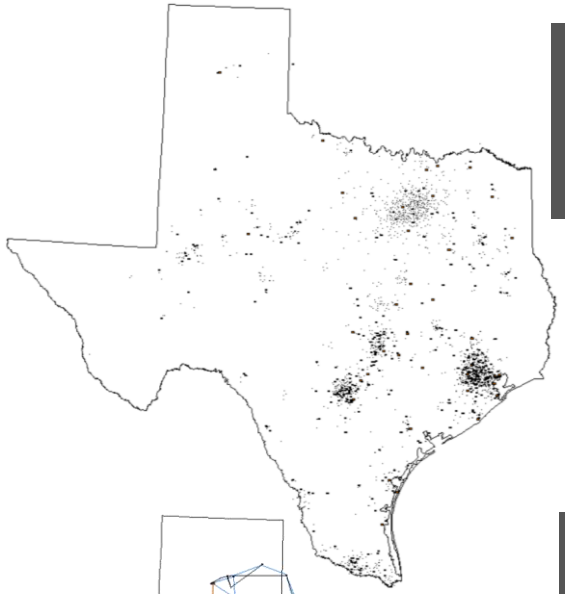
Transmission Planning Approach

- Key Considerations
  - Geography drives transmission planning
  - Network topology parameters
  - Power flow feasibility in base and N-1 contingency conditions
  - Intractability: 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

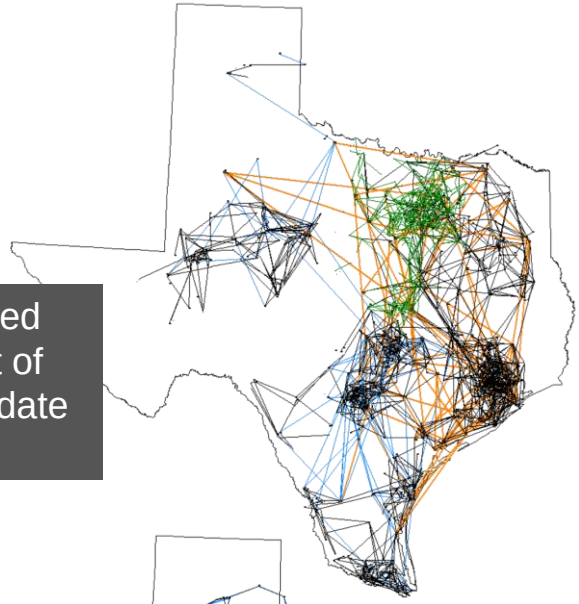
- Outline of Approach
  - Reduce search space from n^2 to $21n$ with Delaunay triangulation (up to 3rd neighbors = 99% of lines)
  - Geographic constraints by voltage level
  - Depth first search to check connectivity
  - Dc Power flow base case and N-1 contingency analysis, determine sensitivity of candidate lines to contingency overloads
  - Iterative process of random removal, analysis, targeted addition for each same-voltage subnet



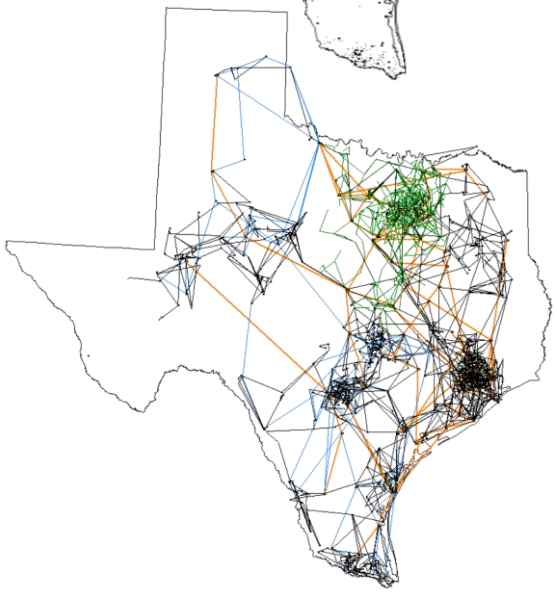
Stages of Transmission Planning Process



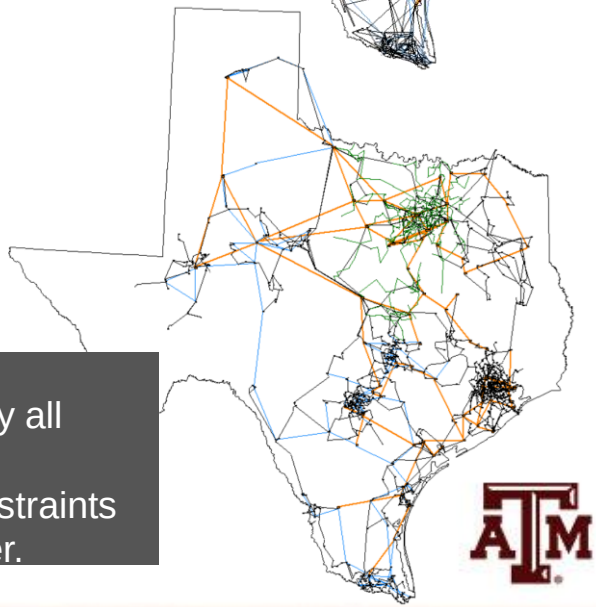
(1) The starting point is the geographic placement of substations



(2) The grid is initialized with a random subset of 1.2n of the 21n candidate transmission lines



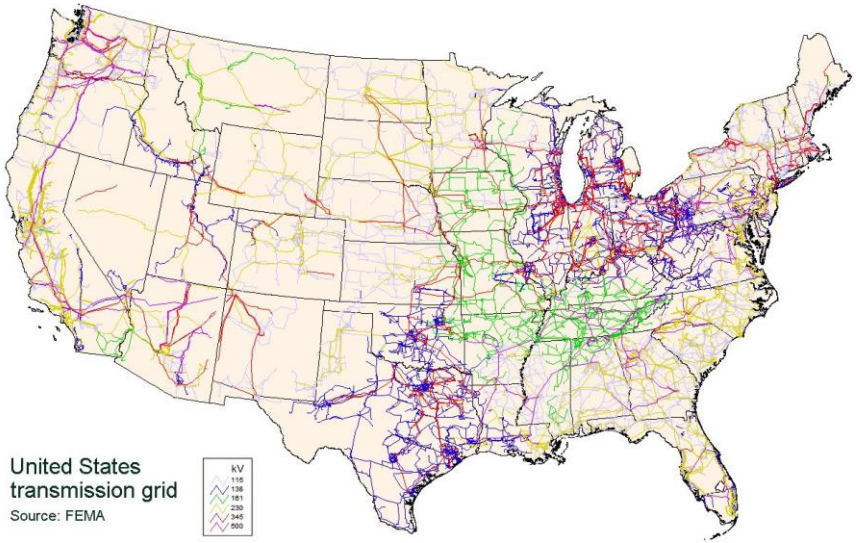
(3) After 100 iterations of random removal followed by targeted addition, the grid begins to match more geographic and reliability constraints

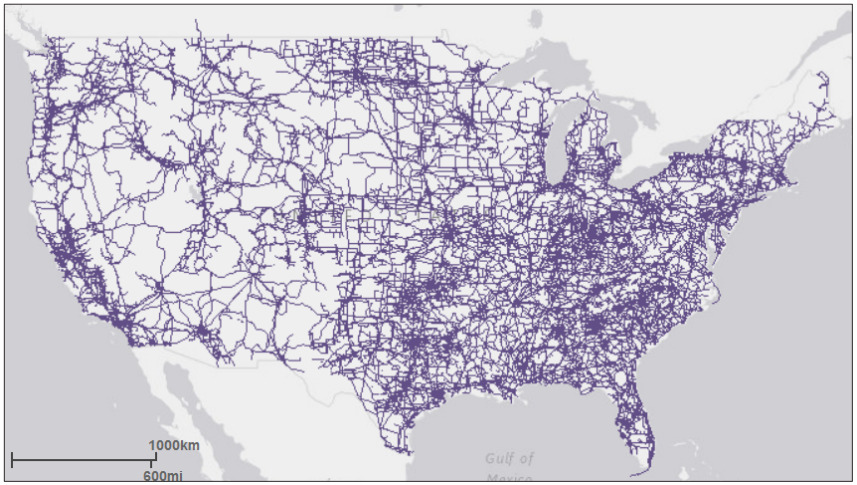


(4) After 10,000 iterations, nearly all reliability and geographic constraints are met together.

Validation: Ensuring High Quality

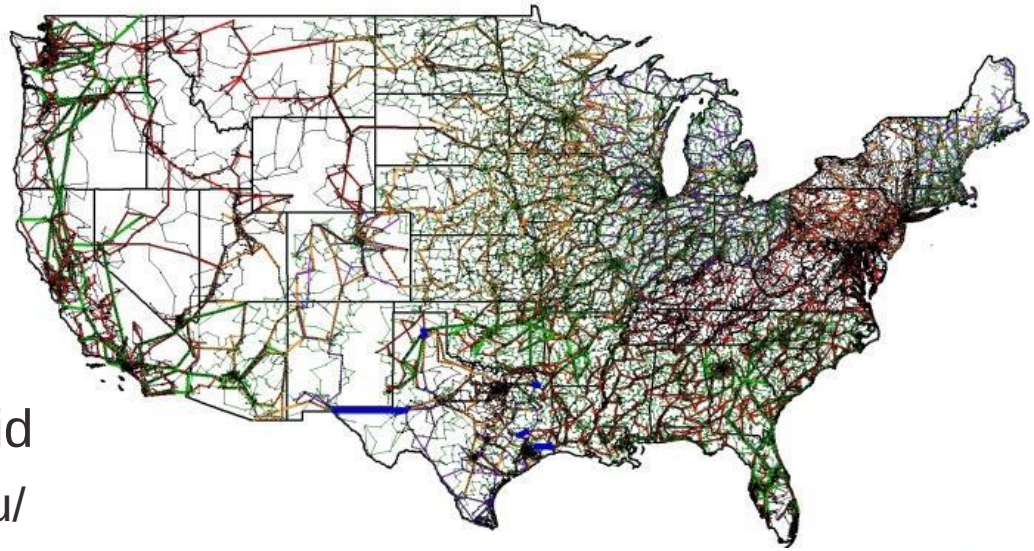
- Based upon data from actual grids we've developed a large and ever-growing number of metrics that cover many aspects of primarily transmission grids
- For example:
  - Buses/substation, Voltage levels, Load at each bus
  - Generator commitment, dispatch
  - Transformer reactance, MVA limit, X/R ratio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





Federal Emergency Management Agency

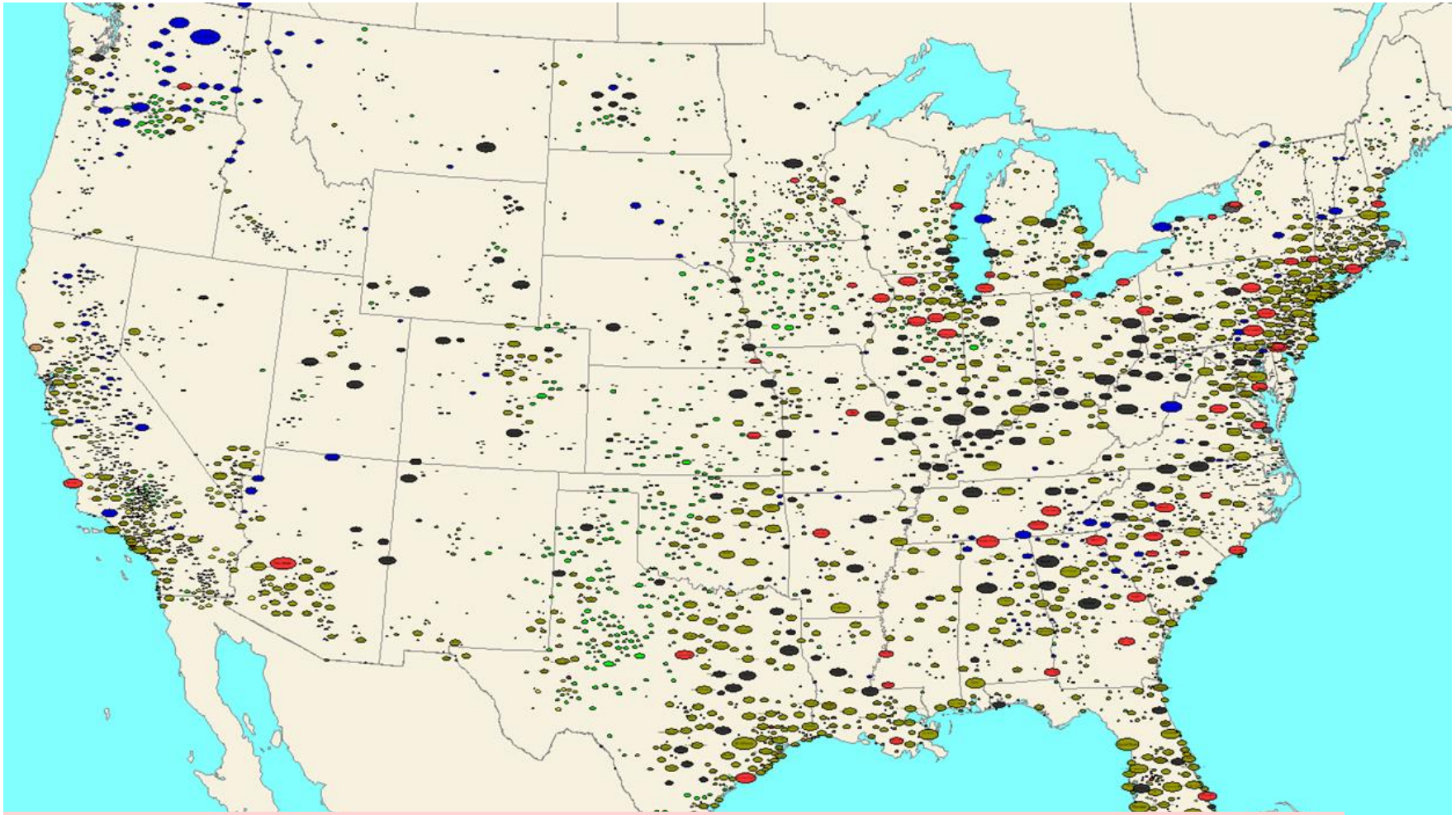
FEMA



The US 82K Bus Synthetic Grid

https://electricgrids.engr.tamu.edu/

Visualizing the EIA-860 Data



Oval size is proportional to the substation generation capacity, and color indicates primary fuel type (red nuclear, black coal, brown natural gas, blue hydro, green wind, yellow solar). Image shows public data from EIA Form 860; image created using PowerWorld Simulator.

Augmentations and Adjustments

- Generator Parameters
- Shunt Type Conversion
- Price Responsive Demand
- Phase Shifting Transformers
- Scenario Creation
- Bus Splitting

Generator Cost/ Load Benefit Data

- Actual Gen. Fuel and Unit Types from EIA 860
- Gen Costs based on Fuel Types, Unit Types, and Heat Rates from EIA-923 and the EIA Annual Energy Outlook
- Variable O&M Costs, Fixed Start-up Costs
- Cost Curve Co-efficients
- Cubic Cost Model and Piecewise Linear using 4 Break Points for both
- Up to 3-10% controllable load with high prices up to 3000 $/MWh which may be shed

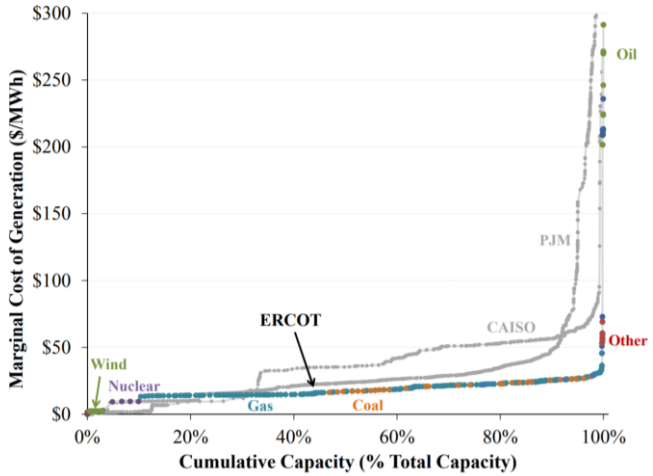
Temporal Generator Parameters

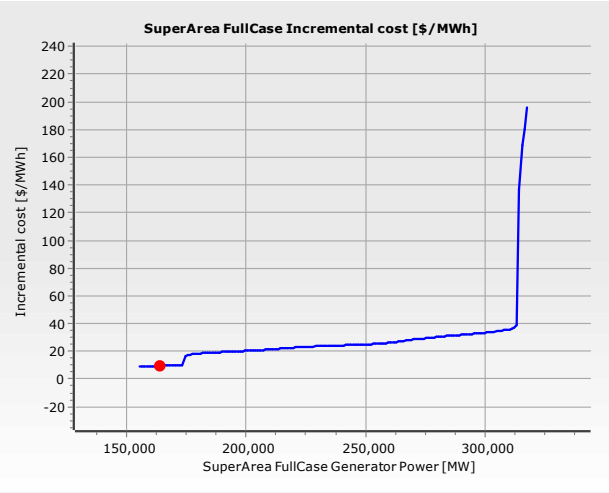
Field	Description	Units	Primary Source	Sec. Source
Ramp Rate Up, Down	% of Pmax	%/min	JBG	ERCOT RTC Tool Input Files (MW/min)
Minimum Up Time		hours	Vaid, IRENA for IC units	JBG
Minimum Down Time		hours	JBG Table 3.10, IRENA	
Variable O&M cost		$/MWh	Vaid	JBG
Fuel Cost		$/MMBtu	EIA 923 Sched. 2: Fuel Receipts and Costs	
Generator Cost Midwest	Heat-rate curve parameters		CEMS Heat Rates (2016-2017)	ERCOT 60-Day SCED Disclosure Reports
Generator Cost ERCOT	Bid Curves	(MW, $)	ERCOT 60-Day SCED Disclosure Reports	ERCOT RTC Tool Input Files

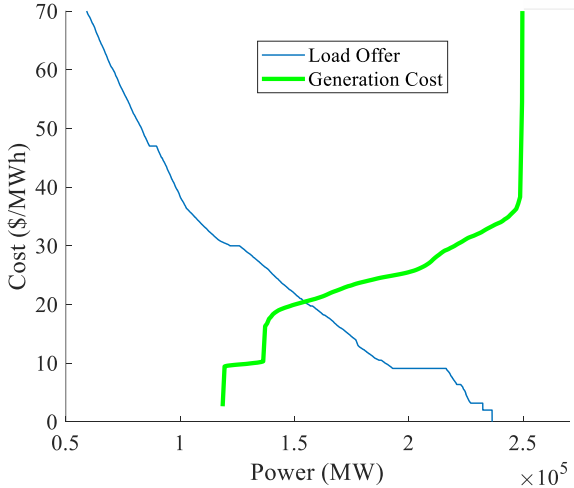
References for Unit Commitment Parameters and Cost Curves

- CEMS: Continuous Emissions Monitoring System; RTC: Real Time Co-optimization
- Vaid: P. Vaid, Analyses and Tabulation of Heat Rates, Unit Commitment Generator Constraint Parameter Values and Emissions Estimates of the Electricity Generators of Power Plants in Texas, MS Thesis, UT Austin, 2019
- JBG: Garrison, J. B. (2014). A grid-level unit commitment assessment of high wind penetration and utilization of compressed air energy storage in ERCOT (Doctoral dissertation).
- IRENA: IRENA (2019), Innovation landscape brief: Flexibility in conventional power plants, International Renewable Energy Agency
- CEMS Heat Rates: Rossol, Michael; Brinkman, Gregory; Buster, Grant; Denholm, Paul; Novacheck, Joshua; Stephen, Gordon (2018): A National Thermal Generator Performance Database. National Renewable Energy Laboratory. https://data.nrel.gov/submissions/100
- ERCOT RTC Tool Input Files: https://www.dropbox.com/sh/7wg5yz35ycred1f/AABgX_tGebTYcp8pym0k5crca/2017publicdata.zip?dl=0
- ERCOT 60-Day SCED Disclosure Reports: https://sa.ercot.com/misapp/GetReports.do?reportTypeId=13052&reportTitle=60-Day%20SCED%20Disclosure%20Reports&showHTMLView=&mimicKey

Supply Cost and Demand Benefit Offer







Source: http://www.ercot.com/content/gridinfo/resource/2015/mktanalysis/Brattle_ERCOT_Resource_Adequacy_Review_2012-06-01.pdf

Creating Load Time Series on Bus Level

- The hourly time series of bus-level load and renewable generation for a typical year are created based on [1-2]
- The geographic coordinates of each bus are used to determine a unique electricity consumption profile at that location
- The MWh values and RCI ratios are extracted from the Annual Electric Power Industry Report and form EIA 861
- An iterative aggregation approach is taken to integrate building- and facility-level load time series to bus-level

[1] H. Li, A. L. Bornsheuer, T. Xu, A. B. Birchfield, and T. J. Overbye, “Load modeling in synthetic electric grids,” in 2018 IEEE Texas Power and Energy Conference (TPEC), 2018.

[2] Li, H., Yeo, J. H., Bornsheuer, A. L., & Overbye, T. J. (2020). The creation and validation of load time series for synthetic electric power systems. IEEE Transactions on Power Systems, 36(2), 961-969.

Renewable Time Series on Bus Level

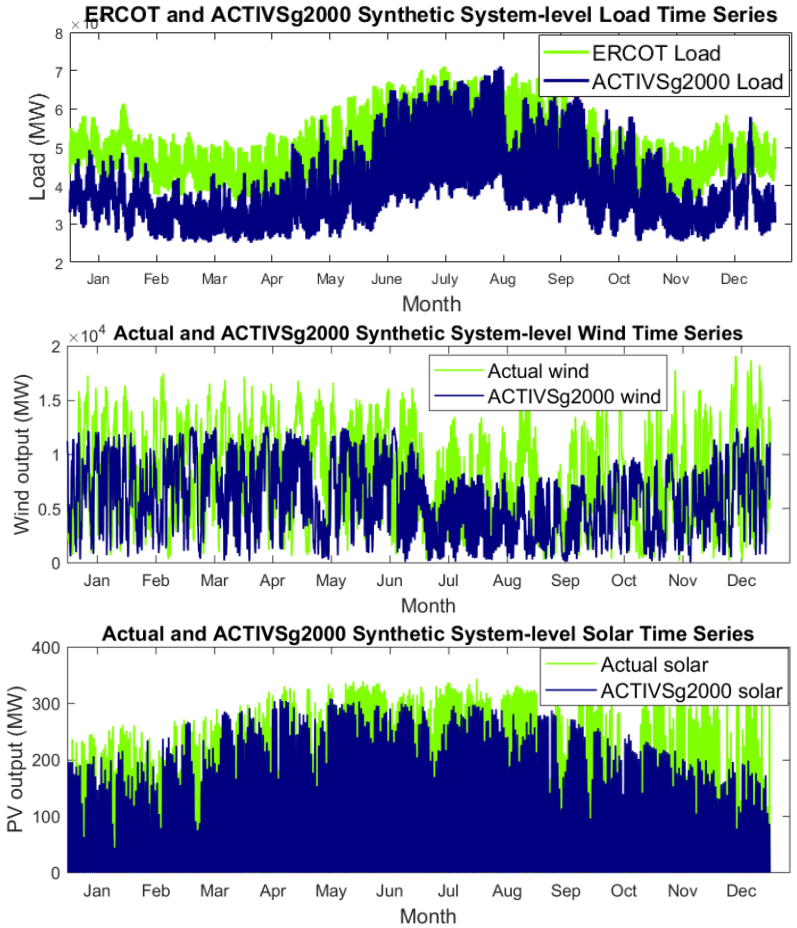
- The National Renewable Energy Laboratory (NREL) 5-minute resolution data of real power generation from Wind Integration National Data Set (WIND) and Solar Resource Data Set (SOLAR) [3]-[4]
- The geographic coordinates of each bus for wind and solar units in the synthetic system are used to identify the closest renewable sites in the actual grid

[3] “Wind ToolKit Data.” [Online]. Available: https://developer.nrel.gov/docs/wind/wind-toolkit/wind-toolkit-extract/

[4] “Solar resource data.” [Online]. Available: https://developer.nrel.gov/docs/solar/solar-resource-v1/

Time Series

- Included in TAMU Synthetic Transmission models
- Geographic location and other metadata used to determine these time series on a bus-level



Scheduled Outages

Outages emulate regular maintenance outages

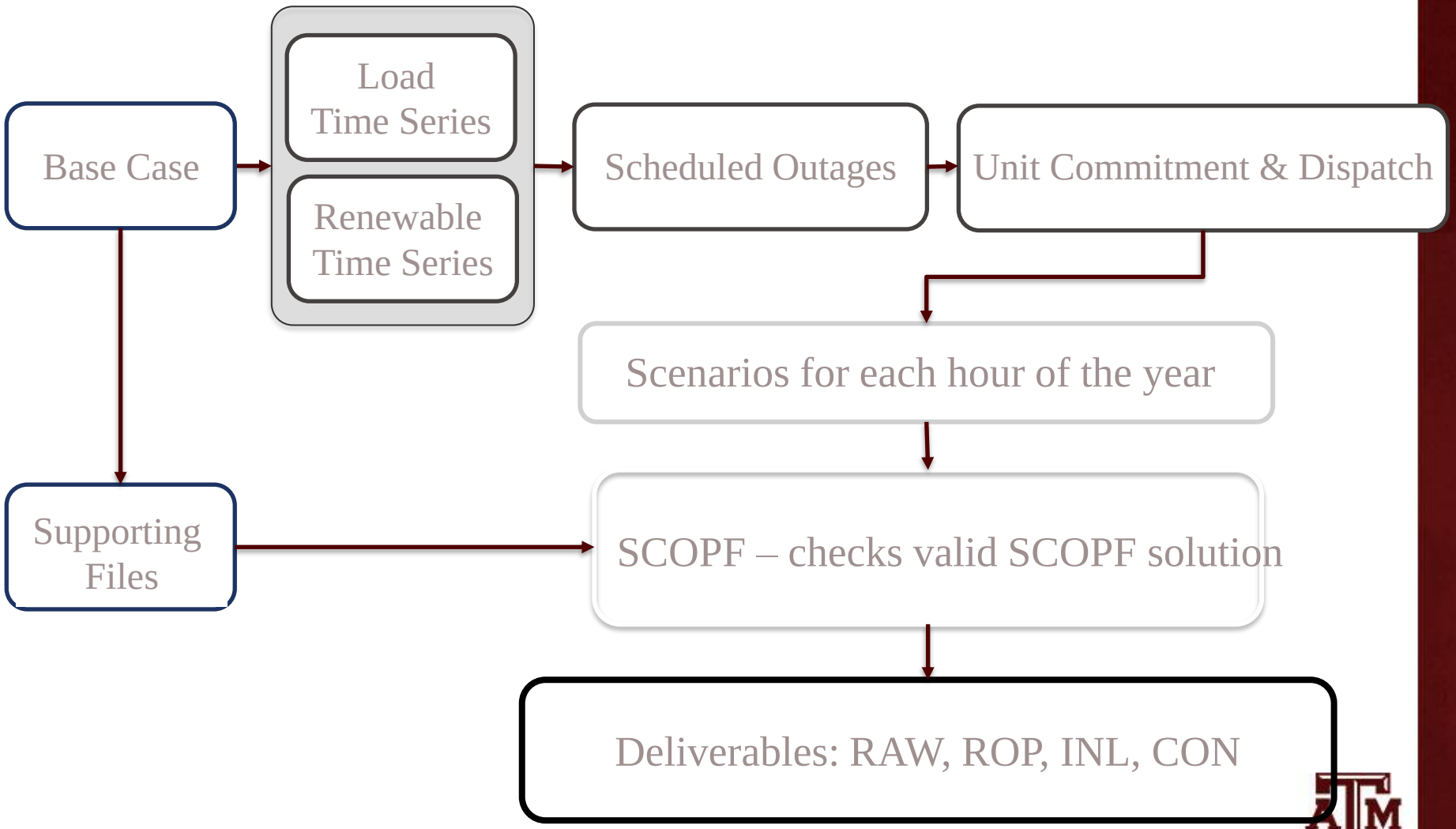
- **Generator**
- Total capacity from Seasonal Assessment of Resource Adequacy report
- Period between maintenance

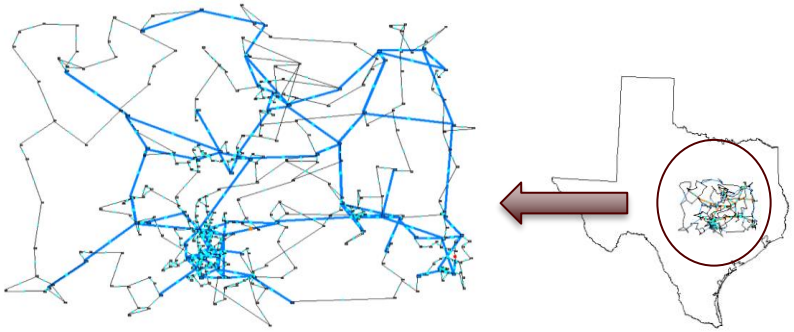
Transmission

Outages considered by selecting a combination of lines such that the system satisfies N-1 security

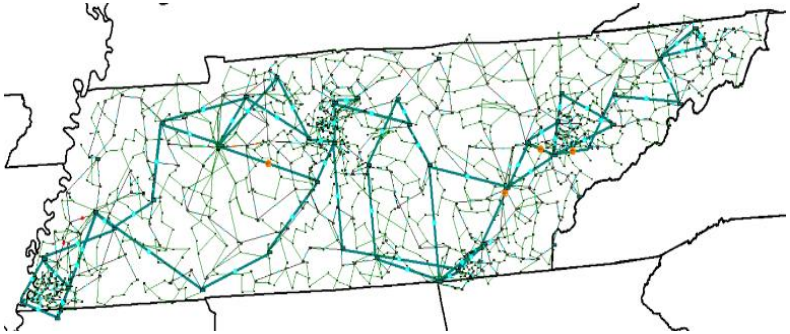
Unit Commitment & Dispatch of initial case

- Unit commitment in the initial case
- For a given hour
  - Sort generators
  - Consider generator minimum power output and ramping constraints
  - Select subset capable of supplying system power with lowest operational cost
- Dispatch calculated using economic dispatch after units committed

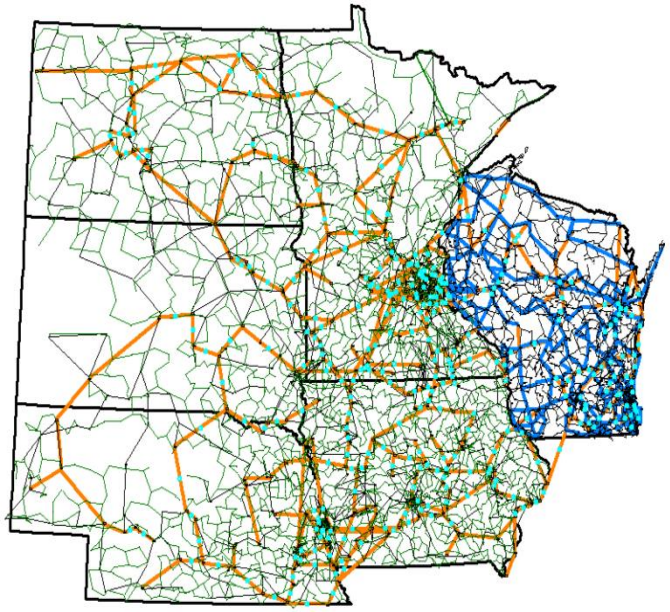

Base Case
Load Time Series
Renewable Time Series
Scheduled Outages
Unit Commitment & Dispatch
Scenarios for each hour of the year
Supporting Files
SCOPF – checks valid SCOPF solution
Deliverables: RAW, ROP, INL, CON



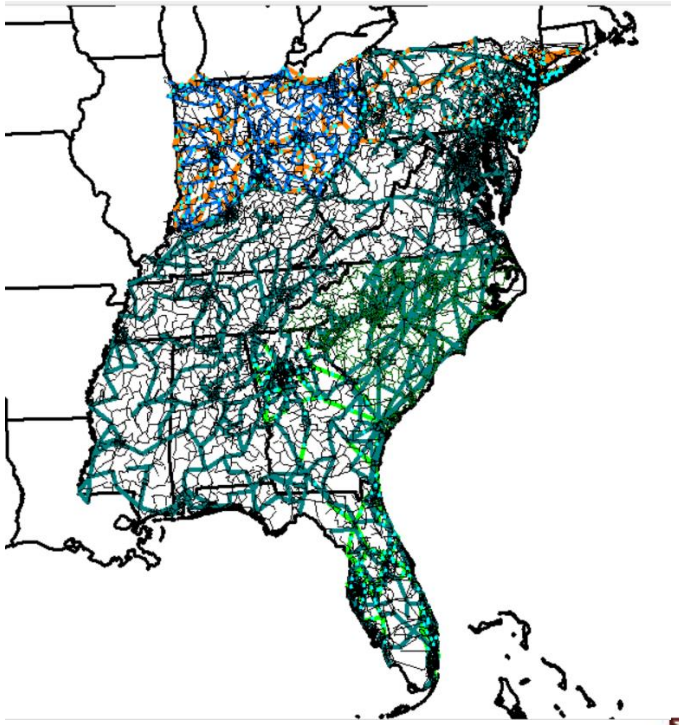
GOTx600 grid



GOTx12K grid

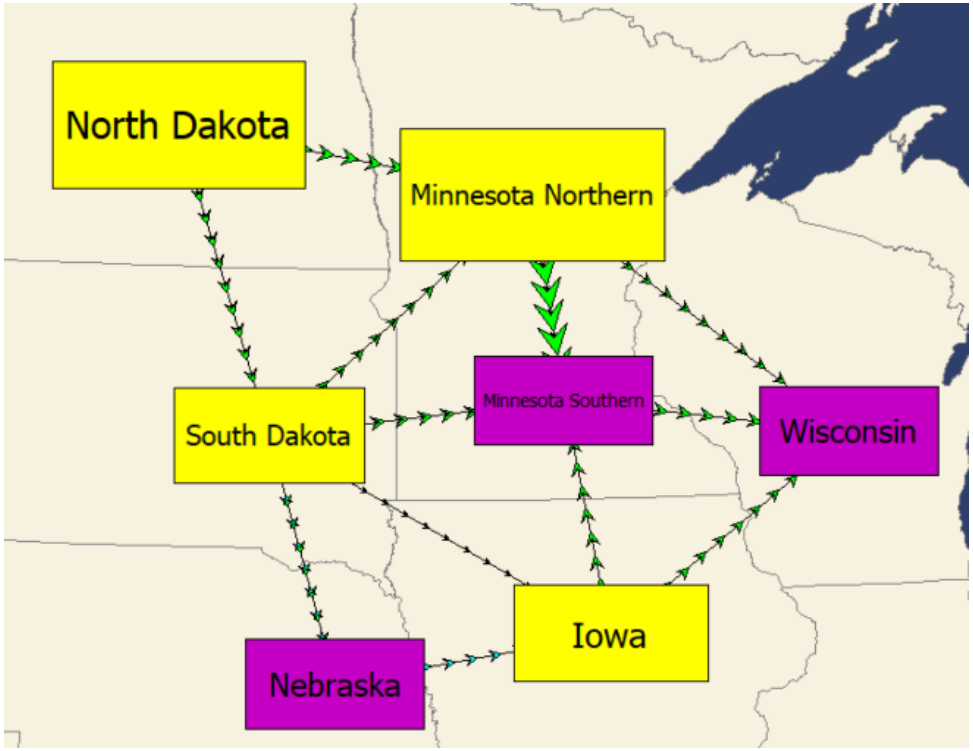


GOTx12K grid



GOTx31K grid

Geographical Data View of flows between areas for situational awareness and validation



Texas A &M University (TAMU) synthetic grids:

Grid	GOTX600	GOTX2000	GOTX12K	GOTX31K
Buses	617	2020	12209	31777
Substations	737	1250	7500	15500
Areas	1	1	7	24
Transmission Lines	723	2318	13216	34713
Transformers	130	538	2,184	6858
Loads	405	1392	6986	16578
Generators	94	194	2009	4663
Shunts	50	98	724	1996
Phase Shifters	2	2	5	4
Total Load GW	8	17	51	372

Base Case Development	Scenario Creation	Deliverable Preparation	Deliverable Validation
• Create new synthetic grids • Augmentations • Initial CON File	• Load and renewable scenarios • Scenario Narratives	• RAW File • RAW_Base File • CON File • JSON File	• N-1 Criterion • PNNL's Checker

Base Case Development

Scenario Creation

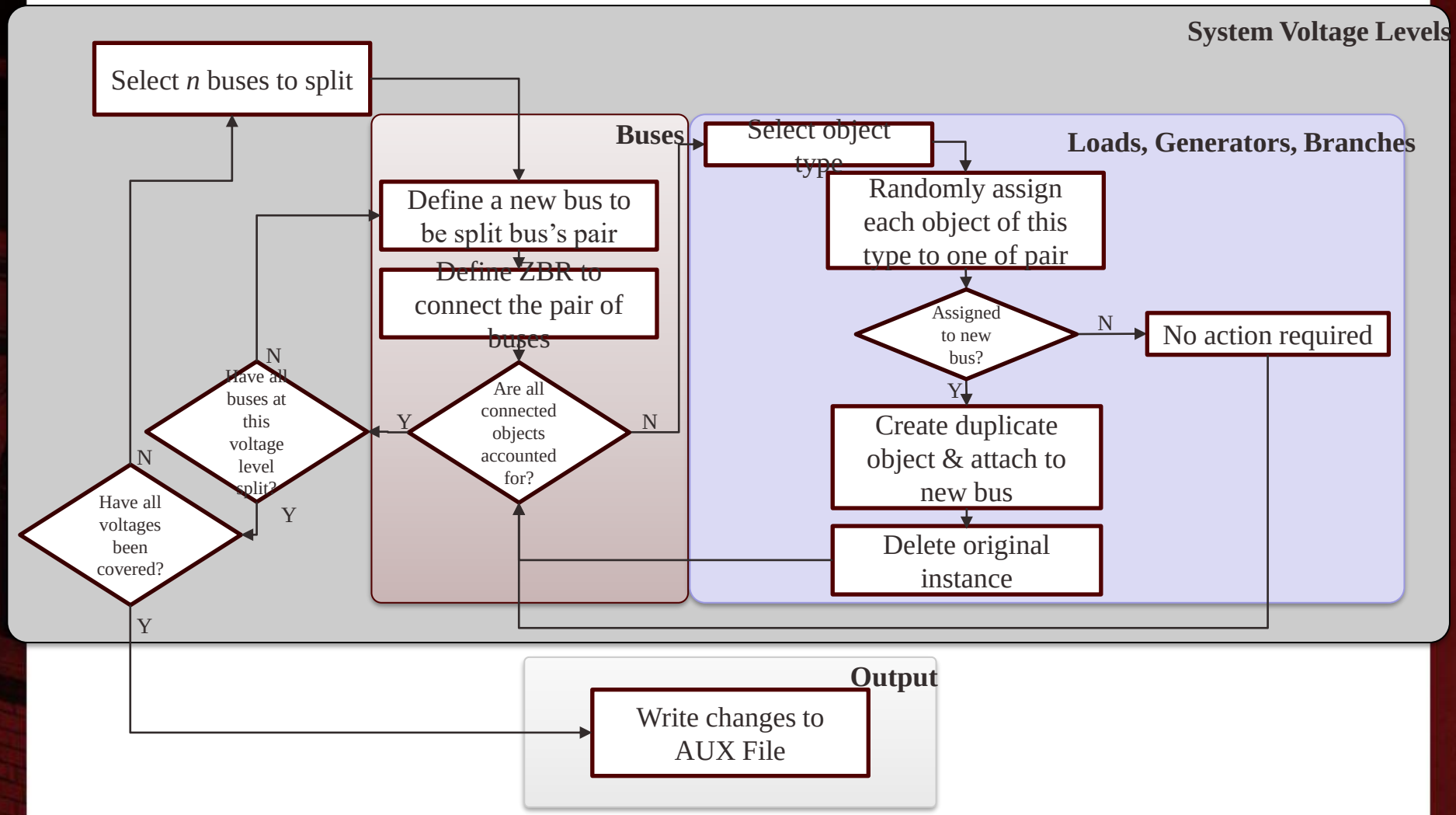
Deliverable Preparation

Deliverable Validation

Timeseries Development

JSON File Parameters

Bus Splitting in Synthetic Grids



V ≤ 500kV, ~13% buses split

Industry Grids

Industry grids are actual grids, which are used for the GO competition 2 but are CEII and cannot be published. The main challenge with these grids was selecting, organizing and adjusting the real data according to the competition format.

Grid	MSRBB	FRANCE-EHV-LYONBB	GOTxSPP	France_BB	AUS2	GOTxWECC
Buses	403	3411	3593	6705	16955	22720
AC Lines	438	3628	2160	7384	16071	17859
Transmission Lines	112	871	2004	1578	4675	10110
Loads	384	2959	1355	5696	9419	8369
Generators	139	969	602	2042	1868	4203
Shunts	9	56	370	77	1630	1635
Generator Contingencies	138	968	80	2024	0	100
Branch Contingencies	276	2220	421	4555	3803	900

Numerical results and analysis

- Analyzing results of synthetic grids vs. Industry grids
- Finding interesting scenarios such as a different performance on synthetic and industry grids
- In addition, most synthetic grids have the same top-ranked team for different scenarios while most industry gids have different top-ranked teams, with slight differences in the objective value.
- A hypothesis for this difference between the results of synthetic and industry grids is that the competitors did not have access to the full cases and had a limited amount of time to run simulations on the industry grids.
- Another hypothesis is the presence of bad data in industrial grids.
- Overall, these Grid Optimization (GO) competitions are beneficial for the power industry and give motivation to the researchers to improve optimization algorithms.

Thank You!

Questions?

TEXAS A&M UNIVERSITY