# ECEN 667
# Power System Stability

## Lecture 22: North American East-West Interconnection Study

Prof. Tom Overbye
Dept. of Electrical and Computer Engineering
Texas A&M University
overbye@tamu.edu

# Announcements

- Read Chapter 9
- Homework 7 is due on November 30
- More details on today's lecture are available on papers on my website https://overbye.engr.tamu.edu/publications/

# In a Nutshell

- This project, which ran from March 2020 to Dec 2020, was done for SPP through PSERC
- The focus was primarily on the dynamic aspects of an AC interconnection of the East and WECC
  - The study did not consider ERCOT
- The study considered nine connection points and used the most detailed dynamic models available
  - The grid model size had 110,000 buses
- There are no technical showstoppers to doing this interconnection, and a good amount of interchange capability could be achieved with relatively little investment

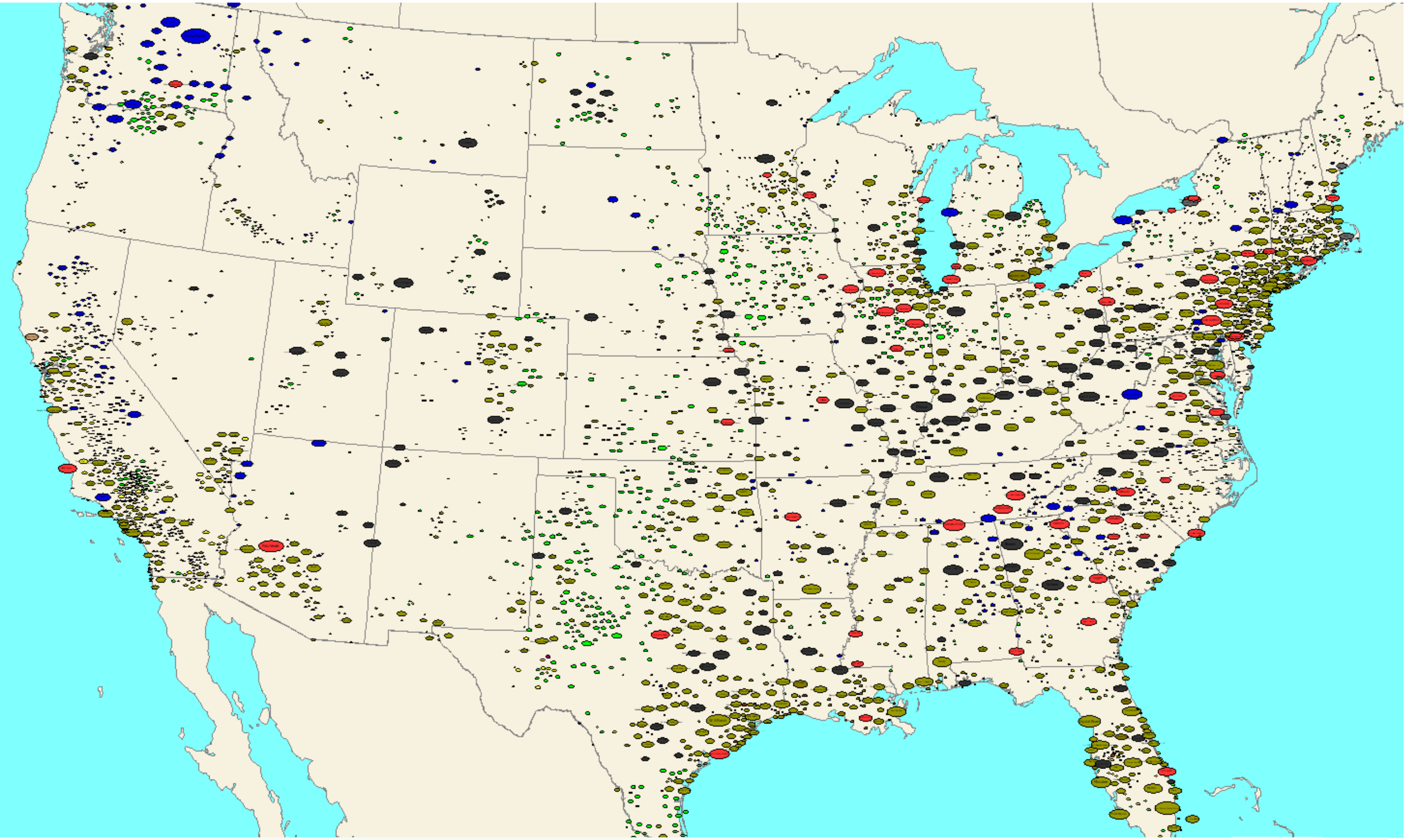
# In a Nutshell, cont.

- The study conclusion is technically the grids can be interconnected
  - We did not address in-depth whether they should be interconnected (more of a political and economic question)
  - Adding ERCOT would be a natural extension
- In relation to the large HVDC overlay studies
  - Our study results indicate that both AC and HVDC solutions should be considered; synchronizing the grids does not preclude the use of HVDC; it just provides more flexibility since AC lines can also be considered
  - These studies can and should consider the impact of power system dynamics

# Background: Major North America Interconnects


Image Source: North American Electric Reliability Corporation

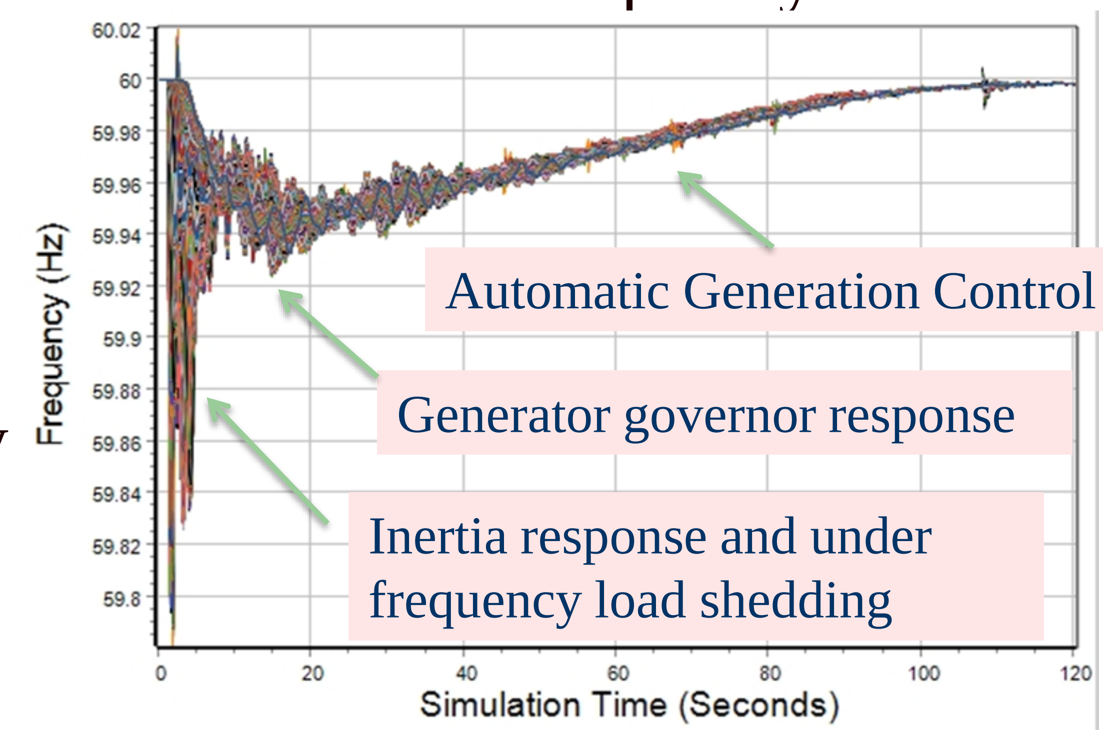
# 2019 US Generation by Capacity and Fuel



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.

# Quick Aside: Power System Dynamic Response to Load/Gen Mismatch

- An electric grid frequency is constantly changing, but it usually within a few mHz of desired (e.g., 60 Hz)
- Too much generation increases the frequency and and too little decreases it
- All grid elements have the same average frequency but during disturbances the frequency can oscillate



# Background: East-West History

- The East and the West have been joined in the past, at least from 1967 to the 1970's
  - In the [a] (from 1970), the authors say,

    "The nation's largest synchronized network now extends from coast to coast and includes 94 percent of United States generating capacity."
  - In a 2018 IEEE Proceedings article Julie Cohn says they were joined from 1967 to 1975; they separated because of problems with maintaining synchronism and the introduction of HVDC
- A 1994 WAPA report looked at the reconnection

[a] Cohn, Biddle, Lex, Preston, Ross, Whitten, "On-line Computer Applications in the Electric Power Industry," IEEE Proc., January 1970, pp. 78-87

# Background: Grid in 1970 (From [a])

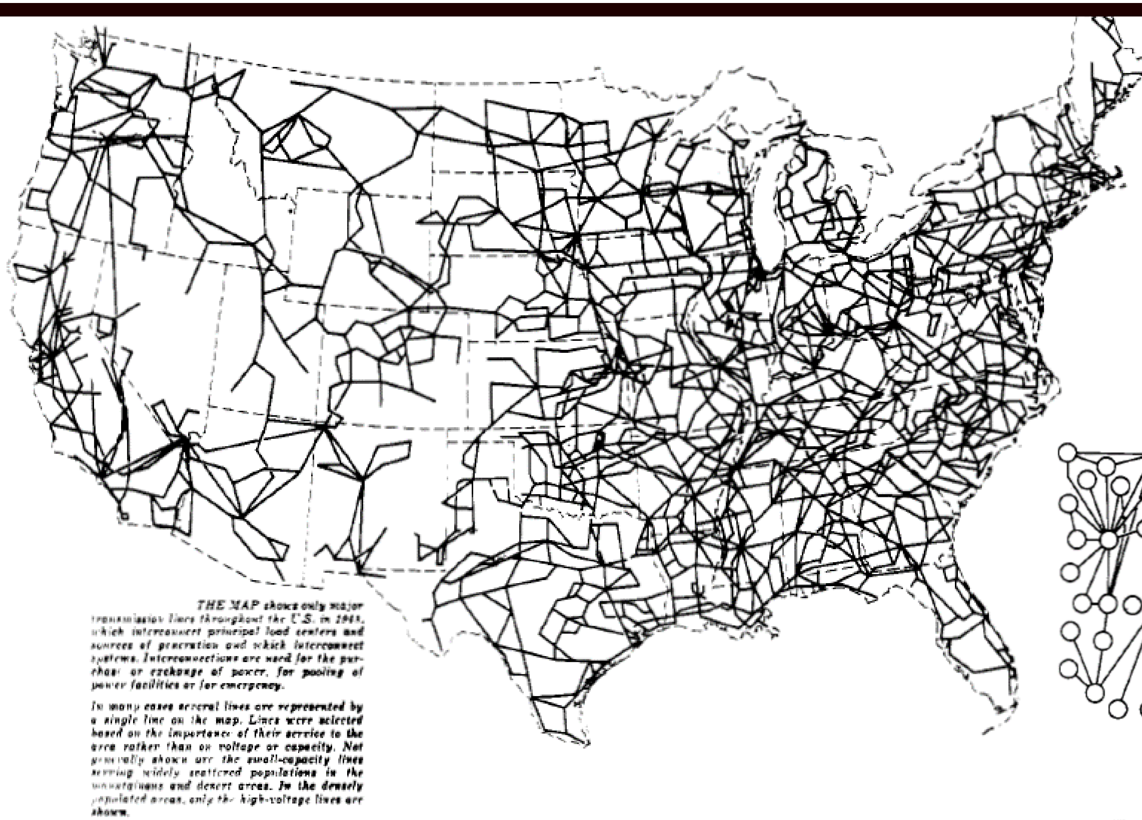


Fig. 2. Schematic backbone transmission map illustrating the major interconnecting tie lines in the United States as of the end of 1969 (courtesy of Edison Electric Institute).

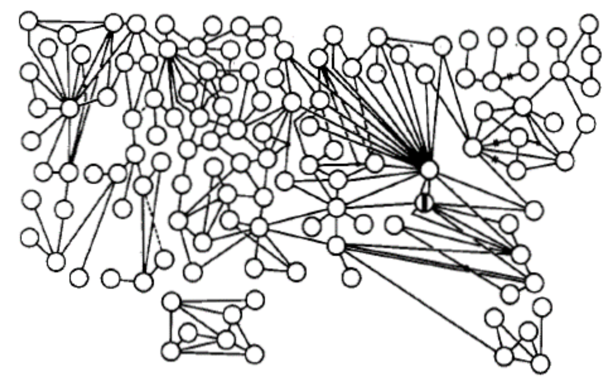


Fig. 3. Interconnected control areas of the continental United States and Canada.

[a] Cohn, Biddle, Lex, Preston, Ross, Whitten, "On-line Computer Applications in the Electric Power Industry," IEEE Proc., January 1970, pp. 78-87

Another good background article is by Julie Cohn in the January 2019 *IEEE Proceedings*, titled, "When the Grid Was the Grid: The History of North America's Brief Coast-to-Coast Interconnected Machine"

# Details on Combining the Models

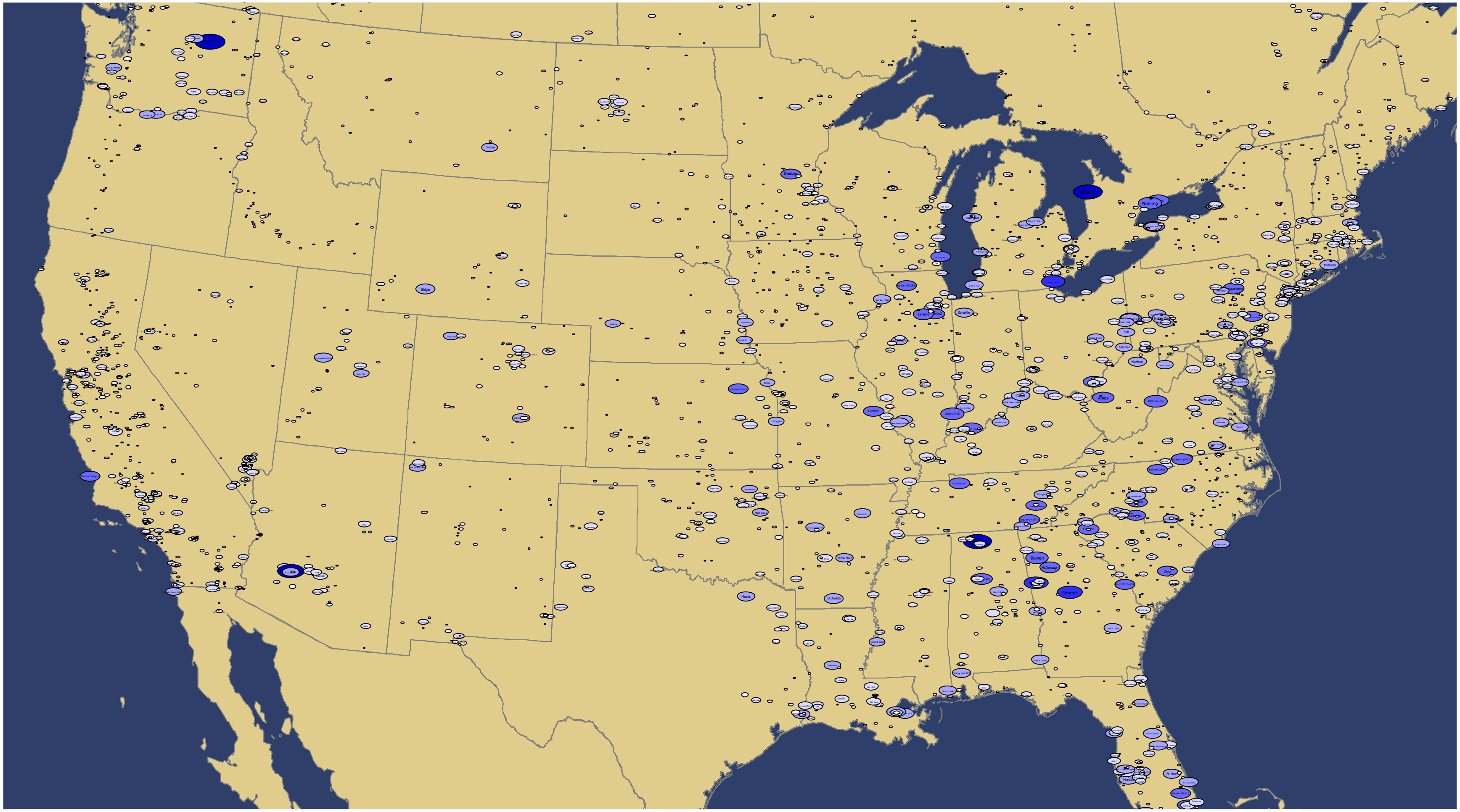
- The input data for the project was high and low demand power flow and dynamics cases for the Eastern Interconnect and the WECC (West)
  - These are the best electric grid models available
- Power flow and dynamic data were provided for the East in PSSE format and for the West in PowerWorld format, based on PSLF
  - Not all the models are compatible between PSSE and PSLF, but PowerWorld supports both
- To avoid overlapping bus numbers the West was renumbered by adding 2 million to the West
- A combined case was created in PowerWorld with 110,000 buses

# Details on the Models

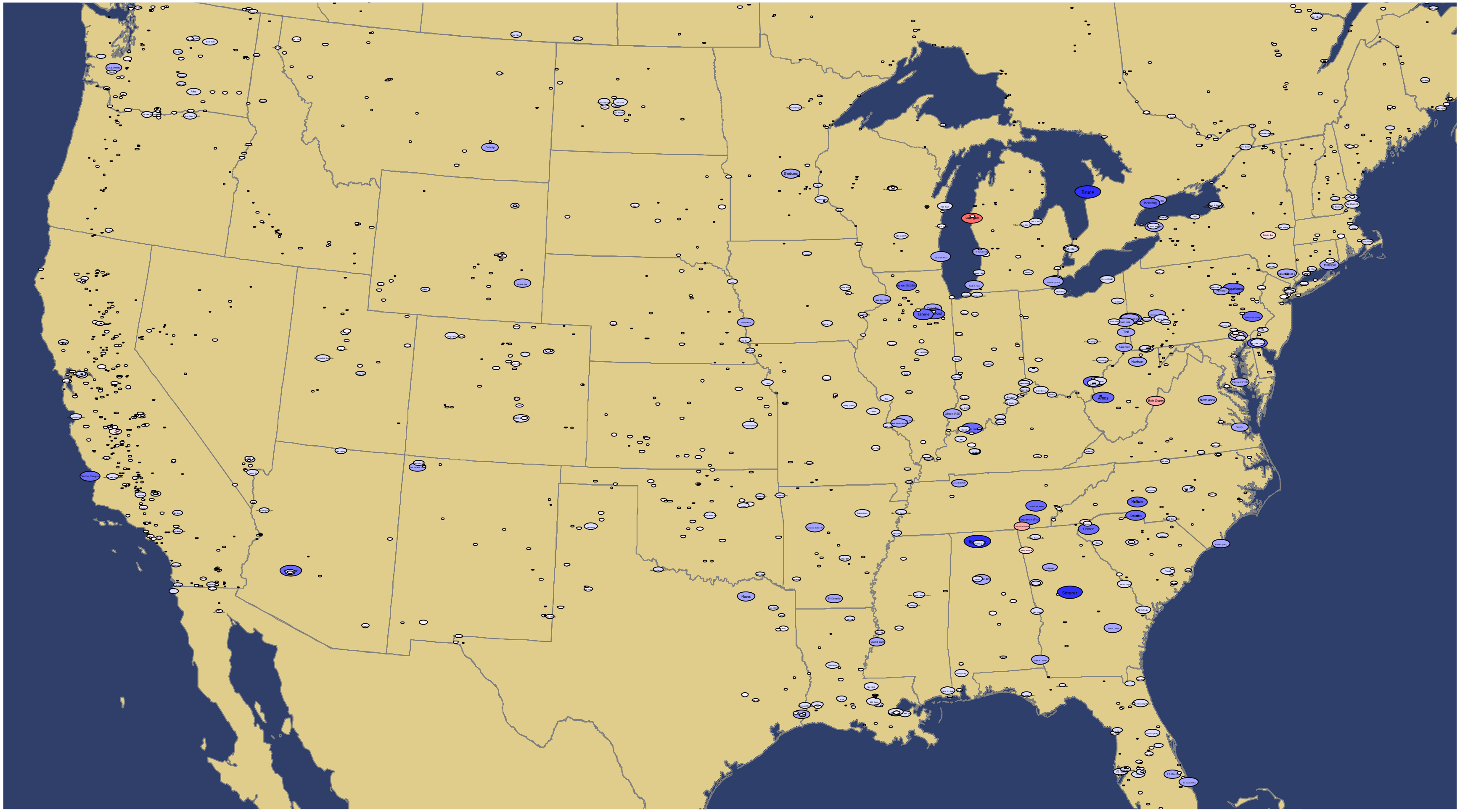
- The grids were combined using nine short ac interconnections at voltages from 161 to 345 kV
- There are no showstoppers with doing such an interconnection with the key constraint that during dynamic disturbances with lost generation in the West, about 75-80% of the lost generation will flow East to West; modelling the AGC response is important
- The studied also showed that existing, large-scale dynamic models can run stable for long periods of time (up to 360 seconds here)
- Some results will be shown with synthetic grids

# Base Model 1: Heavy Load Conditions

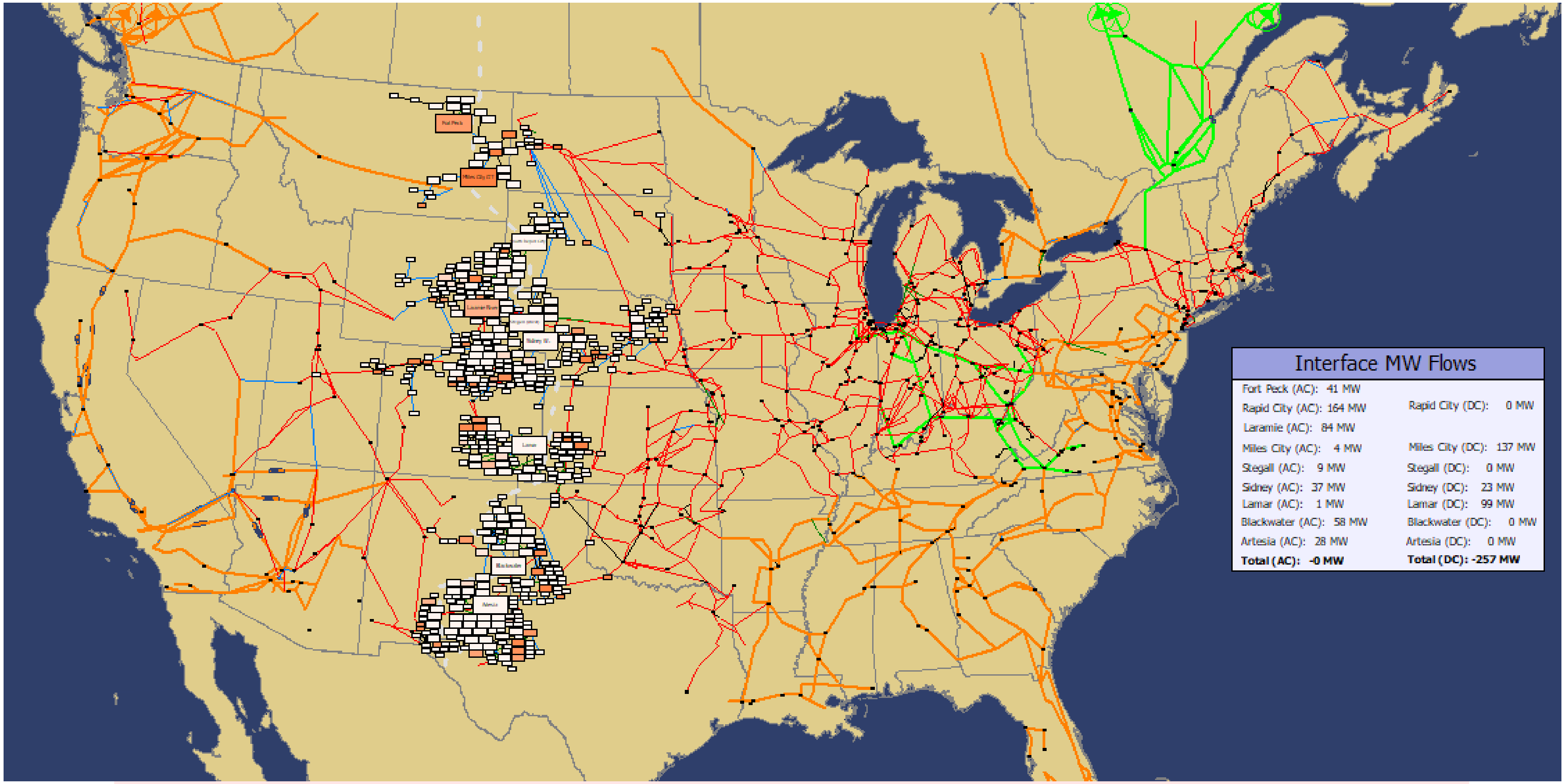
## Substation Generation Sized and Colored by MW Value



# Base Model 2: Light Load Conditions
## Substation Generation Sized and Colored by MW Value



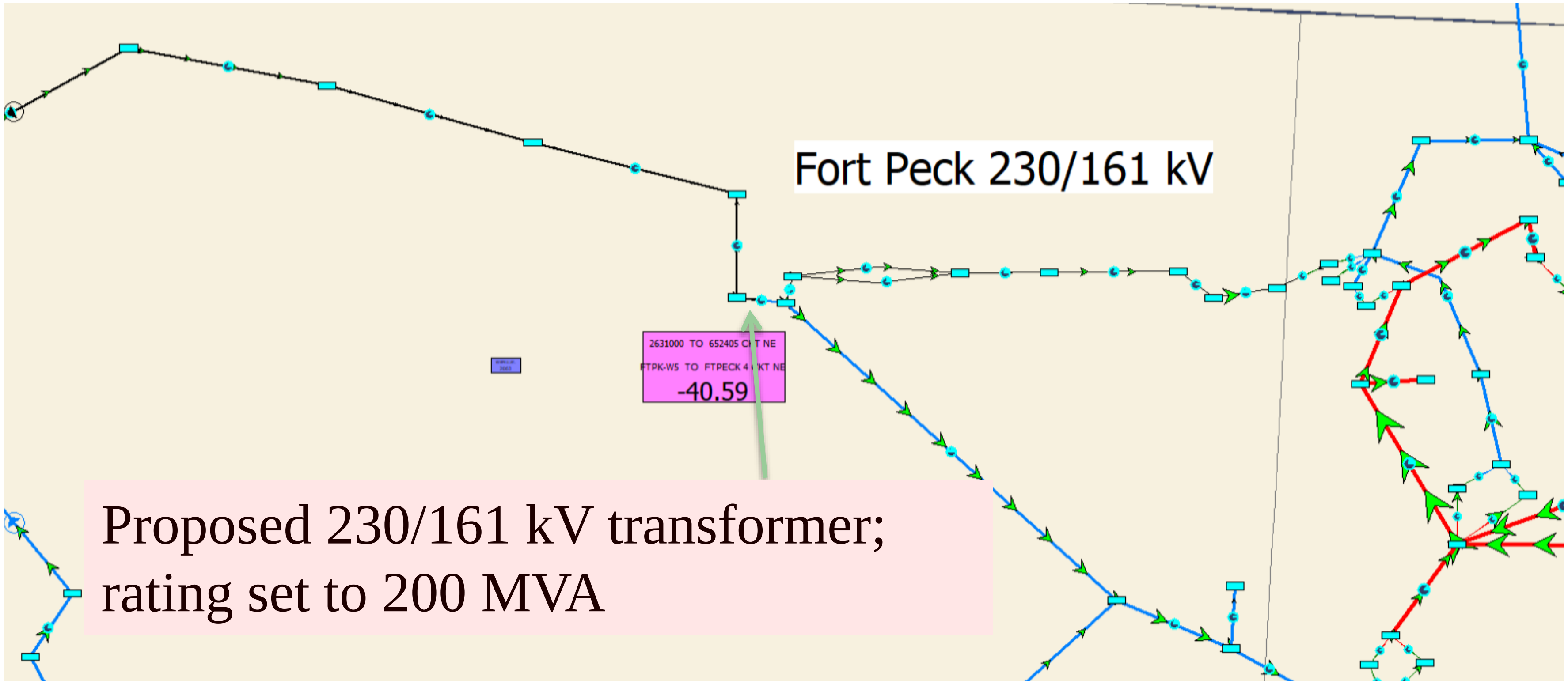
# The Combined Grid Overview




The study included Canada but we did not consider any ac interconnections between the grids in Canada

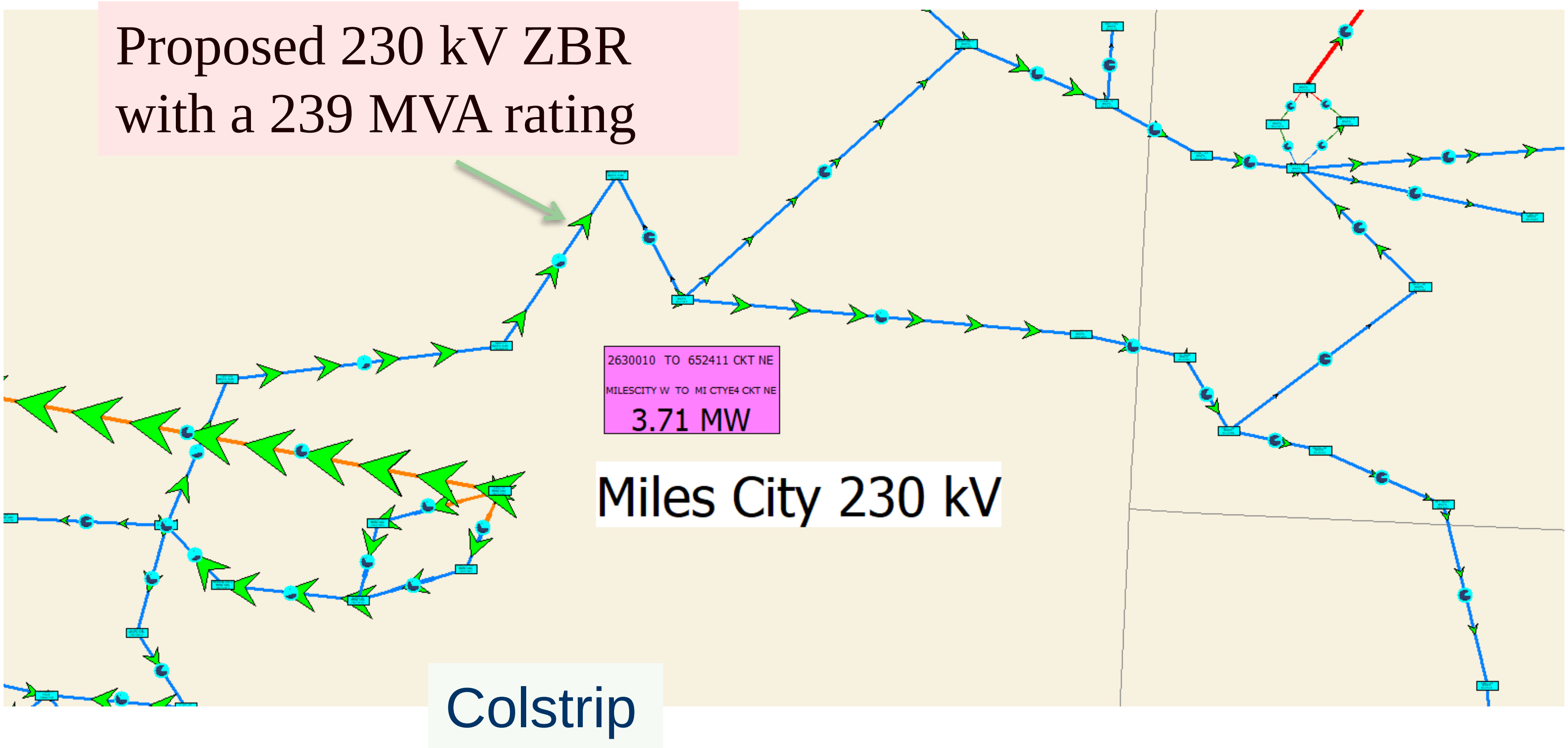
# Fort Peck 230/161 kV

- Rating of 161 kV to west is 112/123 MVA; rating of 230 kV to east is 160/176 MVA; rating of 115 kV to east is 120 MVA; new transformer was set to 200 MVA



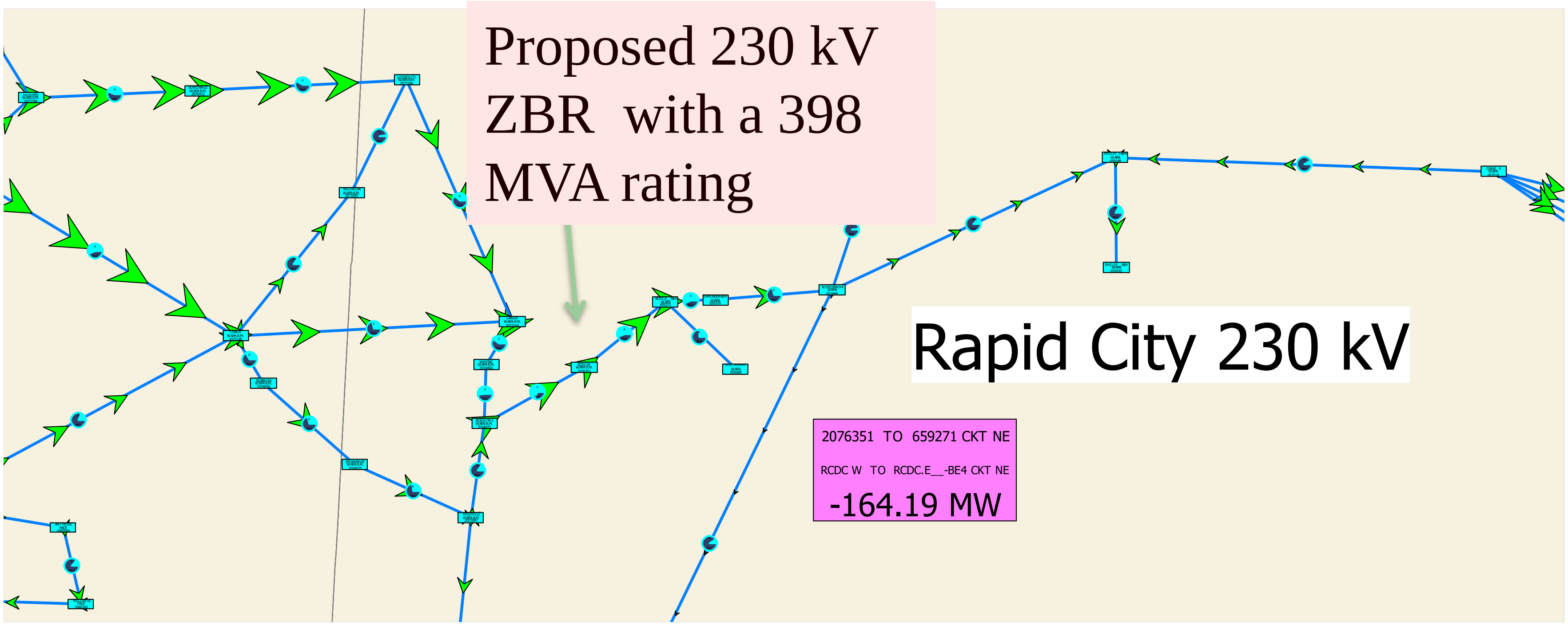
# Miles City 230 kV

- Rating of 230 kV to west is 239/260 MVA; rating of line to NE is 320 MVA and line to east is 239/260 MVA



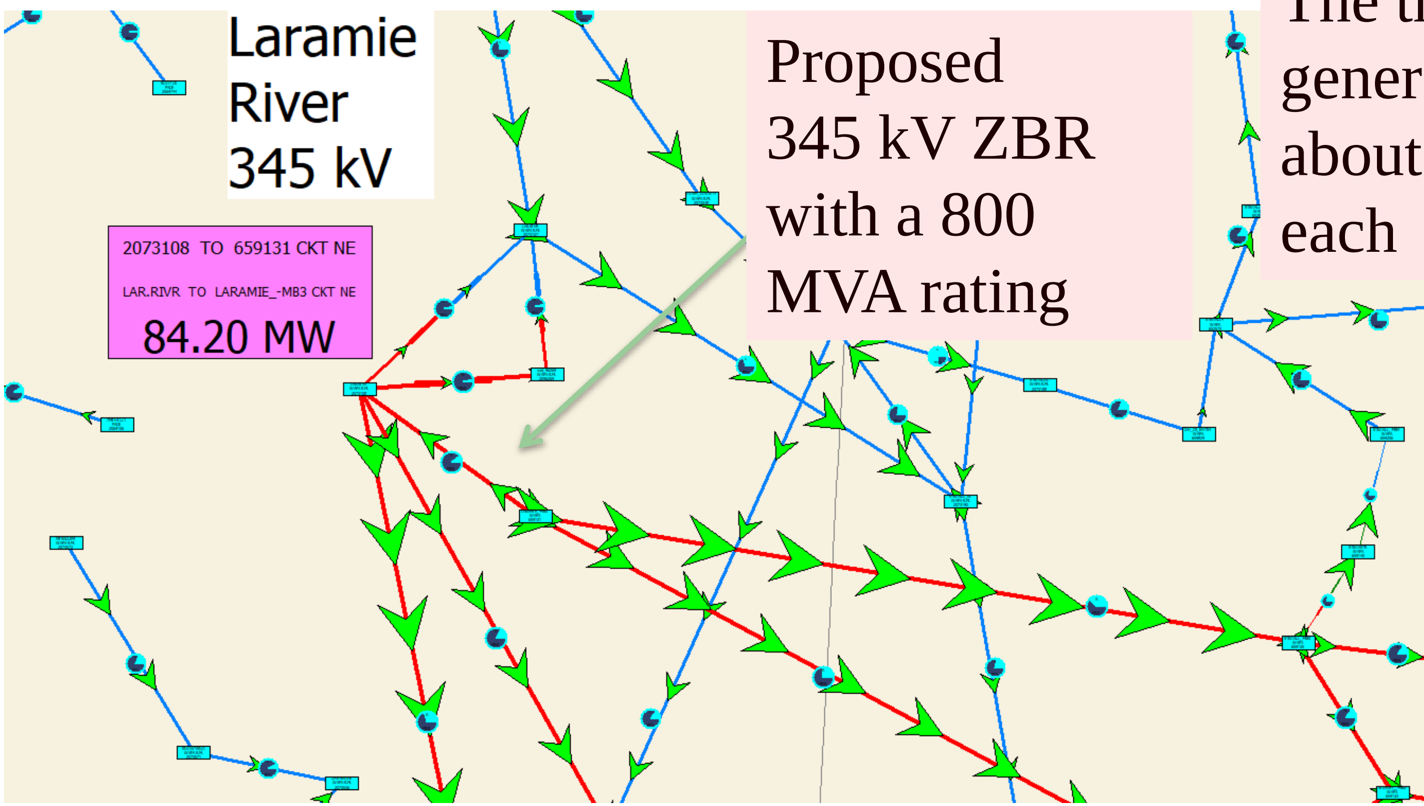
# Rapid City 230 kV

- There are three 230 kV lines going west, with an MVA of mostly more than 400 MVA each; there are three lines to the east with at least 300 MVA each.



# Laramie River 345 kV

- In the west two 345 kV, 956 MVA lines go south and in the east two 345 kV, 760 MVA lines go east. There are two 600 MVA 345/230 kV transformers.

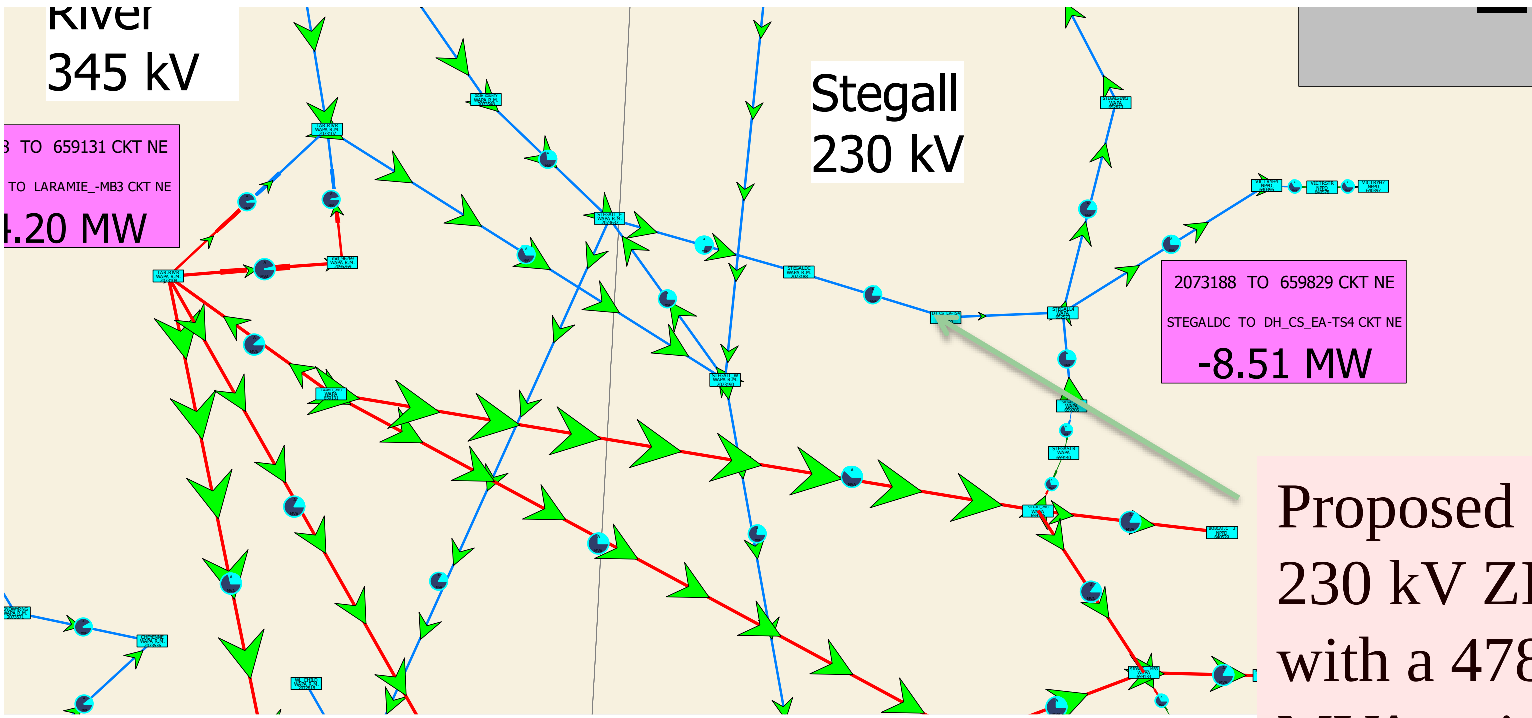



Proposed 345 kV ZBR with a 800 MVA rating

The three generators at about 600 MW each

# Stegall 230 kV

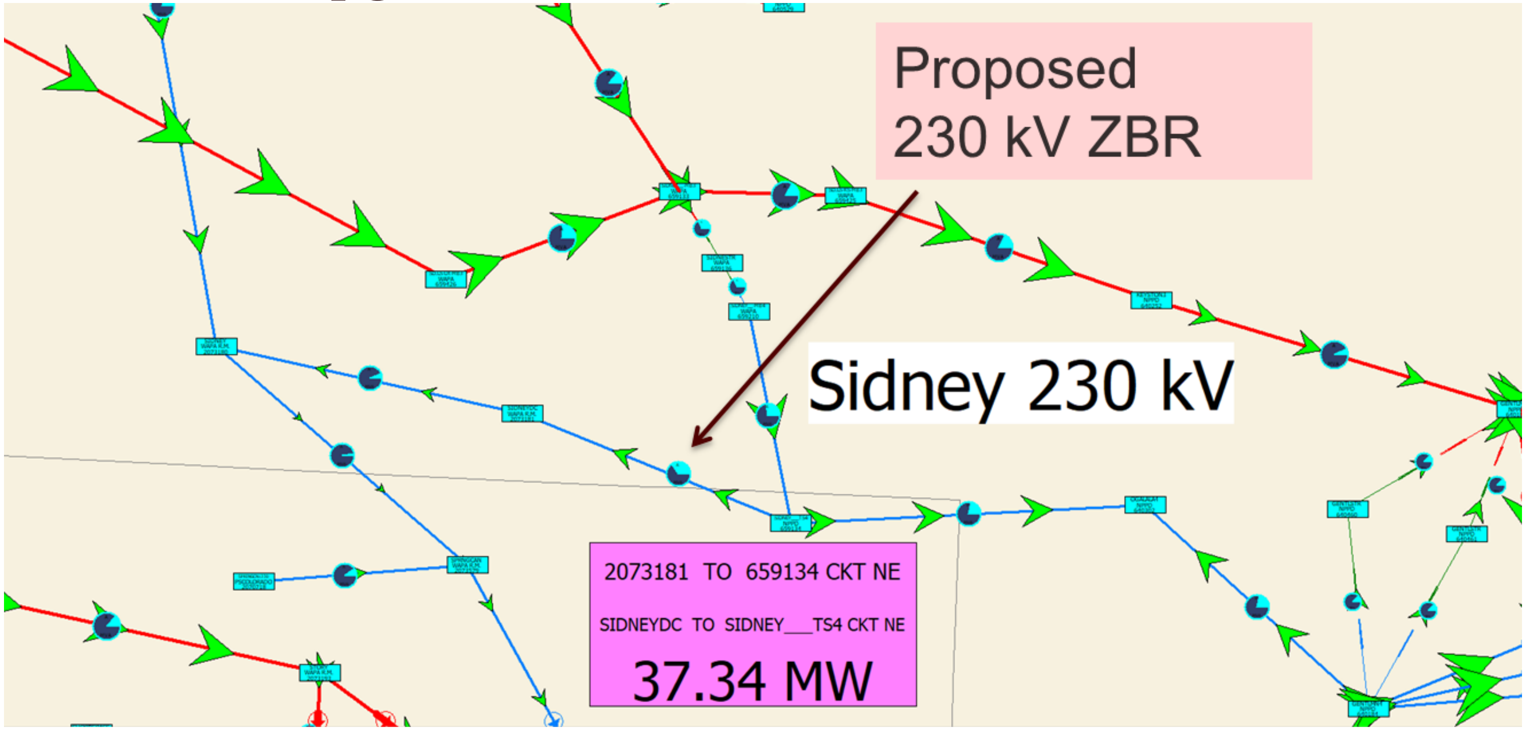
- On the west there are four 230 kV lines with average ratings of about 400 MVA; on East there is a 400 MVA and a 240 MVA 230 kV lines, and a 478 MVA 345/230 kV transformer.




Proposed 230 kV ZBR with a 478 MVA rating

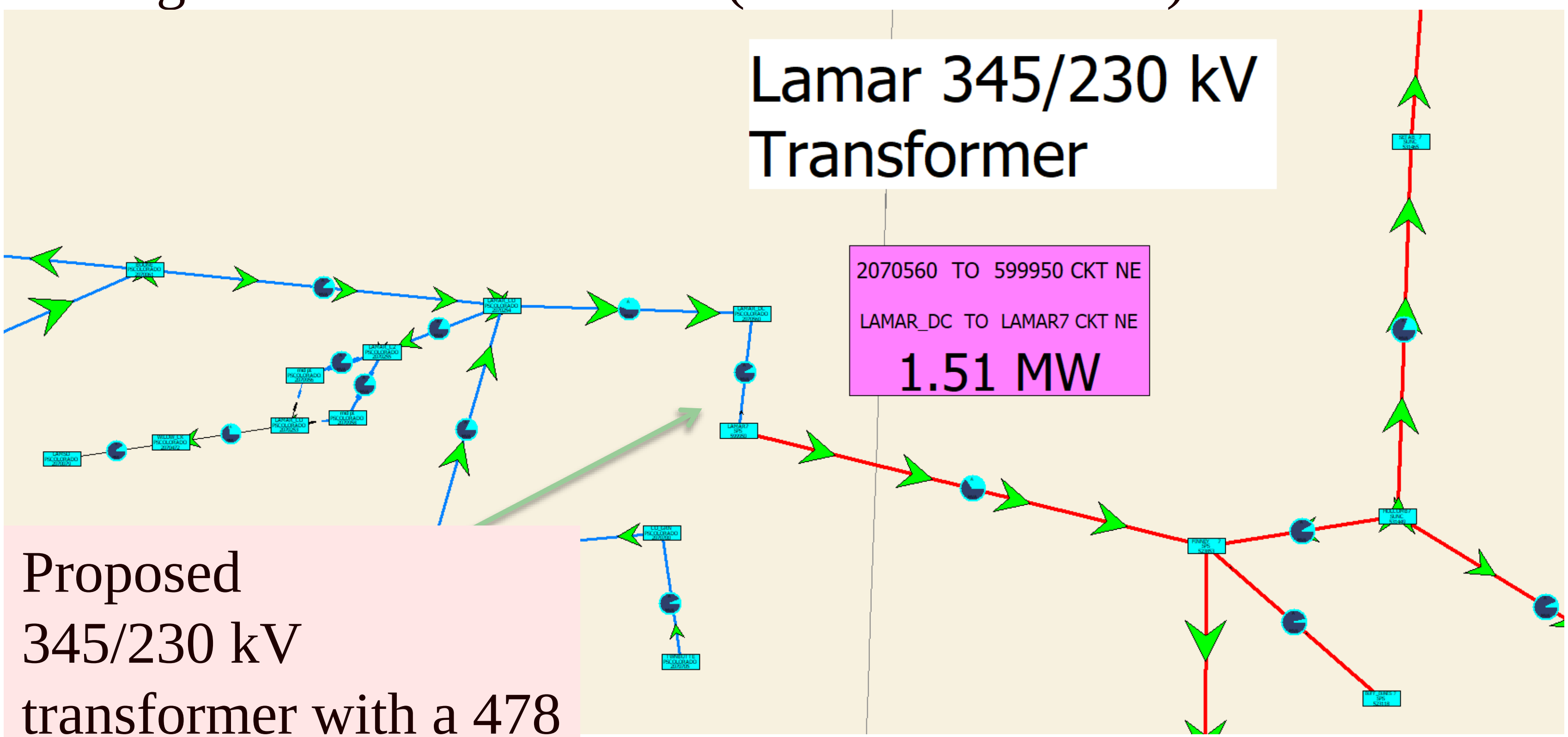
# Sidney 230 kV

- On the west there are 230 kV lines, with ratings of 318 and 442 MVA; on the east there is a 478 MVA 345/230 kV transformer and a 320 MVA 230 kV line going east which could be upgraded to 478 MVA



# Lamar 345/230 kV Transformer

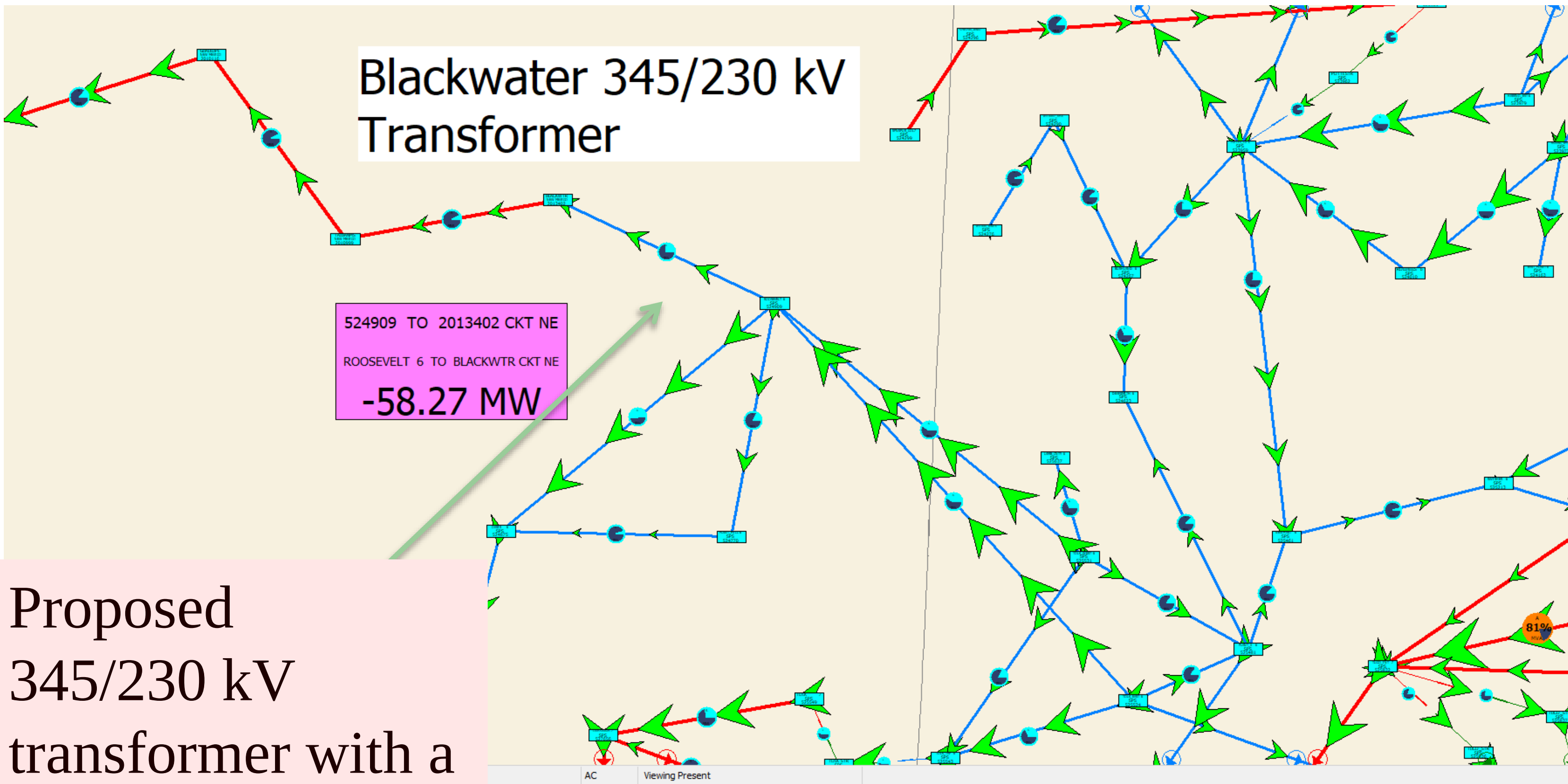
- Rating of the 230 kV line to the west is 478 MVA ; the 345 kV line to the east is rated at 380 MVA; connecting to three much higher rated 345 kV lines (at least 700 MVA)




Proposed 345/230 kV transformer with a 478 MVA rating

# Blackwater 345/230 kV Transformer

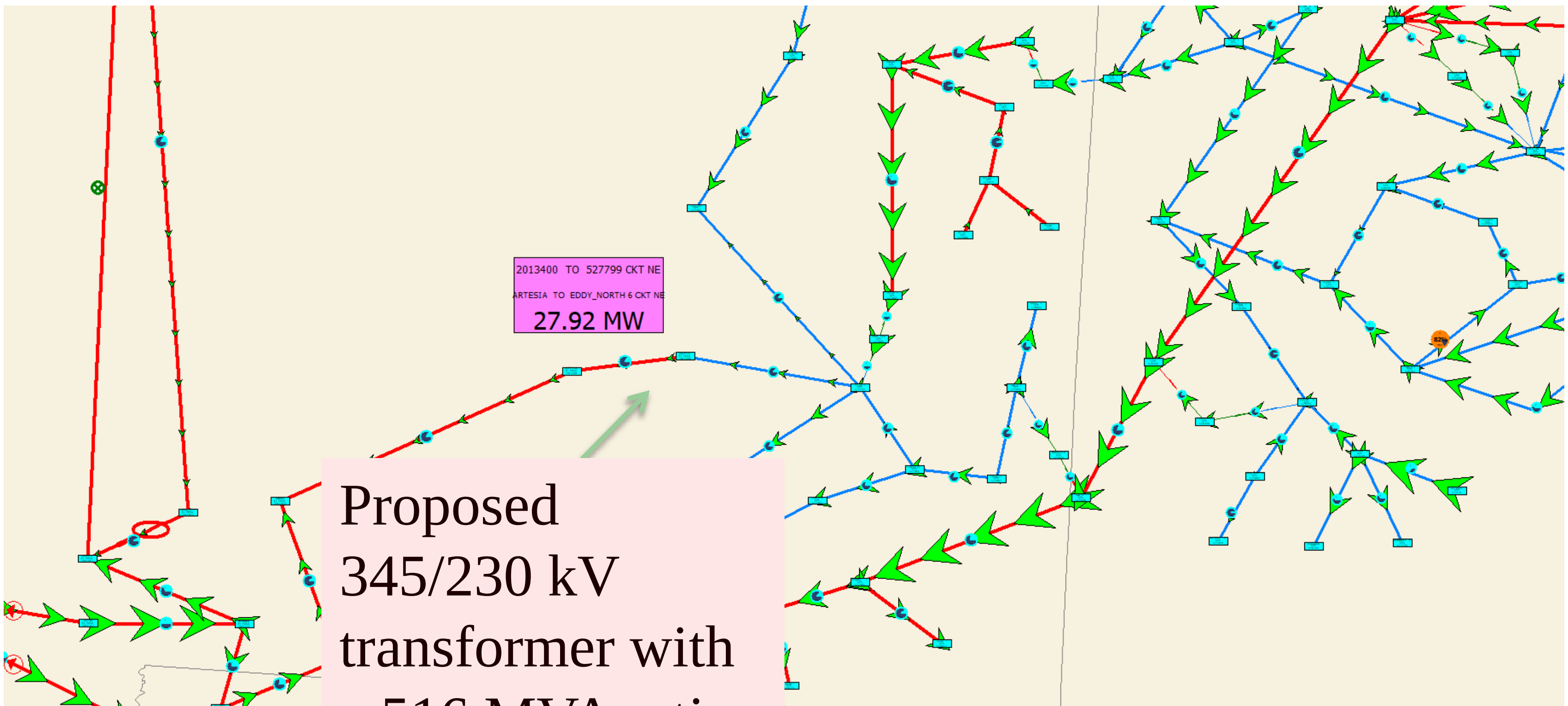
- Rating of the 345 kV line to the west is 753 MVA; two 230 kV lines go to the east rated at 478 MVA each.




Proposed 345/230 kV transformer with a 753 MVA rating

# Artesia 345/230 kV Transformer

- Rating of the 345 kV line to the west is 277 MVA (though it probably higher); to the east is a 500 MVA 345/230 kV transformer and three 230 kV lines (min of 300 MVA) each



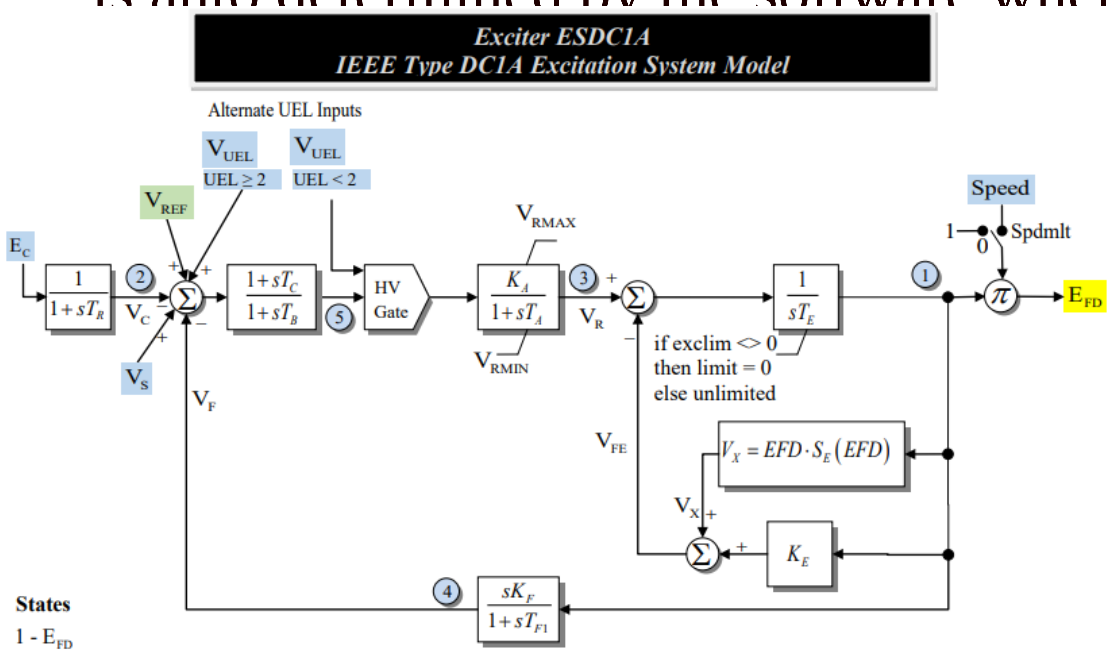

Proposed 345/230 kV transformer with a 516 MVA rating

# Dynamic Model Setup

- A primary project task was to perform dynamic (transient stability level) studies on the combined grid, and to compare the results with the separate grids
  - Key dynamic contingencies were the loss of a large amount of generation (greater than 5000 MW in the East)
  - The model has 110,000 buses, 14,000 generators, 37,000 dynamic model devices with 243 different model types
  - The Integrations were solved using a ½ cycle time step

# Modeling Considerations

- While many of the dynamic models used in the East and West are similar (or identical), there are sometimes subtle differences
  - Example is with an ESDC1A exciter in which the KE value is auto determined by the software when it is set to zero

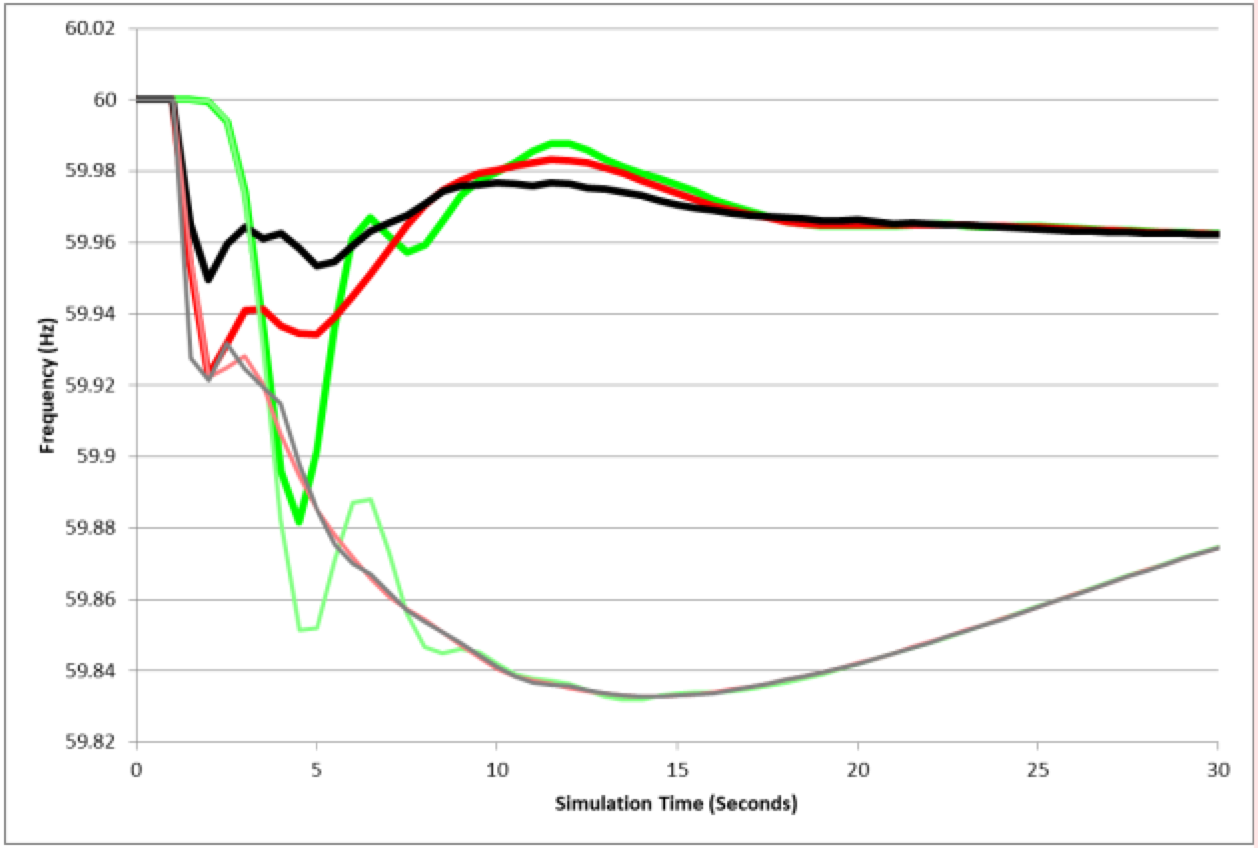



How this adjustment occurs differs between software packages, and changing the approach can result in unstable simulation results.

# Dynamic Studies

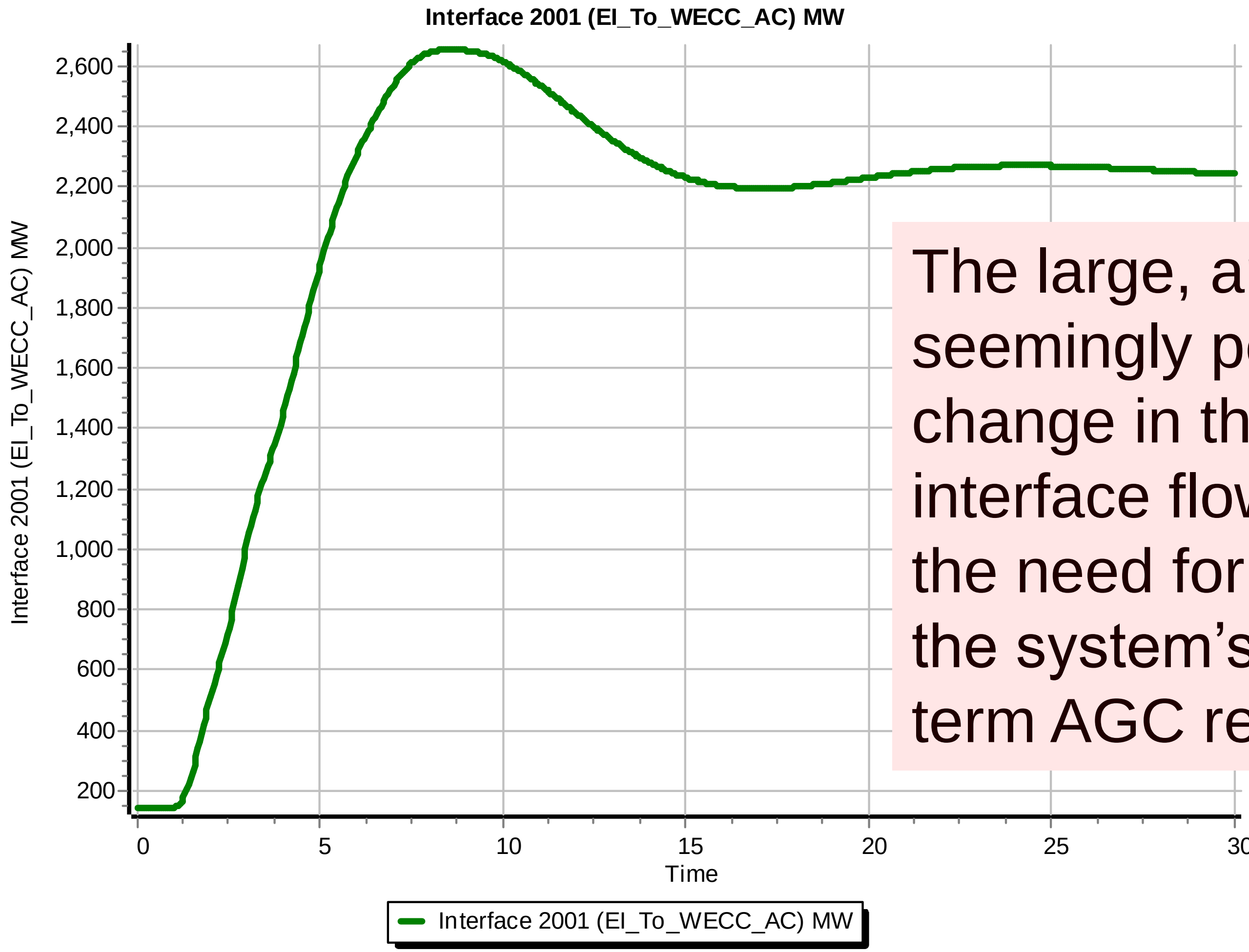
- Over the course of the project we did a large number of simulations, ranging for short (10 second) fault studies to longer (six minute) automatic generation control (AGC) response scenarios
- Even for severe events (> 5 GW losses in the East) the interconnected grid maintained synchronism
- However, a key issue is for the loss of generation in the West about 80% of the makeup power flows across the interface from East to West
  - The converse is true for generation loss in the East, about 20% of the makeup power flows across the interface from West to East

# WECC Frequency Response Comparison: With and Without the AC Interconnection




The graph compares the frequency response for three WECC buses for a severe contingency with the interface (thick lines) and without (thin lines)

# AC-Tie Interface, Severe Contingency




The large, and seemingly persistent, change in the interface flow required the need for modeling the system's longer term AGC response.

# Adding AGC Modeling

- As noted following any disturbance about 80% of the governor response will occur in the East, with the change in flow going across the new ac interface if the disturbance is in the West.
- The governors don't restore the system frequency to its setpoint value; rather this is done by the automatic generation control (AGC) utilizing the balancing authority area control error (ACE) signal
- The ACE has a frequency component

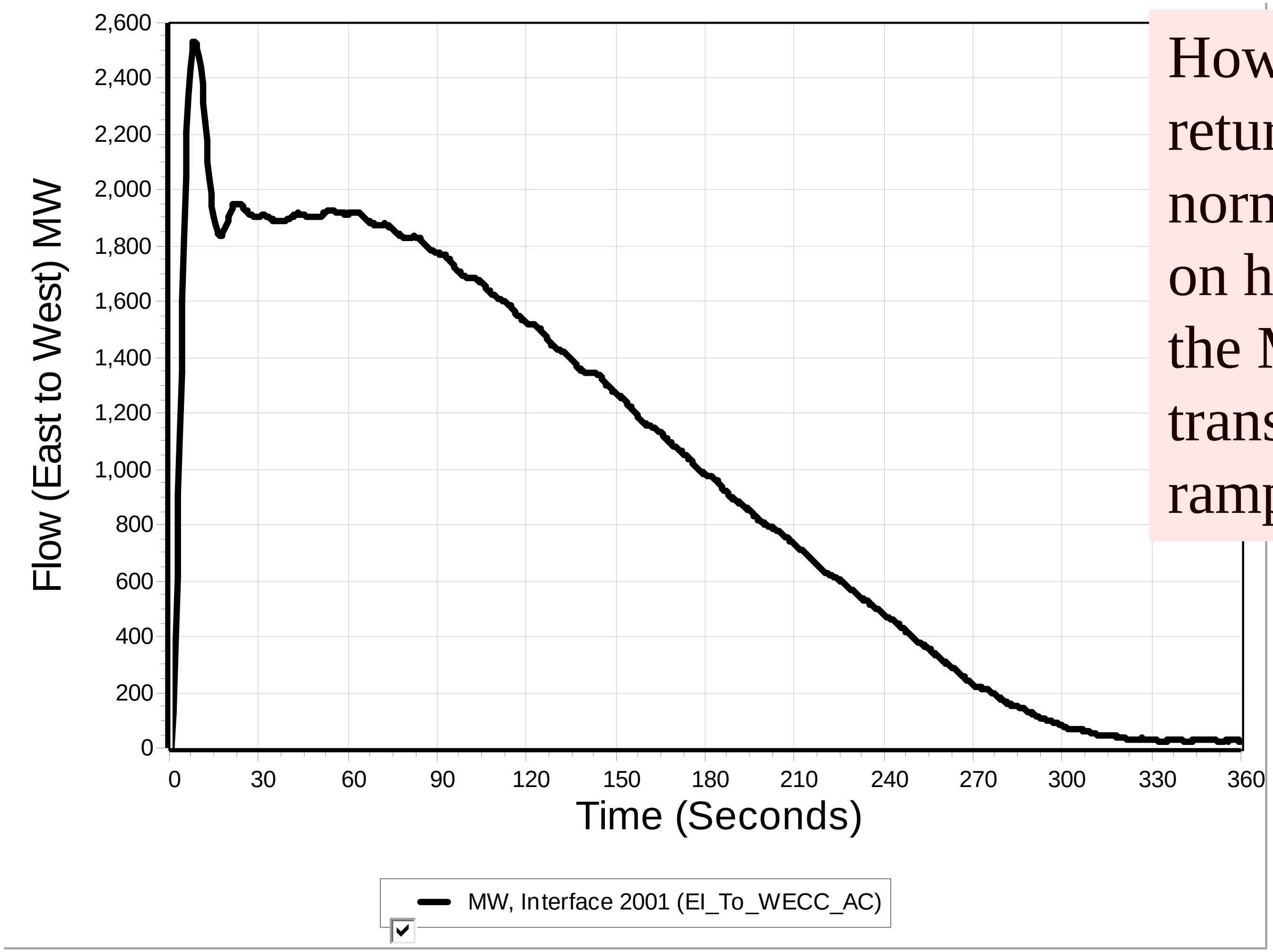
  $ACE = P_{actual} - P_{sched} - 10\beta(freq_{act} - freq_{sched})$

  $\beta$ is the frequency bias; it has a negative sign, units of MW/0.1 Hz and is about 1% of the peak load/generation

# Example AGC Response

- Six minute simulation with severe generator loss, with emergency transactions implemented between several of the utilities
- These transactions were initiated and ramped faster than normal to keep the simulation length reasonable (starting at 30 seconds and ramping over four minutes)
- Initially much of the makeup generation flowed through the interface, but it ramped down to zero

# New Interface Flow



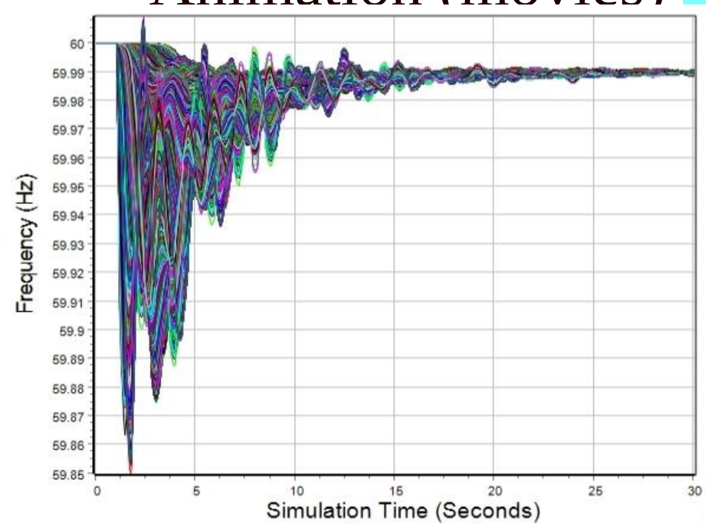

How fast it returns to normal depends on how fast the MW transactions ramp

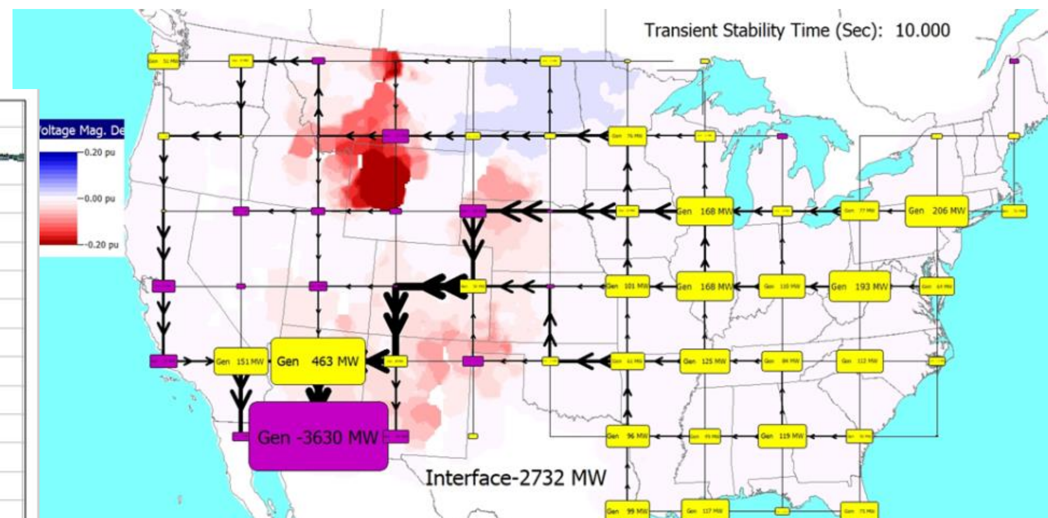
# Situational Awareness

- A key challenge with this project was understanding the results of these dynamic studies
  - Even a 30 second study produced many GBs of results
- Situational awareness (SA) is defined informally as “knowing what’s going on” and more formally as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”
- In this study we wanted to have good SA to make sure we didn’t miss something

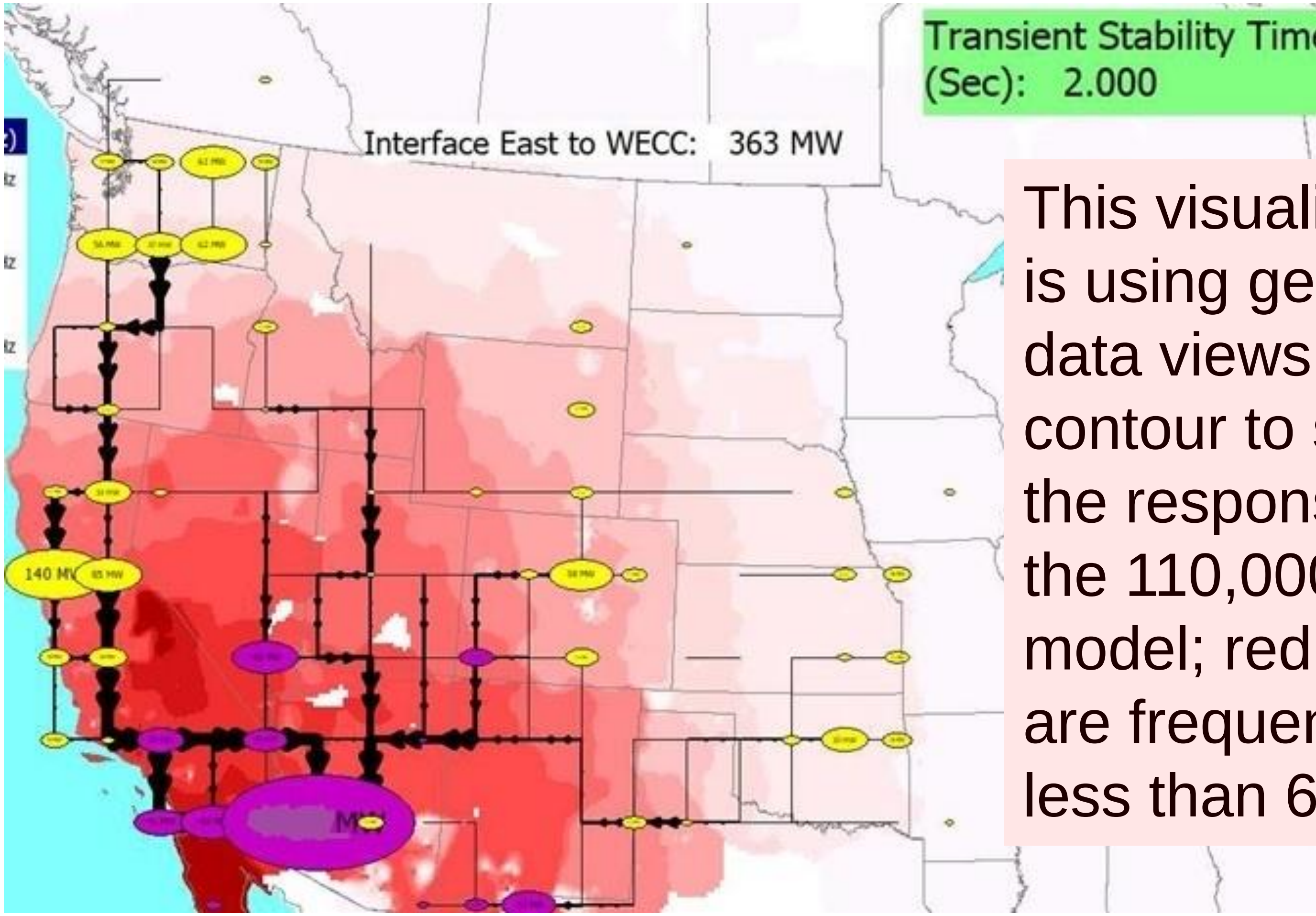
# SA Techniques

- For this project we leveraged a number of different techniques including
  - Time-domain graphs
  - Geographic data views including planar flow visualizations
  - Contours
  - Animation (movies)



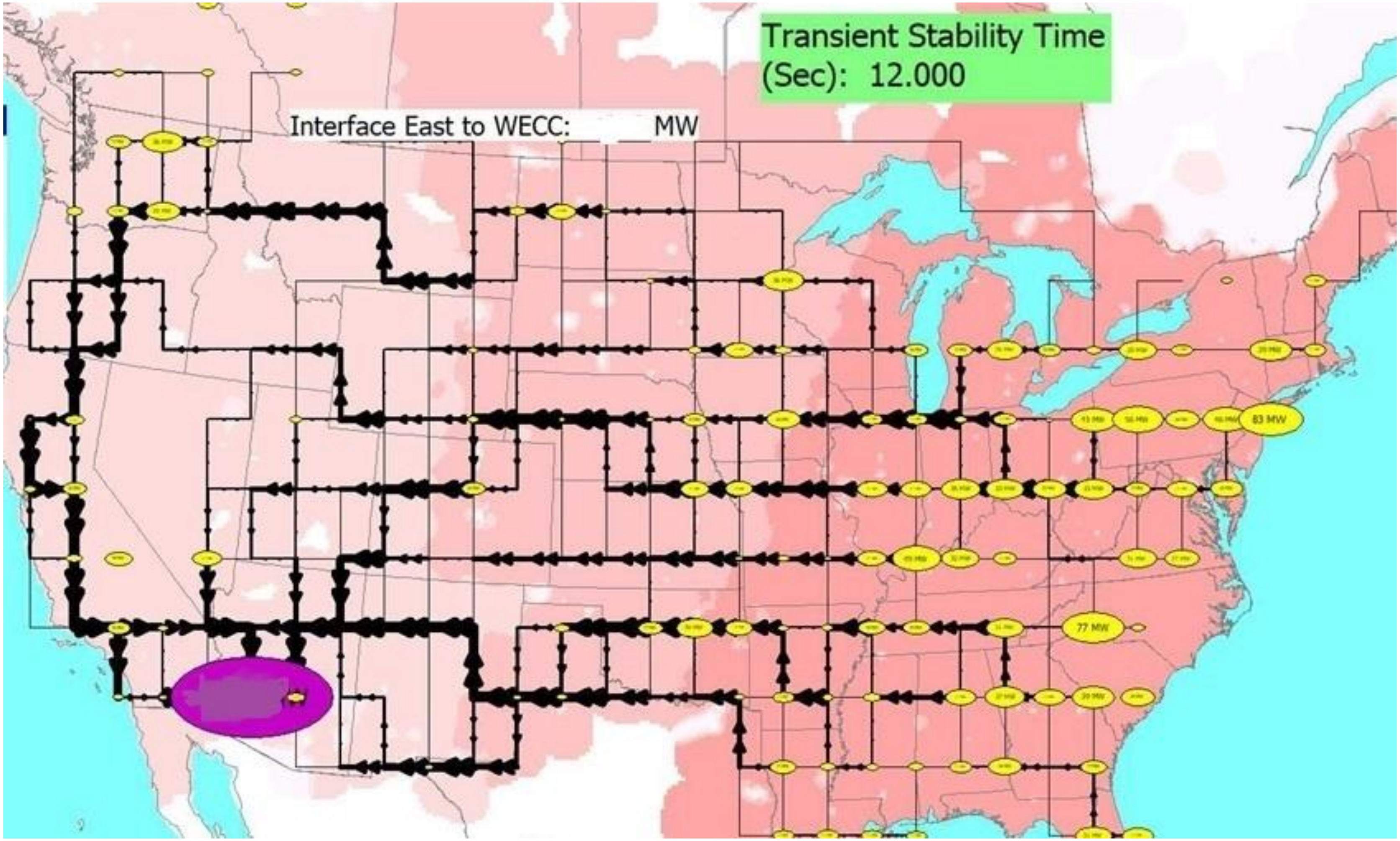
# Results Example at 2.0 Seconds



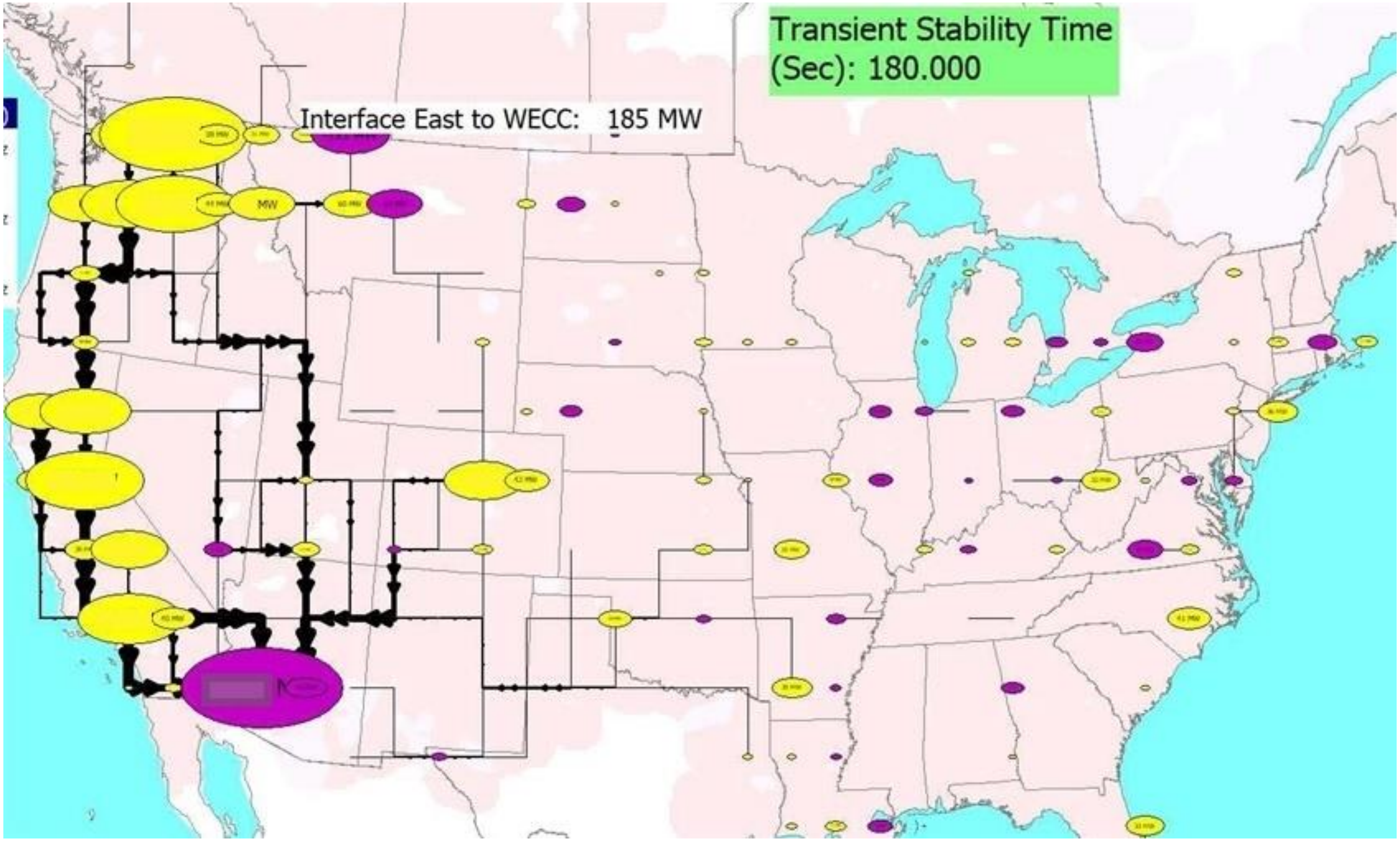

This visualization is using geographic data views and a contour to show the response of the 110,000 bus model; red values are frequencies less than 60 Hz

These visualization techniques are presented in the paper by T.J. Overbye, J.L. Wert, K.S. Shetye, F. Safdarian, A.B. Birchfield, "The Use of Geographic Data Views to Help With Wide-Area Electric Grid Situational Awareness," 2021 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, USA, Feb. 2021; available at overbye.engr.tamu.edu/publications/

# Results Example at 12.0 Seconds



# Results Example With AGC Response



# Synthetic Electric Grids Models

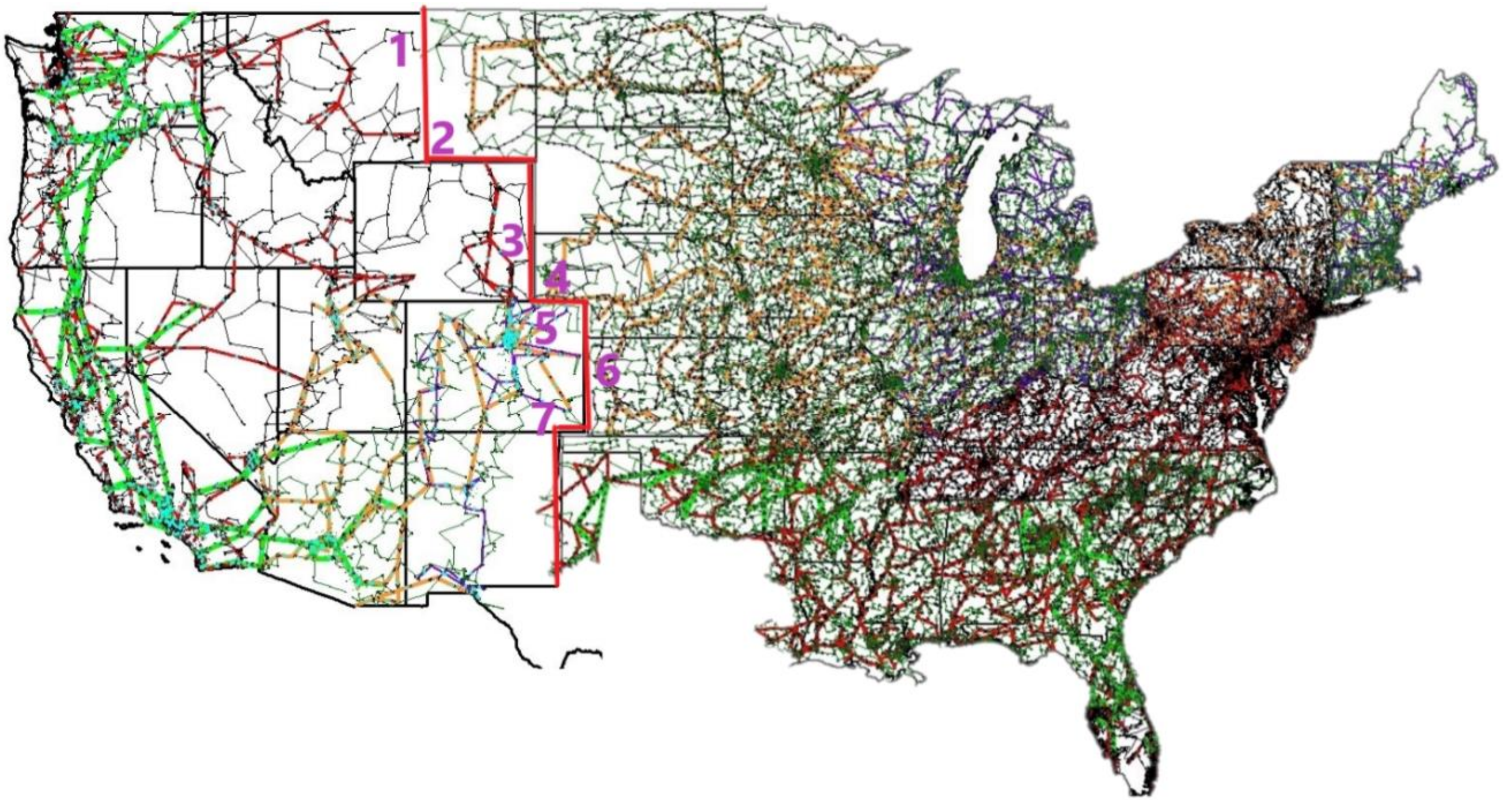
- The project had a synthetic grid component in order to provide access to detailed results while not disclosing any CEII.
- Synthetic electric grids and associated datasets are fictional electric grids that are designed to be statistically similar to actual systems
  - "Realistic but not real"
- Synthetic grids are particularly helpful for visualization research
- Kudos to the US DOE ARPA-E for funding work over the last five years in this area

# 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!)

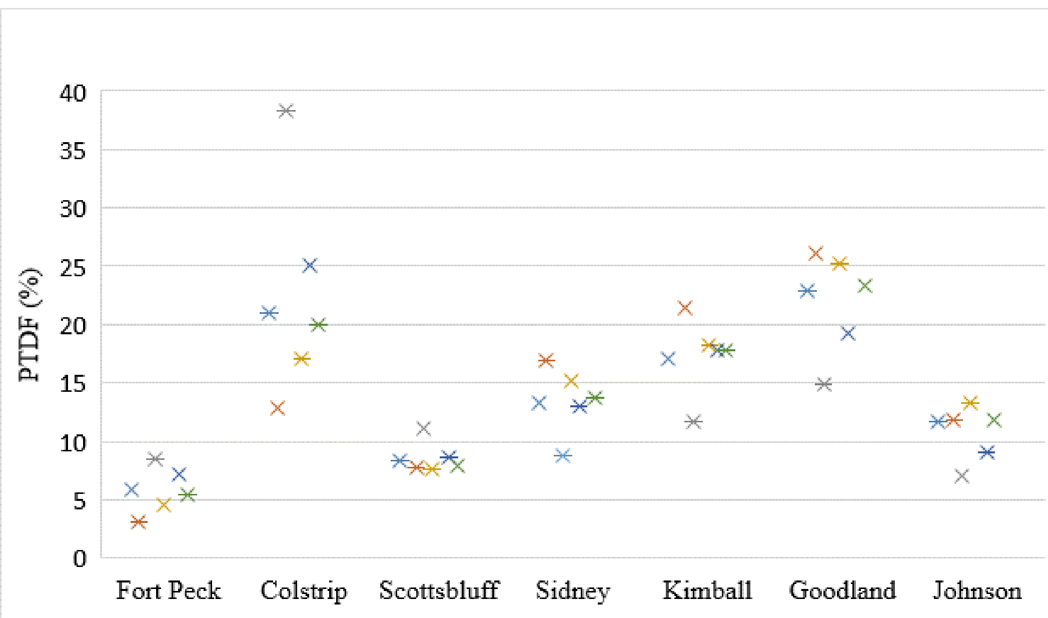
# Synthetic Grid Component

- We're using an 80,000 bus model that can be freely shared that has a synthetic East grid joined to a synthetic West grid at seven points



# Synthetic Grid Interconnection Points and PTDF Analysis

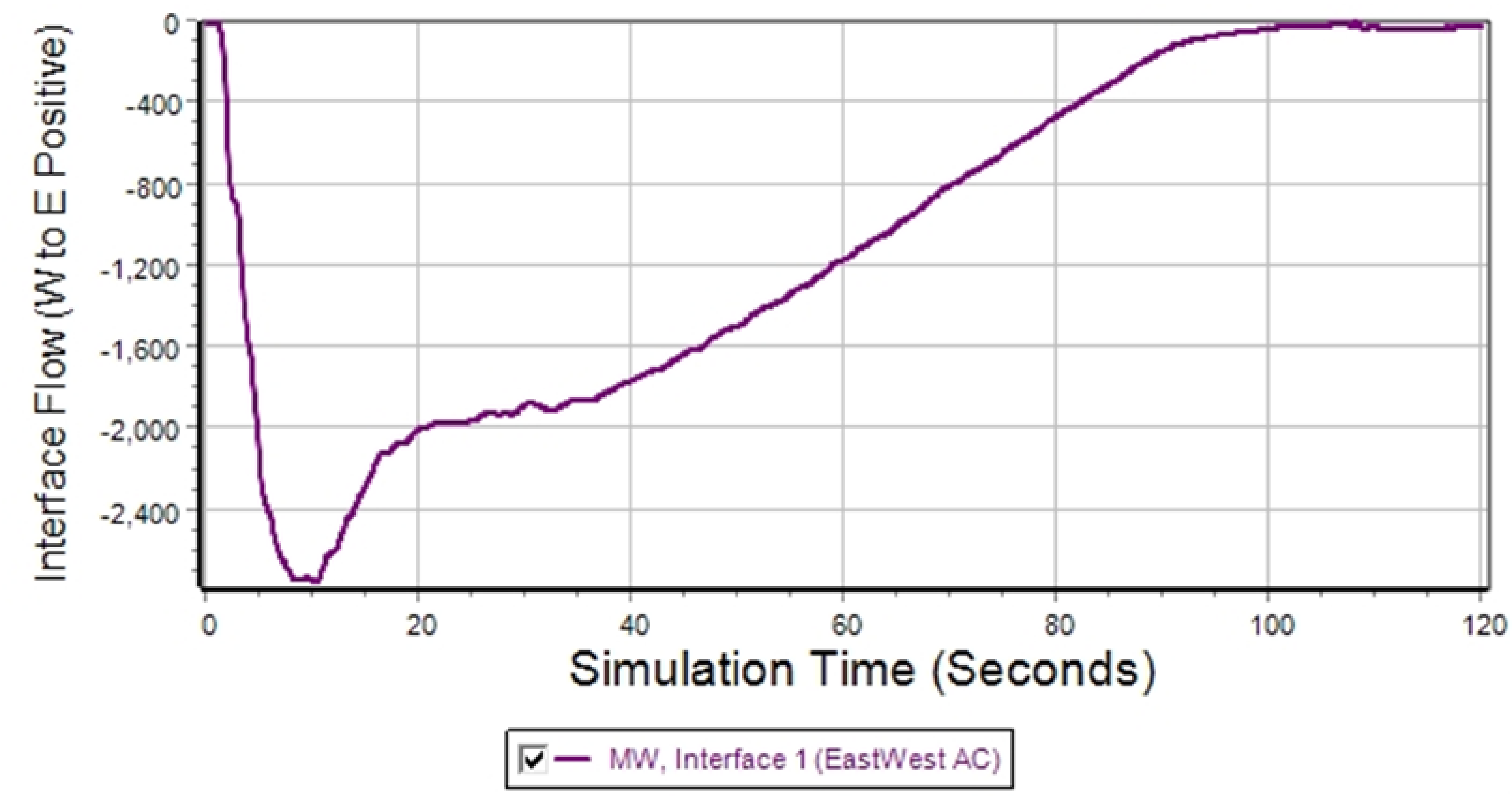
| No. | From Bus (kV) | To Bus (kV) | X (p.u.) | Lim (MVA) |
|---|---|---|---|---|
| 1 | Glasgow (138) | Fort Peck (500) | 0.055 | 600 |
| 2 | Hardin (345) | Colstrip (500) | 0.06 | 1200 |
| 3 | Wheatland (345) | Scottsbluff (500) | 0.07 | 1400 |
| 4 | Peetz (500) | Sidney (500) | 0.03 | 2000 |
| 5 | New Raymer (500) | Kimball (500) | 0.02 | 2000 |
| 6 | Burlington (500) | Goodland (500) | 0.03 | 2000 |
| 7 | Lamar (500) | Johnson (161) | 0.04 | 800 |




The power transfer distribution factors (PTDFs) tell how different transactions impact the interface flows

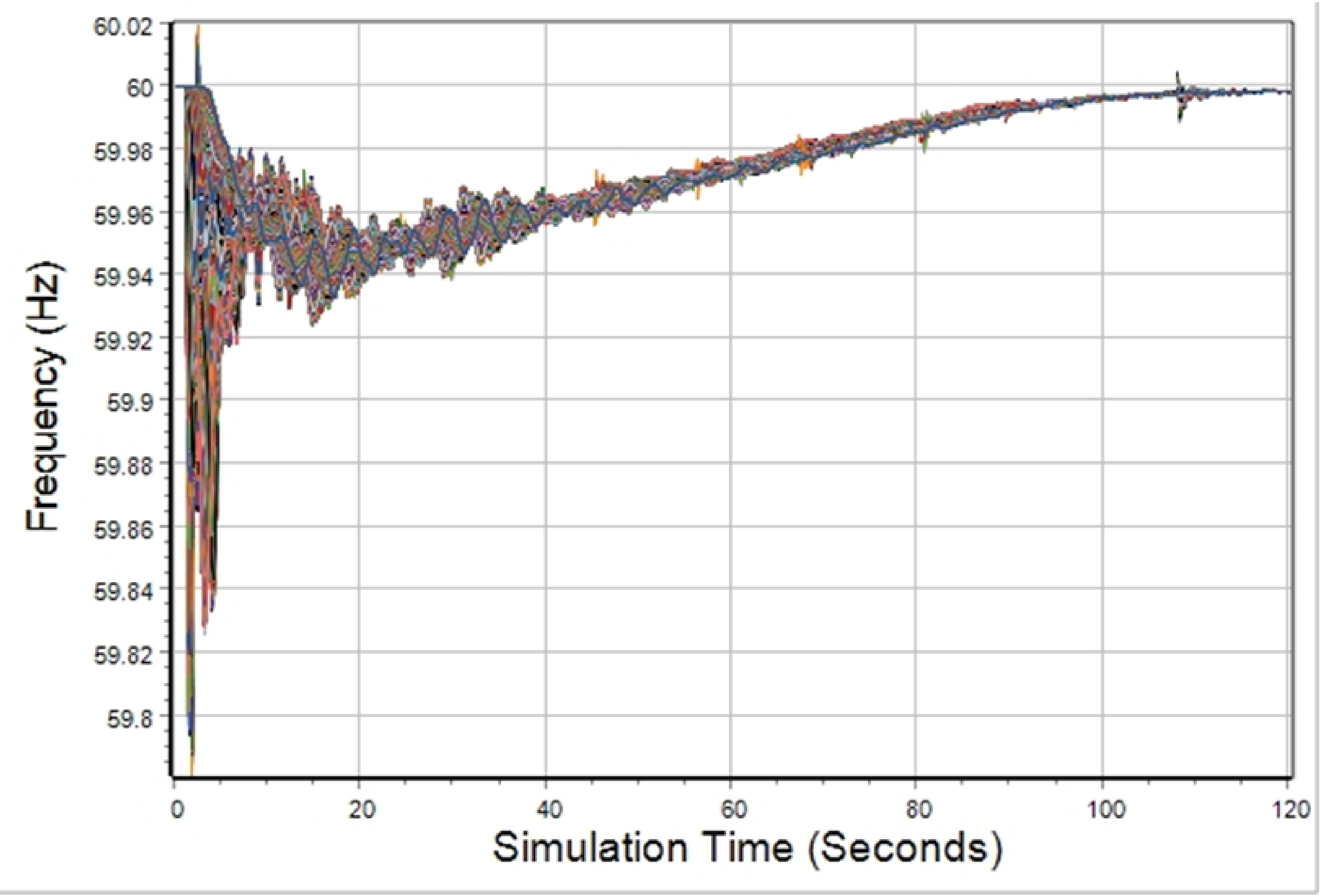
The maximum transfer capacity is about 5000 MW West to East and 3500 East to West

# Synthetic Grid Interface Response for a Generator Loss Contingency in the West

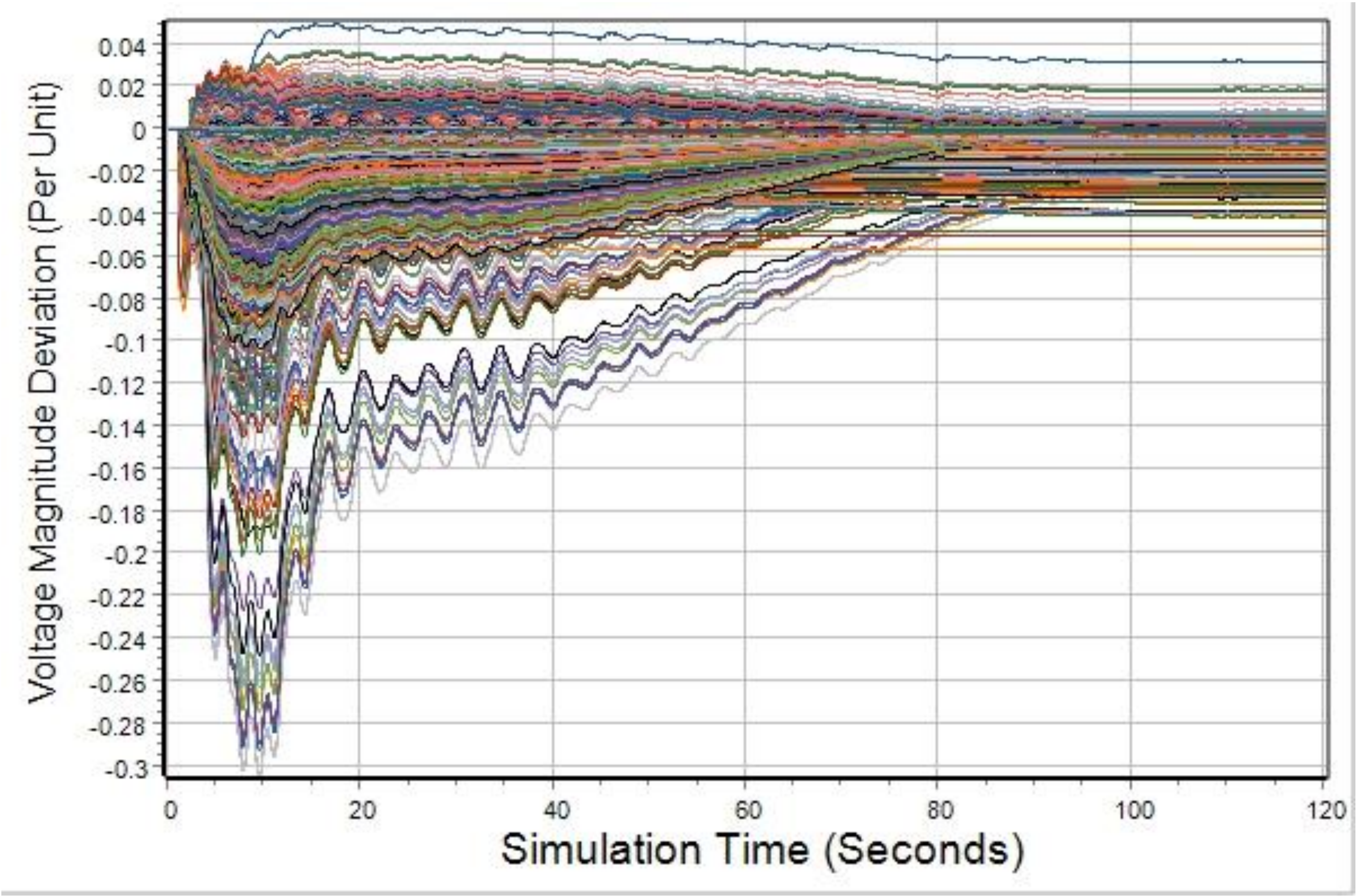



The sign convention on the interface is positive flow is from West to East; within seconds large amounts of power flow in!

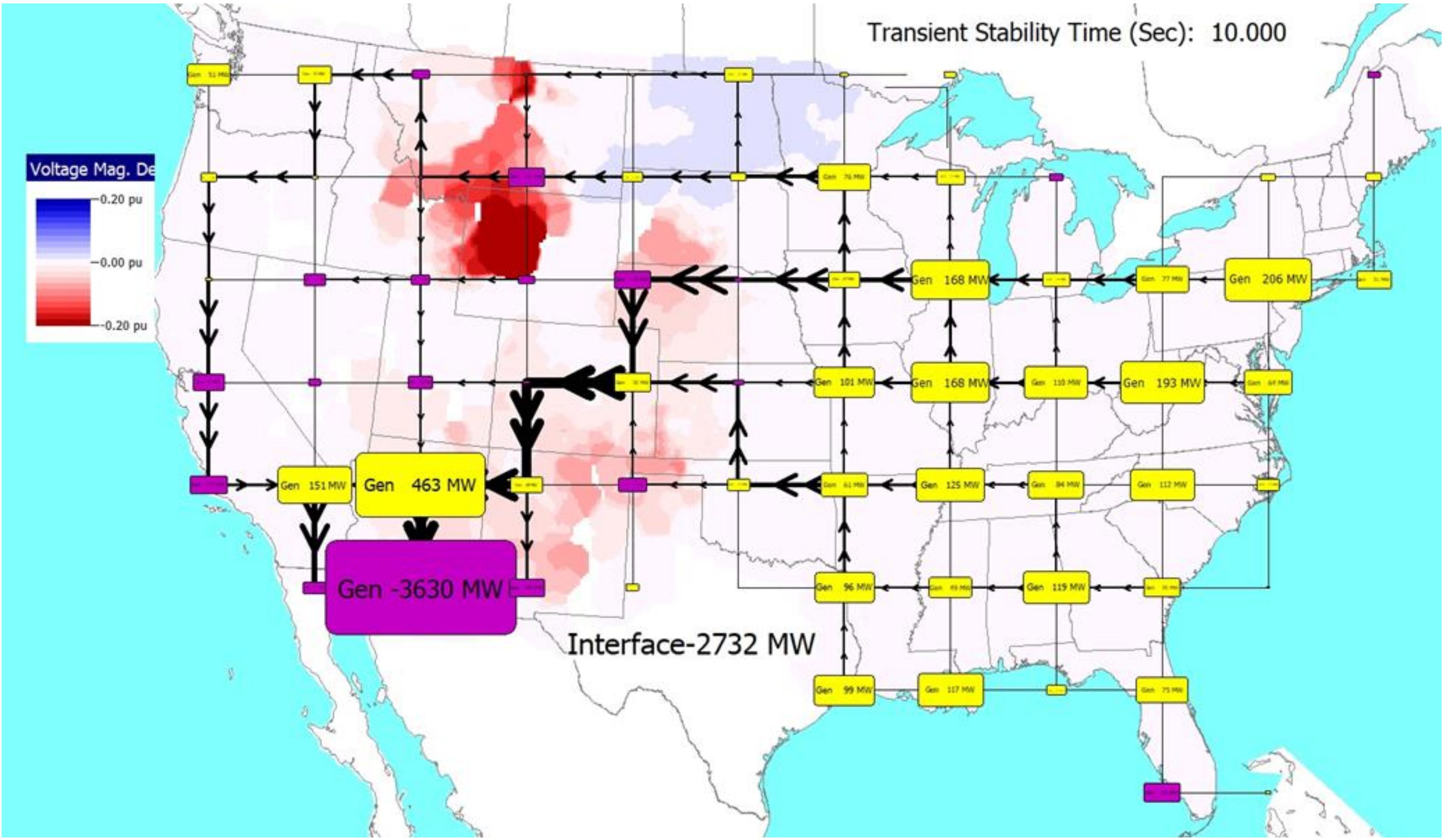
# Synthetic Grid Frequency Response, All Locations



# Synthetic Grid Voltage Deviation, All Locations



# Synthetic Grid Voltage Contour



# Summary

- The electric grid is rapidly changing and there are lots of engineering opportunities!!
- From a technical perspective we believe the North American Eastern and Western grids could be connected with a modest number of ac interties that would allow for stable operation under even quite severe contingencies
- A key constraint is that following a generation (or load) disturbance in the West, most of the makeup power would flow through the interface, potentially causing voltage or thermal issues
- Visualization of results for large systems is crucial