The Texas Blackout of February 2021

Thomas Overbye
O'Donnell Foundation Chair III
Electrical and Computer Engineering
overbye@tamu.edu

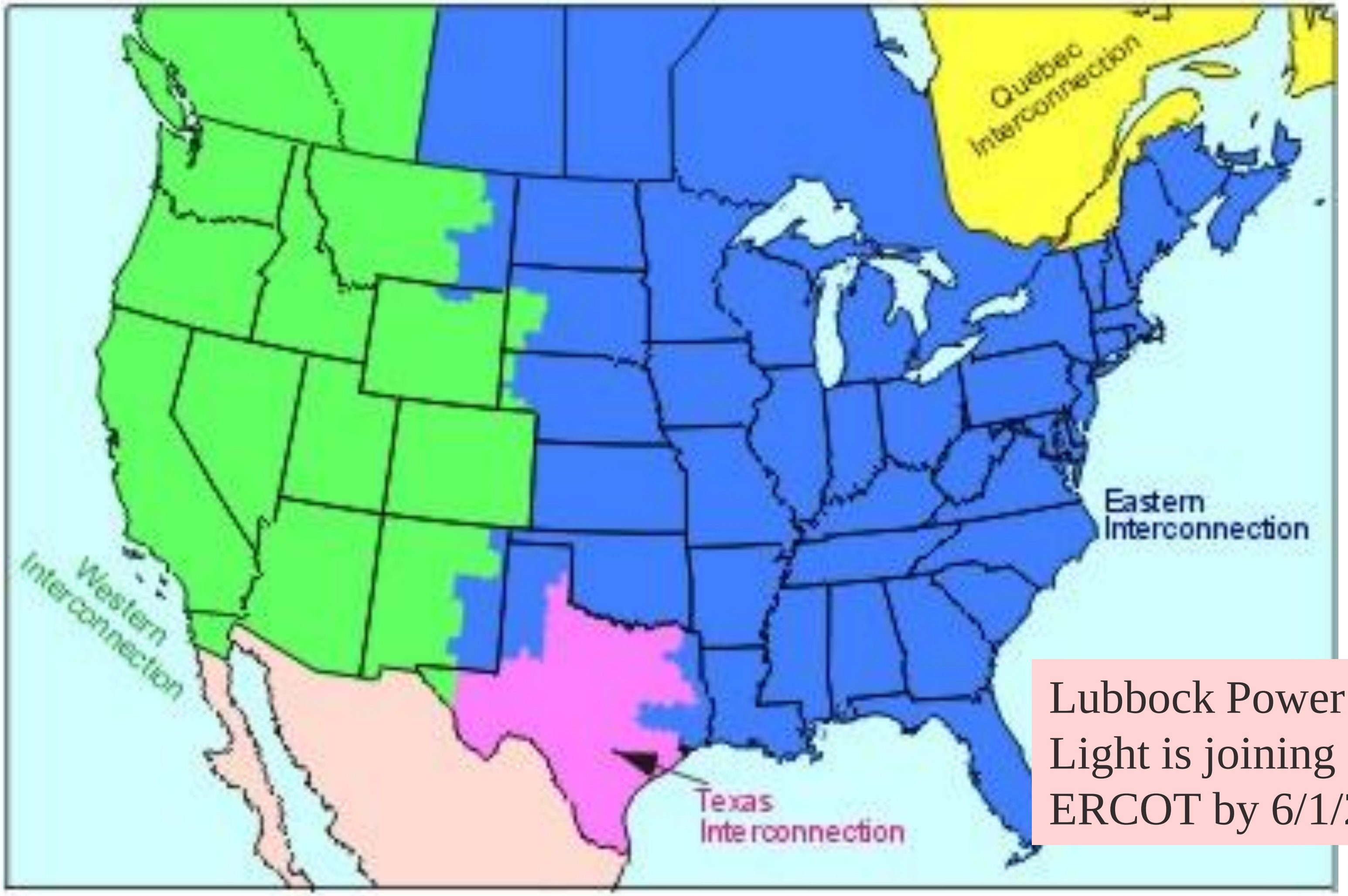
IEEE PES Chicago Chapter
May 26, 2021

TEXAS A&M UNIVERSITY

Our Energy Future Could be Quite Bright!

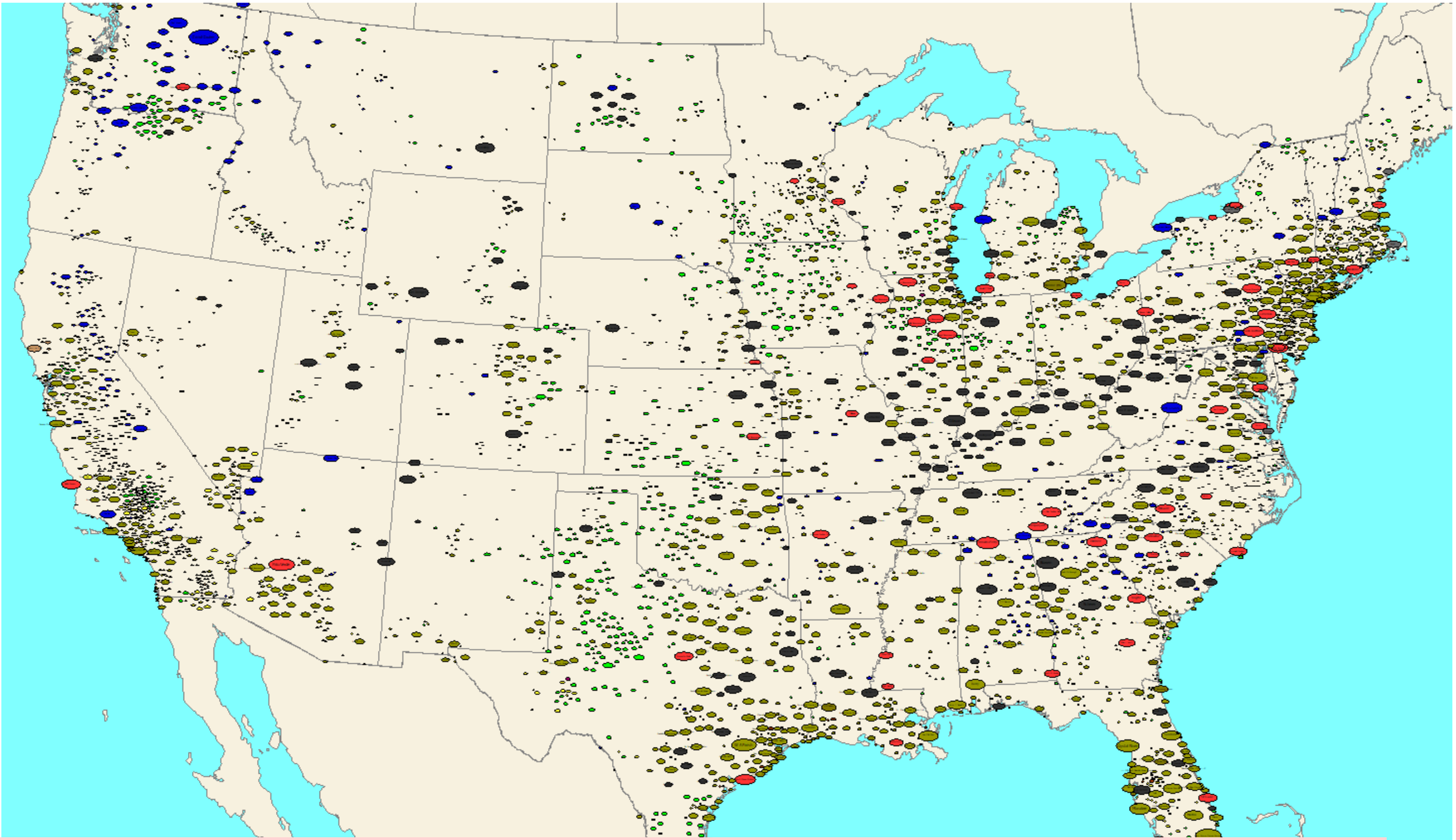
- My professional goal is to help in the development of a sustainable and resilient electric infrastructure for the entire world.
- Electric grids are in a time of rapid transition, with lots of positive developments.
- I think our electric energy future could be quite bright! But there are lots of challenges with this transition, including maintaining human situational awareness, particularly during times of stress.
- This presentation covers the Texas 2021 blackout and related resiliency issues

North America Grid Interconnections



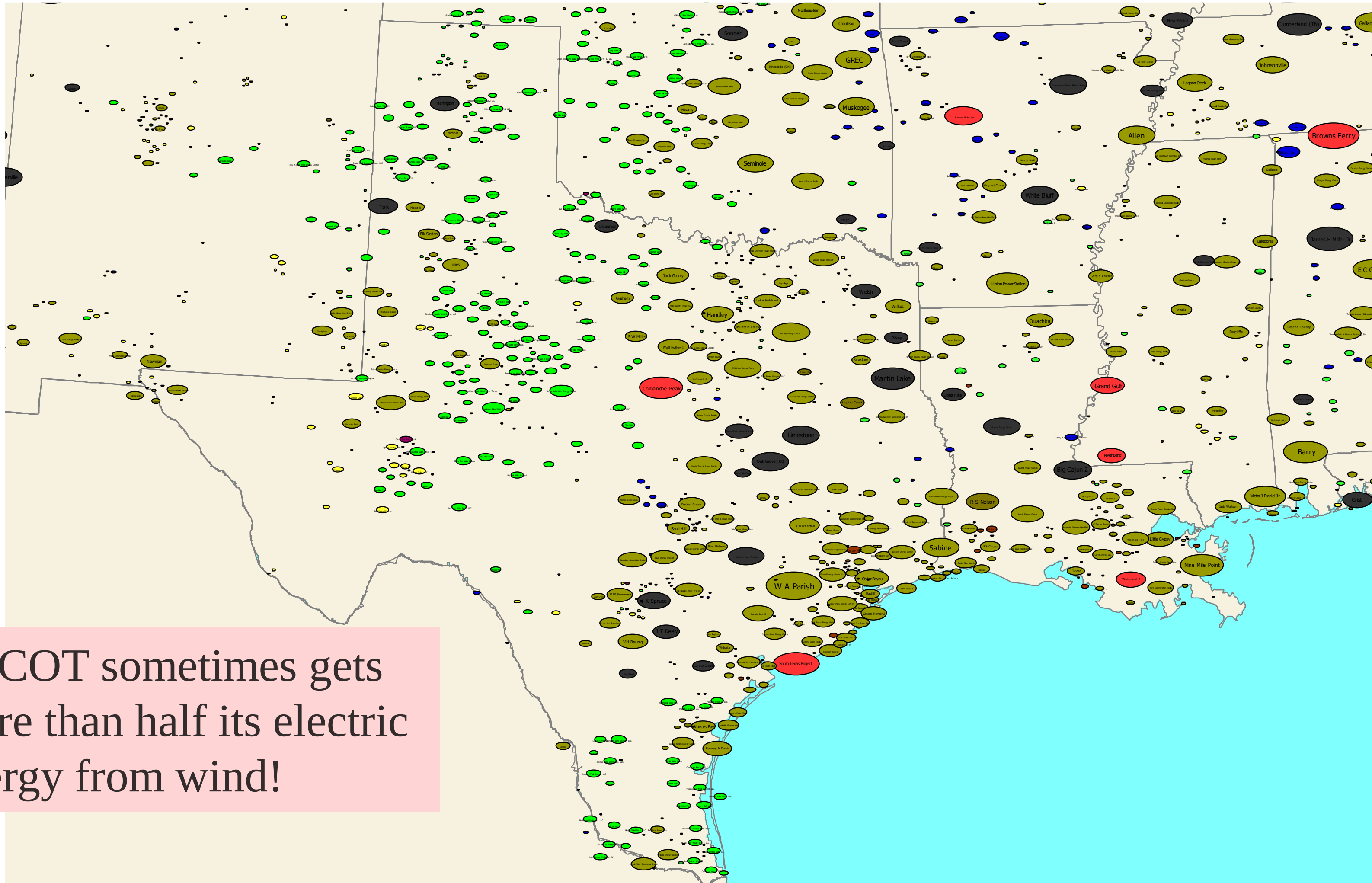
Lubbock Power and Light is joining ERCOT by 6/1/21

US Generation by Fuel Type



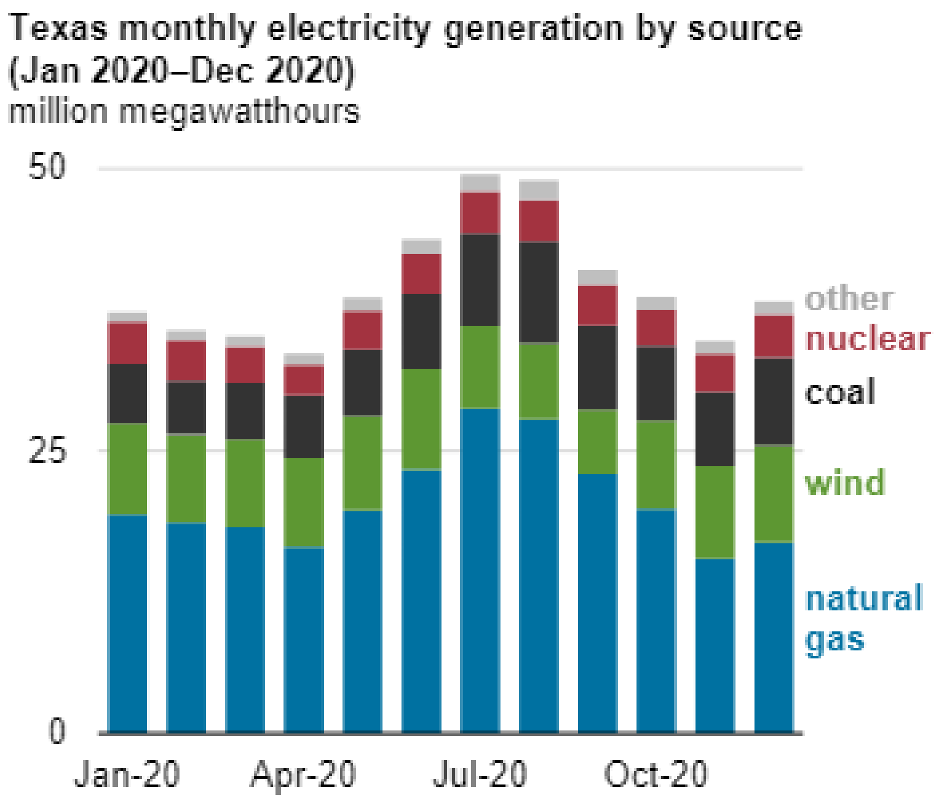
Oval size is proportional to the substation generation capacity, and color indicates primary fuel type (red nuclear, black coal, brown natural gas, blue hydro, green wind, yellow solar). Image shows public data from EIA Form 860; image created using PowerWorld Simulator.

2019 US Generation by Capacity and Fuel Type (Zoomed on Texas



ERCOT sometimes gets more than half its electric energy from wind!

Texas Generation Sources and Home Heating Sources



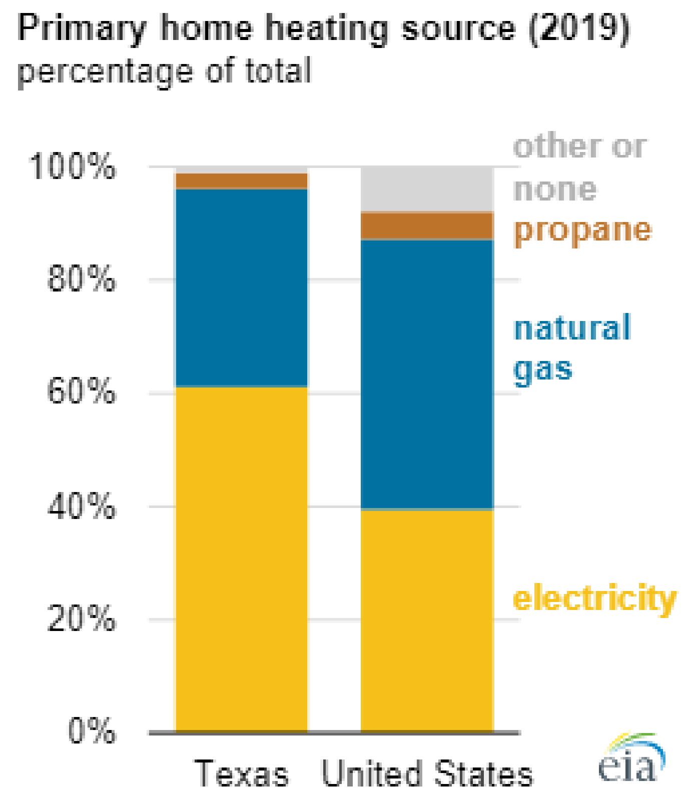
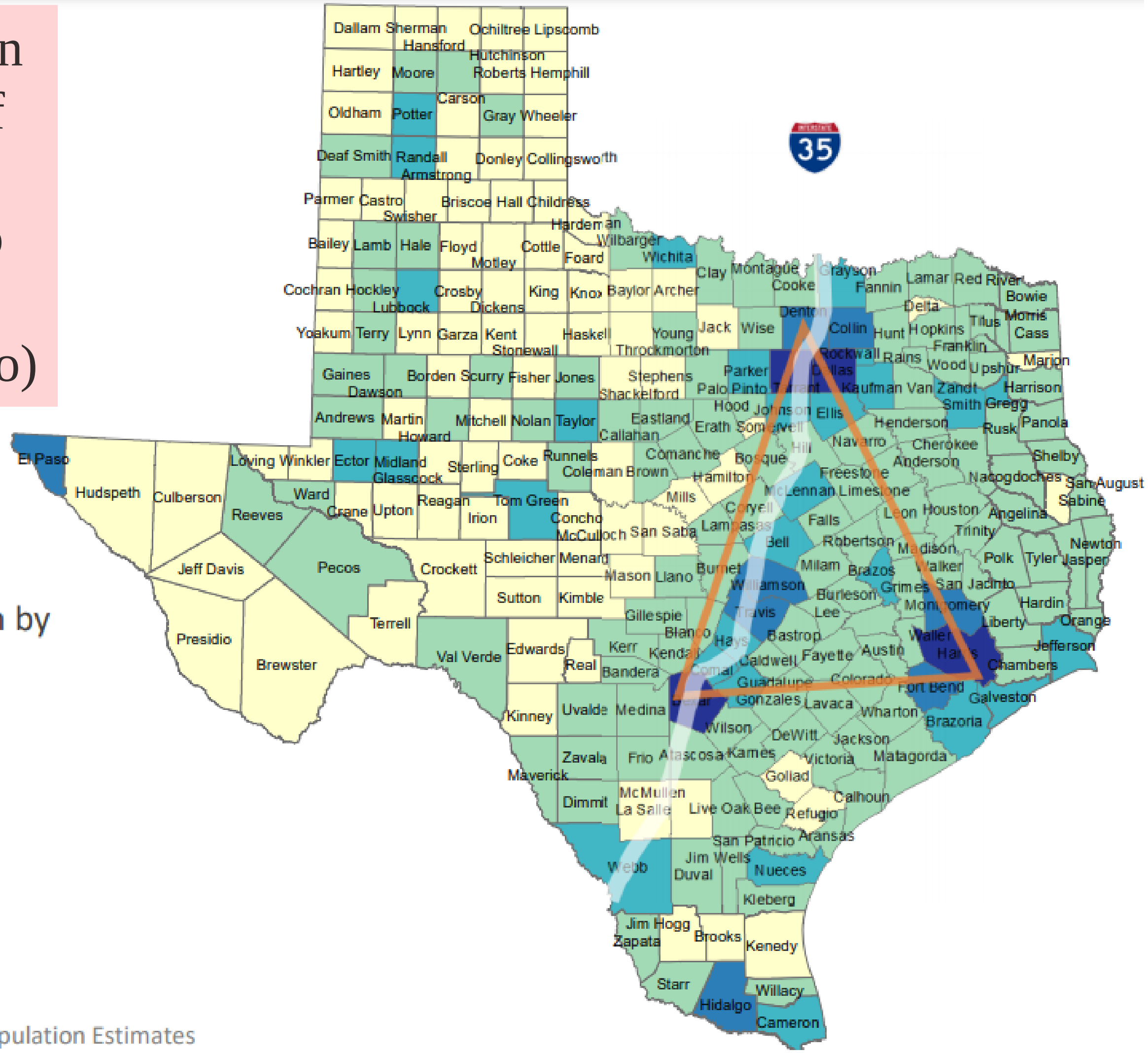


Image Source: www.eia.gov/todayinenergy/detail.php?id=47116

Texas population is growing, increasing 16% from 25.1 million in 2010 to 29.2 million on 2020

Texas Population Density

85% of population is along or east of the I35 corridor (DFW to Waco to Austin to San Antonio to Laredo)



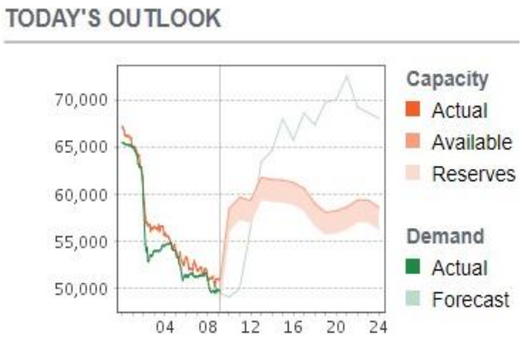
Total Estimated Population by County, 2019

- 169 - 10,000
- 10,001 - 100,000
- 100,001 - 500,000
- 5000,001 - 2,000,000
- 2,000,001 - 4,713,325

Source: U.S. Census Bureau, 2019 Population Estimates

Texas Near Total Blackout, February 14-18, 2021

- Unfortunately electric grids often make the news for all the wrong reasons!



- Starting on Feb 14, 2021 statewide Texas had temperatures much below avg., though not record cold
  - In College Station on Feb 15 is low was 9°F and very windy (and 5°F on Feb 16); avg. high is 65°F and low of 45°F
  - Our record low is -3°F (1/31/1949), our coldest February temperature was 5°F (2/5/1951) and last single digit was 9°F (12/22/1989)

- This stressed many infrastructures including the ERCOT electric grid

ERCOT Generation Feb 11-18, 2021

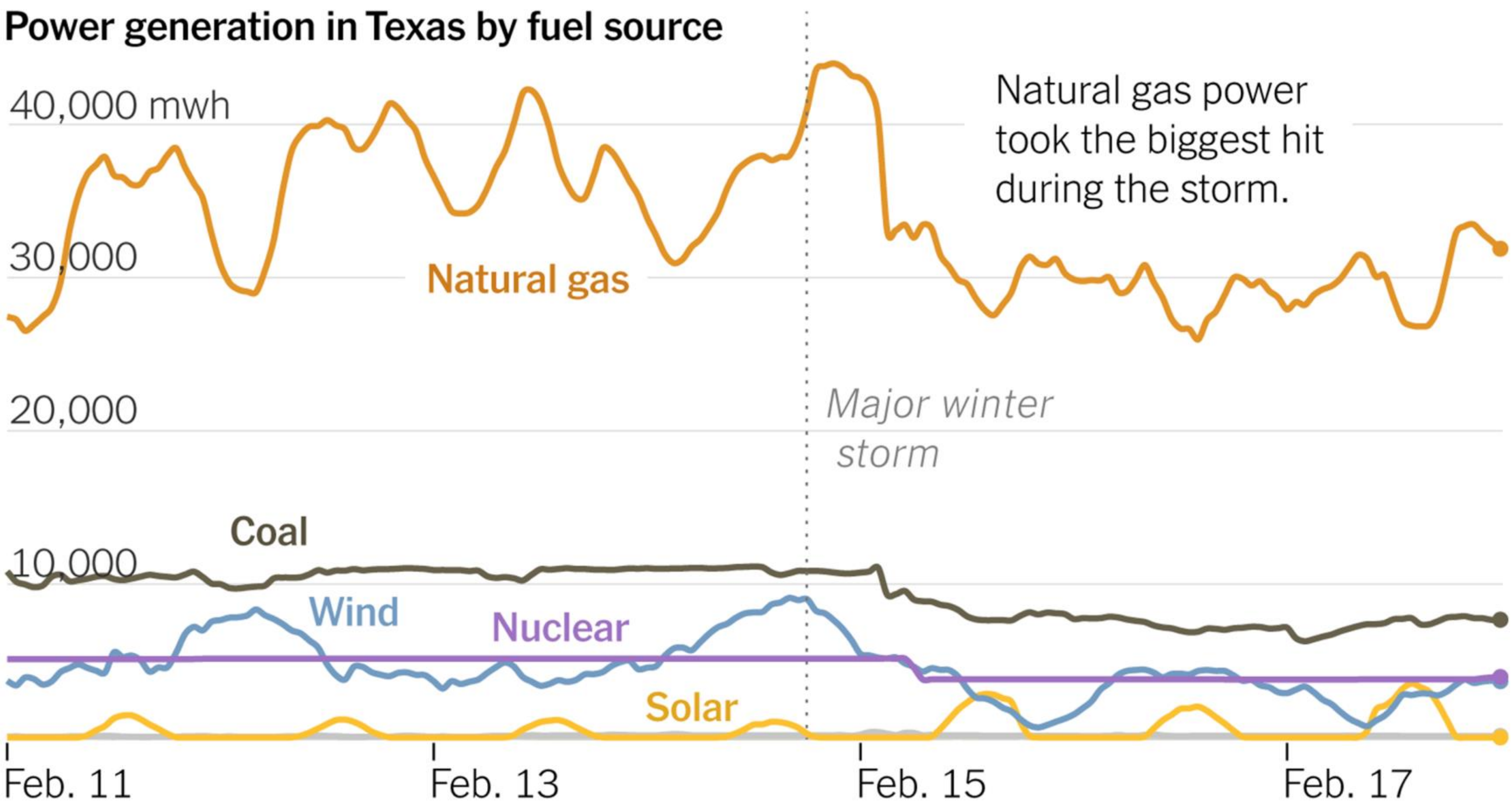
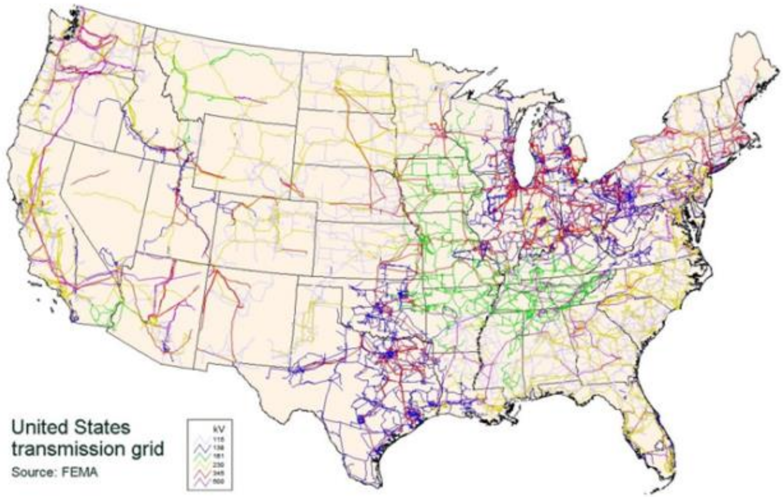


Image source: New York Times, Feb 23, 2021

Important Electric Grid Considerations

- Electricity cannot be economically stored
  - Generation must be continually adjusted to match changes in electric load and losses
- Electric power flows on high voltage transmission lines cannot usually be directly controlled
  - Control is mostly indirect, by changing generation



- Customers have been in control of their load
- Transmission system has finite limits; often operated close to its limit for economic reasons

Electric Grid Time Frames

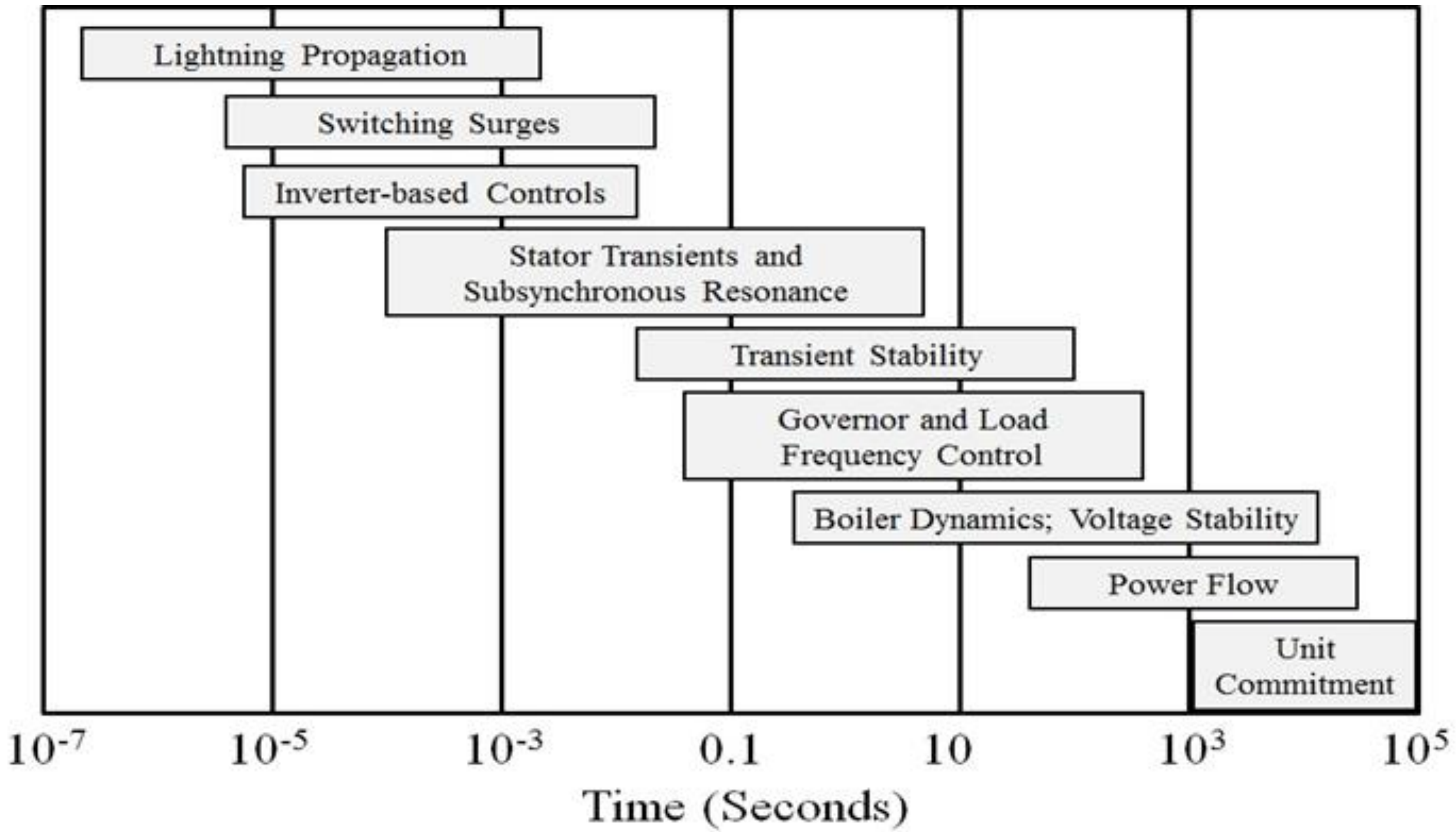
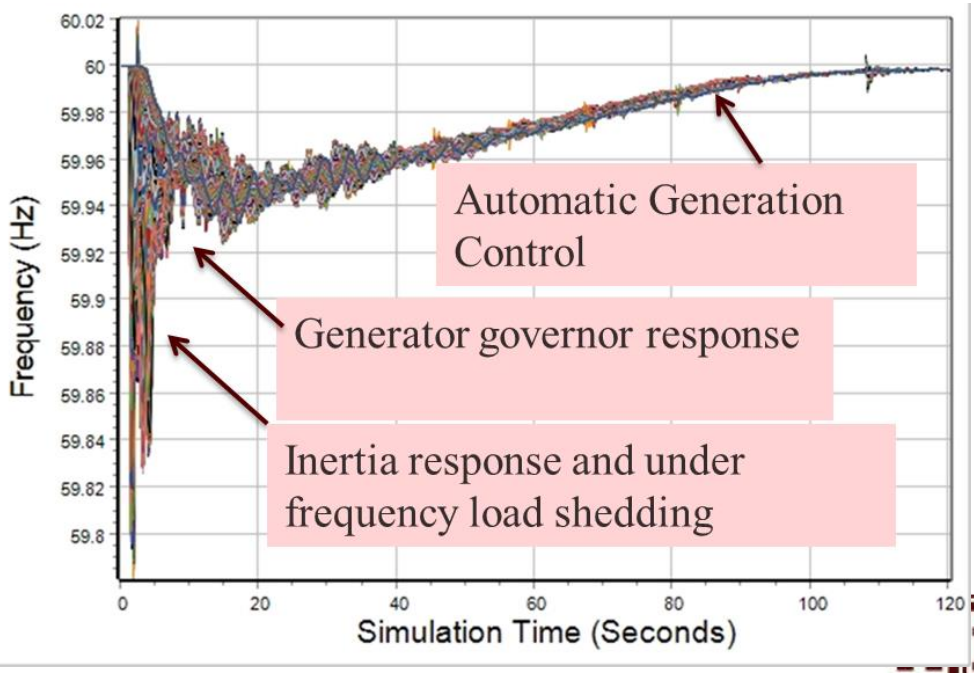


Image: Sauer, P.W., M. A. Pai, *Power System Dynamics and Stability*, Stripes Publishing, 2007

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 too little decreases it
- All grid elements have the same average frequency but during disturbances the frequency can oscillate



ERCOT Frequency, Feb 15, 2021

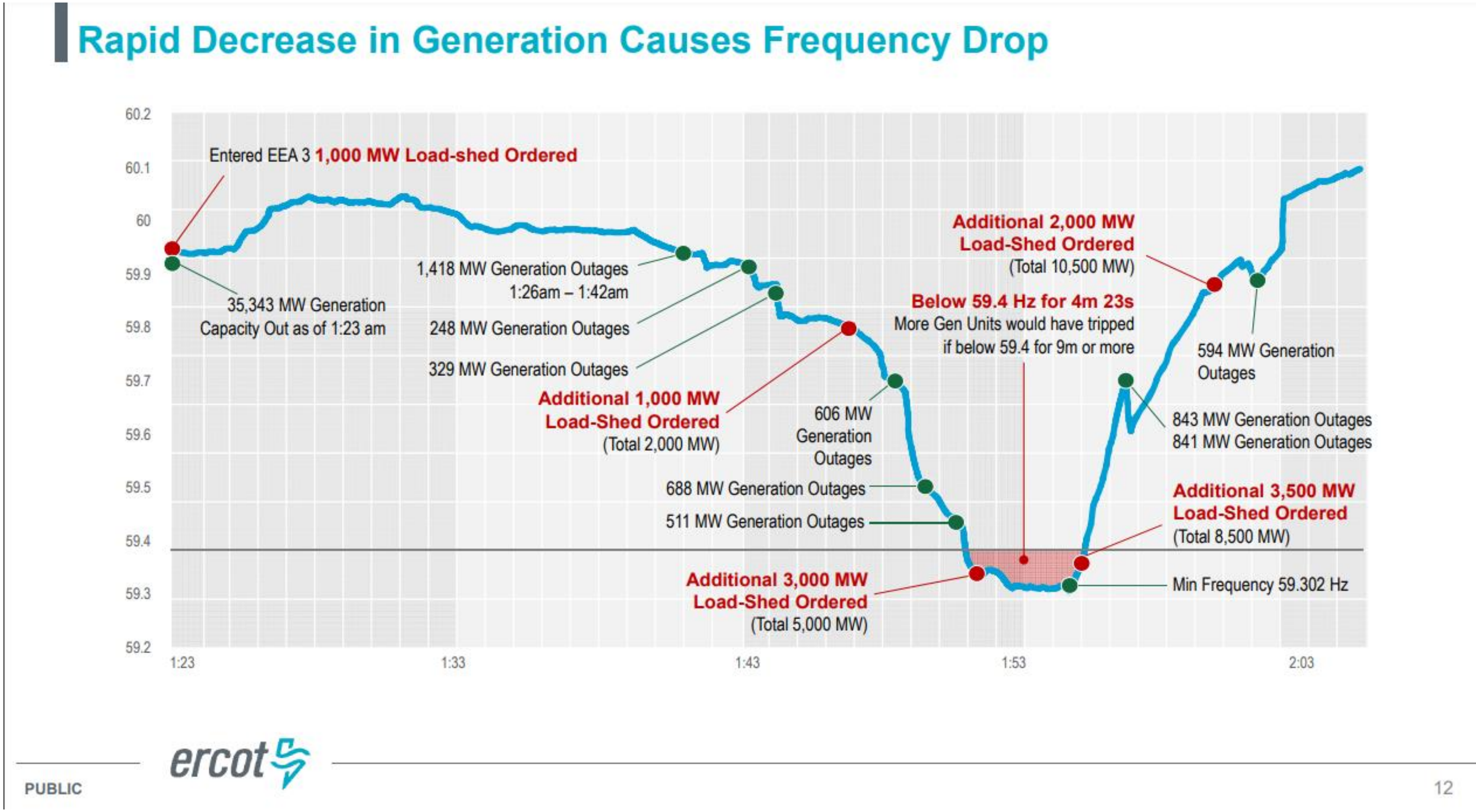


Image source: ERCOT Presentation by Bill Magness, February 25, 2021

ERCOT Load Shed and Rotating Blackouts

- The vast majority of the lost load was due to load shed and then rotating blackouts

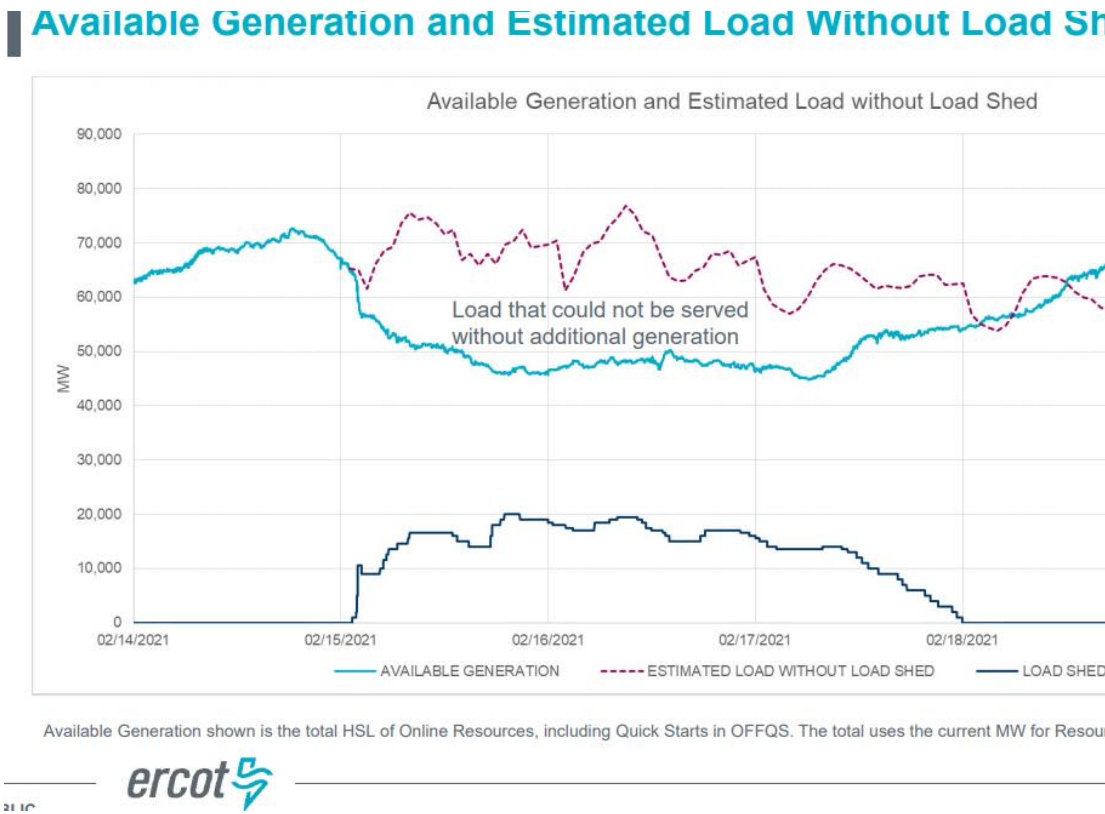
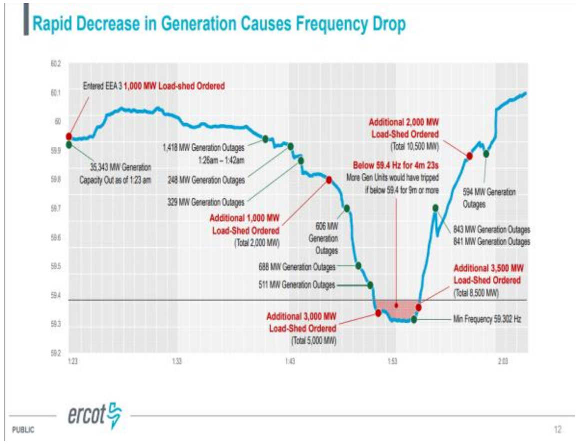


Image source: ERCOT Presentation by Bill Magness, February 25, 2021

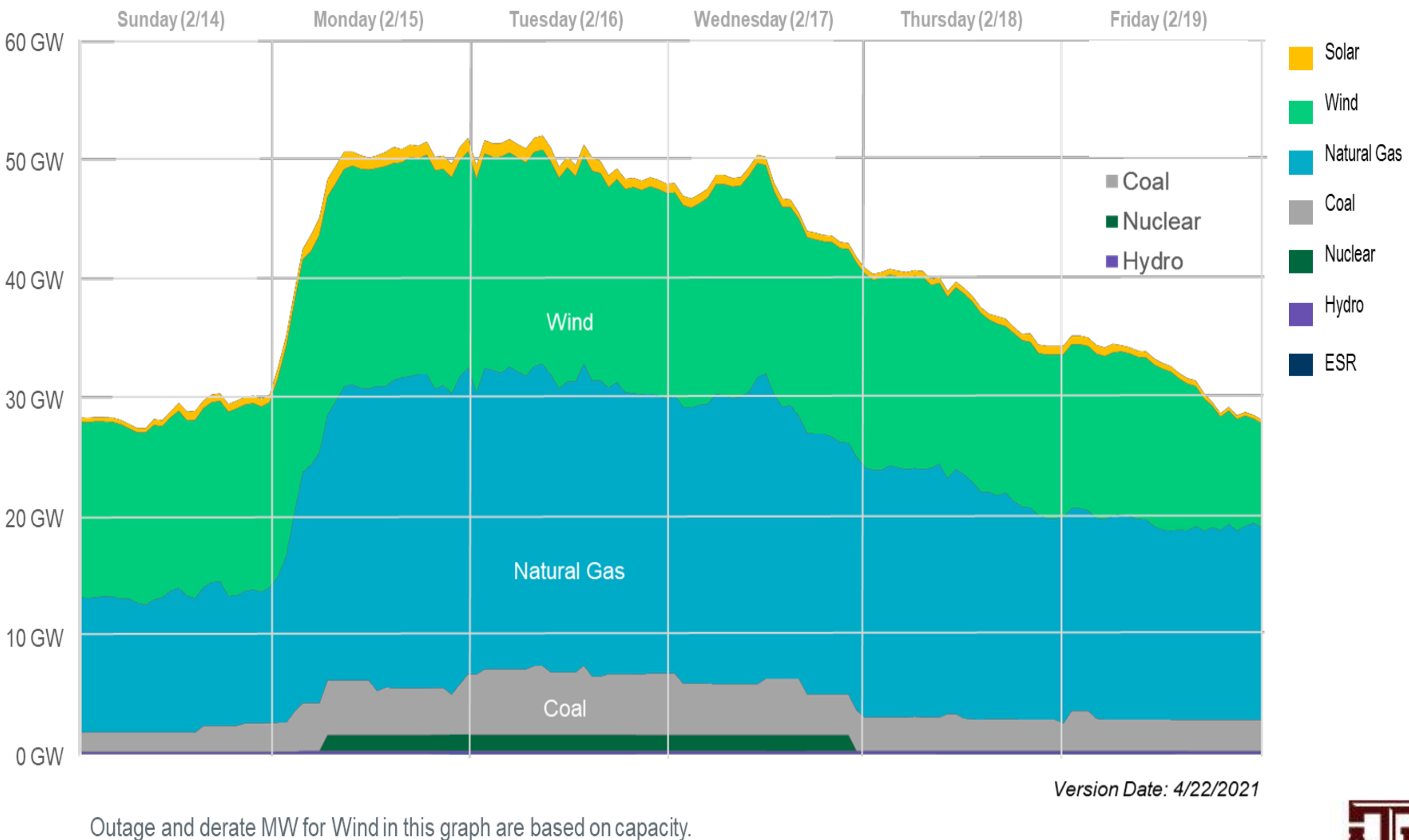
ERCOT peak load is 74.8 GW (summer); winter peak of 69.2 GW was set on 2/14/21 (previous winter peak was 65.9 GW)

How can Grids Cascade?

- ERCOT reported that they were minutes away from a catastrophic blackout that would have taken down the entire grid, requiring many days to restore
- Grids can cascade due to a number of different reasons with many related to the transmission grid flows and voltages
- For ERCOT the situation was the prolonged (minutes) low frequency would have result in generators tripping due to under frequency resulting in a cascading collapse in the frequency and hence the entire system

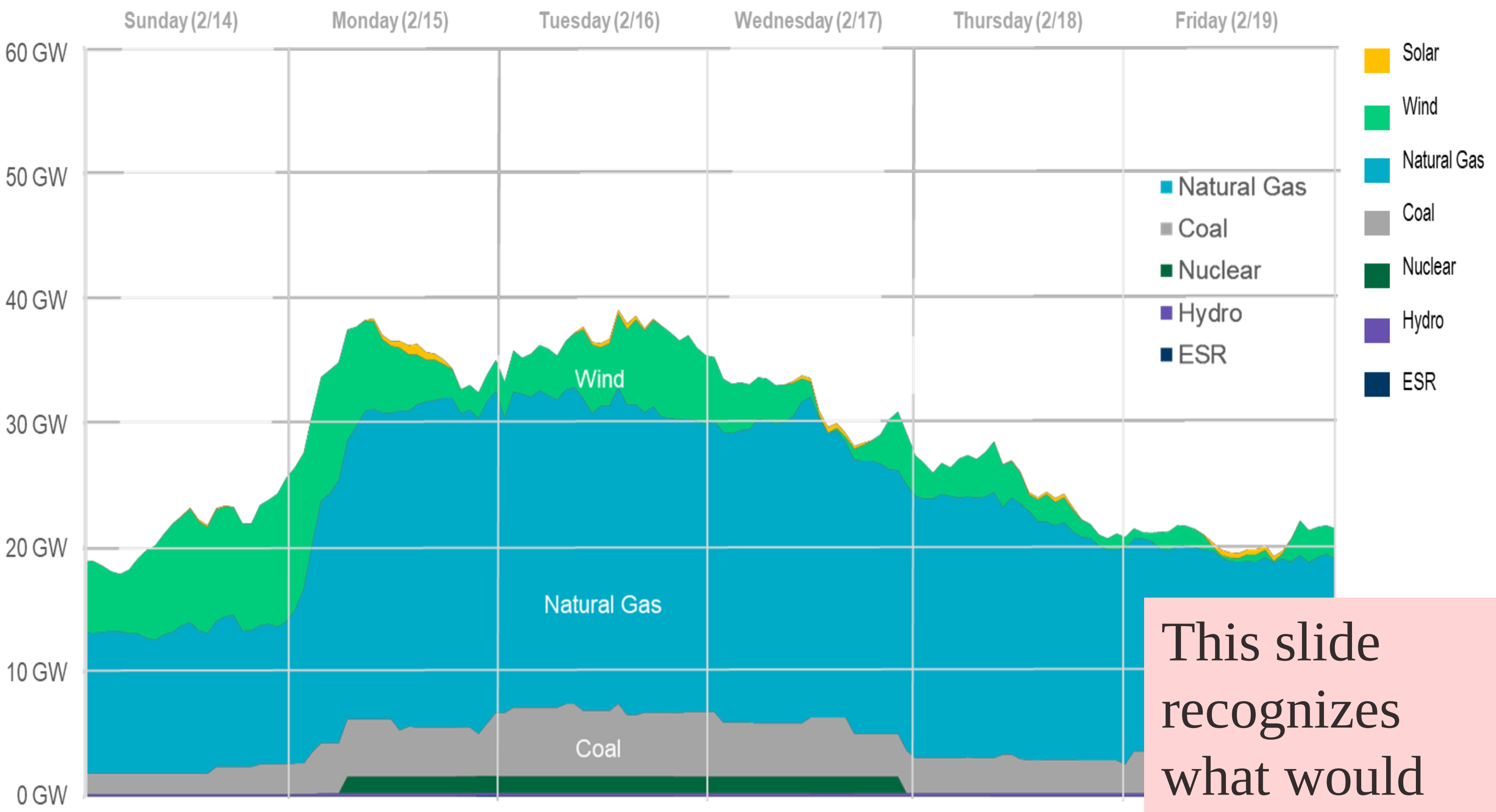


How Much Generation Capacity was Lost?



This and following images are from a 4/27/21 ERCOT presentation

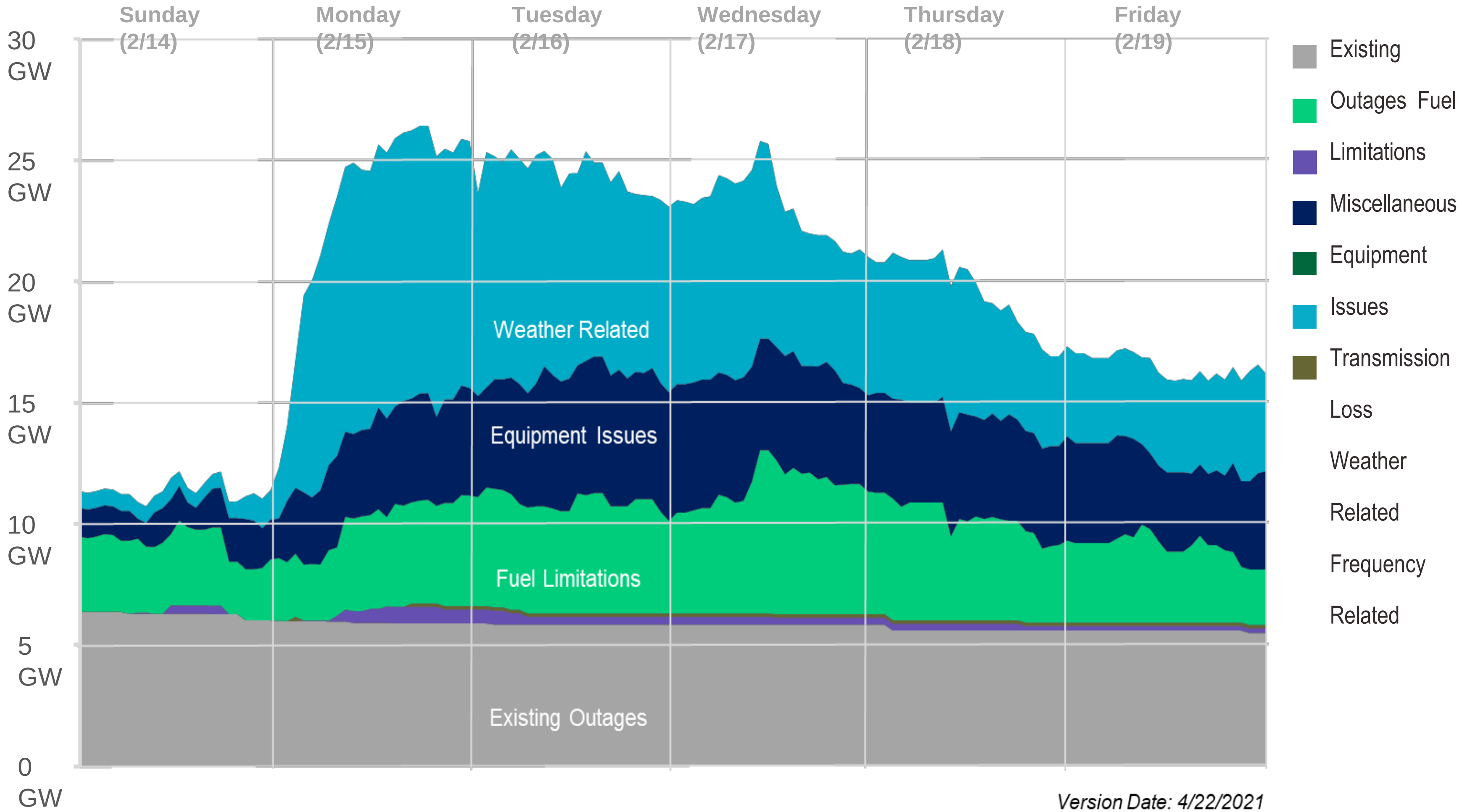
How Much Generation was Lost?



Wind and solar MW values based on estimated lost output due to outages and derates from slides 15 and 16.

This slide recognizes what would actually have been available

Lost Natural Gas Generation

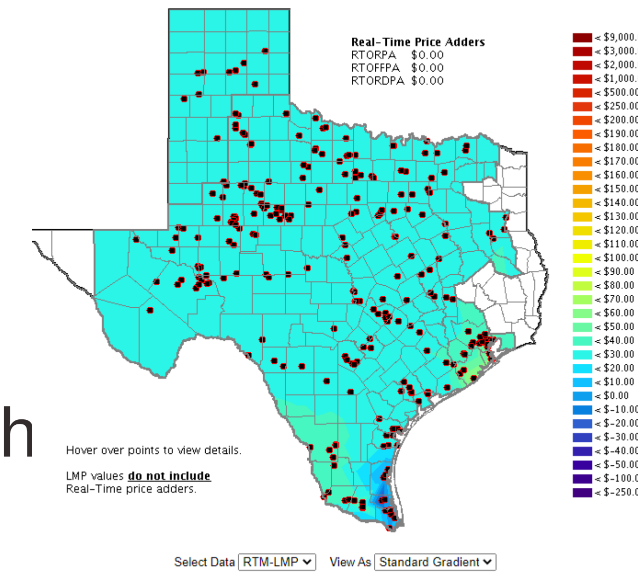


Winterizing Wind Turbines

- In general wind turbines can operate in quite low temperatures
- However, most of the wind turbines in Texas were not configured with the systems needed to deal with low temperatures
  - They mostly were not available because of turbine blade icing
- Wind turbines can be winterized with systems such as heated blades or coatings; packages can also be installed to protect the gearbox and motors, such as adding heating to the nacelle

Why Were Electric Prices High?

- In ERCOT, like much of the rest of the country, electricity is priced using a locational marginal price (LMP) market, that has both day-ahead and real-time markets
  - The price of electric varies by location and time of day
- Usually the price is relatively low say $30/MWh (or $0.03 by kWh)
- It had been capped at $9000/MWh but this was recently lowered in March 2021 to $2000/MWh



- Operating for days at price was considered unlikely!

Background: Why is ERCOT Separate

- ERCOT operates asynchronous from the rest of North America, but has high voltage dc (HVDC) ties with the Eastern Interconnect and Mexico
- The advantage is ERCOT avoids some federal regulation. The legal basis for this is complex, based on the US Constitution, the Federal Power Act, the 5/4/76 midnight connection, other legislation, court rulings, and FERC decisions

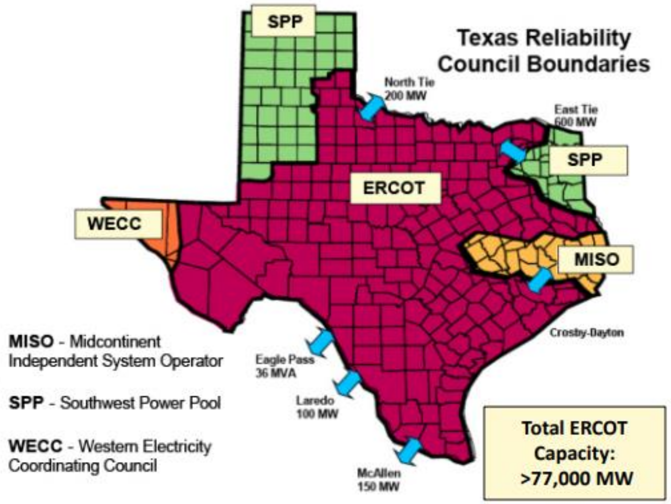


Image Source: aect.net/documents/2017/AECT%20LSB%20012617.pdf

High Voltage Direct Current (HVDC) Transmission

- Most electricity is transmitted in ac form, at either 60 or 50 Hz (with 60 Hz in North America)
- HVDC is sometimes used to transmit electricity either within an interconnect or between interconnects (back-to-back HVDC)
  - Within an interconnect, HVDC is usually used for long distance transfer, or in underground or undersea cables
- HVDC avoids issues with reactive power, but incurs the costs associated with the rectification (ac to dc) and inversion (dc to ac)
- HVDC power flow can be quickly controlled (milliseconds)

Southern Cross HVDC Transmission Project

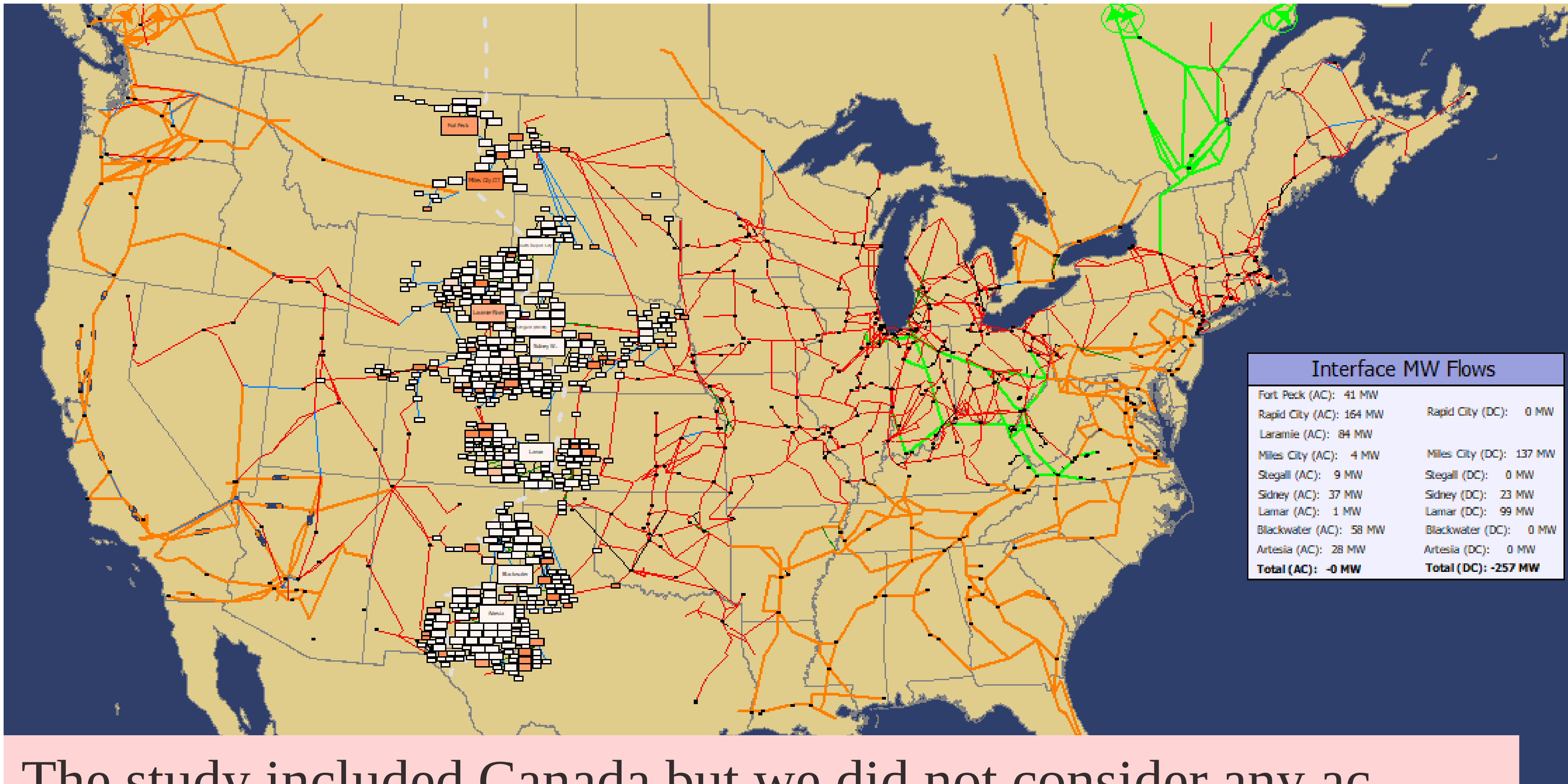
- The Texas Public Utility Commission has approved an application to build a 38 mile, 345 kV ac transmission line to connect to a 400 mile long, 500 kV HVDC between the Mississippi/Alabama and the Louisiana/Texas borders
  - As planned it would have a capacity of 2000 MW
  - It could be operational in 2022 with a cost that might be more than $1 billion
  - Up-to-date information on the project is available at www.ercot.com/mktrules/puctDirectives/southernCross

Image source: southerncrosstransmission.com/wp-content/uploads/2021/03/SC_factsheet_2021_V3.pdf

Joining the East and West Grids

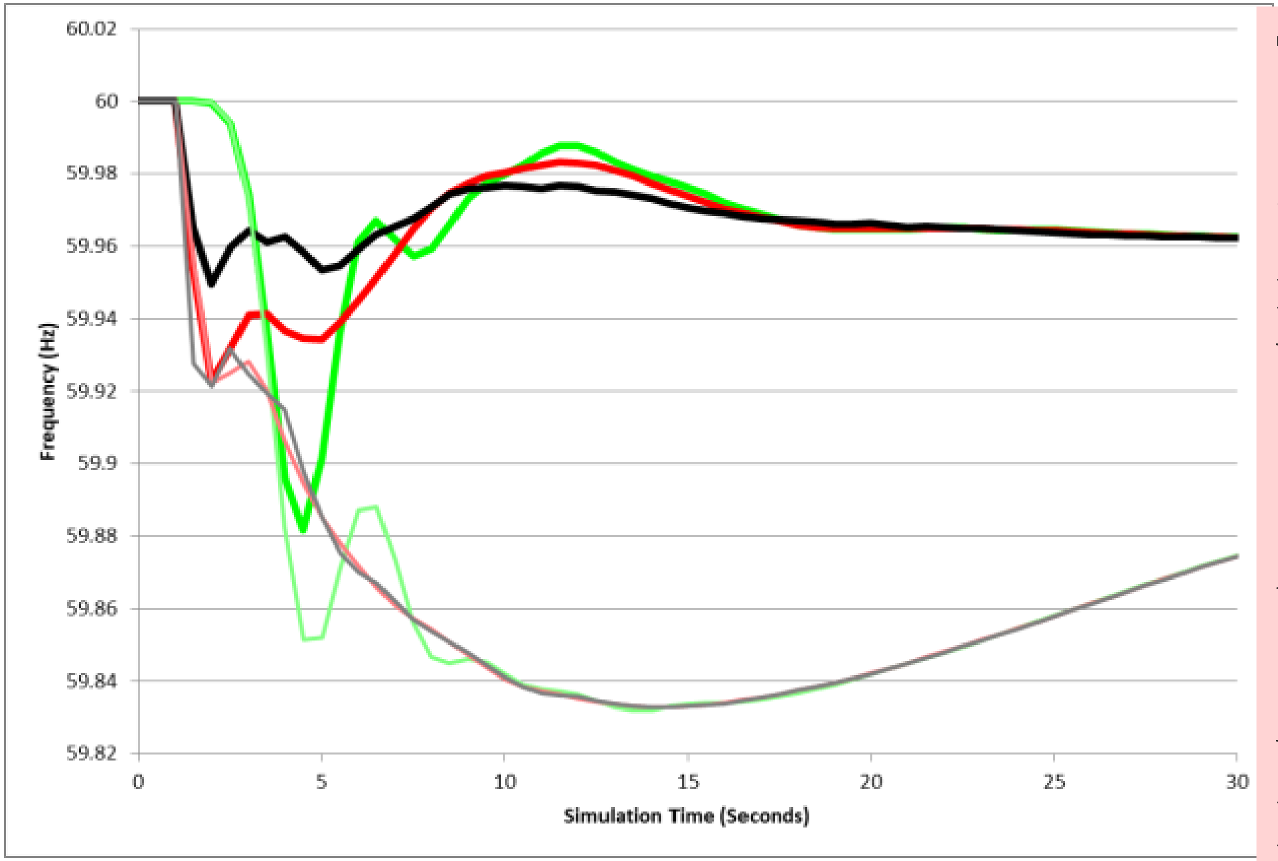
- In 2020 we did a research project for SPP looking at an ac interconnection of the East and West grids
  - This did not include ERCOT, but did include parts of Texas
- There are nine locations where the grids are close and could be tied together
- The study required lots of dynamic simulations using quite detailed full system models (transient stability level, 110,000 buses)
- The result was there are no show stoppers to doing this, and there could be good benefits!

East-West Combined Grid



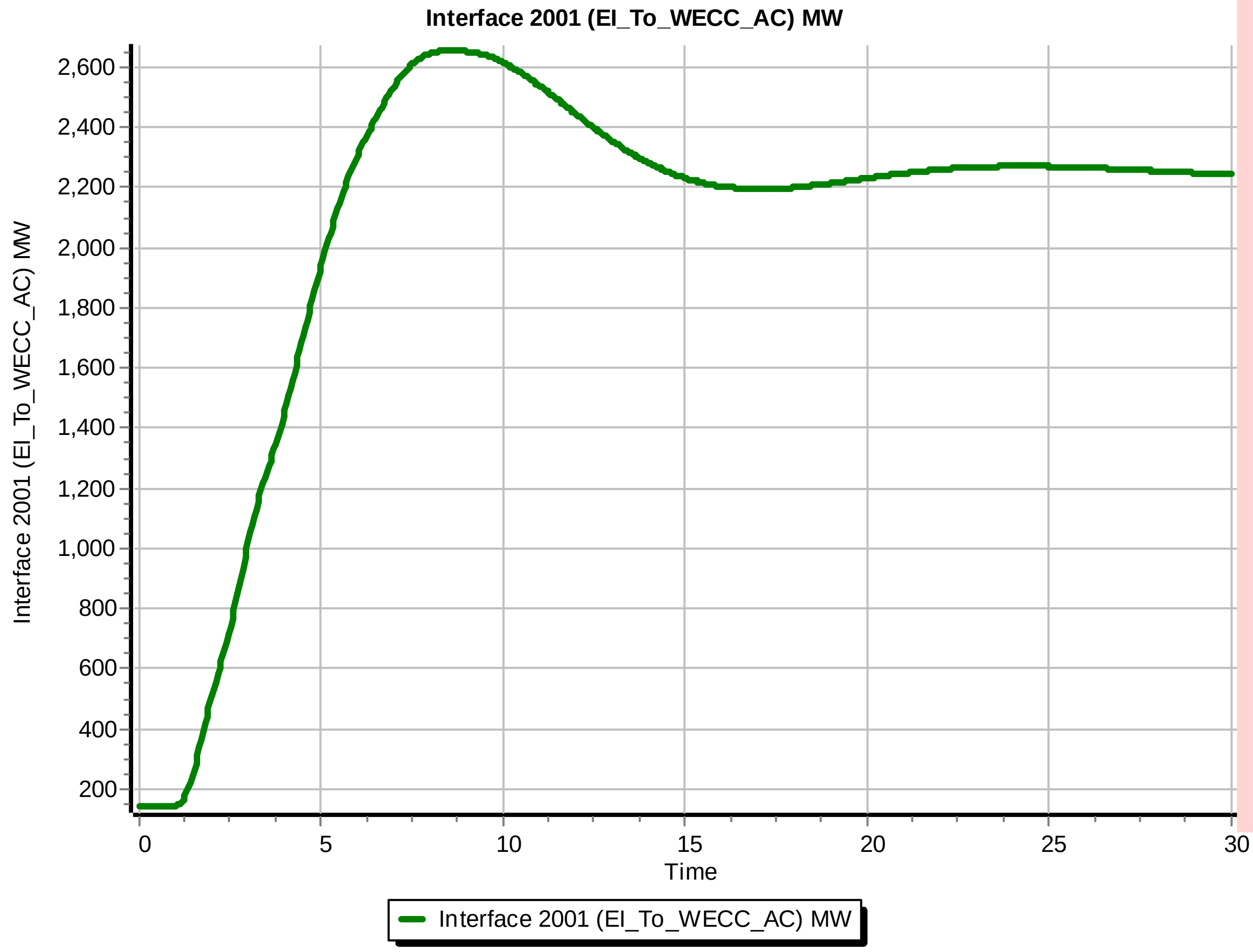
The study included Canada but we did not consider any ac interconnections between the grids in Canada; the grids were connected at nine points from Montana to New Mexico

WECC Frequency Response: 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.

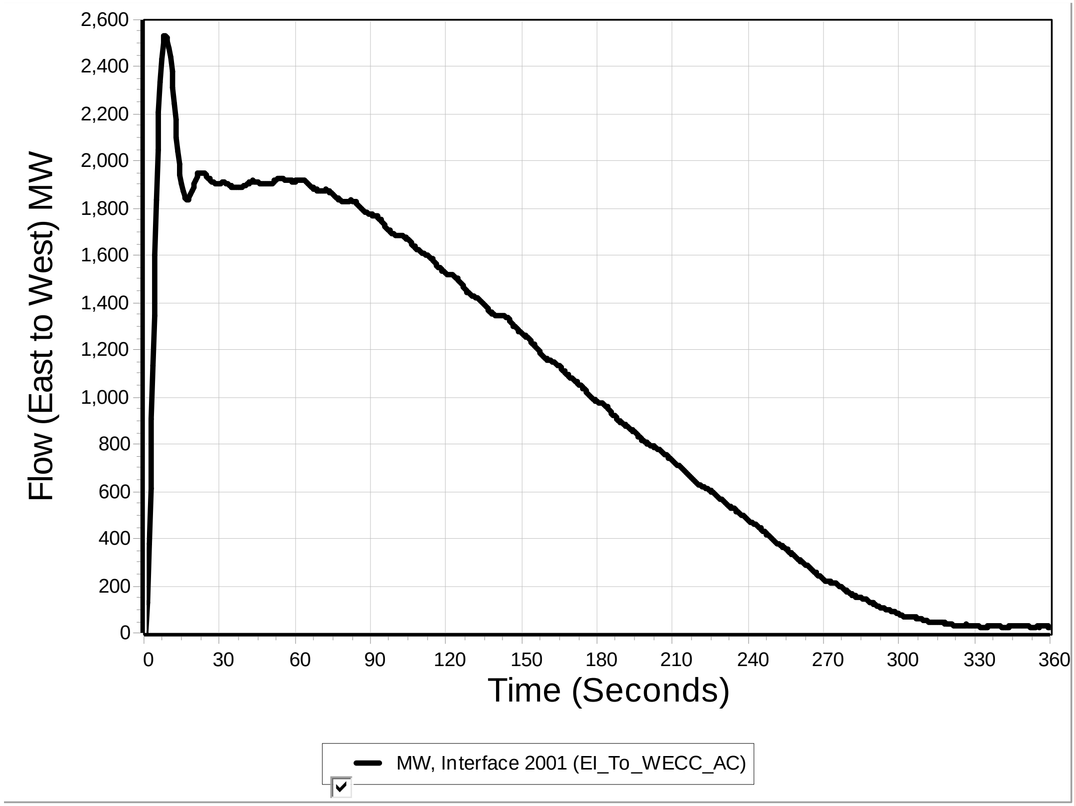
Adding AGC Modeling

- 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

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

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

Interface Flow with AGC Modeling



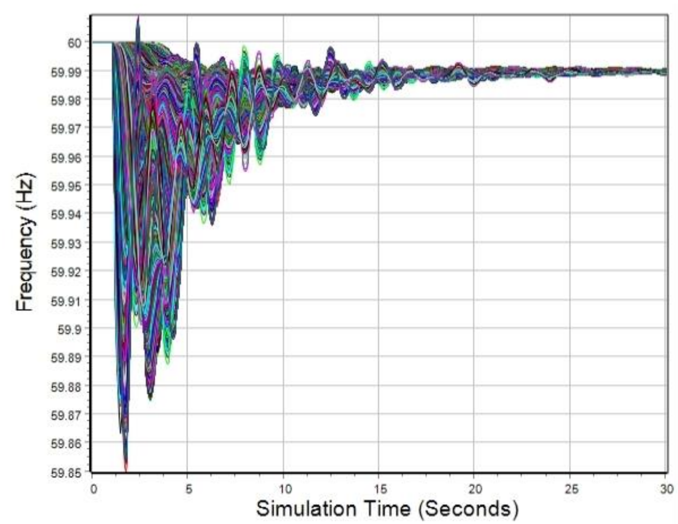
The AGC studies were run for up to six minutes with emergency transactions implemented. Graph shows a WECC generator loss contingency with the emergency transactions between WECC utilities. How fast the interface flow returns to normal depends on how fast the MW transactions ramp.

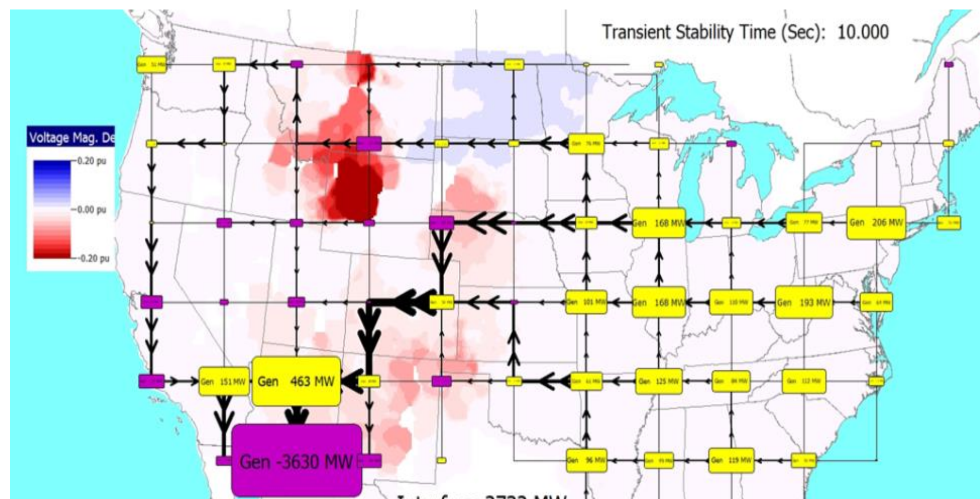
Situational Awareness

- 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

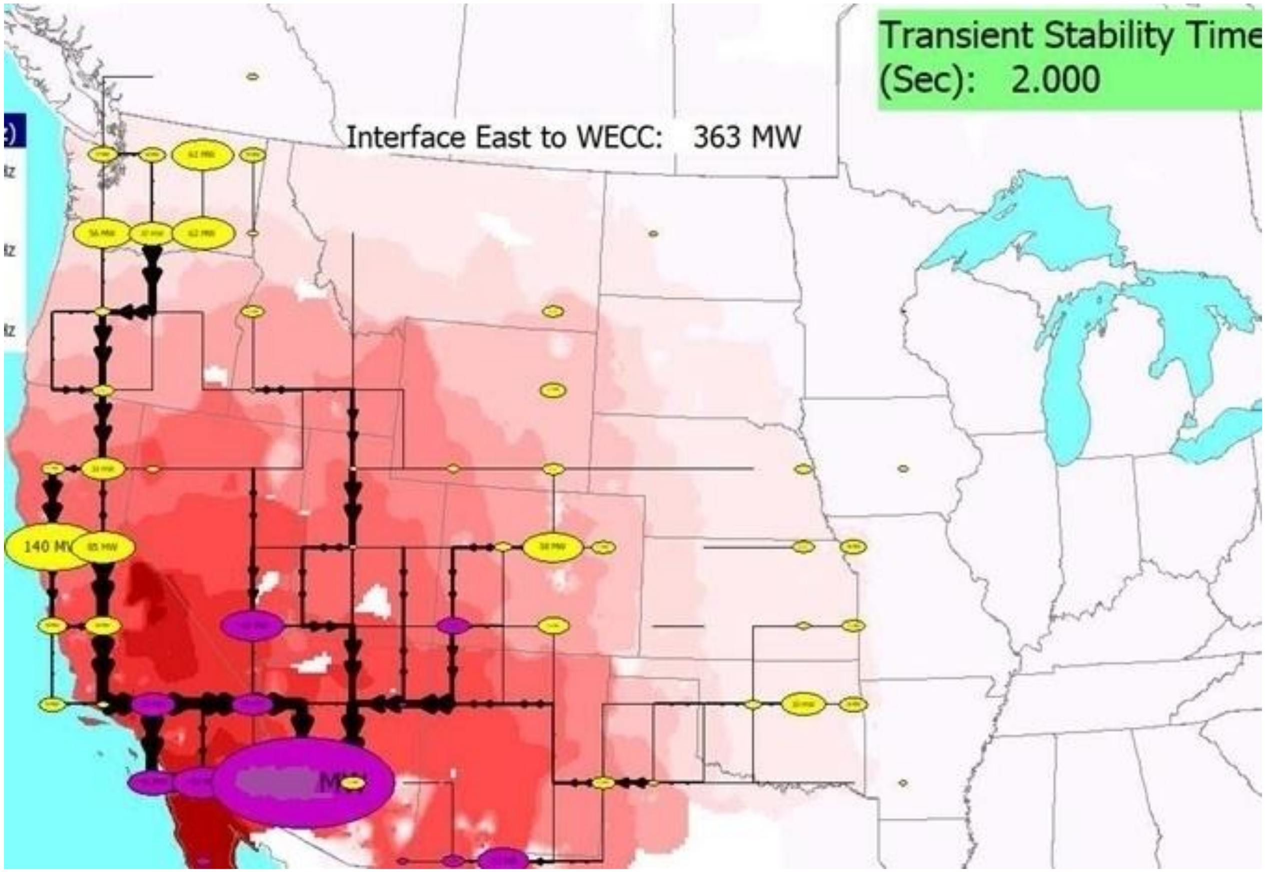
Situational Awareness Techniques

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



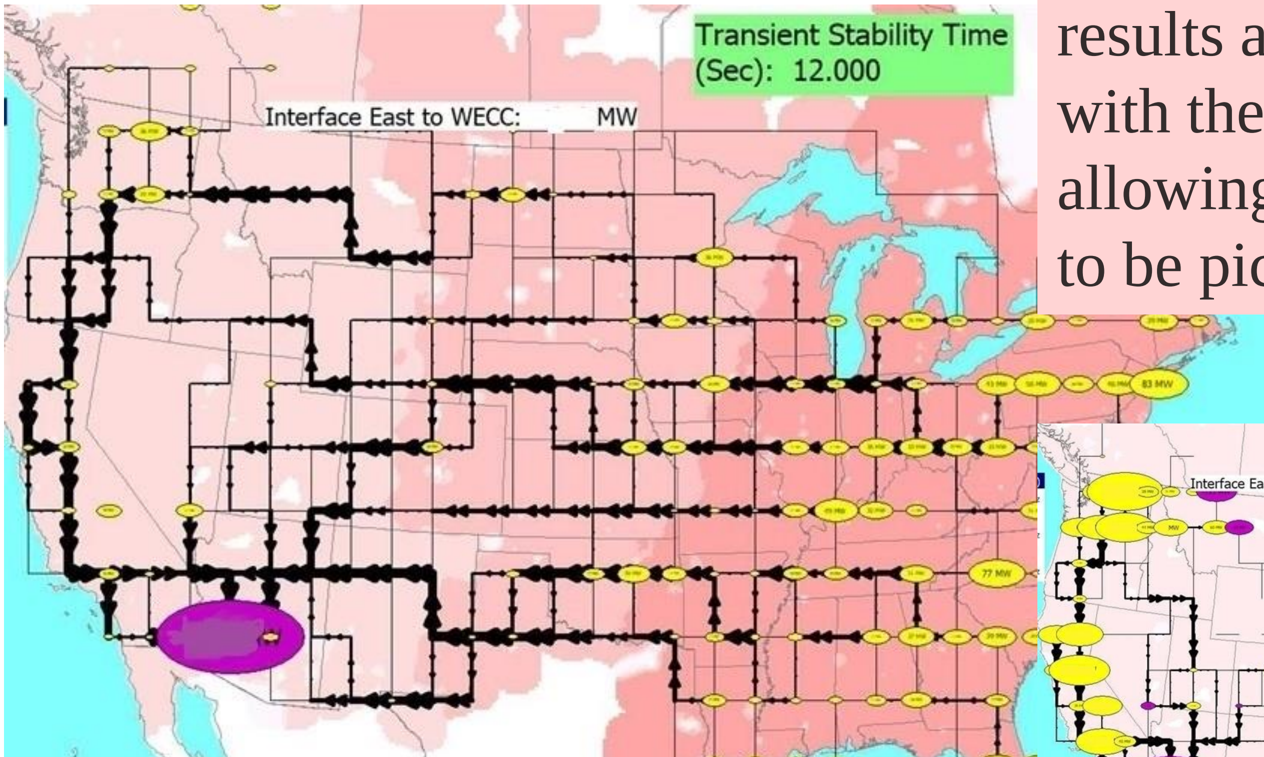


Results Example at 2.0 Seconds

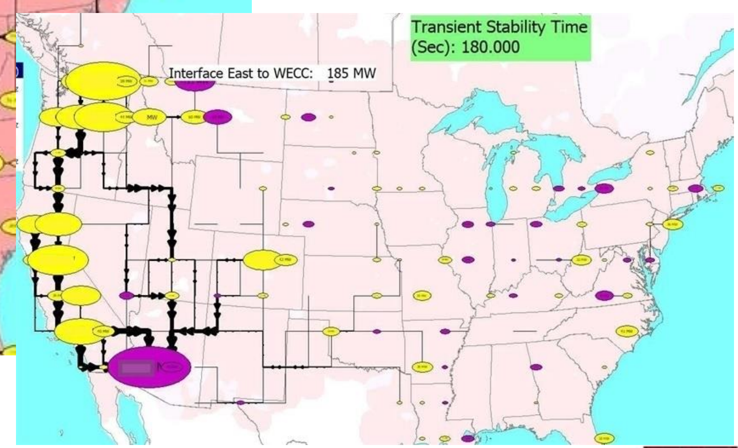


This visualization is using geographic data views and a contour to show the response of the 110,000 bus model; red values are frequencies less than 60 Hz

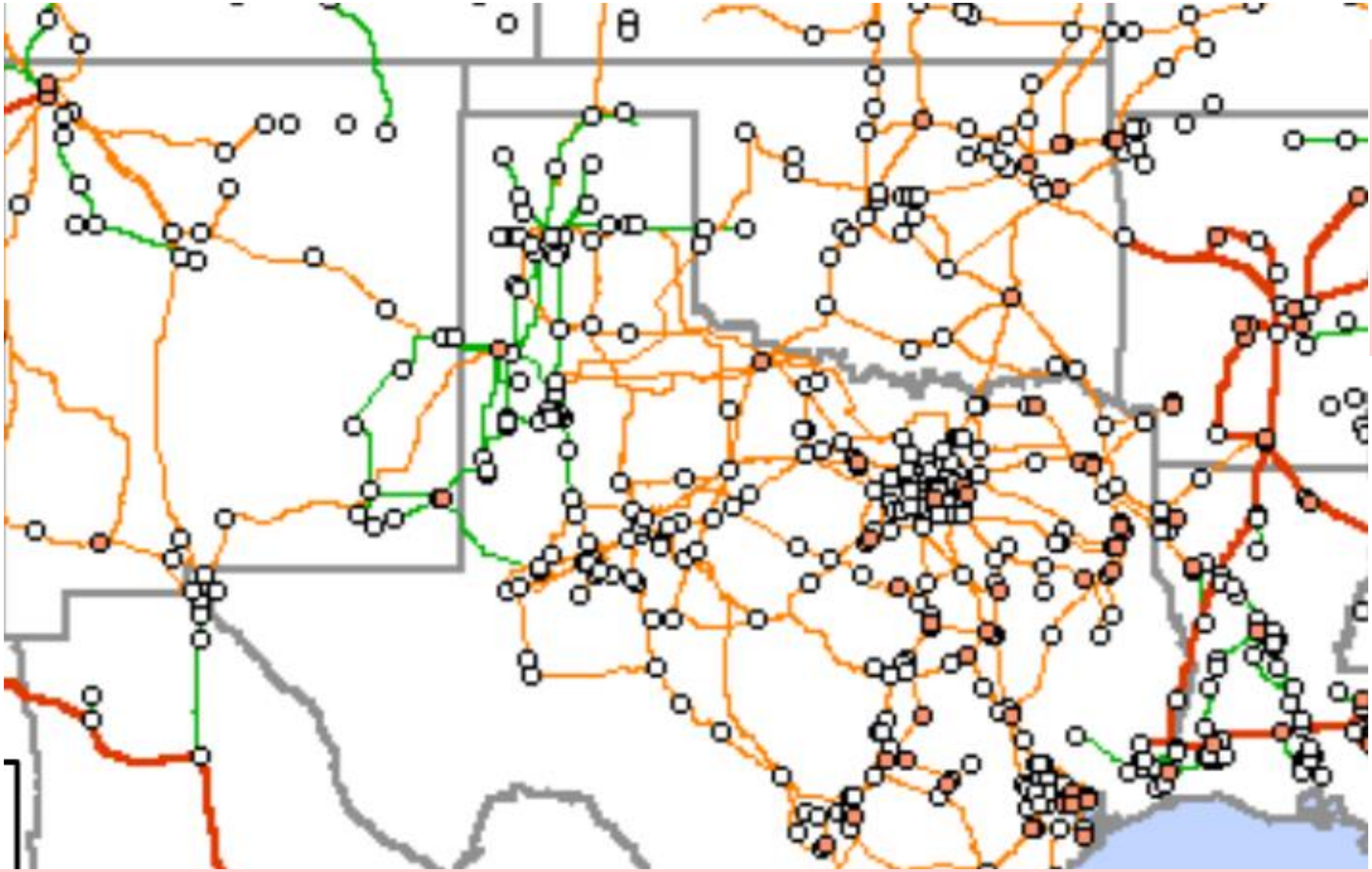
Results Example at 12 Seconds and Three Minutes



Bottom image shows the results after three minutes, with the AGC response allowing the generator loss to be picked up with WECC



ERCOT-East-West Transmission



Orange is 345 kV, Red is 500 kV

An ac interconnection would probably be the least expensive approach to greatly increase the ERCOT import/export capability

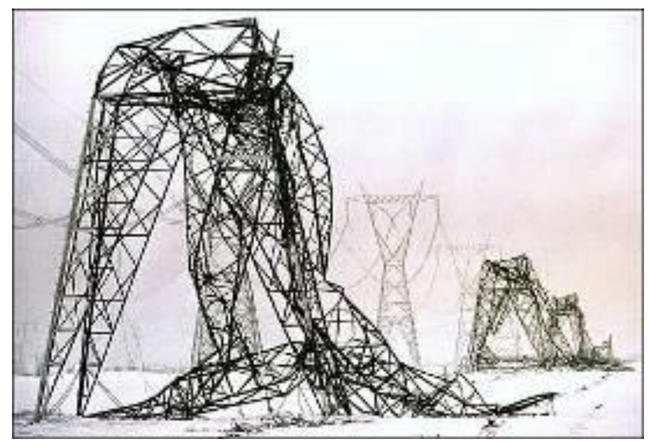
Public Source Map: www.nerc.com/comm/CIPC/Agendas%20Highlights%20and%20Minutes%202013/2015%20December%20Compiled%20Presentations.pdf

Broadening to Electric Grid Resiliency

- The ability of electric grids to resiliently respond to high impact, low frequency events is an important but often overlooked aspect of operation, design and research
  - There is always a tradeoff between risk and mitigation cost
- The best reference we know of is the free 2017 report from the US National Academies titled, “Enhancing the Resilience of the Nation’s Electricity System”
  - It does mention the threat of cold weather, and specifically mentions the February 2011 Texas cold snap

The Grid Needs to Be Resilient to Lots of Disturbances on Different Time Frames

- Events short and long-term
  - Lightning strikes can usually be cleared within seconds
  - But ice, tornados and hurricanes can bring large-scale damage over long timer periods



- Need to consider all operating conditions

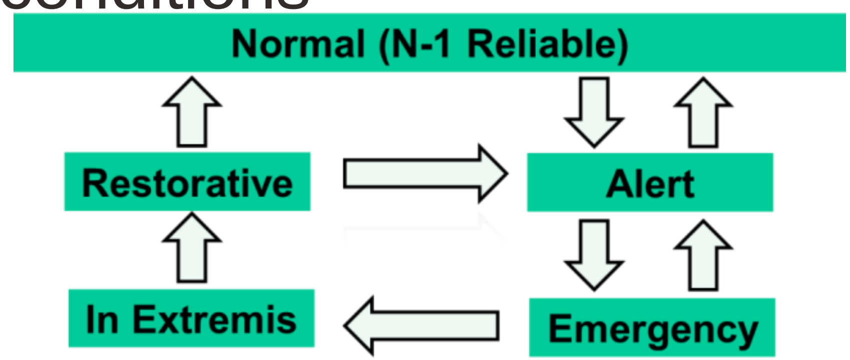


Image Derived From L.H. Fink and K. Carlsen, Operating under stress and strain, *IEEE Spectrum*, March 1978, pp. 48-53

Some Electric Grid Risks (National Academies 2017 Report)

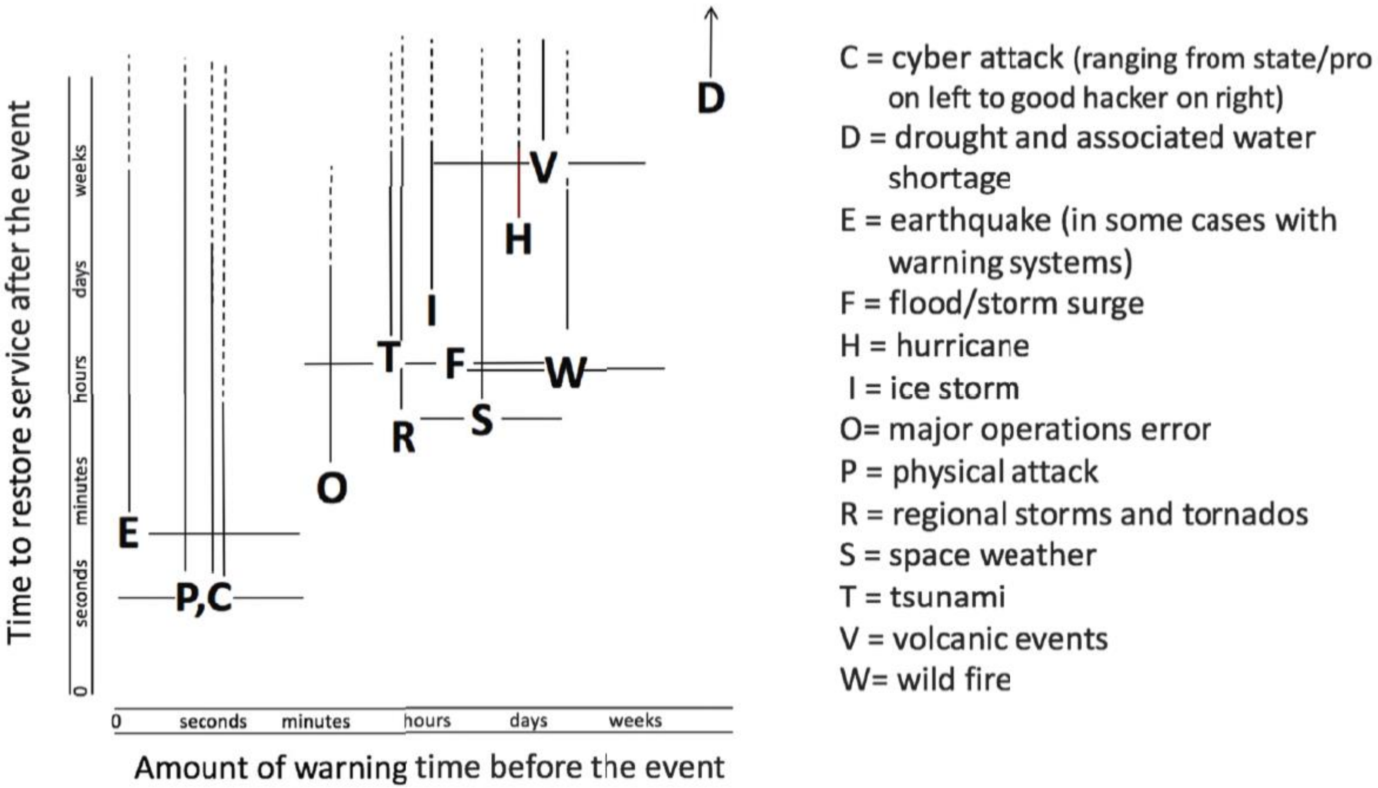
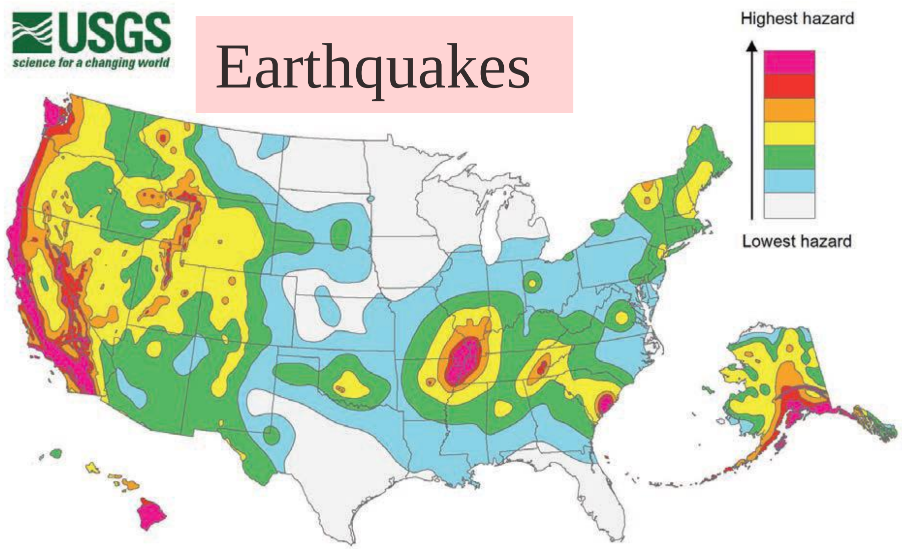


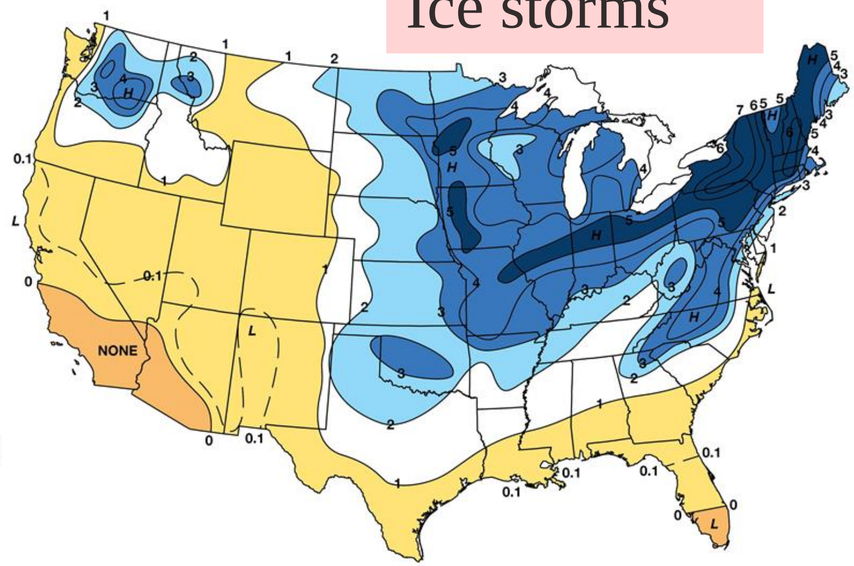
FIGURE 3.1 Mapping of events that can cause disruption of power systems. The horizontal placement provides some indication of how much warning time there may be before the event. The vertical axis provides some indication of how long it may take to recover after the event. Lines provide a representation

Some Electric Grid Risks

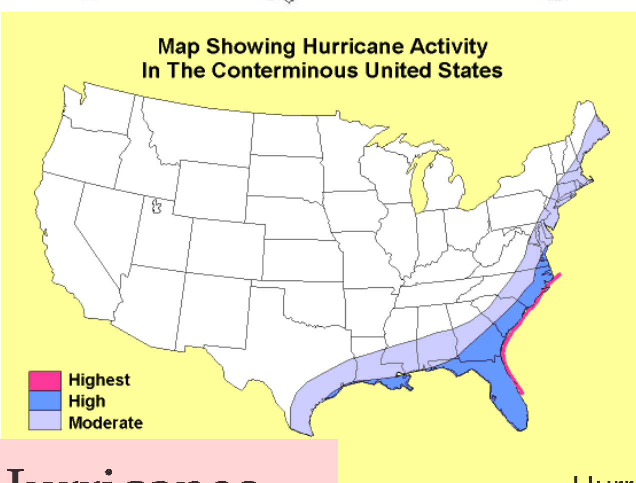
Earthquakes



Ice storms



The average annual number of days with freezing rain, based on 1948-2000 data. *From Changnon and Karl, 2003.*



Hurricanes

And many more! But all need to be considered from a risk/benefit perspective

Hurricane risk image source: USGS

High-Impact, Low-Frequency Events

- In order to enhance electric grid resiliency we need to consider the almost unthinkable events
- These include what the North American Electric Reliability Corporation (NERC) calls High-Impact, Low-Frequency Events (HILFs); others call them black sky days

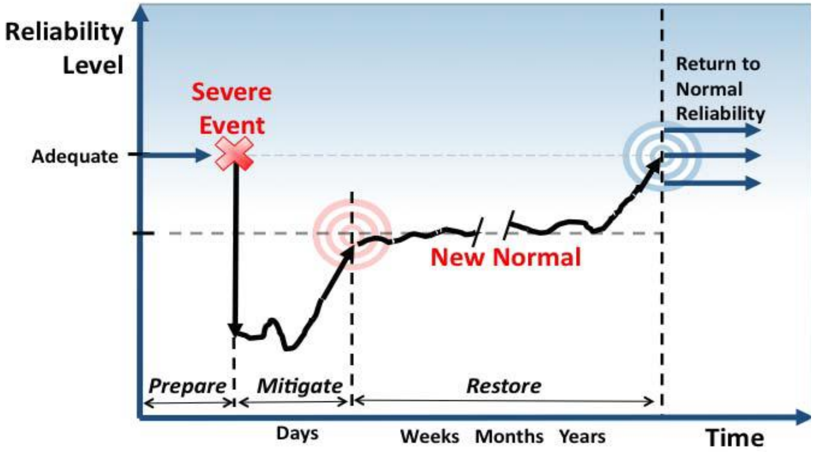


Image Source: NERC, 2012

  - Large-scale, potentially long duration blackouts
  - HILFs identified by NERC were 1) a coordinated cyber, physical or blended attacks, 2) pandemics, 3) geomagnetic disturbances (GMDs), and 4) HEMPs

Cyber-Physical Considerations

- Effectively operating the grid involves a heavy interaction between humans, the cyber and the physical; maintaining situational awareness will be key and is a crucial area for more research
- This is an often overlook area of research because it is so challenging.
- The number of couplings between the grid and other infrastructures is growing
  - Electrification of transportation
- We need realistic simulations that can consider key aspects of the electric grid and coupled infrastructures

Increasing Resiliency

- The National Academies 2017 report has lots of specific recommendations
- All recommendations need to be considered from a cost-benefit point of view
  - we can't prevent all blackouts, but we need to mitigate the effects of severe HILF events
- Electric grid analysis tools need to be designed to handle severe events, allowing events to be simulated and appropriate mitigation plans to be developed
  - What would we do if "?" Example, if temperatures in College Station went to -3°F (like in 1949)?

Conclusion

- The electric grid is crucial to our society, and for decades into the future we will be relying on it
- The Texas 2021 event illustrates a vulnerability
- A perfect electric grid is impossible, and we need to be prepared for long-term, wide-area blackouts
- However, much can and should be done to reduce to reduce this risk
- A broad, sustained effort is needed in this area including the entire electric grid sector
- Focusing on the interaction between the cyber, physical and the humans will be key

Thank you and Questions