Weak Grid Experiences in ERCOT

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WECC Webinar

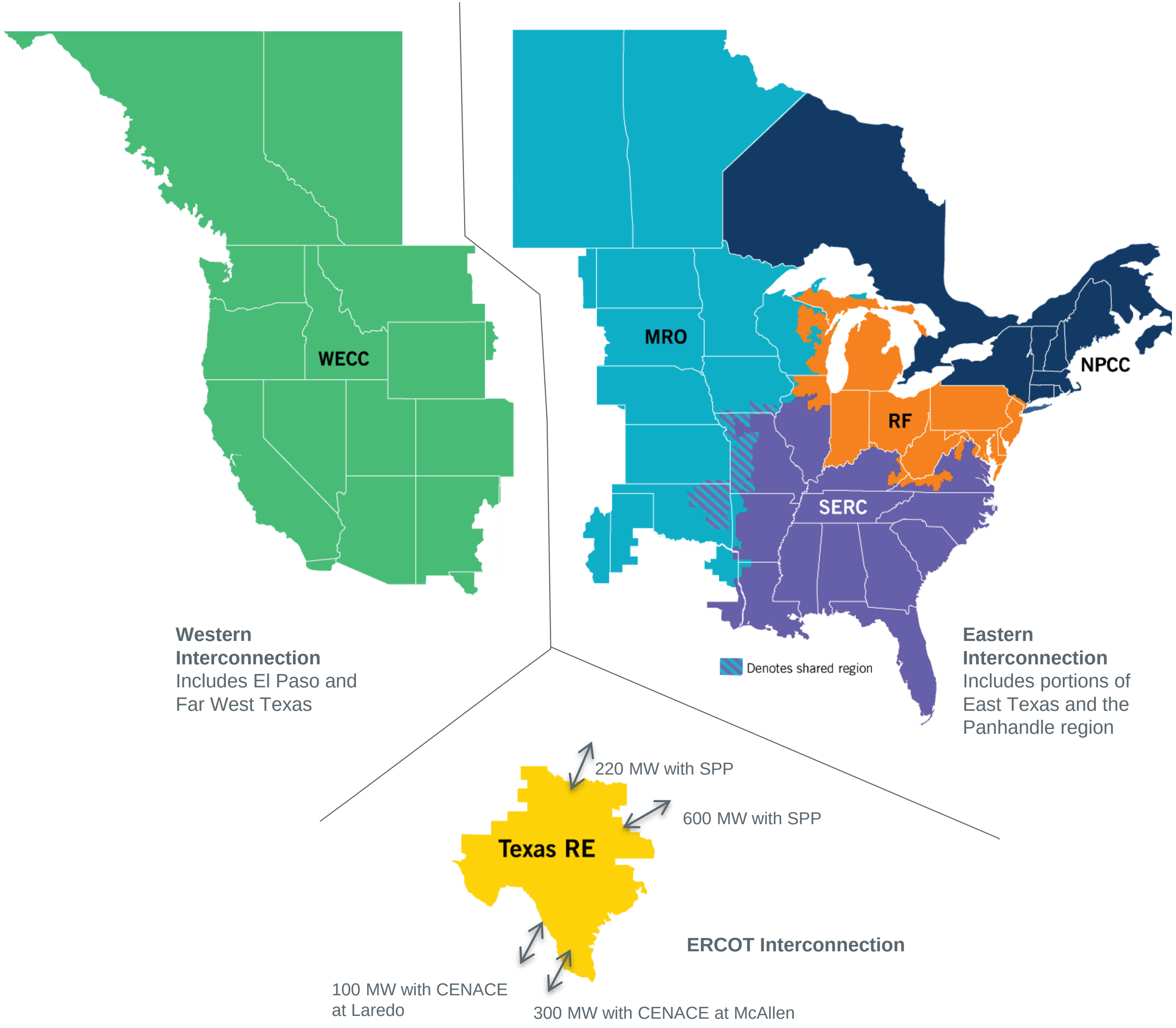
October 13th, 2021

The ERCOT Region

The interconnected electrical system serving most of Texas, with limited external connections

- 90% of Texas electric load; 75% of Texas land
- 74,820 MW peak, Aug. 12, 2019
- More than 46,500 miles of transmission lines
- 710+ generation units (excluding PUNs)

ERCOT connections to other grids are limited to ~1,220 MW of direct current (DC) ties, which allow control over flow of electricity

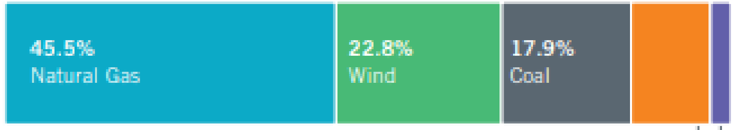


ERCOT Facts

More than
26 million
customers in the ERCOT region

- 1,800+ active market participants that generate, move, buy, sell or use wholesale electricity
- 86,000+ megawatts (MW) of expected capacity for summer 2021 peak demand

2020 Energy Use



*Other includes solar, hydro, petroleum coke, biomass, landfill gas, distillate fuel oil, net DC-tie and Block Load Transfer imports/exports and an adjustment for wholesale storage load

382 billion kilowatt-hours of energy were used in 2020, a 0.6 percent decrease compared to 2019.

74,820 MW

Record peak demand (Aug. 12, 2019)

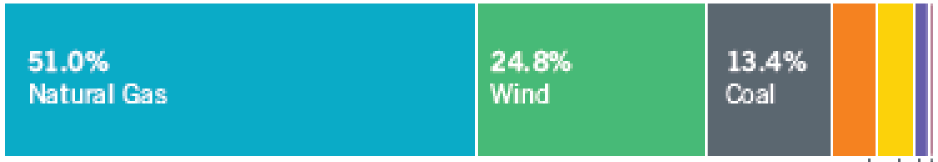
71,930 MW

Weekend peak demand record (Aug. 11, 2019)

1 MW of electricity can power about 200 Texas homes during periods of peak demand.

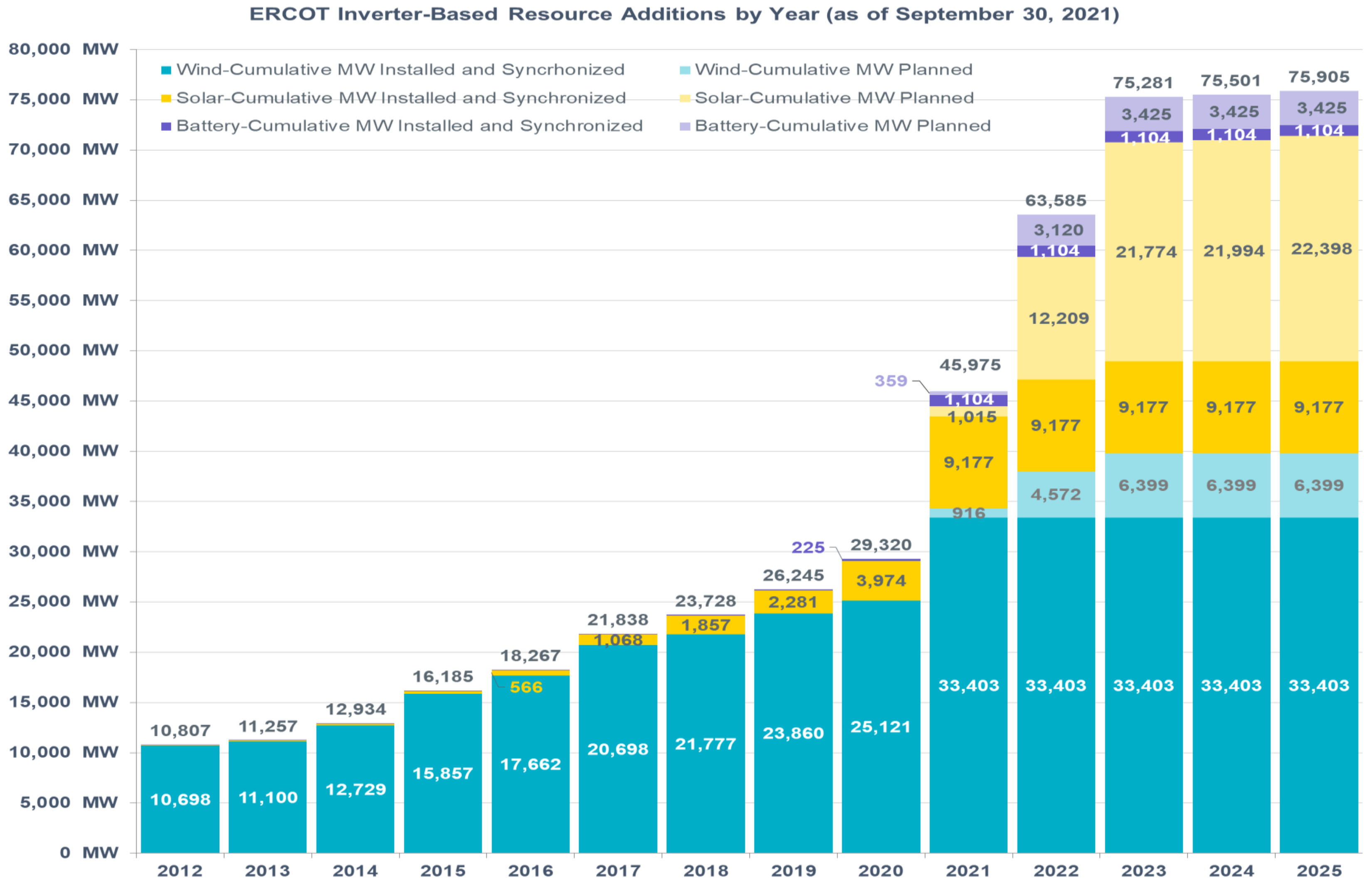
- 710+ generating units, excluding PUNs
- Transmission projects endorsed in 2020 total $1,071 million
- 46,500+ miles of high-voltage transmission

2021 Generating Capacity *Reflects operational installed capacity based on the December 2020 CDR report*



Other includes hydro, biomass-fired units and DC tie capacity

Inverter-Based Resource Capacity – September 2021

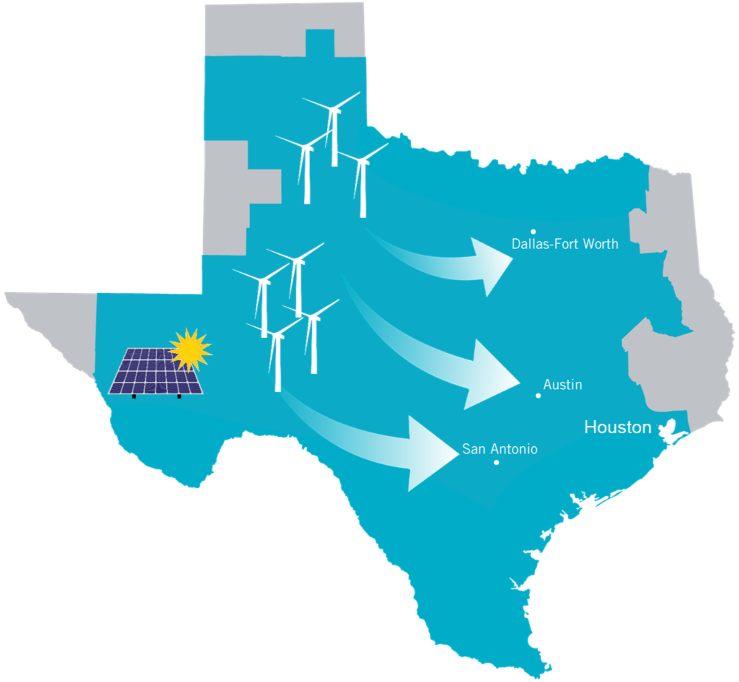


Cumulative MW Planned include projects with signed interconnection agreeements

Inverter-Based Resources in ERCOT

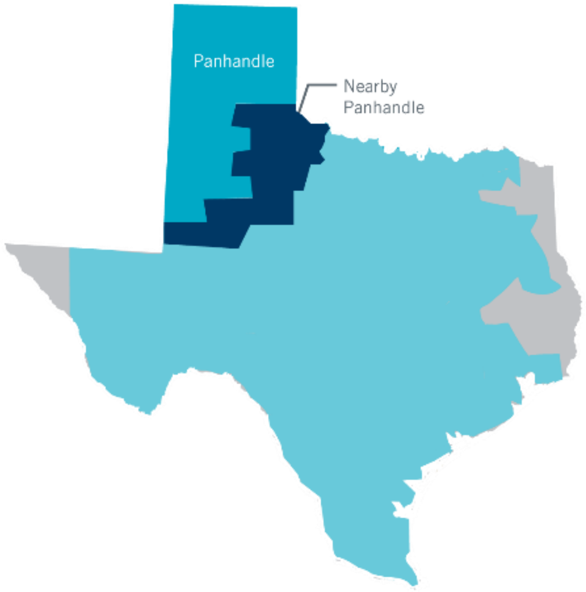
- > 45 GW IBRs are expected to be connected to the ERCOT transmission grid by the end of 2021.
- Most wind and solar generation are in West Texas:
  - Long distance transfer to load centers
  - Limited/no online synchronous generators in West Texas during high IBR output periods

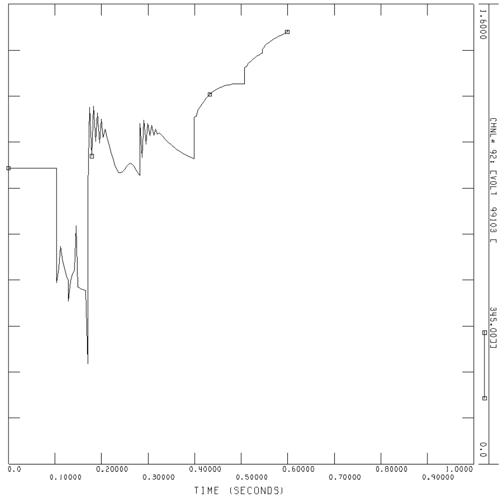
2021	2023
• >34GW Wind • >10 GW Solar • >1.4 GW Battery	• >39 GW Wind • >30 GW Solar • >4.5 GW Battery



ERCOT Panhandle

- > 10 GW IBRs connect to Panhandle and nearby Panhandle
  - IBRs are located at remote areas (high IBR penetration)
  - Limited/no online synchronous generators (low short circuit)
  - Long distance large power transfer (high impedance)
- Indicators of weak grid
  - High frequency oscillation or numerical instability in PSS/e
  - High voltage overshoot or even high voltage collapse
  - Low WSCR (weighted short circuit ratio)
- Improvement Options
  - Two synchronous condensers were added to Panhandle: stability associated with condensers needs to be checked
  - Reduce impedance: adding new circuits
  - Control tuning and coordination





What is System Strength?

- The ability of power system equipment to operate in a stable manner and for the system to recover from major disturbances, is influenced by the electrical ‘strength’ of the system at the point where equipment connects.

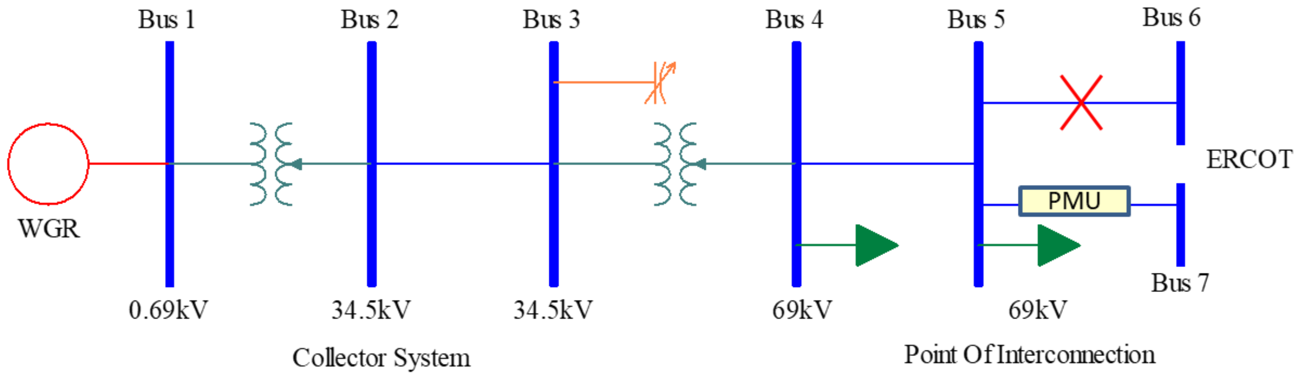
- ‘Stronger’ systems are more tolerant to variations and perturbations occurring within connected plant and recover more easily from major disturbances such as faults and the sudden loss of equipment.

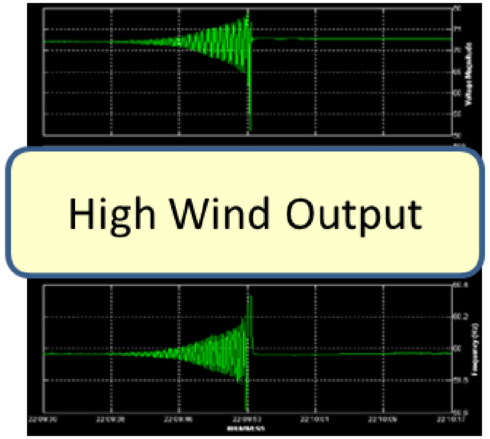
Source: Babak Badrzadeh et.al., “System strength”, CIGRE Science and Engineering, February 2021

System Strength

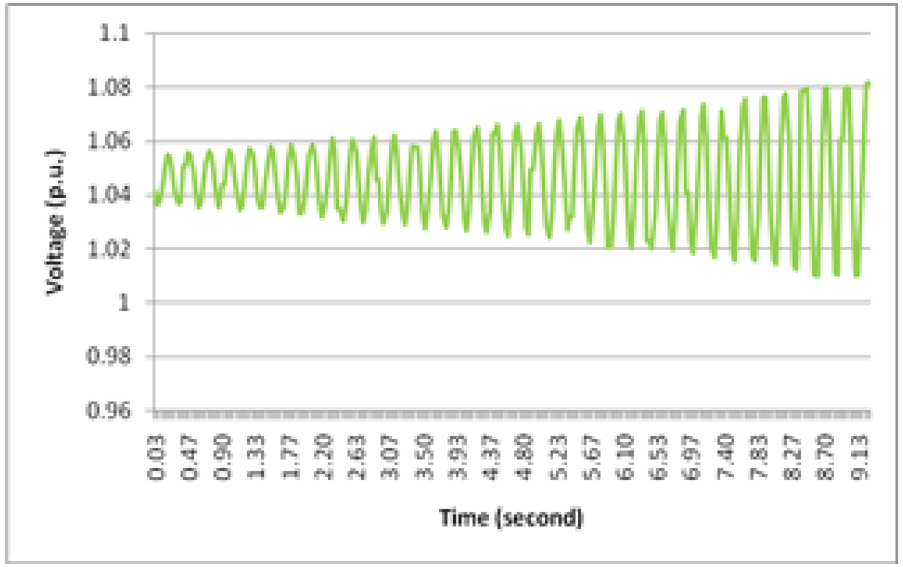
- There is a limit of how many conventional (grid following) Inverter Based Resources (IBRs) can be accommodated (due to system strength and inertia issues).
- System operators may limit the output of IBRs and supply the remaining load with synchronous generators to ensure sufficient system strength and/or inertia (e.g., Australia, Ireland, Texas).
  - Such operational constraints in the long run may impact further development of IBRs.
- Alternatively, synchronous condensers are installed to provide grid support, but the associated constraints (e.g.. stability) must be assessed.

Weak Grid: Operations Example





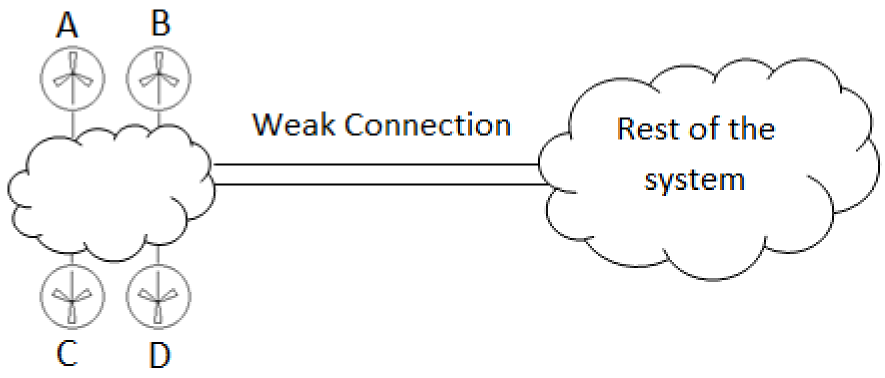
- Lessons Learned:
  - Model and tool adequacy
  - Impact on IBR control
  - Mitigation options:
    - IBR dispatch
    - IBR control tuning
    - System strength enhancement



Weighted Short Circuit Ratio (WSCR)

- 2014 Panhandle study recognized limitations of a single plant Short Circuit Ratio for characterizing system strength:
  - Ignores the interactions between neighboring IBRs in a region
  - May give an overly-optimistic estimation of system strength
- ERCOT proposed the concept of WSCR:
  - Recognizes interactions between neighboring IBRs
  - Assumes all interacting IBRs are connected at the same bus (!)
    - $WSCR = \frac{\sum_i^N S_{SCMVAi} * P_i}{(\sum_i^N P_i)^2}$
- WSCR=1.5 was proposed as the minimum pre-contingency system strength for Panhandle (based on PSS/E study results).

Example of WSCR Calculation



Wind Plant	Wind Power Production (MW)	Short Circuit Capacity (S_{SC_MVA})	Single Plant SCR
A	1,200	6,500	5.42
B	1,000	8,000	8.00
C	800	8,500	10.63
D	2,000	7,000	3.5

$$WSCR = \frac{1200 * 6500 + 1000 * 8000 + 800 * 8500 + 2000 * 7000}{(1200 + 1000 + 800 + 2000)^2} = 1.46$$

Determination of WSCR

ERCOT re-evaluated Panhandle area in both phasor-domain stability studies and detailed Electromagnetic Transient Studies (EMT) in 2016, 2018 and 2019:

- WSCR of 1.5 for Panhandle region was found appropriate.
- WSCR concept was found applicable in the absence of local load and synchronous generation, as well as electrically close IBRs remotely connected to the main grid.
- The application of WSCR and its threshold are highly system- dependent and should be verified and regularly reviewed through detailed studies (e.g. EMT) as the system evolves.

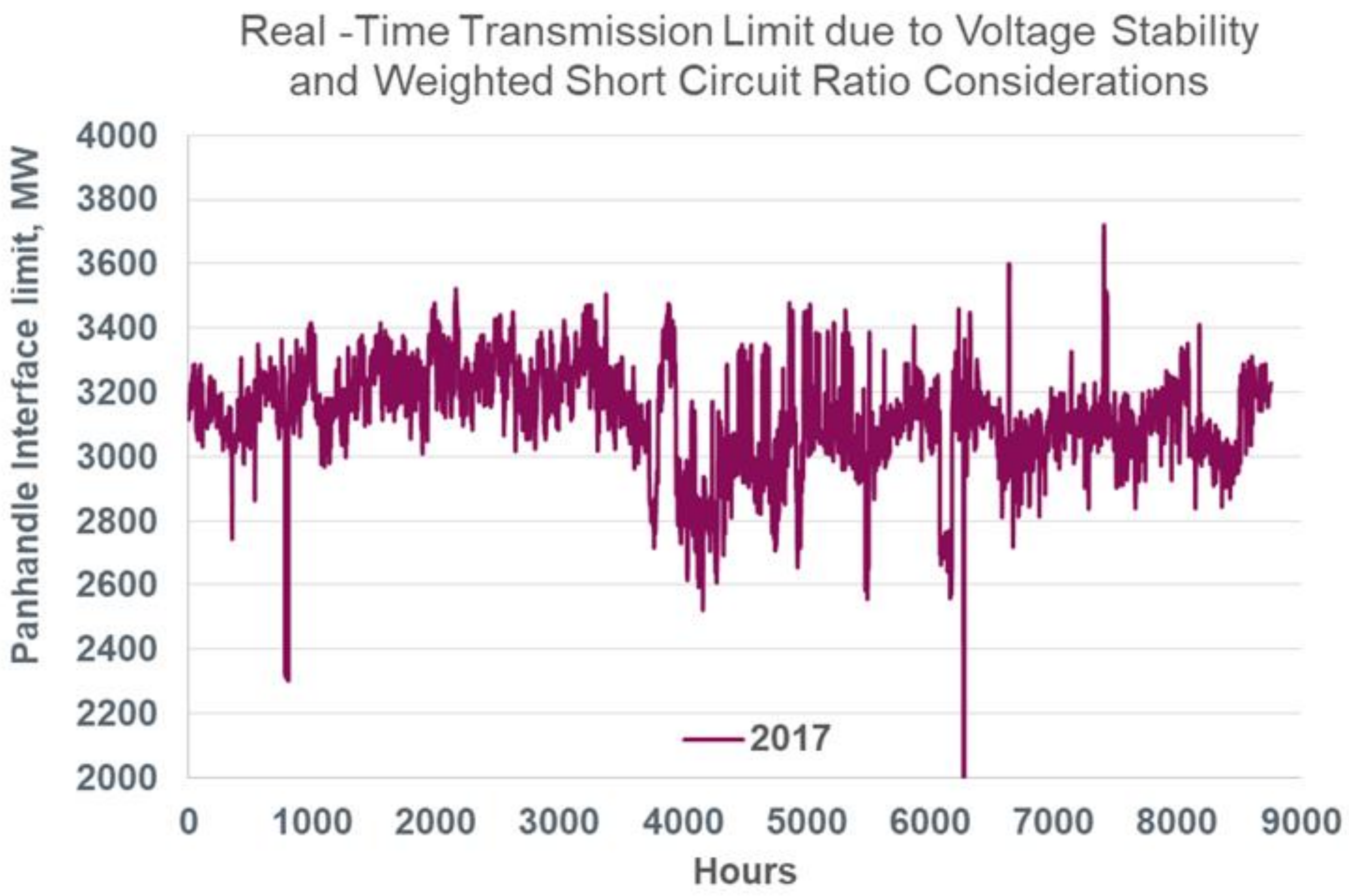
Evaluation of Panhandle Export Limit in Real-Time

- For the past 6 years, WSCR≥1.5 was maintained in Panhandle by curtailing wind generation, if WSCR was the most limiting constraint.

- WSCR calculation is built into real-time VSAT*, from which Panhandle export limit is determined every 10 minutes:
  - $WSCR = \frac{\sum_i^N S_{SCMVAi} * P_i}{(\sum_i^N P_i)^2}$
  - $\sum_i^N P_i$ is total Panhandle generation at the time of evaluation
  - If WSCR <1.5, scale down all P_i proportionally so that WSCR = 1.5 under pre-contingency condition
  - New $\sum_i^N P_i$ determines Panhandle export limit based on WSCR

*VSAT – Voltage Stability Assessment Tool by Powertech Labs

Real-Time Panhandle Export Limit

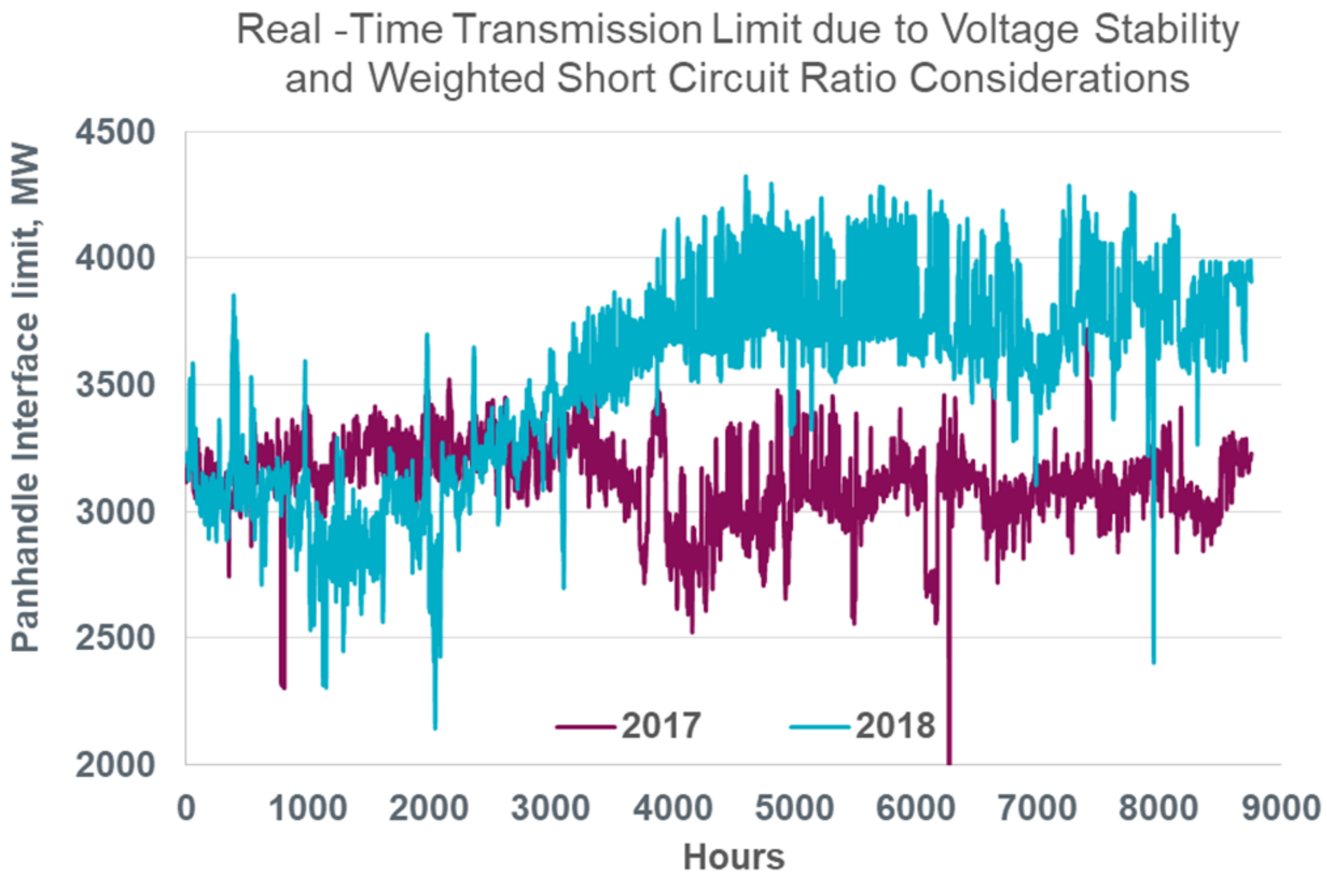


Synchronous Condenser (SynCon) Characteristics

- Two Synchronous Condensers were installed in Panhandle in 2018, each with the following specifications:
  - ~175/-125 MVAR, for +/- 10% voltage variation range
  - ~1600 Amps short circuit capability on the high-voltage side
- Placed in locations that increase WSCR but also improve voltage support and transient response.
- High availability design is required since SynCons’ outage directly translates into reduction of the maximum power export.
  - Redundancy in cooling system aux supply, control and protection systems
  - The wide range of the machine operating voltage
  - Brushless excitation system to reduce maintenance time

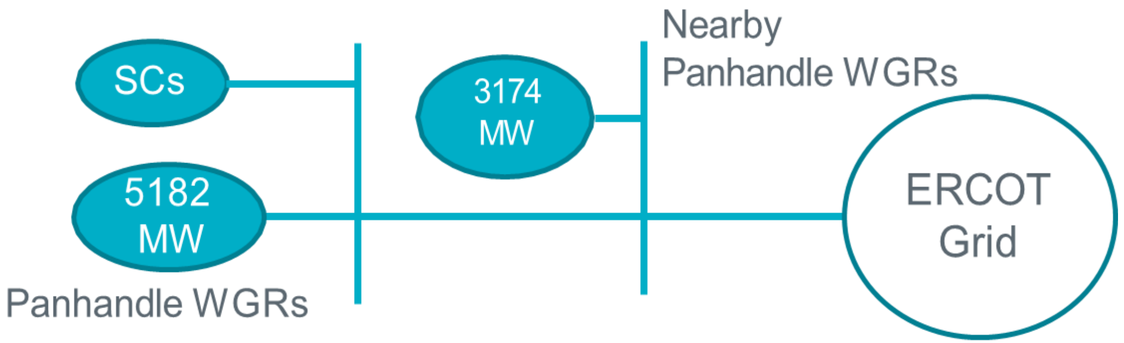
Impact of SynCons on Panhandle Export Limit

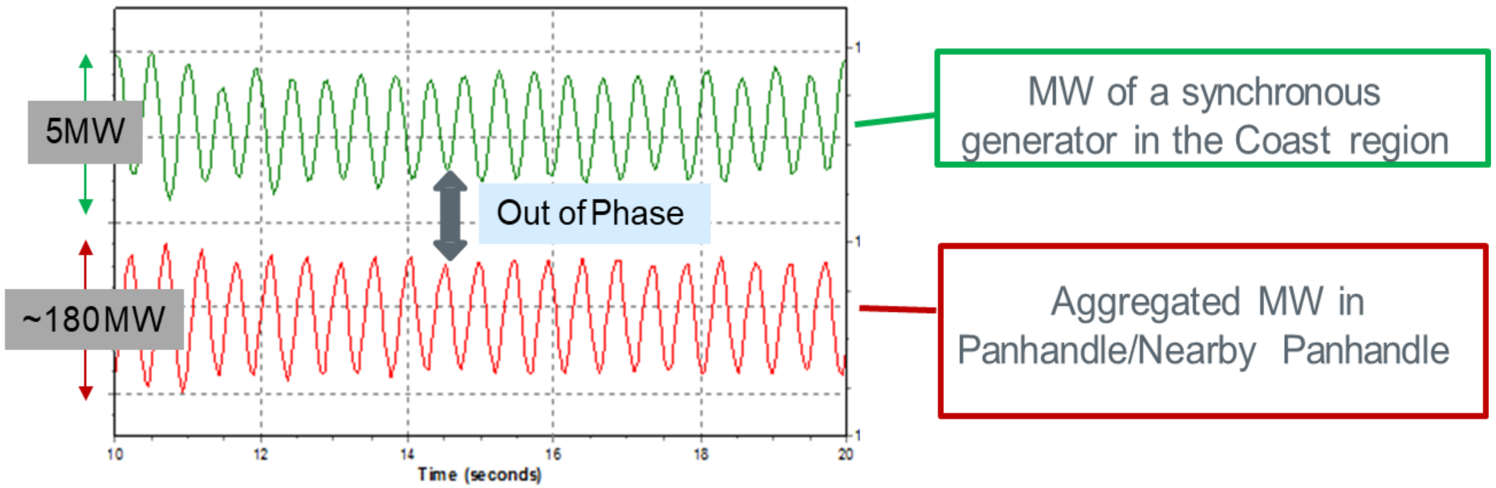
- SynCons have enabled increase in Panhandle export limit by ~470 MW.
- The benefit may diminish with additional IBRs and topology changes.



Intra-Area Oscillations Observed with SynCons

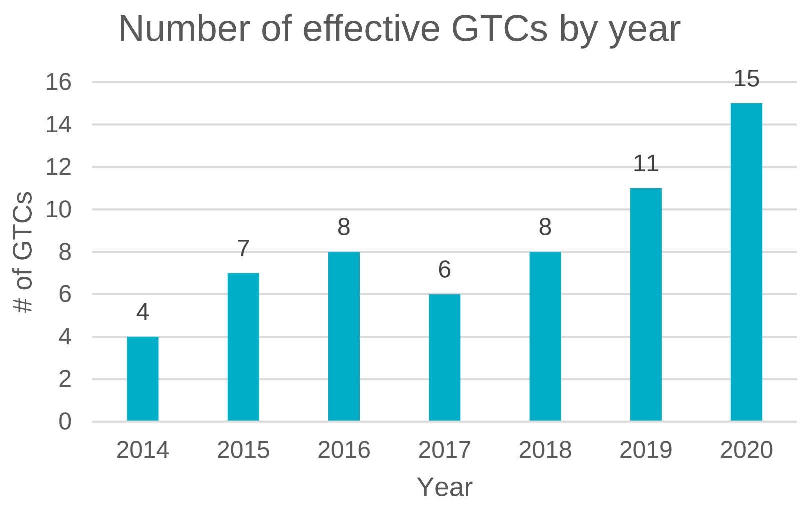
- 2019 Panhandle dynamic studies identified oscillatory behavior (~1.8 Hz) between SynCons and rest of ERCOT's synchronous generators.

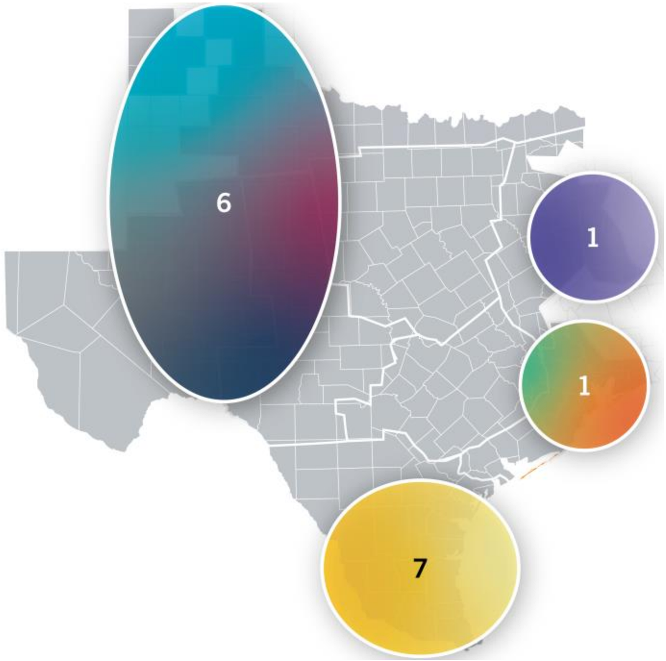




Increasing Stability Constraints

- Much of the IBR growth is concentrated in West and South Texas, contributing to stability constraints associated with the long-distance transfer of power to urban load centers.
- These stability constraints can limit power transfers below the physical thermal ratings of the individual transmission lines.
- A Generic Transmission Constraint (GTC) is a tool that ERCOT uses to manage stability limitations in real-time operations.
- ERCOT has seen an increase in stability constraints in recent years, particularly in West Texas and South Texas, which has led to an overall increase in the number of GTCs.
- ERCOT needs better real time tools to identify and manage stability constraints.

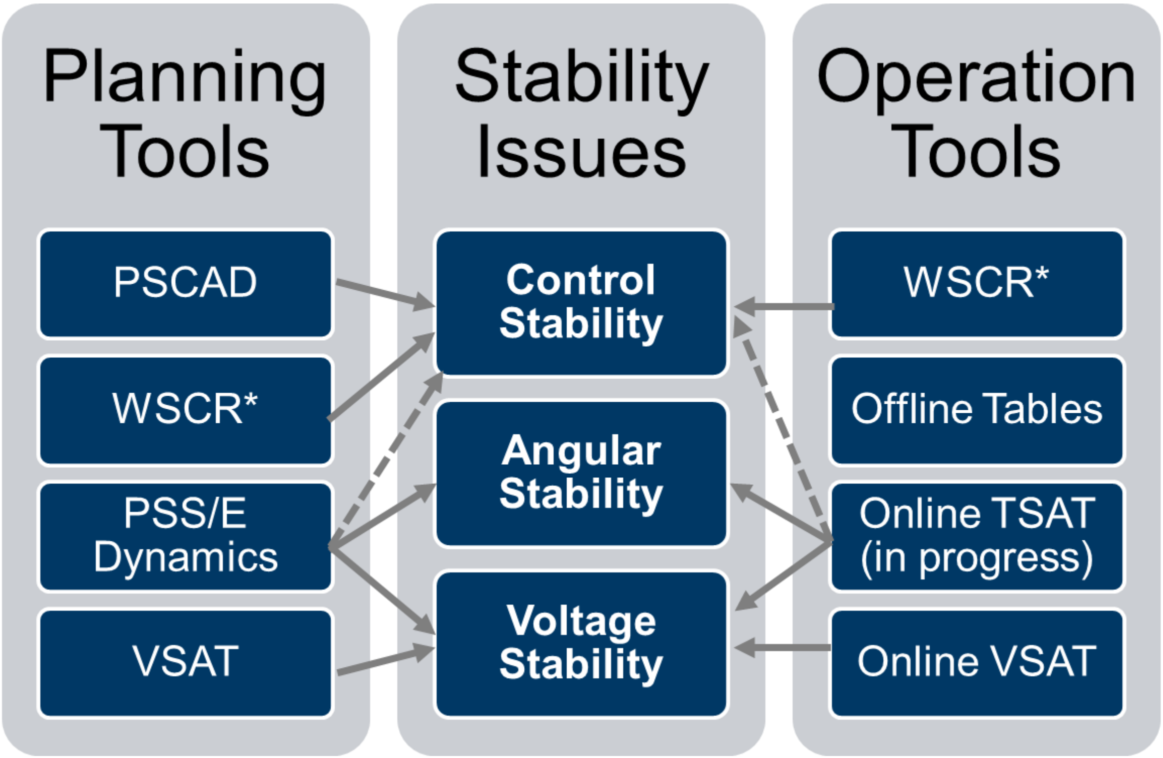




Stability Assessment and Tools

- With more IBR
  - Increasing stability challenges
  - Require PSCAD studies: complex and time consuming

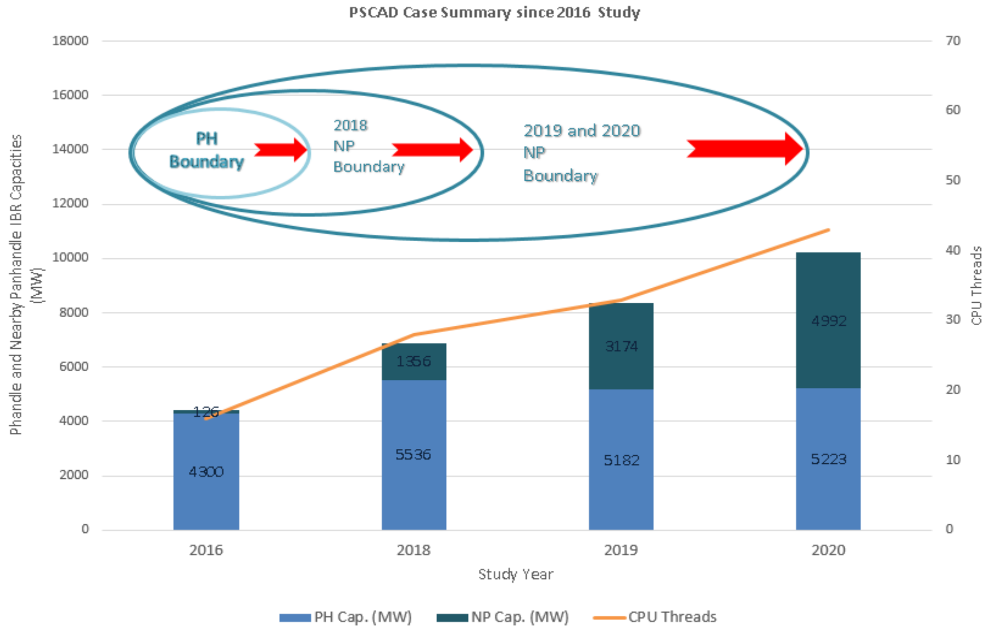
- Needs and improvements
  - Model accuracy and usability
  - Tool and simulation efficiency
  - Better communication and coordination

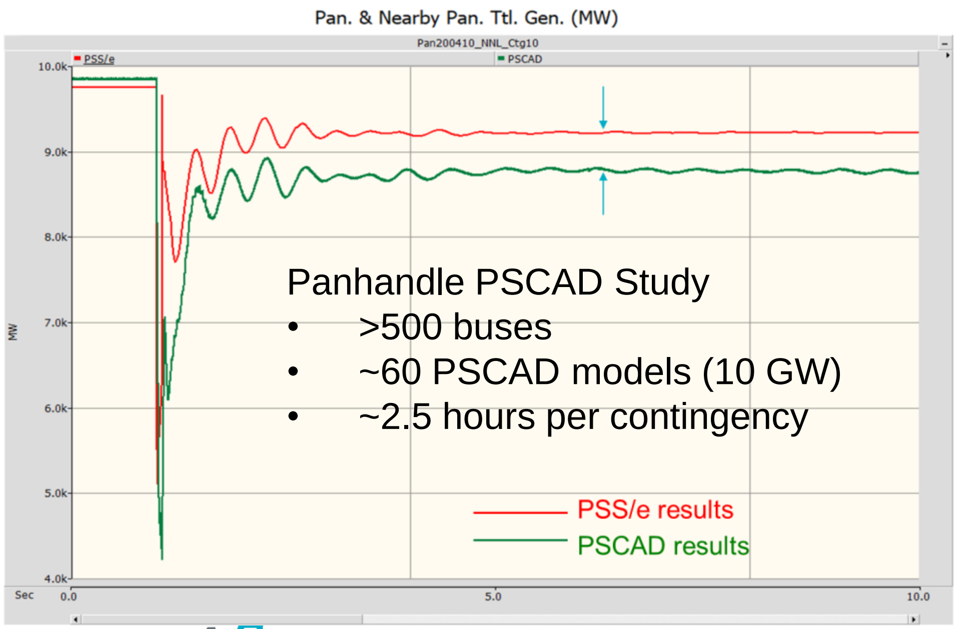


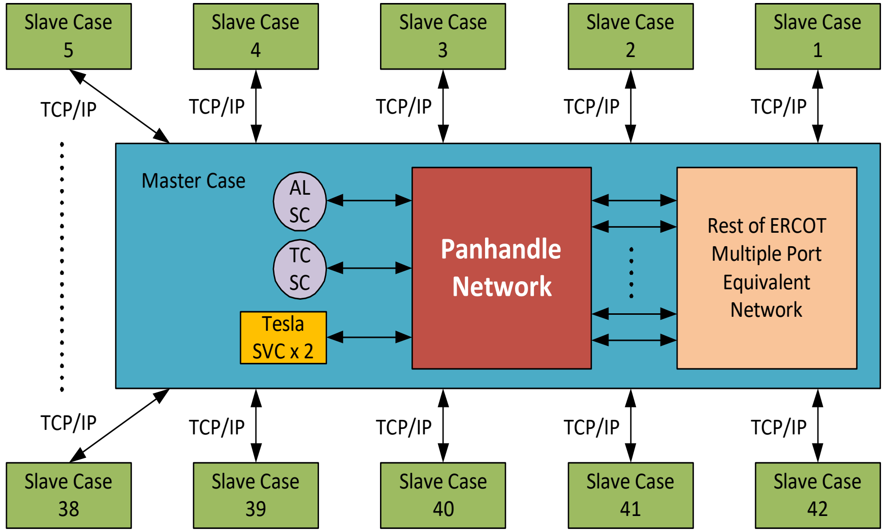
* WSCR (weighted short circuit ratio) is used to identify the system strength of an area with multiple IBRs. Detailed PSCAD studies are required to validate the adequacy of WSCR application and its threshold for weak grid identification.

EMT (PSCAD) Studies

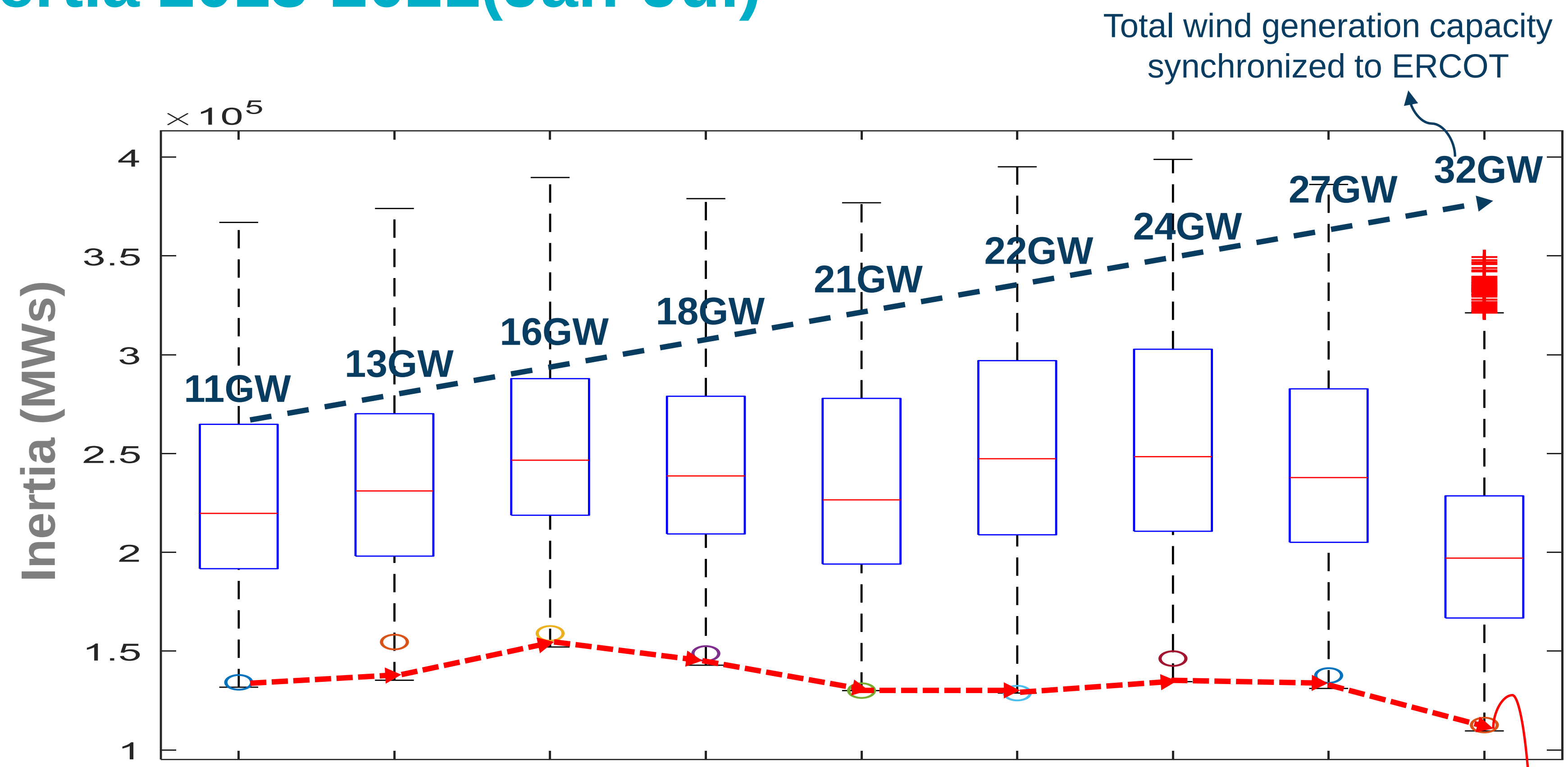
- Require regular PSCAD studies
  - To assess the instability that may not be identified in PSS/E.
  - To confirm the adequacy of dynamic models and simulation tools.
  - To identify the adequacy and threshold of WSCR application.







ERCOT Inertia 2013-2021(Jan-Jul)



Date	2013	2014	2015	2016	2017	2018	2019	2020	2021
Min synch. Inertia (GW*s)	132	135	152	143	130	128.8	134.5	131.1	109
System load at min. synch. Inertia (GW)	24.7	24.6	27.2	27.8	28.4	28.4	29.9	30.7	32.6
Non-synch. Gen. in % of System Load	31	34	42	47	54	53	50	57	65

Inertia and Frequency Containment

- Defined critical inertia level as minimum level of system inertia that will ensure frequency containment reserve has sufficient time to respond before frequency reaches 59.3 Hz (UFLS threshold).
- Monitoring of inertia in real-time and forecasting several hours ahead.
- If inertia is getting close to critical level, operator will start additional synchronous generation to bring inertia back up.
- Above critical inertia, based on expected inertia conditions, needed amounts of frequency containment reserves are procured.
- Faster frequency response is more effective than traditional governor response in low inertia conditions.
- Fast Frequency Response has been introduced to ensure faster and earlier response. This allows reduction of critical inertia level and reduces overall amount of frequency containment reserves.

Summary: ERCOT Practices and Experience

- Increasing stability and system strength challenges with more IBRs connected to the grid
  - Complex, time consuming, model and tool adequacy
  - Additional stability challenges (control instability, overvoltage/high voltage collapse)
  - May require tight voltage control (may no longer be a local issue)
  - Identification and management of stability constraints in planning and operations
  - Early communication and coordination is always better
  - Continue to explore ways to reliably operate under weak grid conditions or improve the system strength
- Diminishing inertia and faster rate of change of frequency with more IBRs
  - Can be addressed through inertia floor and adequate amounts of reserves
  - Faster Frequency Response helps to reduce critical inertia and amounts of reserves needed.

Appendix References

- http://www.ercot.com/content/wcm/lists/168284/ERCOT_Model_Quality_Guideline.zip
- http://www.ercot.com/content/wcm/key_documents_lists/89026/2020_PanhandleStudy_public_final__004_.pdf
- http://www.ercot.com/content/wcm/key_documents_lists/89026/The_Use_of_GTCs_in_ERCOT_July_2020.pdf
- http://www.ercot.com/content/wcm/lists/144927/Panhandle_and_South_Texas_Stability_and_System_Strength_Assessment_March....pdf
- http://www.ercot.com/content/wcm/lists/144927/Dynamic_Stability_Assessment_of_High_Penetration_of_Renewable_Generation_in_the_ERCOT_Grid.pdf
- http://www.ercot.com/content/wcm/lists/144927/Inertia_Basic_Concepts_Impacts_On_ERCOT_v0.pdf#:~:text=This%20white%20paper%20describes%20ERCOT%20staff%E2%80%99s%20initiatives%20to,the%20future.%20The%20paper%20is%20structured%20as%20follows%3A
- http://www.ercot.com/content/wcm/key_documents_lists/108744/05._RRS_Study_2017_Methodology_11022017.docx
- https://www.youtube.com/watch?v=029gAj7xr30 (ESIG webinar on evolution of ERCOT’s frequency control)