Managing System Oscillations in the ERCOT System

Yunzhi Cheng
Manager of Operations Stability Analysis, ERCOT
Co-Chair of IEEE IBR SSO Taskforce

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OUTLINE

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- About ERCOT and ERCOT IBR SSO Events
- ERCOT's Efforts to manage the IBR SSO
  - MQT (model quality test) – Planning
  - Large scale PSCAD simulation – Planning
  - GTC (generic transmission constrain) – Operations
  - WSCR (weighted short-circuit ratio) – Planning & Operations
  - GFM (grid-forming) – Planning & Operations
  - Synchronous Condenser & Series Capacitor – Planning & Operations

Limited Disclosure

IEEE IBR SSO Taskforce

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Real-World Subsynchronous Oscillation Events in Power Grids With High Penetrations of Inverter-Based Resources

Yunzhi Cheng, *Senior Member, IEEE*, Lingling Fan, *Fellow, IEEE*, Jonathan Rose, Shun-Hsien Huang, John Schmall, Xiaoyu Wang, *Senior Member, IEEE*, Xiaorong Xie, *Senior Member, IEEE*, Jan Shair, Jayanth R. Ramamurthy, *Senior Member, IEEE*, Nilesh Modi, Chun Li, *Senior Member, IEEE*, Chen Wang, Shahil Shah, *Senior Member, IEEE*, Bikash Pal, *Fellow, IEEE*, Zhixin Miao, *Senior Member, IEEE*, Andrew Isaacs, Jean Mahseredjian, *Fellow, IEEE*, and Jenny Zhou, *Senior Member, IEEE*

***Abstract*—This paper presents a survey of real-world subsynchronous oscillation events associated with inverter-based resources (IBR) over the past decade. The focus is on those oscillations in the subsynchronous frequency range known to be influenced by power grid characteristics, e.g., series compensation or low system strength. A brief overview of the historical events is presented followed by detailed descriptions of a series of events. This paper also examines causation mechanisms and proposes future research directions to meet grid needs worldwide.**

***Index Terms*—Inverter-based resources, oscillations, stability.**

I. Introduction

PENETRATIONS of inverter-based resources (IBRs) are increasing worldwide. The maximum instantaneous penetration levels of IBRs in South Australia, Texas, Ireland, and Tasmania have reached 150%, 66%, 92%, and 95%, respectively [1]. The operation with such high levels of IBRs has introduced undesirable dynamics, including subcycle overvoltage [2], ac overcurrents [3] and subsynchronous oscillations (SSOs) [4], [5]. Stability issues related to IBRs have caught attention by

IBR SSO

IBR SSO

Series Capacitor + Type 3 WTG

Typical Example: 2009 South Texas SSCI Event

High Penetration of IBRs in Weak Grid

Typical Example: 2015 Northwest China SSO Event

Y. Cheng *et al.*, "Real-World Subsynchronous Oscillation Events in Power Grids with High Penetrations of Inverter-Based Resources," in *IEEE Transactions on Power Systems*, 2023

Some Reported IBR SSO Events

Year	Location	Frequency (Hz)	Mechanism
2021	Scotland	8	Offshore WTG + Weak grid (?)
2020 – 2021	West Murray, Australia	15 – 20	IBR + Weak grid (?)
2019	Great Britain	9	Offshore WTG + Weak Grid
2015 – 2019	West Murray, Australia	7	IBR + Weak Grid
2017	First Solar, USA	7	Solar PV + Weak Grid
2015	Northwest China	27 – 34	Type 4 WTG + Weak Grid
2015	Hydro One, Canada	20	Solar PV + Weak Grid
2011	Texas, USA	4	Type 4 WTG + Weak Grid
2023	South Texas, USA	20 – 30	Type 3 WTG + Series Cap.
2017	South Texas, USA	20 – 30	Type 3 WTG + Series Cap.
2012 – 2016	North China	3 – 12	Type 3 WTG + Series Cap.
2009	South Texas, USA	20 – 30	Type 3 WTG + Series Cap.

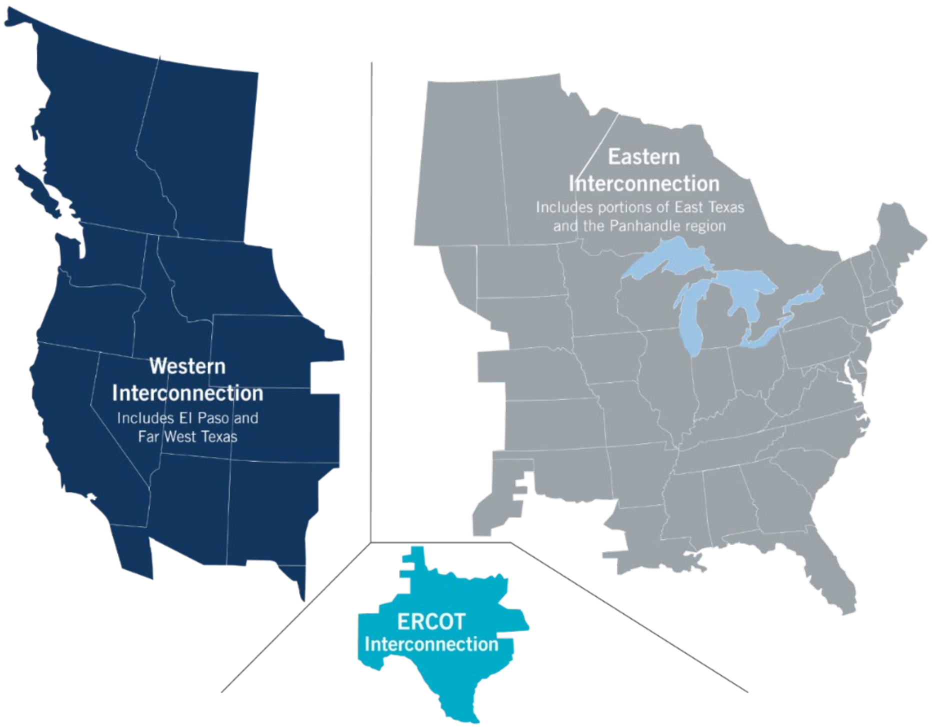
Y. Cheng *et al.*, "Real-World Subsynchronous Oscillation Events in Power Grids with High Penetrations of Inverter-Based Resources," in *IEEE Transactions on Power Systems*, 2023

The ERCOT Region

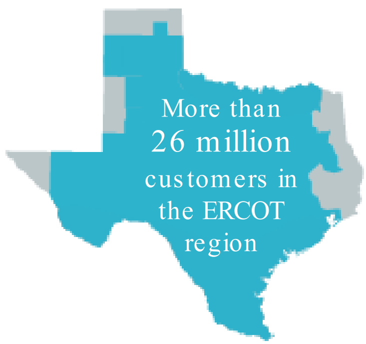
The interconnected electrical system serving most of Texas, with limited external connections

- 90% of Texas electric load; 75% of Texas land
- 85,508 MW peak, August 10, 2023
- More than 54,100 miles of transmission lines
- 1250+ generation units (including PUNs)

ERCOT connections to other grids are limited to ~1,220 MW of direct current (DC) tie capacity



ERCOT Quick Facts



90% of Texas Load

75% of load is competitive choice customers

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

1,100+
generating units, including PUNs

52,700+
miles of high-voltage transmission

98,000+ MW
of expected capacity for summer 2023 peak demand

$3,3 billion
transmission projects endorsed in 2022

1,873+
active market participants that generate, move, buy, sell or use wholesale electricity

85,508 MW
Record peak demand (August 10, 2023, 5-6 pm)

85,116 MW
Weekend peak demand record (August 20, 2023, 4-5 pm)

37,725 MW
of installed wind capacity

17,040 MW
of installed solar capacity

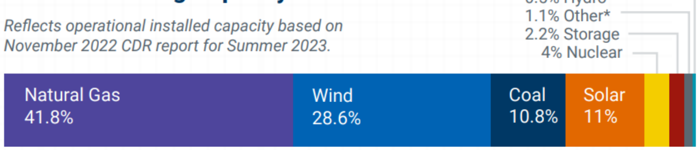
27,548 MW
Wind generation record (Jan. 7, 2024)

13,944 MW
Solar generation record (Dec. 29, 2023)

69.15%
Wind penetration record (April 10, 2022, 1 am)

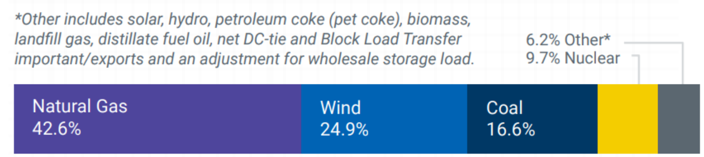
32.93%
Solar penetration record (April 30, 2023, 10 am)

2023 Generating Capacity

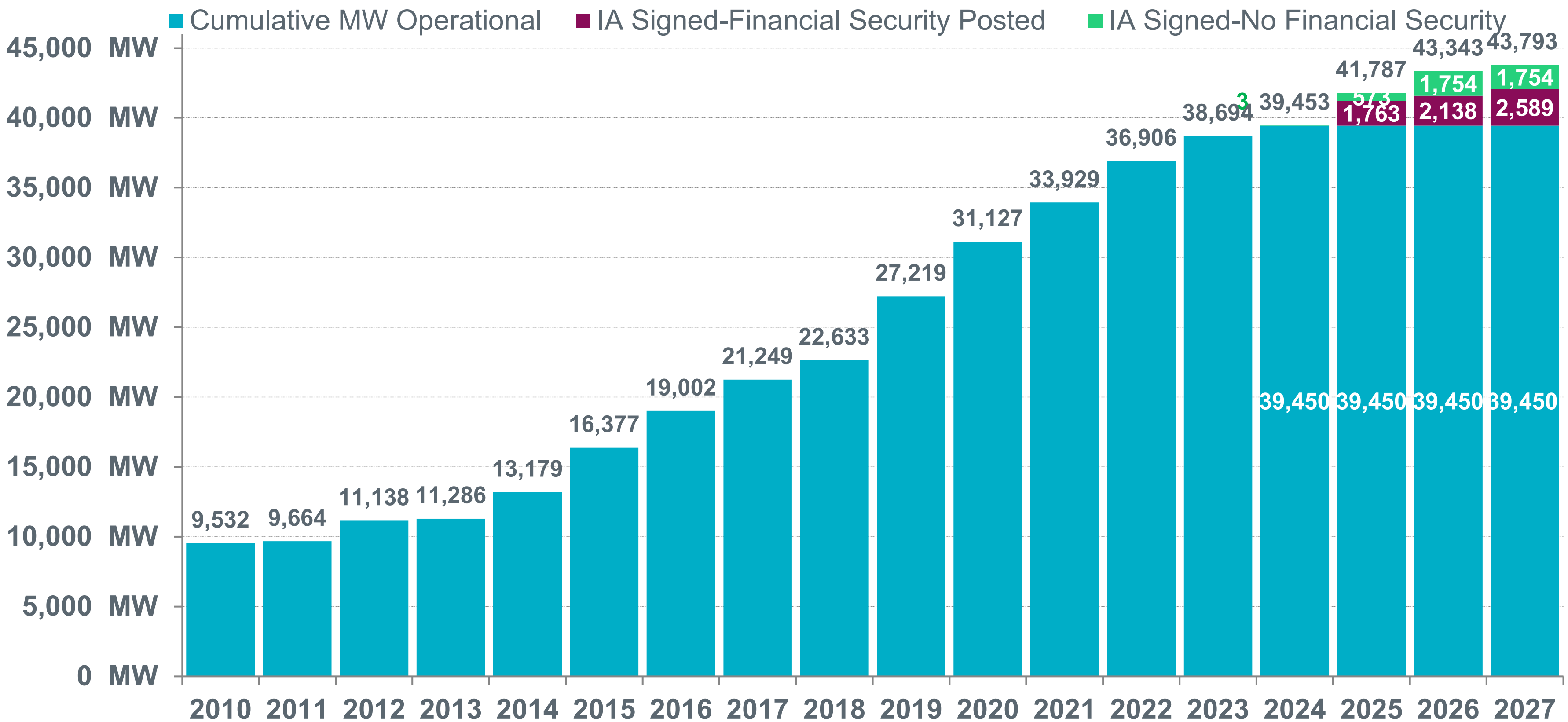


The sum of the percentages may not equal 100% due to rounding.
**Other includes biomass and DC Tie capacity.*

2022 Energy Use

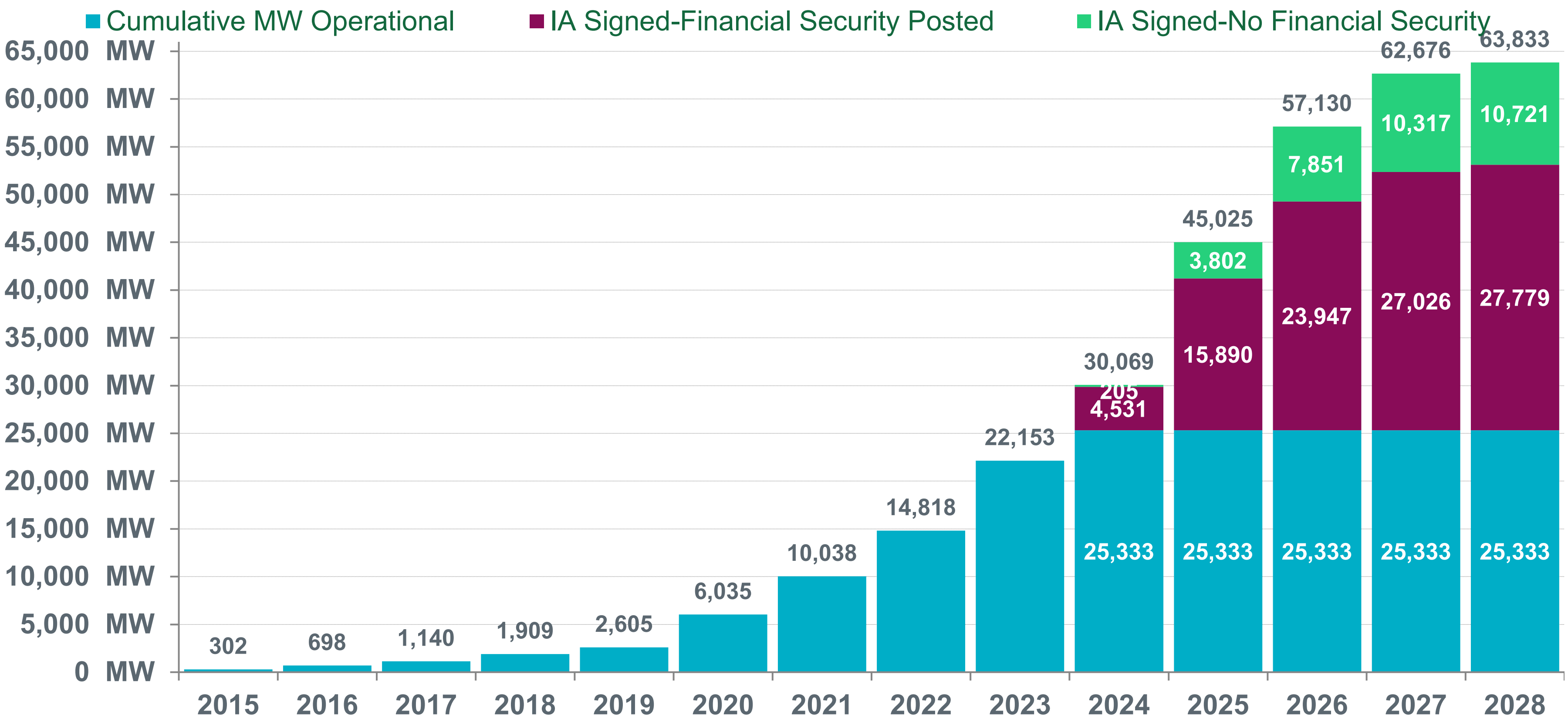


ERCOT Wind Additions by Year



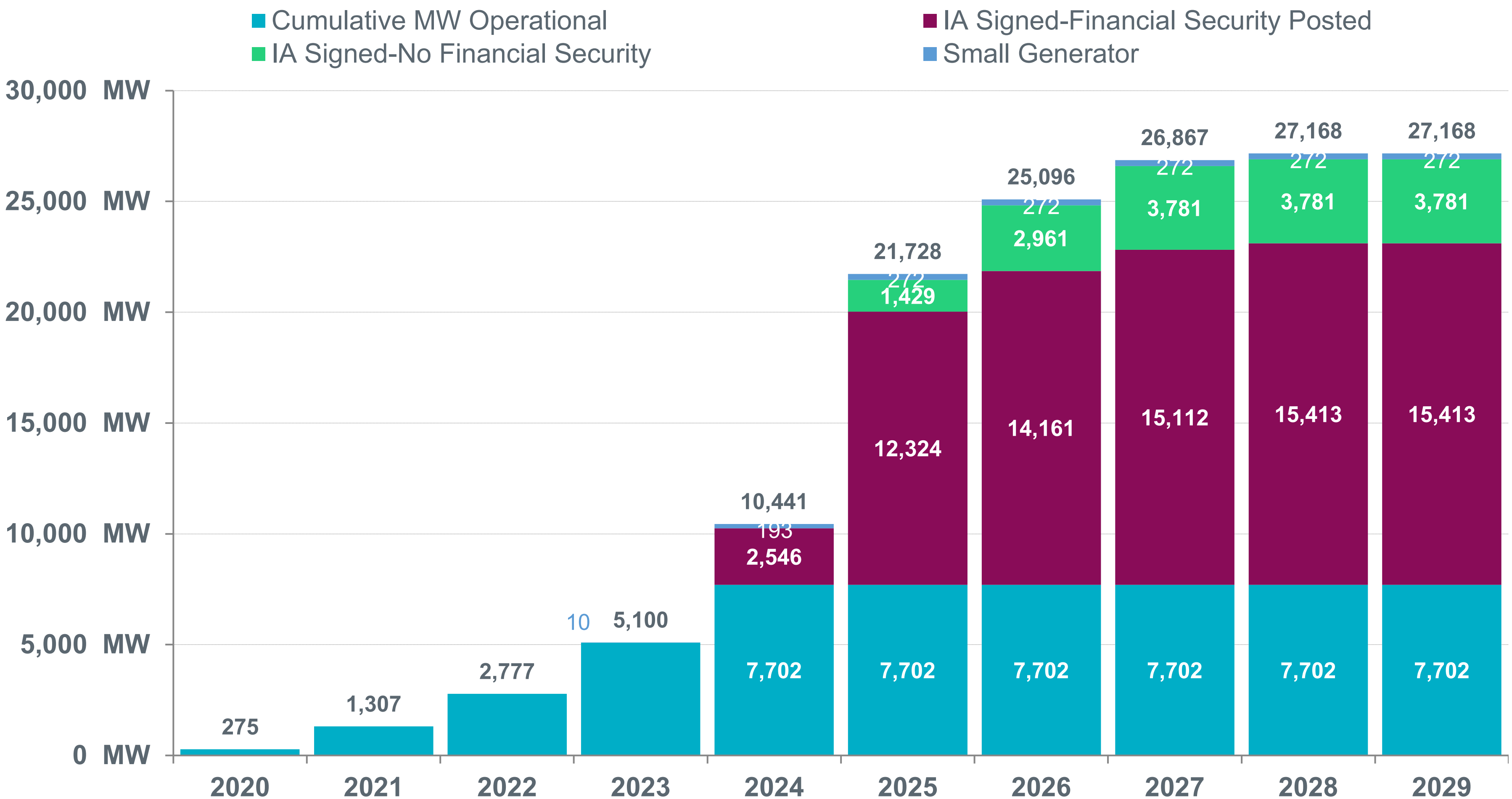
*as of June 30, 2024

ERCOT Solar Additions by Year



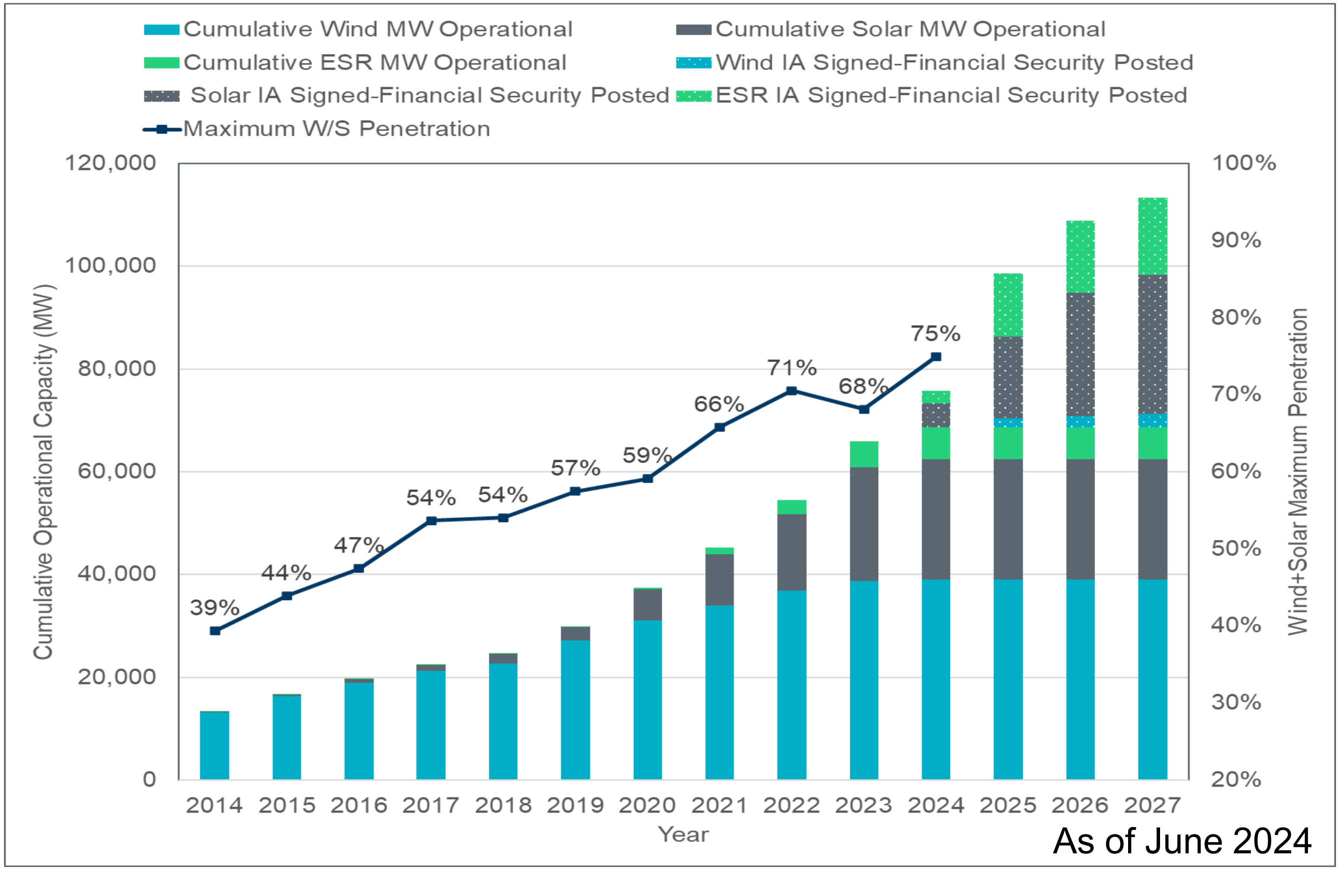
*as of June 30, 2024

ERCOT Battery Additions by Year



*as of June 30, 2024

ERCOT IBR Growth

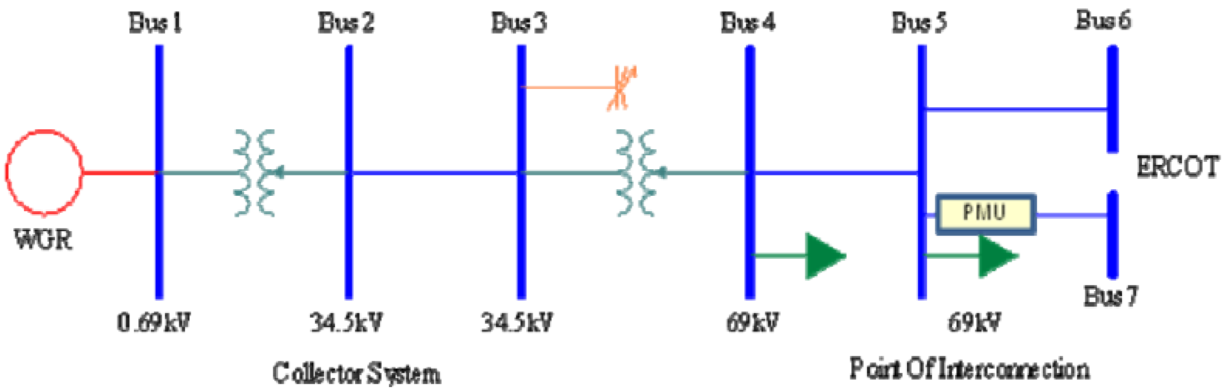


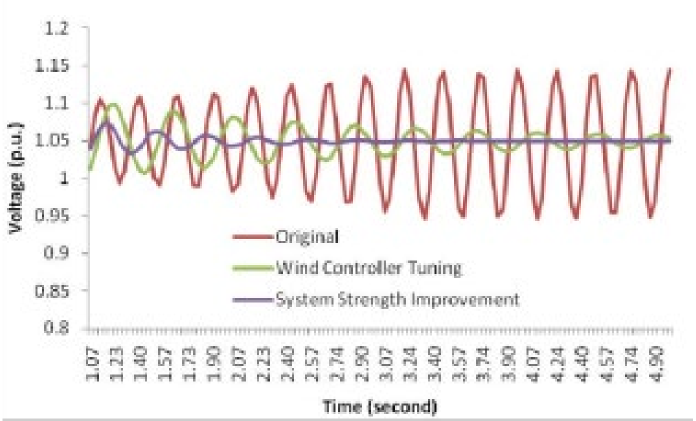
ERCOT could exceed 100 GW IBRs connection by 2025. Further growth is also projected based on the current ERCOT resource capacity trend.

https://www.ercot.com/gridinfo/resource

Weak Grid related SSO Event in ERCOT

- Local SSO event in 2011
- Undamped oscillation (~4 Hz) was observed at high wind speed with the line of Bus 5 – 6 in outage (SCR dropped to 2)

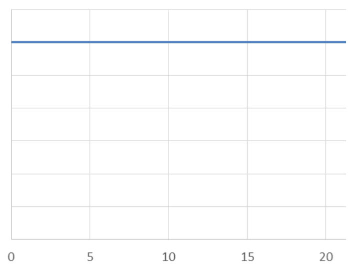


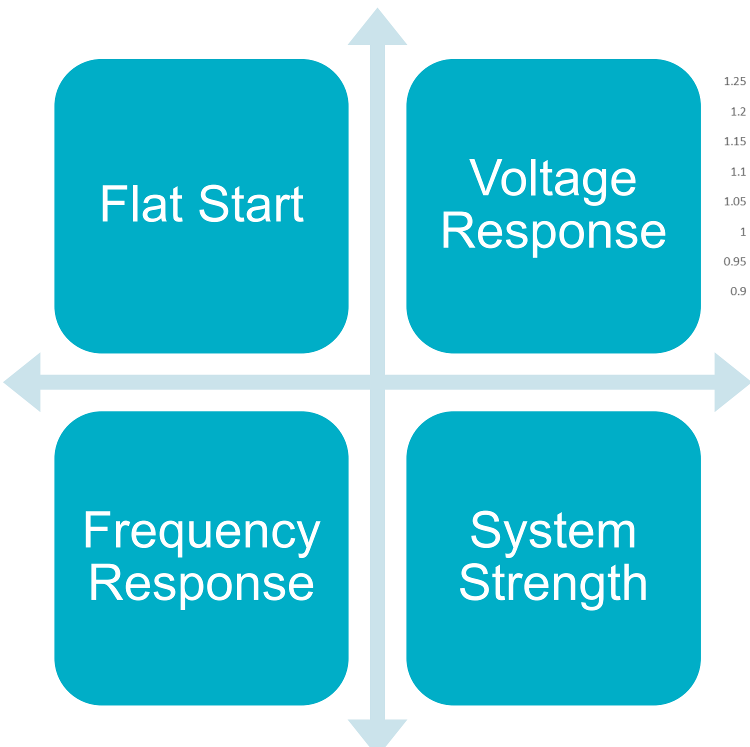


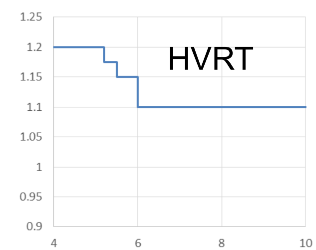
Reference: Shun-Hsien (Fred) Huang, etc., "Voltage Control Challenges on Weak Grids with High Penetration of Wind Generation: ERCOT Experience", 2012 IEEE PES GM

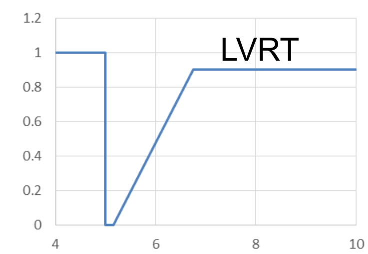
Model Quality Test (MQT)

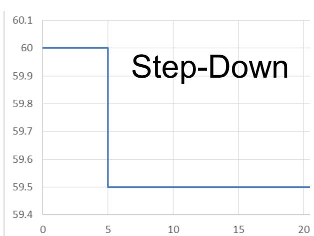
- System Strength (SCR) Test with minimum requirement of SCR = 1.5
- DMView tool for PSS/e available at https://sites.google.com/view/dmview/home
- PMView tool for PSCAD available at https://sites.google.com/view/pmview/home

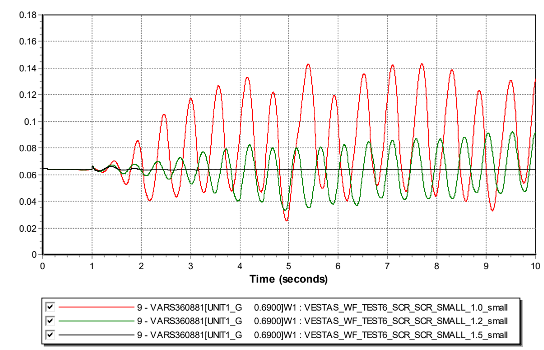






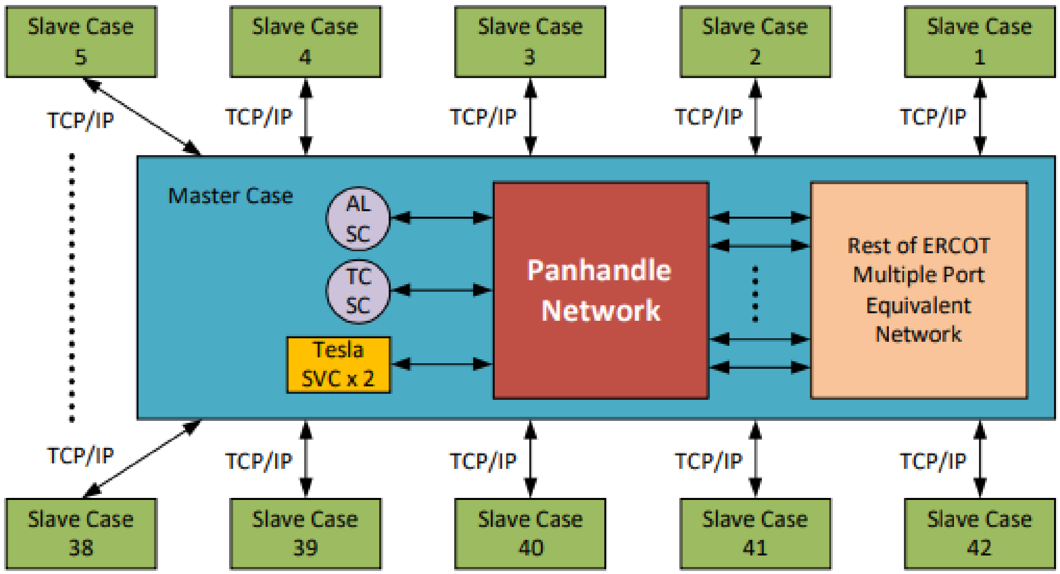






Large Scale PSCAD Simulation

- 2020 Panhandle Study (PSS/e & PSCAD)
  - 46 IBR projects (>10GW)
  - 43 PSCAD cases created for parallel simulation
  - ETRAN Plus tool is used for PSCAD parallel simulation

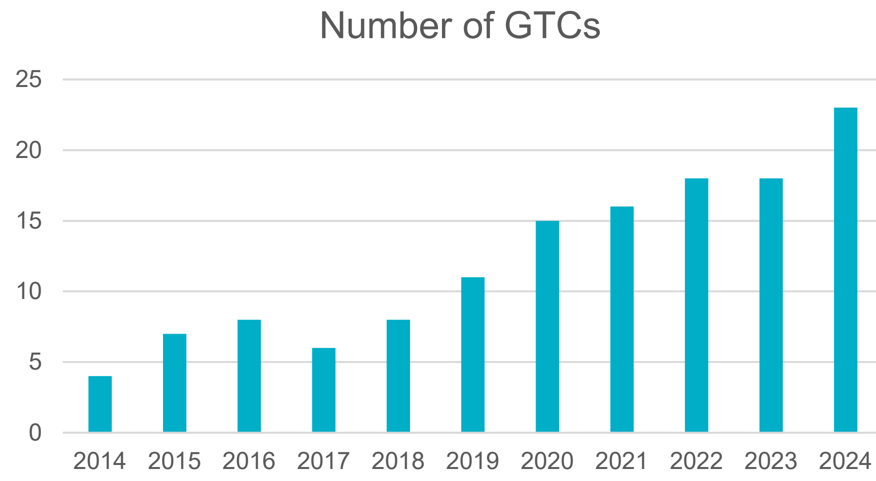


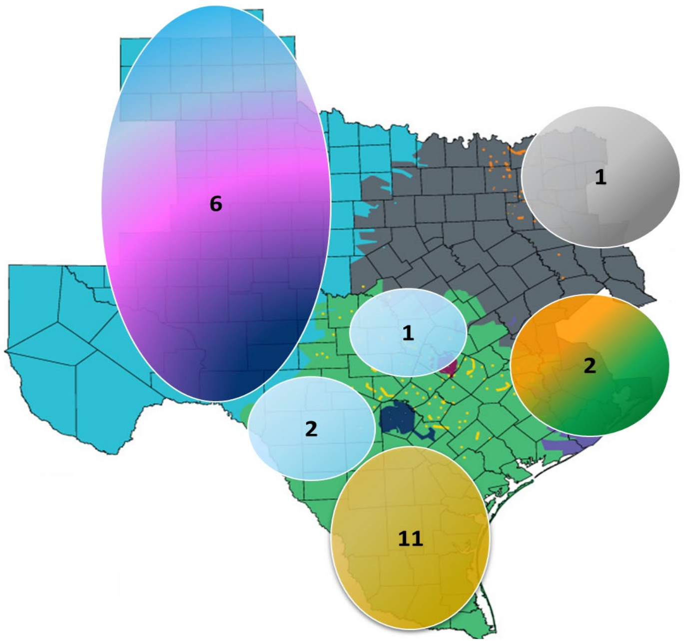
  - For the stable scenarios, the overall performances from PSCAD simulations were consistent with that from PSS/e simulations
  - PSCAD studies are necessary to evaluate potential control stability issues

"2020 Panhandle Regional Stability Study, available at "https://www.ercot.com/files/docs/2020/11/27/2020_PanhandleStudy_public_final__004_.pdf

GTC (Generic Transmission Constrain)

- A Generic Transmission Constraint (GTC) is a tool that ERCOT uses to manage stability limitations (including weak grid related SSO) 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.
- Most of GTC are based on off-line PSS/e dynamic simulation. ERCOT is in the process of implementing real-time stability assessment tool (TSAT) to identify and determine the proper stability constraints based on the real time system conditions. Damping ratio is one of criteria for the stability assessment.

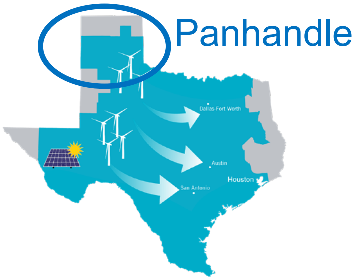




Limited Disclosure

System Strength (Weak Grid) and WSCR

- System strength identified in the simulation of Panhandle area
  - Far away from load centers
  - No synchronous generators
  - No Load
  - All the resources are IBRs (~5GW)



- Two synchronous condensers (175MVA each) were added to Panhandle in 2018
- ERCOT proposed the concept of WSCR (Weighted Short Circuit Ratio) to measure the Panhandle system strength based on actual output of the Panhandle IBRs

$$WSCR = \frac{\sum_i^N S_{SCMVAi} * P_i}{\left(\sum_i^N P_i\right)^2}$$

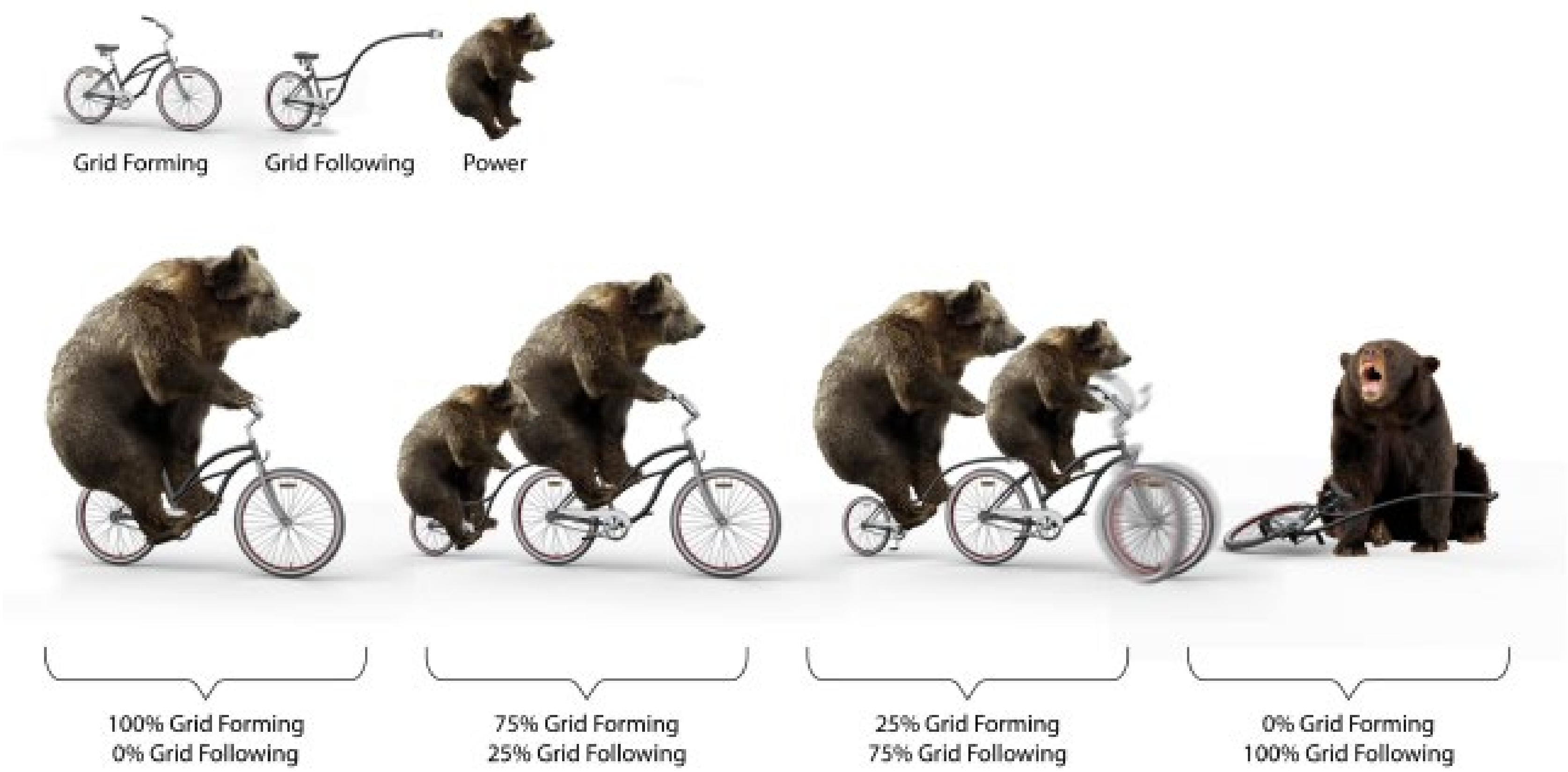
- WSCR=1.5 was proposed as the minimum pre-contingency system strength and implemented in real time operations to limit the Panhandle IBRs output based on the system strength
- WSCR index was retried in 2021 with transmission system upgrade in Panhandle

Y. Zhang, etc., "*Evaluating System Strength for Large-Scale Wind Plant Integration*," in Power and Energy Society General Meeting, 2014 IEEE

Grid Forming

- NERC definition: GFM (Grid Forming) IBR controls **maintain an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame**. This allows the IBR to immediately respond to changes in the external system and maintain IBR control stability during challenging network conditions. The voltage phasor must be controlled to maintain synchronism with other devices in the grid and must also regulate active and reactive power appropriately to support the grid

Grid Forming vs Grid Following



https://www.nrel.gov/docs/fy20osti/75848.pdf

Grid Forming

- ERCOT contracted Electranix in late 2023 to help recommend the required IBR advanced grid support capability and test framework
- ERCOT also reached out to major IBR OEMs to understand the existing and potential advanced grid support capability (like GFM)
  - OEMs for inverter-based ESRs, including Tesla, SMA, Sungrow, and Power Electronics, shared their GFM BESS models to support this project
  - OEMs for wind and solar currently **don't** have commercially available product

https://www.ercot.com/files/docs/2024/07/09/2024_07_ERCOT_IBRWG_ERCOT%20Advanced%20Grid%20Support%20Inverter-based%20ESRs%20Assessment%20and%20Adoption%20Discussion_v1_.pdf

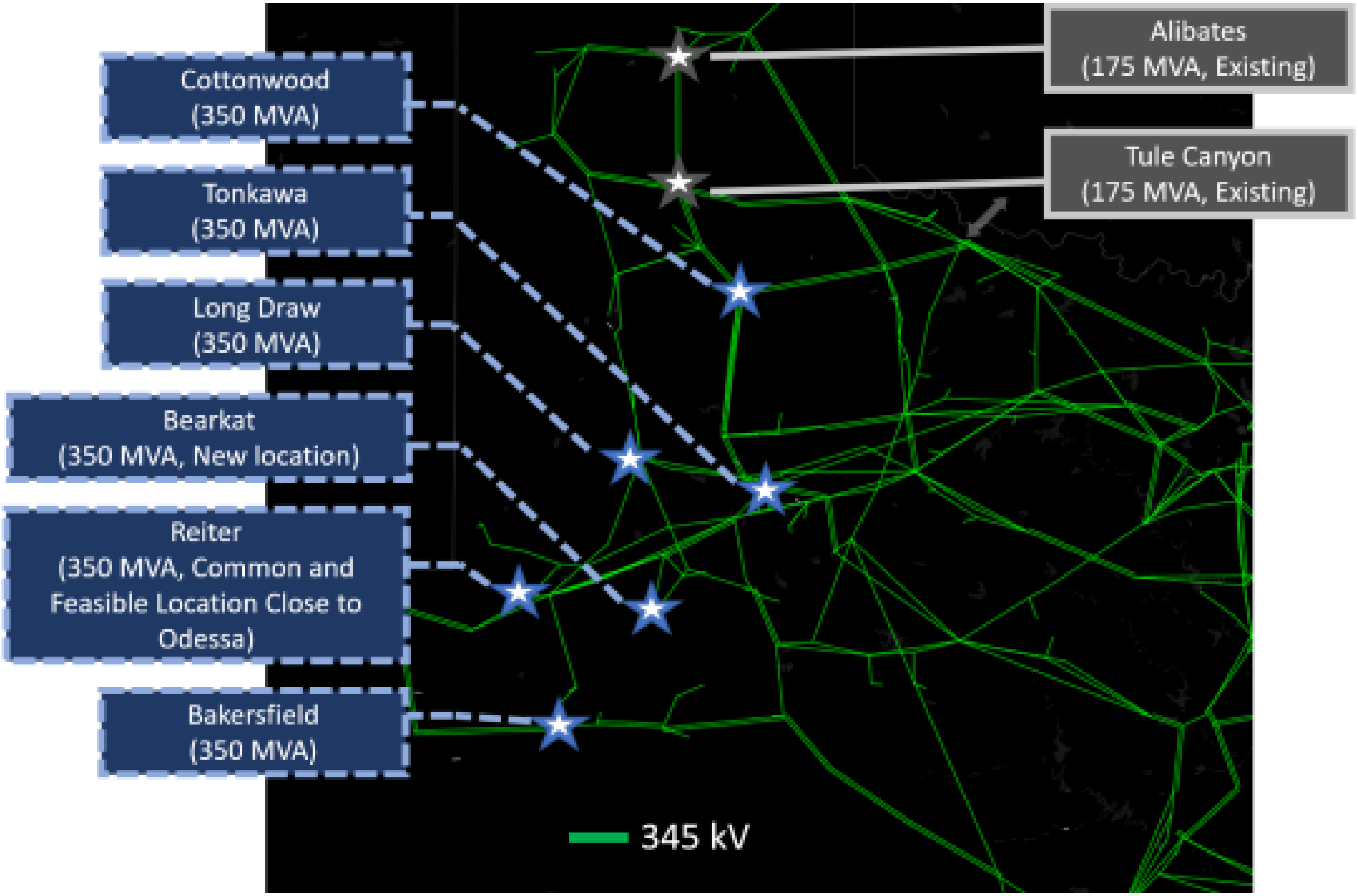
Grid Forming

- ERCOT plans to propose standards for GFM inverter-based Energy Storage Resources (ESRs)
  - Voluntary first; mandatory for new inverter-based ESRs at a near future date
- Inverter-based ESRs are commercially available today to provide advanced grid support; and generally, only require software/control changes with no impact to the hardware or commercial operations
- ERCOT's preliminary assessments have identified the improvement of system stability performance and the benefits to the generic transmission constraints (GTCs)

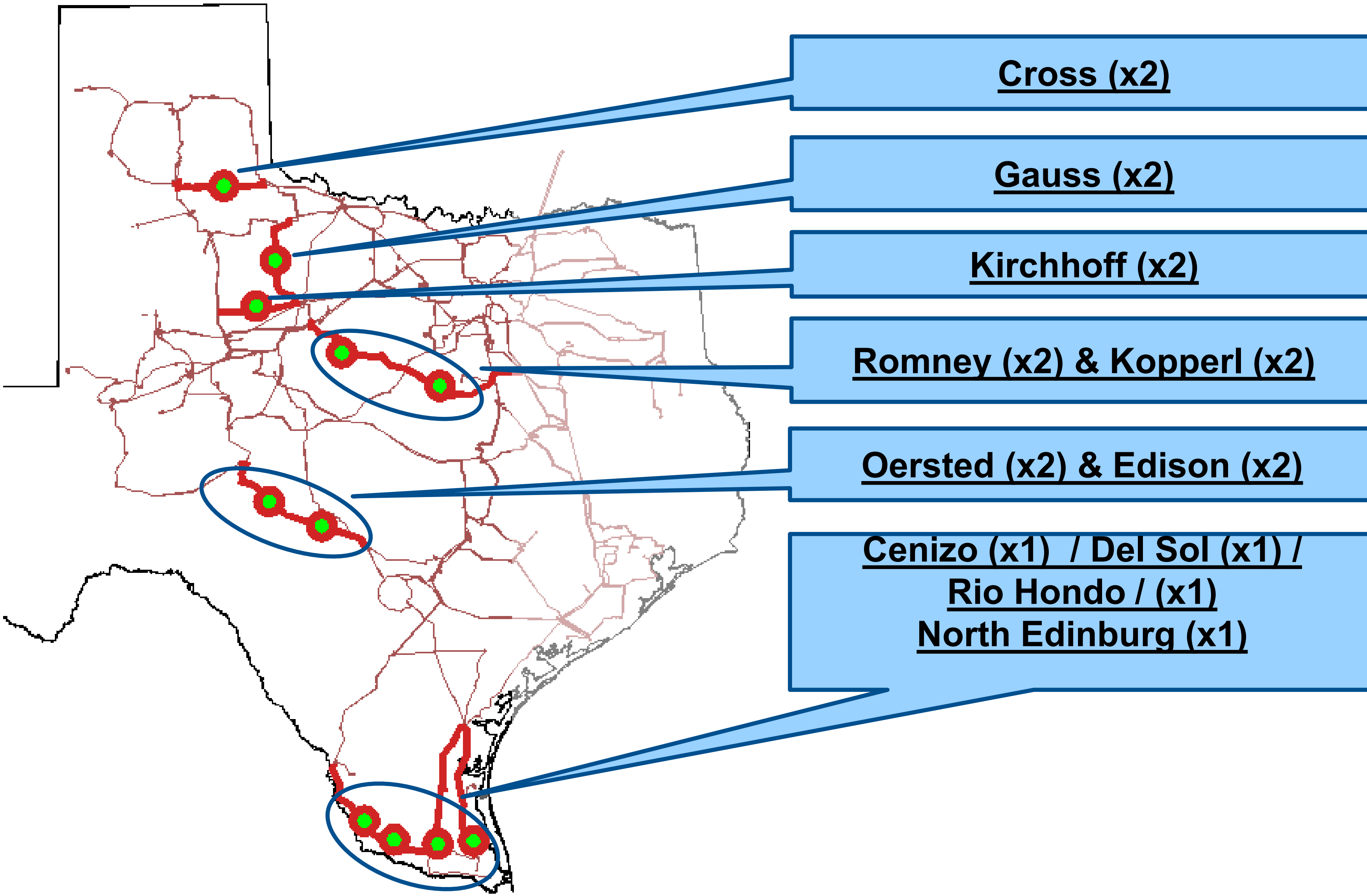
https://www.ercot.com/files/docs/2024/07/09/2024_07_ERCOT_IBRWG_ERCOT%20Advanced%20Grid%20Support%20Inverter-based%20ESRs%20Assessment%20and%20Adoption%20Discussion_v1_.pdf

Six Synchronous Condensers (SynCons) in WTX

- A total of six new SynCons (2100MVA) were identified to increase the system strength of WTX (>40GW IBRs)

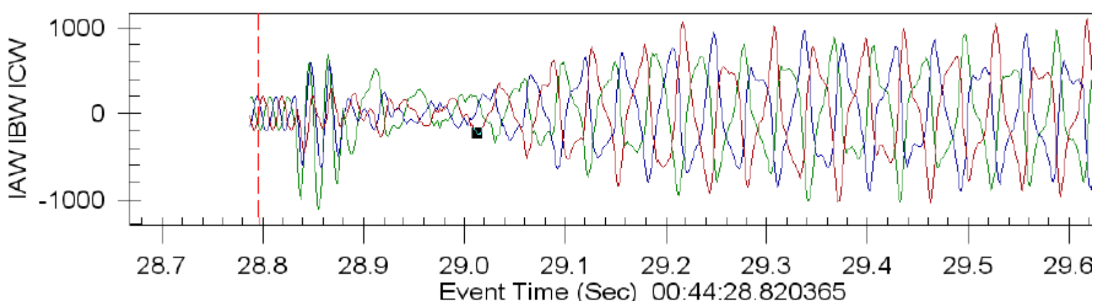


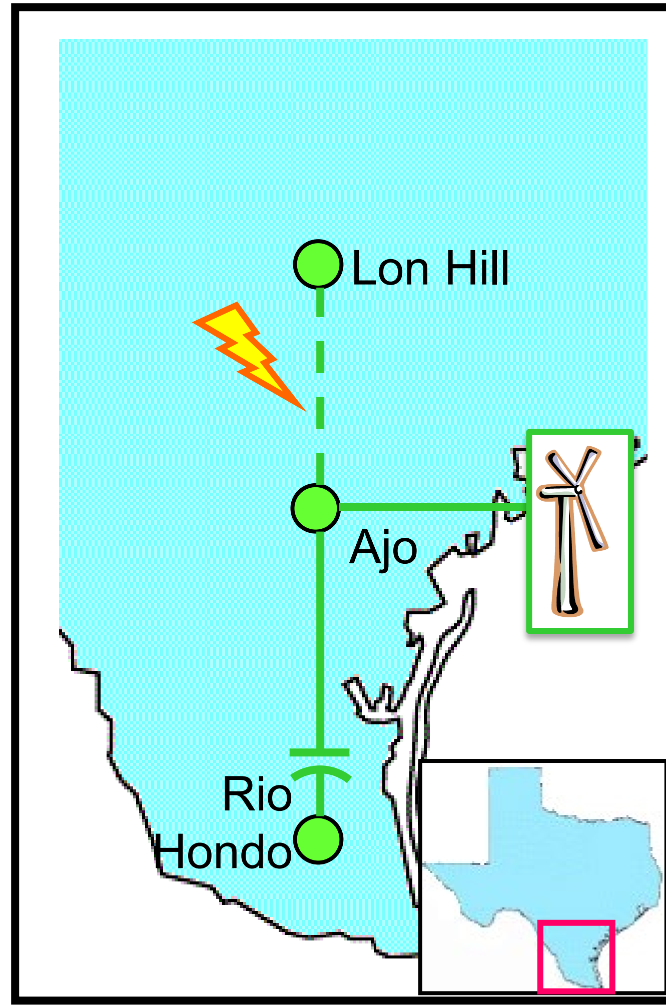
Series Capacitors in ERCOT



South Texas 2009 Event

- Series capacitors installed on long 345 kV line in South Texas.
- A cluster of wind farms (DFIG) connected to Ajo.
- In 2009, a fault caused LonHill – Ajo line to trip, leaving wind radially connected to series caps.
- Very high currents resulted in damage.





References

- “ERCOT SSR Study Scope Guidelines”, available at: https://www.ercot.com/files/docs/2020/12/04/ERCOT_SSR_Study_Scope_Guideline_10-27-2020-external.docx
- Y. Cheng *et al*., "Real-World Subsynchronous Oscillation Events in Power Grids with High Penetrations of Inverter-Based Resources," in *IEEE Transactions on Power Systems*, 2023
- Y. Cheng et al., "A Series Capacitor Based Frequency Scan Method for SSR Studies," in *IEEE Transactions on Power Delivery*, vol. 34, no. 6, 2019.
- Y. Cheng et al., “Subsynchronous Resonance Assessment for A Large System with Multiple Series Compensated Transmission Circuits”, *IET Renewable Power Generation*, vol. 1, no. 1, 2019
- Y. Cheng, et al., "ERCOT subsynchronous resonance topology and frequency scan tool development," *2016 IEEE Power and Energy Society General Meeting (PESGM)*
- Y. Cheng, et al., "Reactance Scan Crossover-Based Approach for Investigating SSCI Concerns for DFIG-Based Wind Turbines," in *IEEE Transactions on Power Delivery*, vol. 28, no. 2, 2013
- X. Xie, et al., "Investigation of SSR in Practical DFIG-Based Wind Farms Connected to a Series-Compensated Power System," in *IEEE Transactions on Power Systems*, vol. 30, no. 5, 2015
- B. Badrzadeh, et al., "General Methodology for Analysis of Sub-Synchronous Interaction in Wind Power Plants," in *IEEE Transactions on Power Systems*, vol. 28, no. 2, 2013