



# Managing System Oscillations in the ERCOT System

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

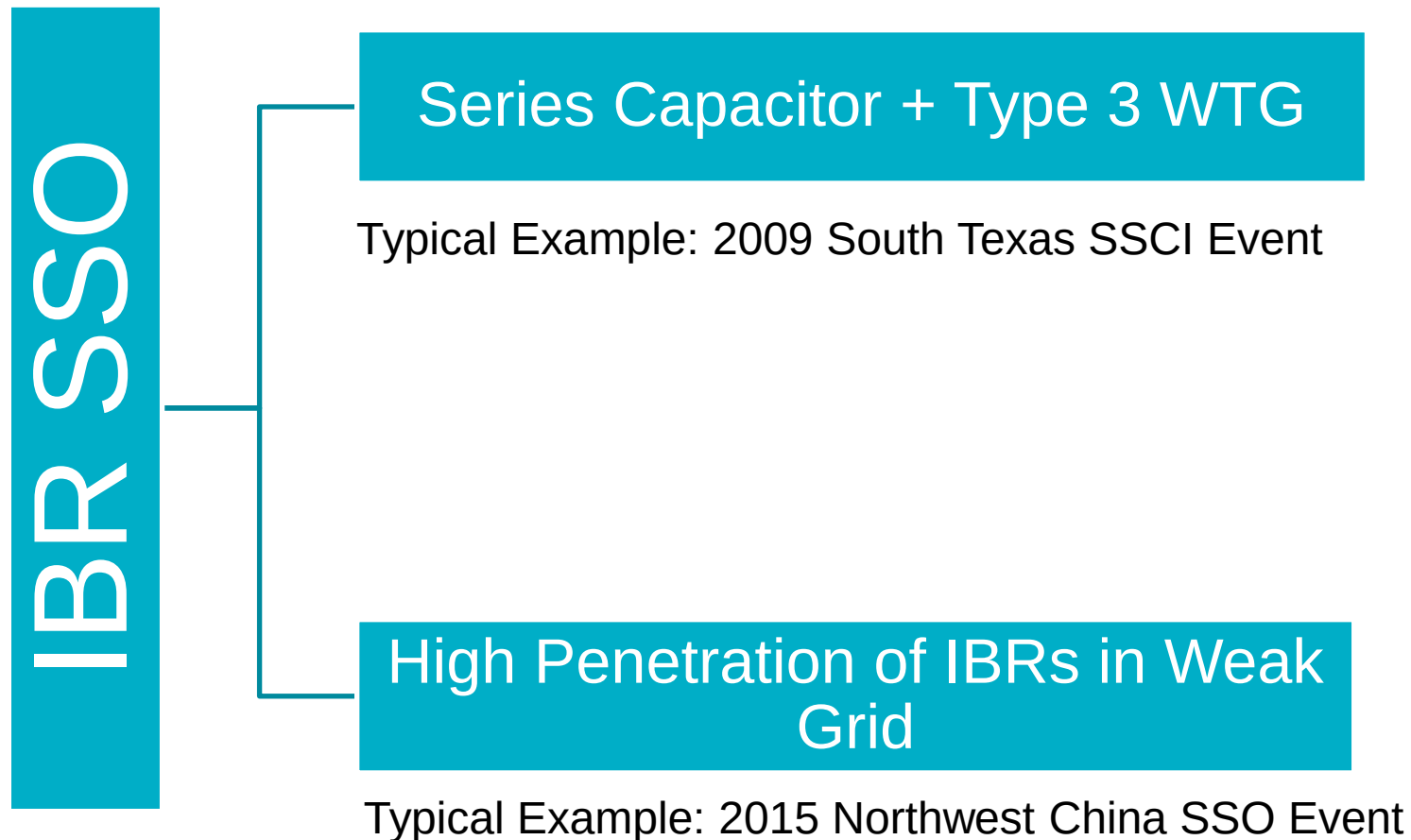
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**Abstract**—This paper presents a survey of real-world subsynchronous oscillation events associated with inverter-based resources (IBR) over the past decade. The focus is on those oscillations in the subsynchronous frequency range known to be influenced 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.

### I. INTRODUCTION

**P**ENETRATIONS 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

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



# Some Reported IBR SSO Events

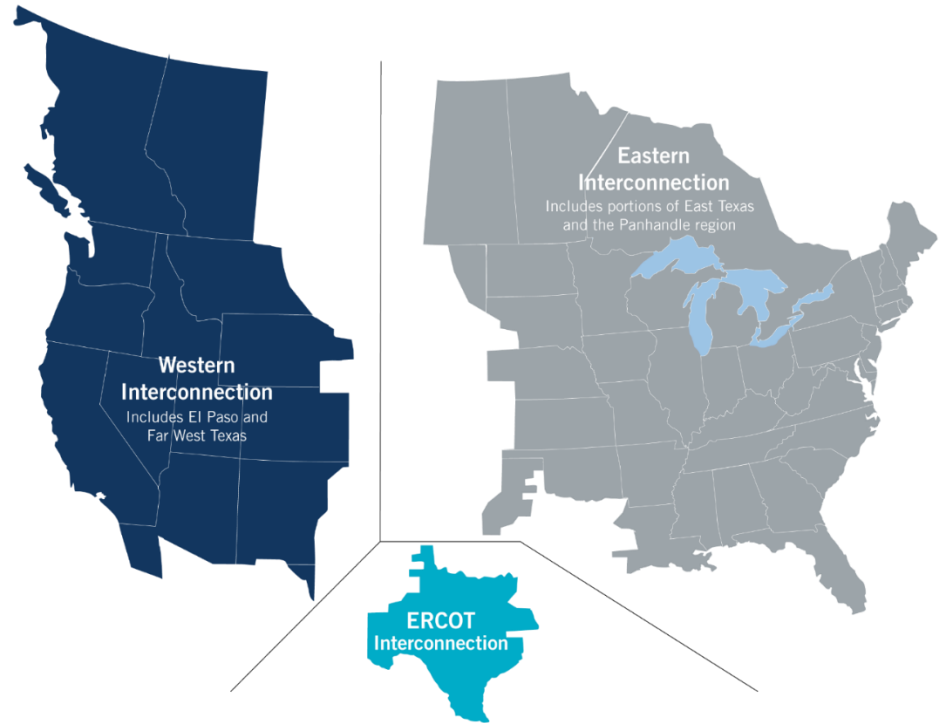
| Year        | Location               | Frequency (Hz) | Mechanism                    |
|-------------|------------------------|----------------|------------------------------|
| 2021        | Scotland               | 8              | Offshore WTG + Weak grid (?) |
| 2020 – 2021 | West Murray, Australia | 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.     |

# The ERCOT Region

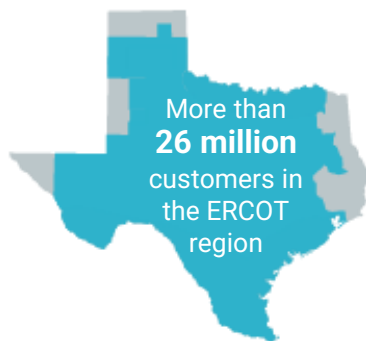
**The interconnected electrical system serving most of Texas, with limited external connections**

- 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

**1,250+**

generating units, including PUNs

**54,100+**

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)

**38,694 MW**

of installed wind capacity  
(as Dec. 31, 2023)

**27,548 MW**

Wind generation record  
(Jan. 7, 2023)

**69.15%**

Wind penetration record  
(April 10, 2022)

**85,116 MW**

Weekend peak demand record  
(August 20, 2023)

**22,258 MW**

of installed solar capacity  
(as Dec. 31, 2023)

**17,201 MW**

Solar generation record  
(Feb. 19, 2024)

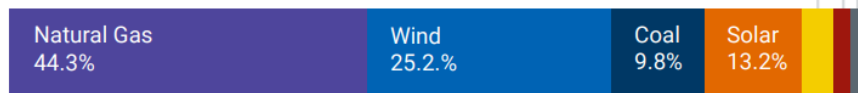
**39.94%**

Solar penetration record  
(Feb. 18, 2024)

## 2024 Generating Capacity

Reflects operational installed capacity based on December 2023 CDR report for Summer 2024.

0.4% Hydro  
0.9% Other\*  
2.7% Storage  
3.5% Nuclear



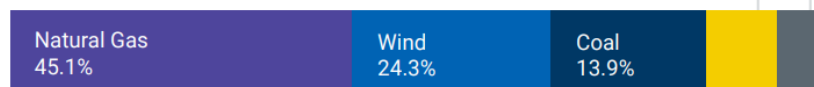
The sum of the percentages may not equal 100% due to rounding.

\*Other includes biomass and DC Tie capacity.

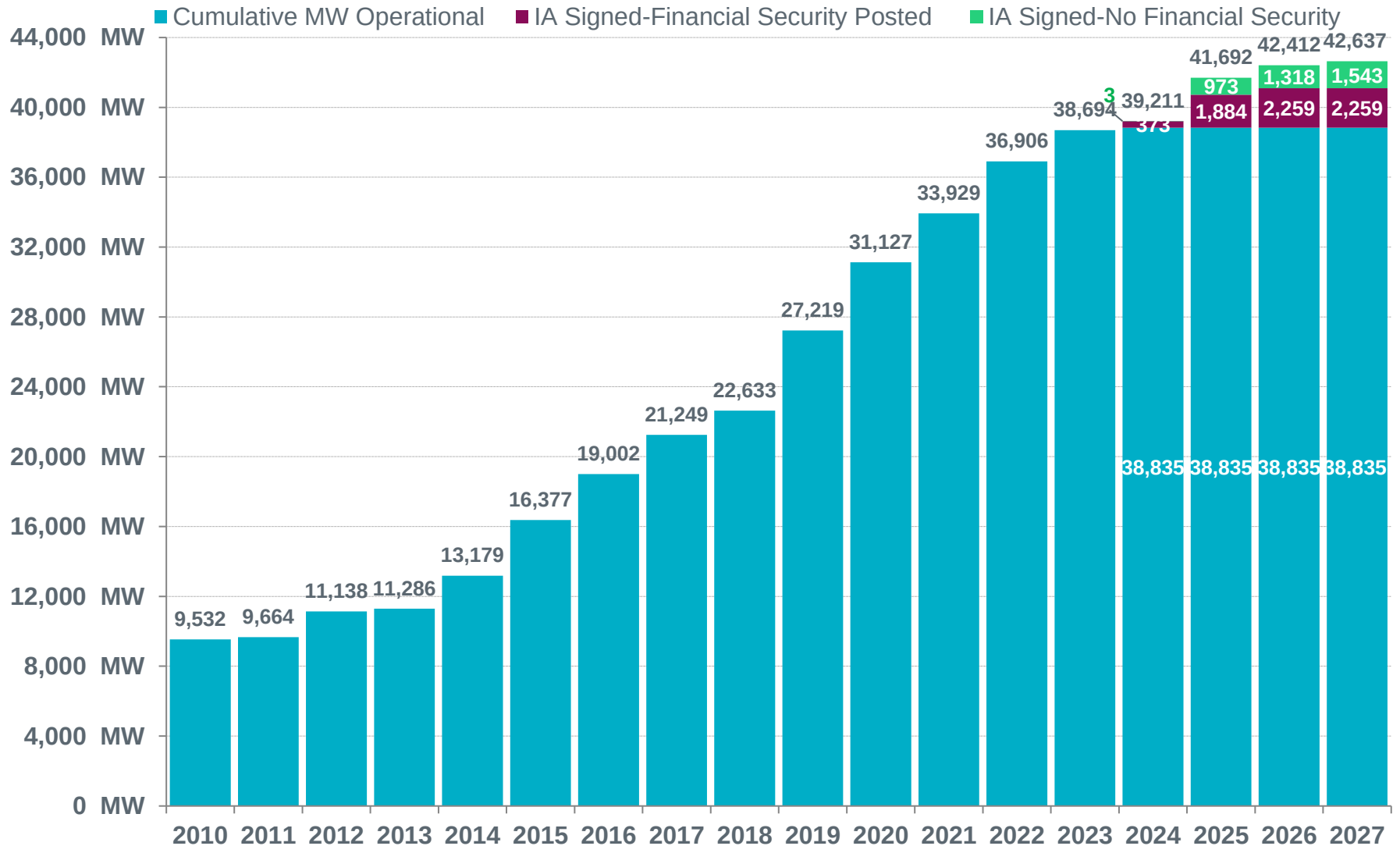
## 2023 Energy Use

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

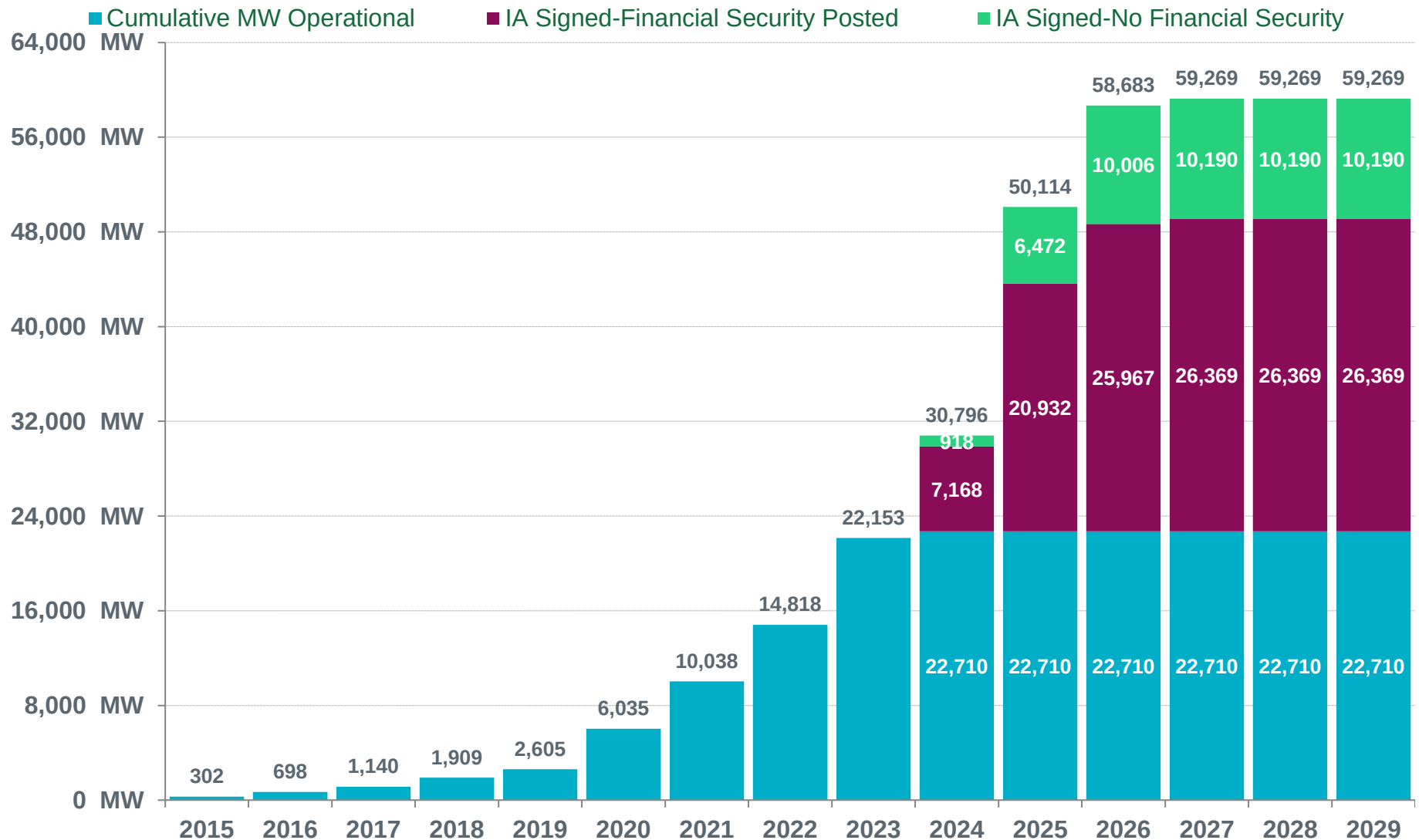
7.6% Other\*  
9.2% Nuclear



# ERCOT Wind Additions by Year (as of Feb. 29, 2024)

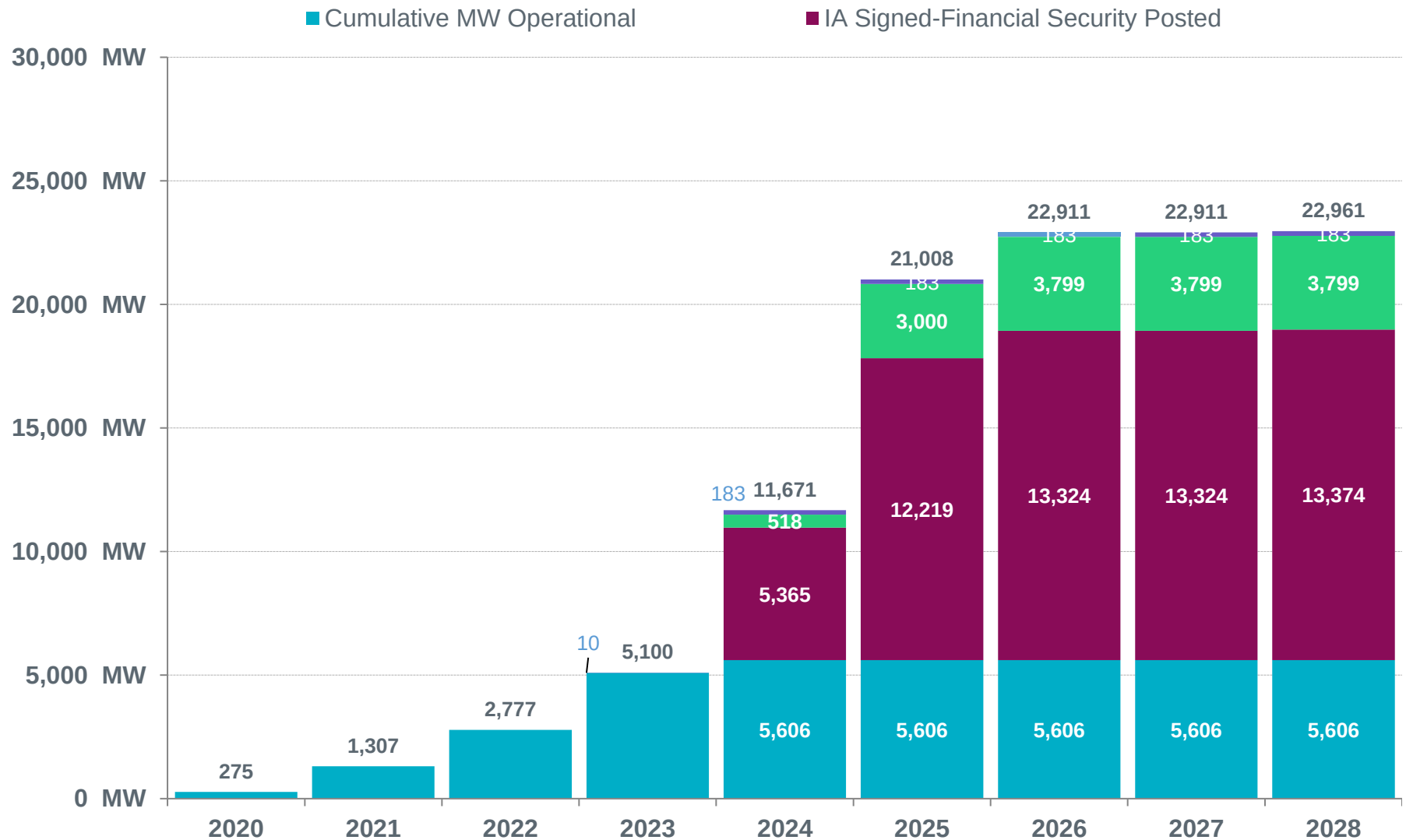


# ERCOT Solar Additions by Year (as of Feb. 29, 2024)



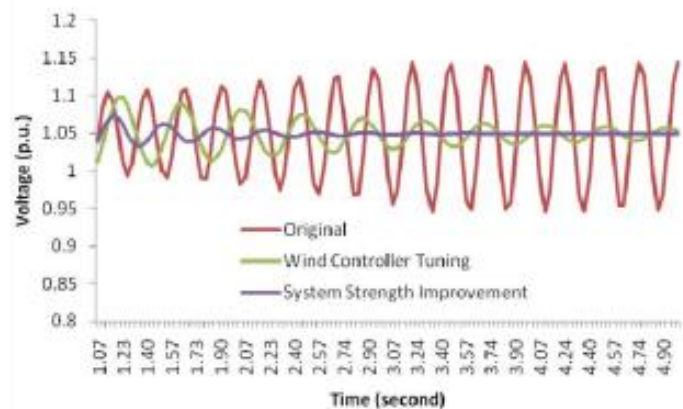
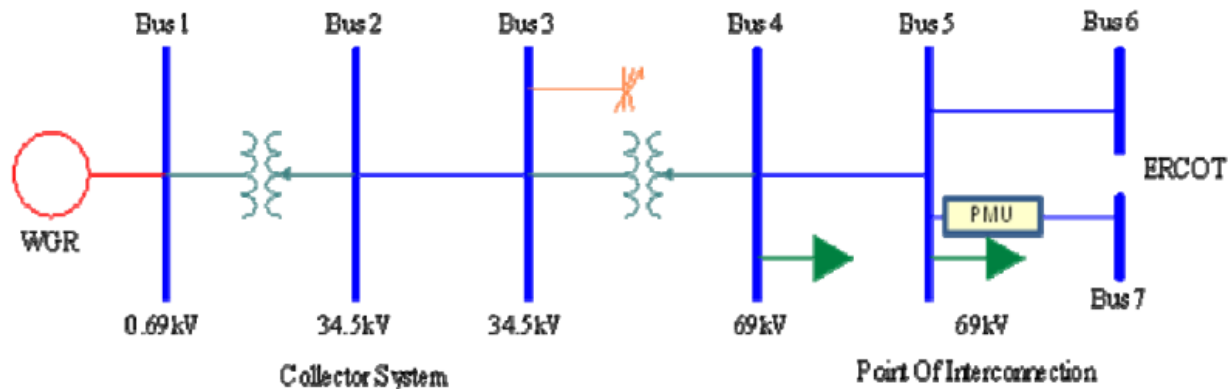


# ERCOT Battery Additions by Year (as of Feb. 29, 2024)



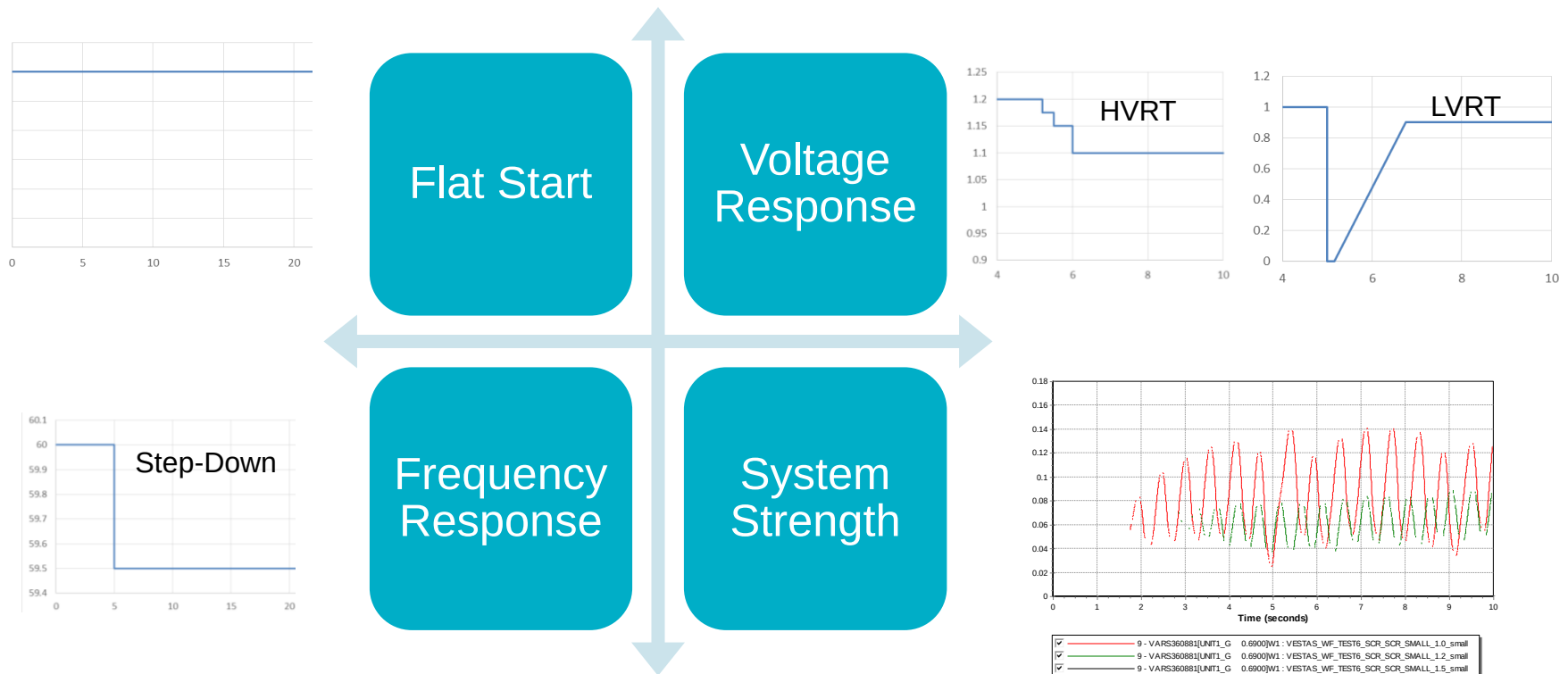
# Weak Grid related SSO Event in ERCOT

- 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)



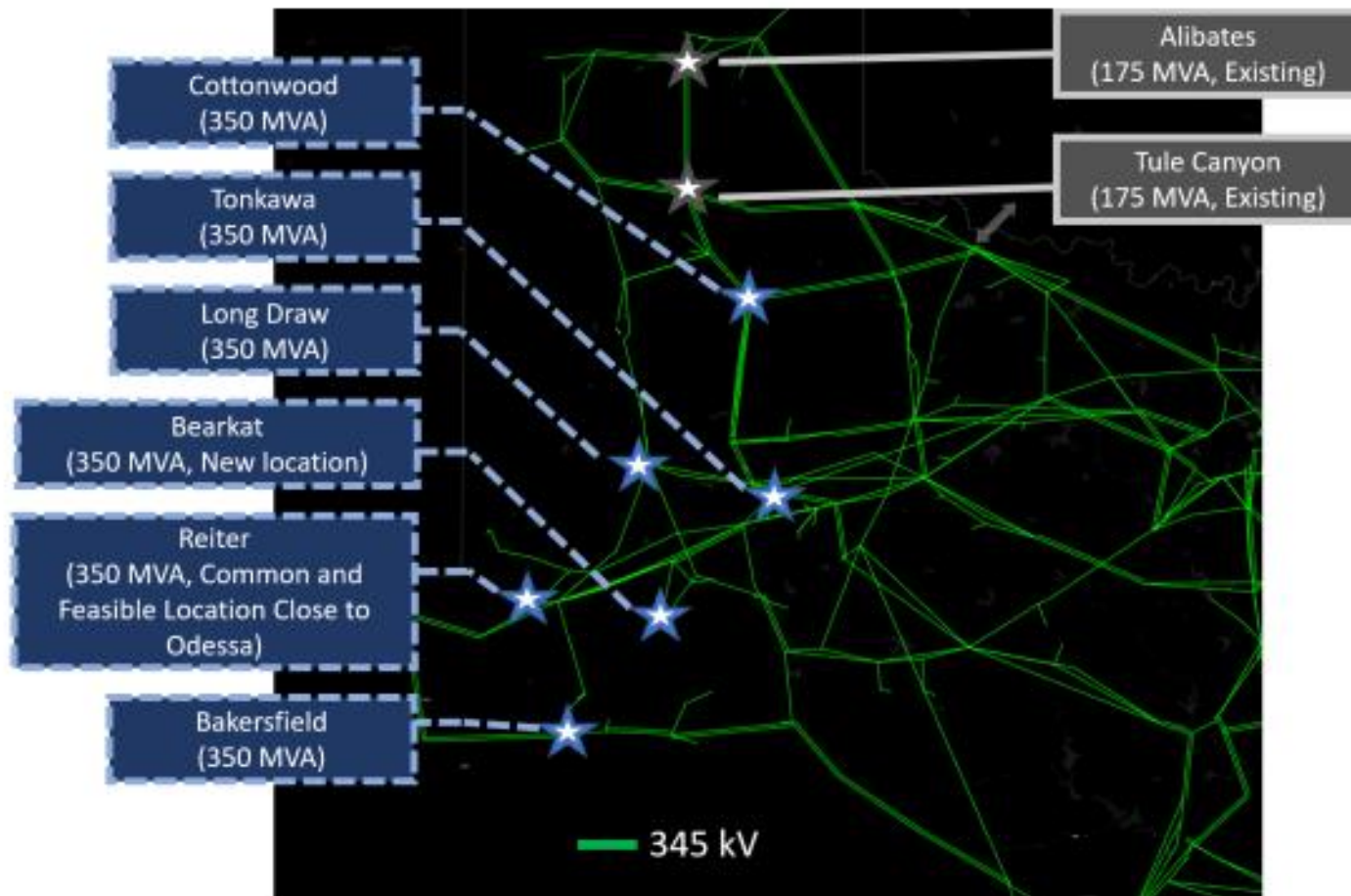
# Weak Grid related SSO Analysis in ERCOT

- Model Quality Test (MQT)
  - System Strength (SCR) Test with minimum requirement of  $SCR = 1.5$
  - DMView tool available at <https://sites.google.com/view/dmview/home>
  - PMView tool available at <https://sites.google.com/view/pmview/home>

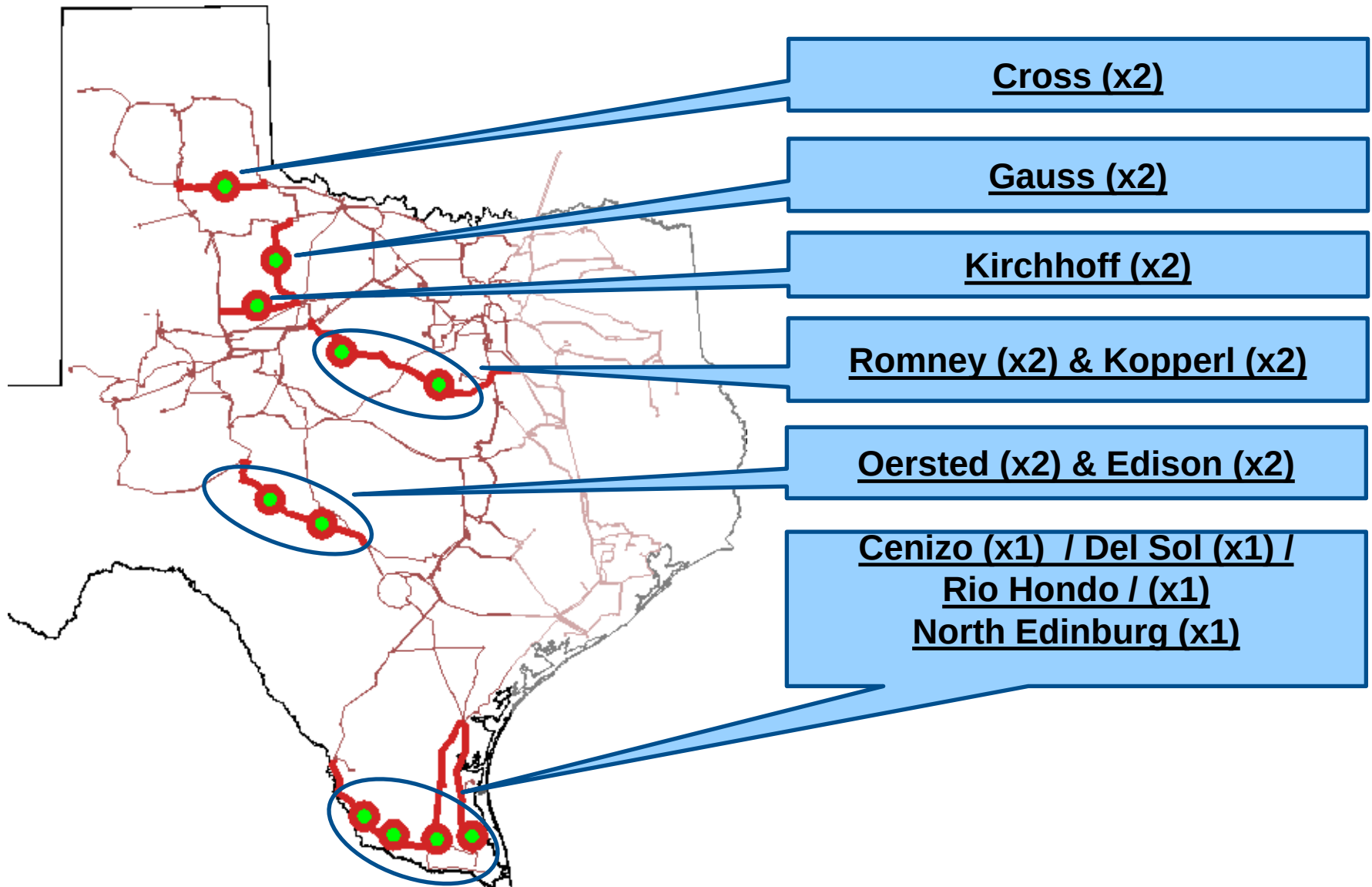


# Six Synchronous Condensers (SynCons) in WTX

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

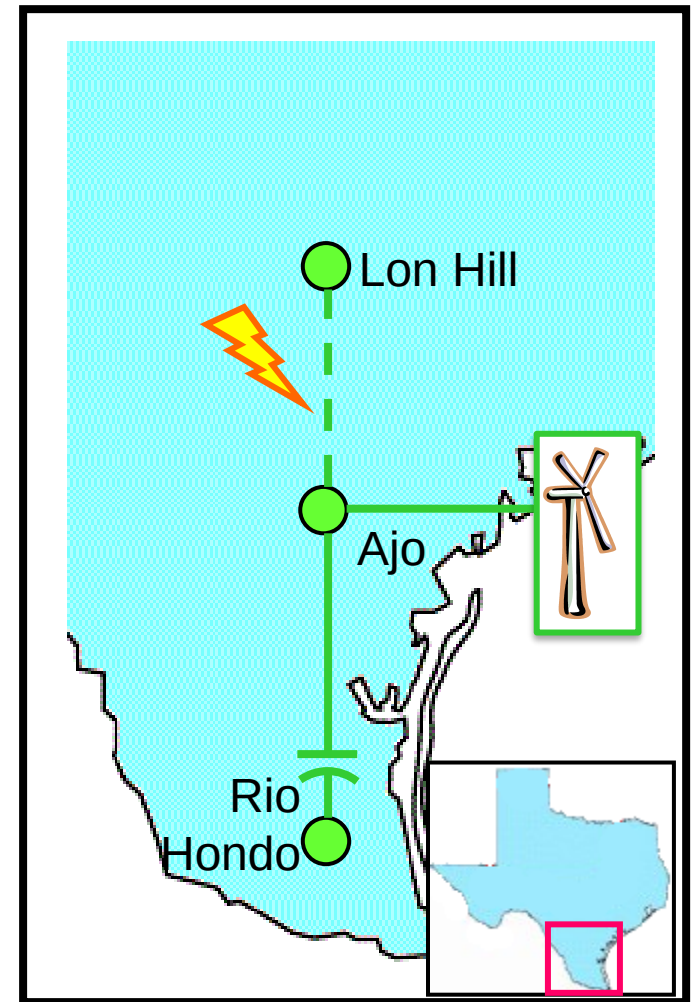
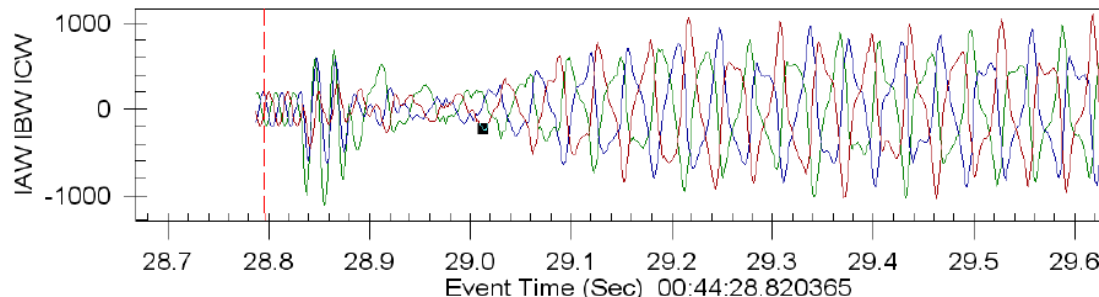


# Series Capacitors in ERCOT



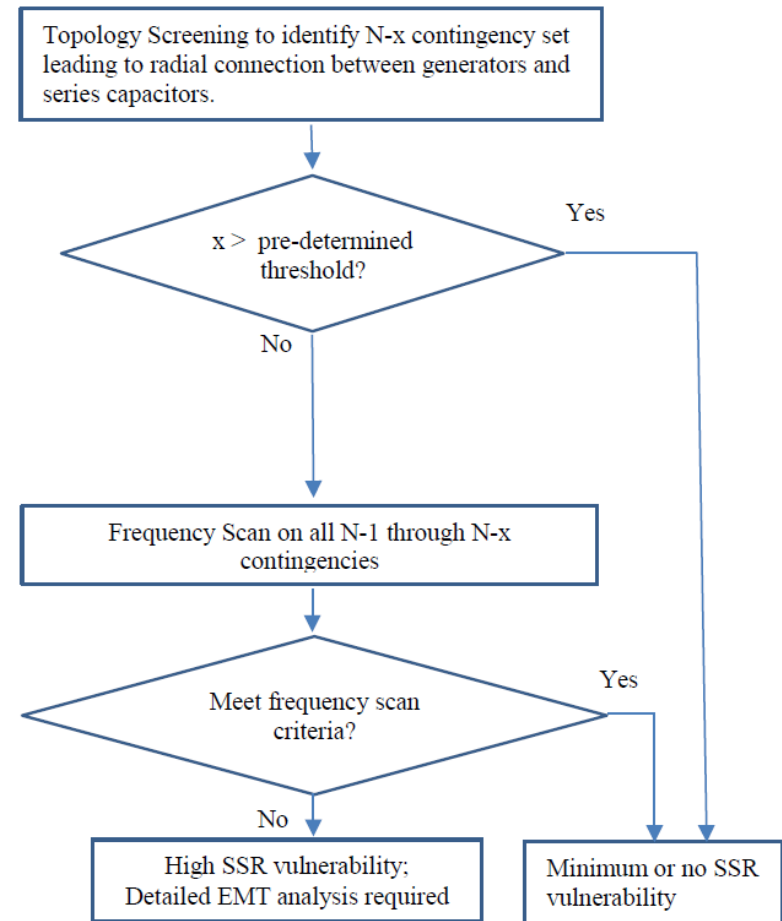
# South Texas 2009 Event

- 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.

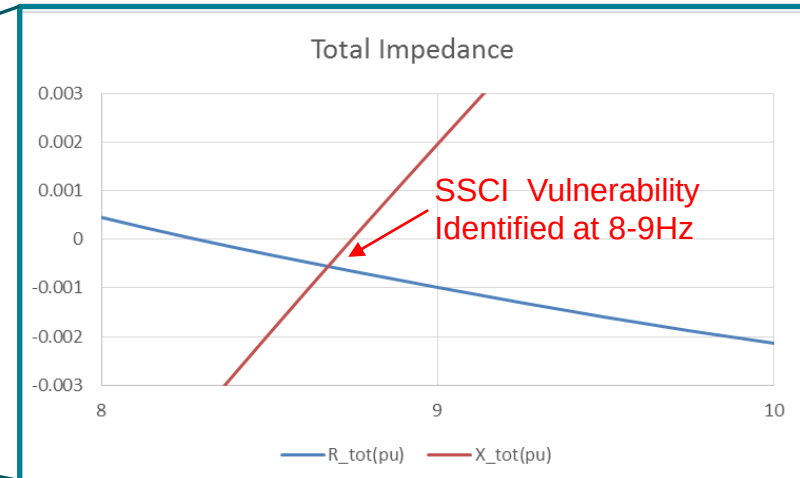
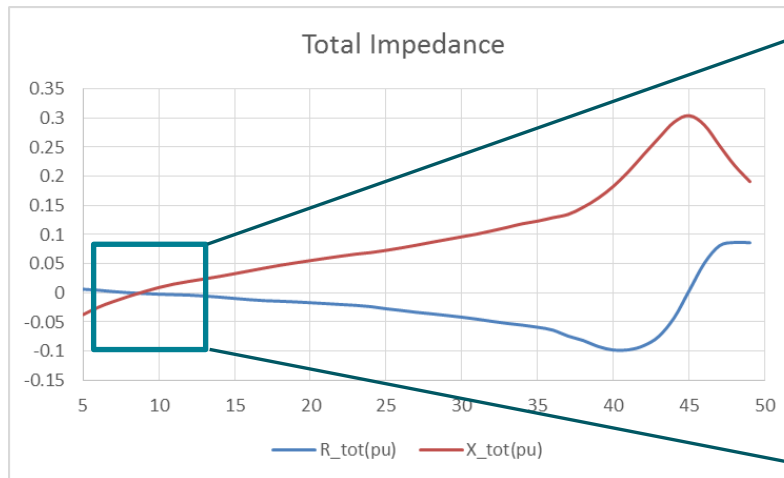
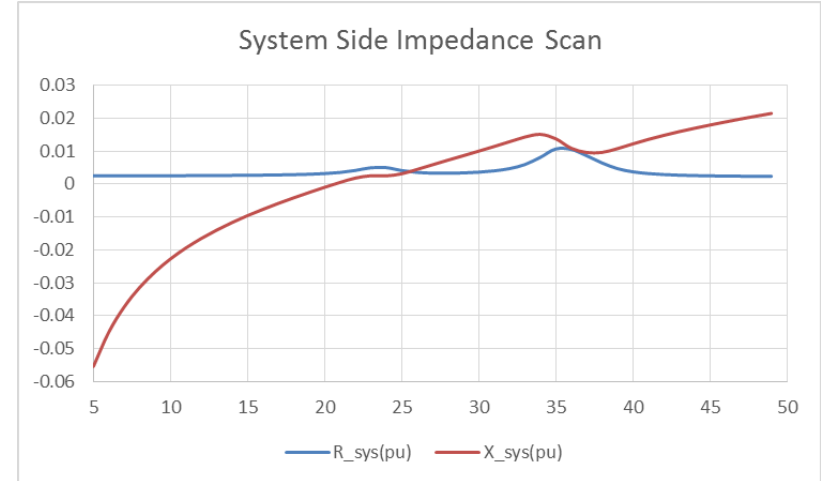
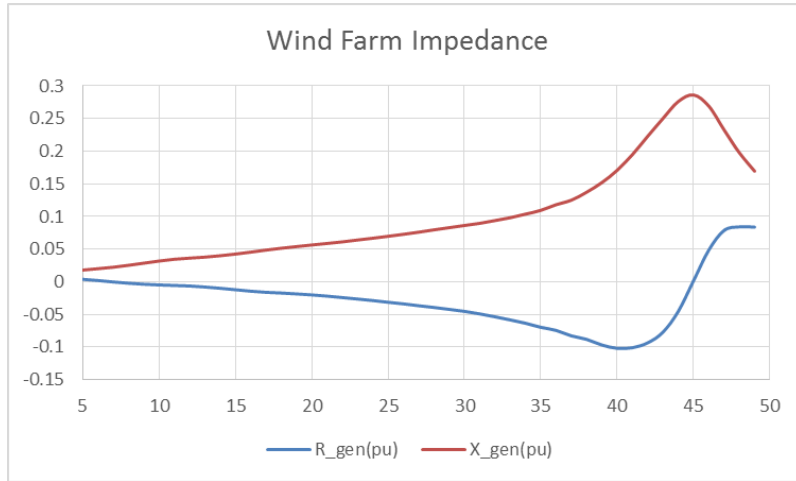


# ERCOT SSR Study Framework

- Step 1: Topology Screening
  - Identify N-x contingency set leading to radial connection
- Step 2: Frequency Scan (FS)
  - Run frequency scan and compare with the FS criteria
- Step 3: EMT analysis
  - Run PSCAD simulation for limited contingencies as identified in FS



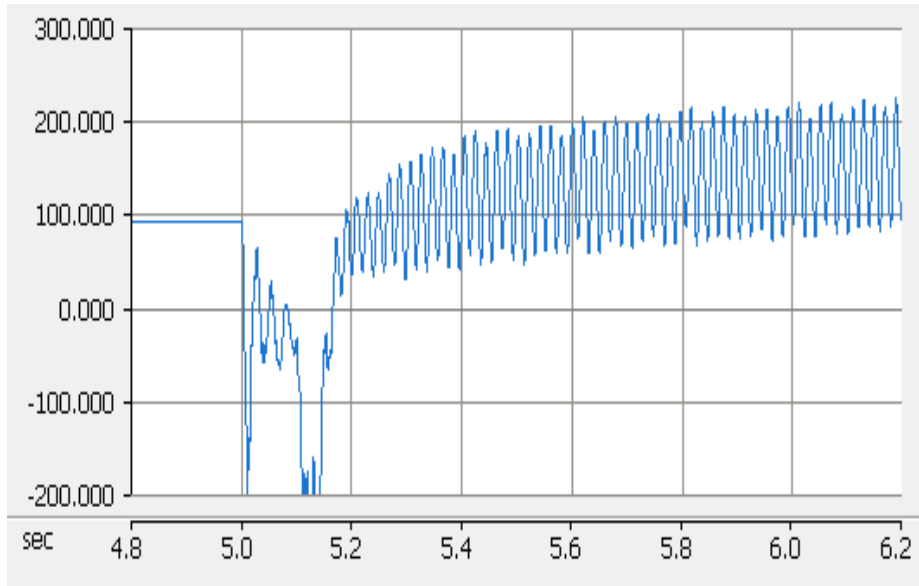
# An Example of Frequency Scan



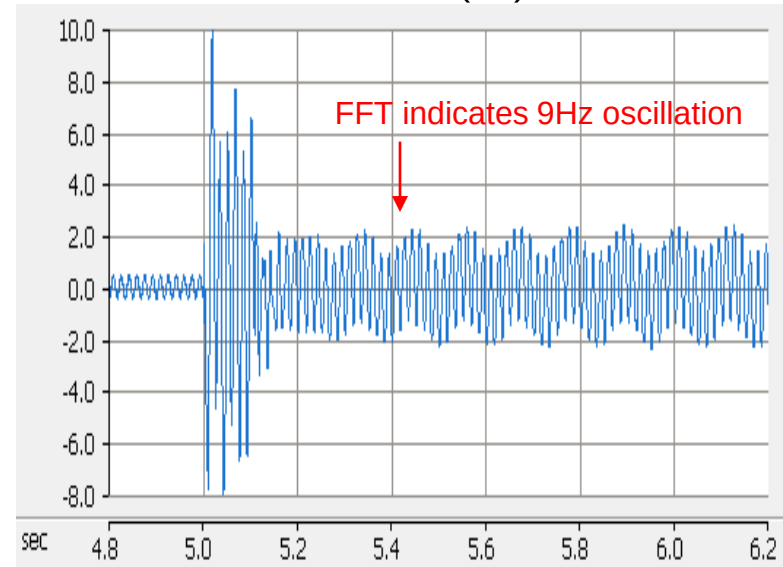


# An Example of PSCAD Simulation

Active power (MW)



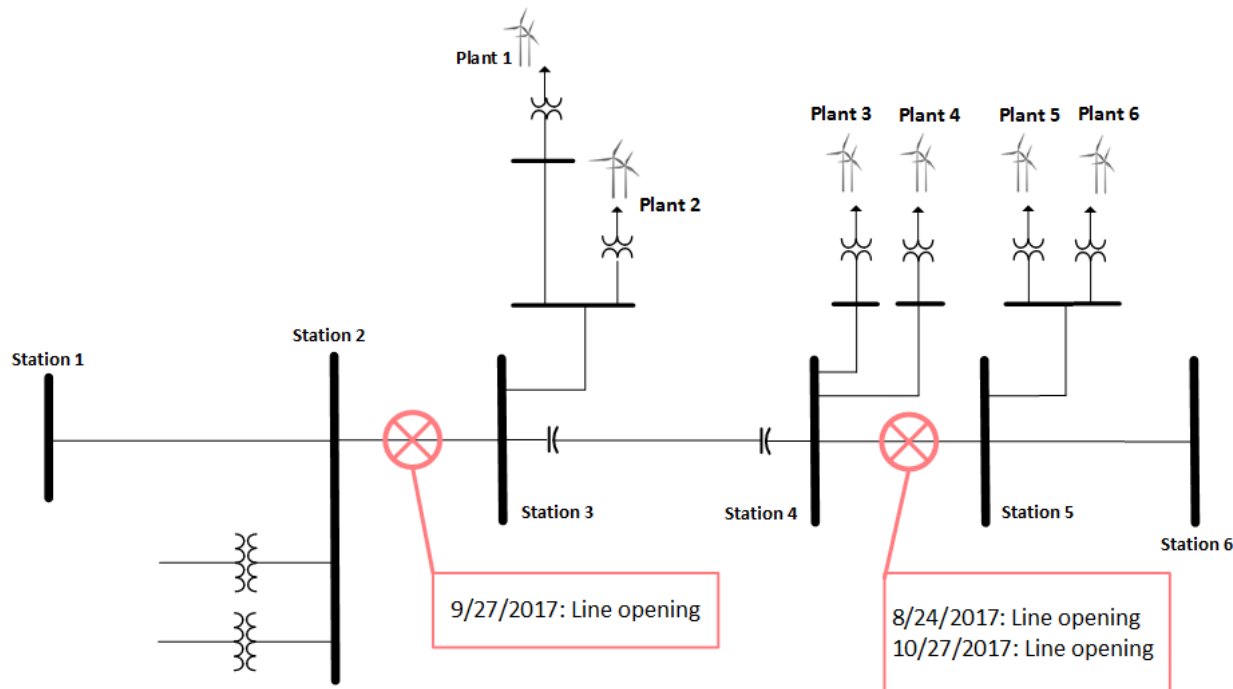
Current (kA)



Active power and Current on the series capacitor  
(PSCAD Simulation Results)

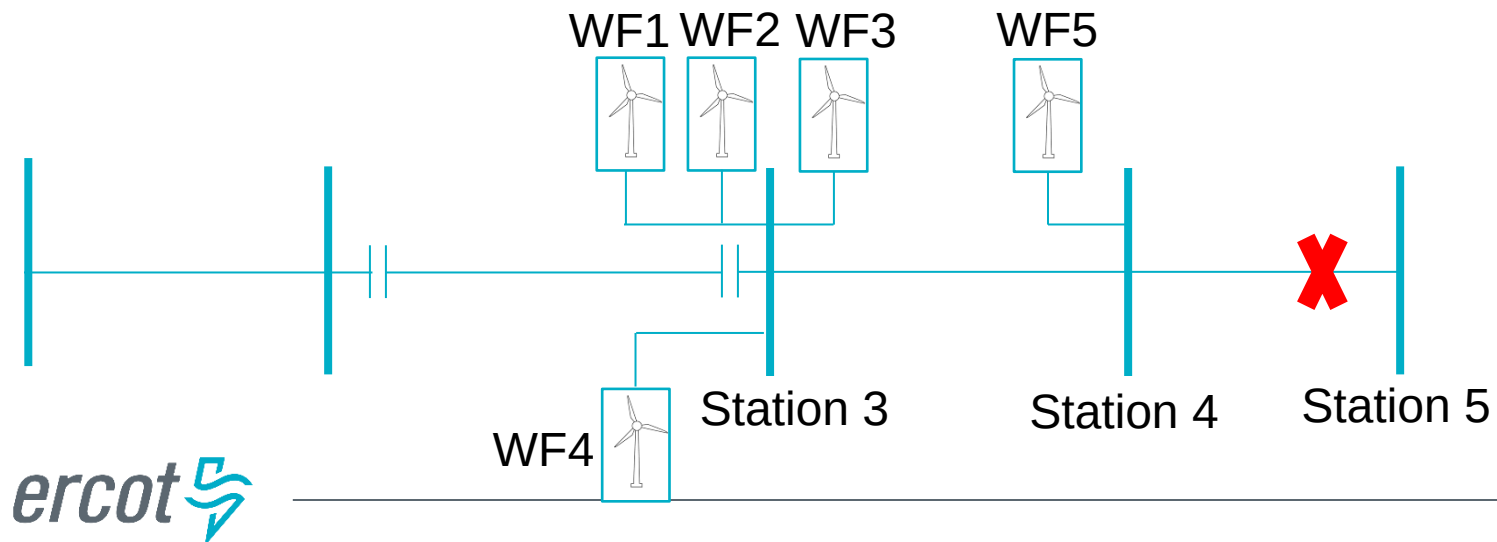
# ERCOT 2017 Events

- Three SSCI events occurred in South Texas in 2017
  - All SSCI events are related to DFIG based wind farms radially connected to series capacitors after outages
  - Both undamped SSCI (20-30Hz) and damped SSCI (20-30Hz) were observed. WTGs were tripped during undamped SSCI events.



# South Texas 2023 SSO Event (3/10/2023)

- Five wind farms (total 1140MW) interconnecting to the other end of series caps
  - DFIG/Type 3: WF2, WF3 and WF5
  - Full converter/Type 4: WF1 and WF4
- 345kV line of Station 4 – Station 5 faulted and tripped leaving WF1–5 radial to two series caps; SSO occurred immediately with the frequency of ~30Hz; Both series caps automatically bypassed by their protection about 1.2-1.3 seconds after fault clearing, WF4 tripped later.



# Conclusions

- Weak Grid SSO
  - System strength test (SCR) as part of Model Quality Test
  - Curtailment may be needed based on SCR metrics
  - Add SynCons to increase the system strength
- Series Capacitor SSO (SSCI)
  - Tuning the IBR SSCI mitigation control is very complex
  - Avoid radial connection between IBRs and series capacitors under normal condition and credible contingencies
  - Avoid direct connection of IBRs to series capacitors

# 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](https://www.ercot.com/files/docs/2020/12/04/ERCOT_SSR_Study_Scope_Guideline_10-27-2020-external.docx)
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