Preliminary assessment of Grid Forming Inverter-based Energy Storage Resources (GFM-IBR-ESR) in the ERCOT Grid

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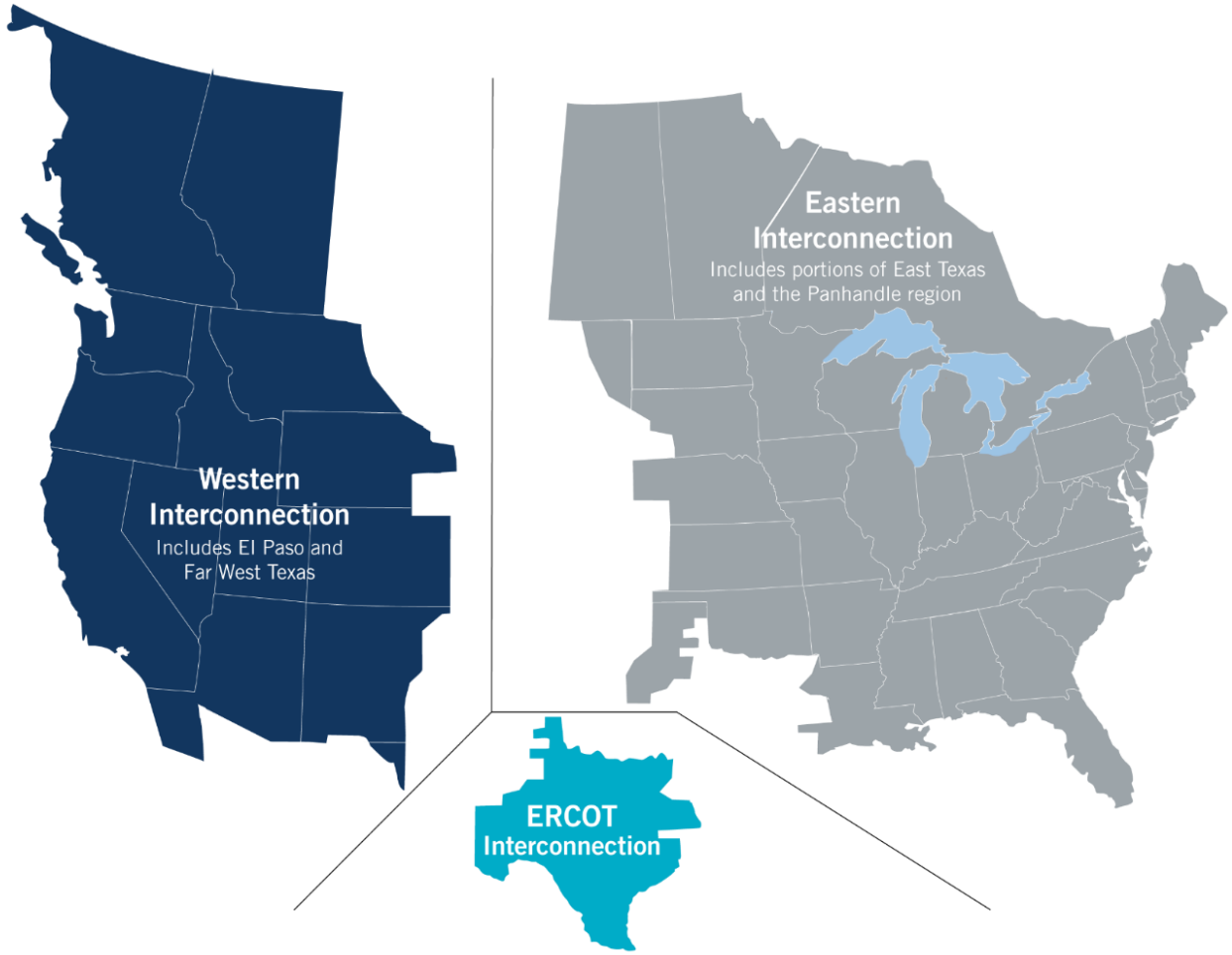
The ERCOT Region

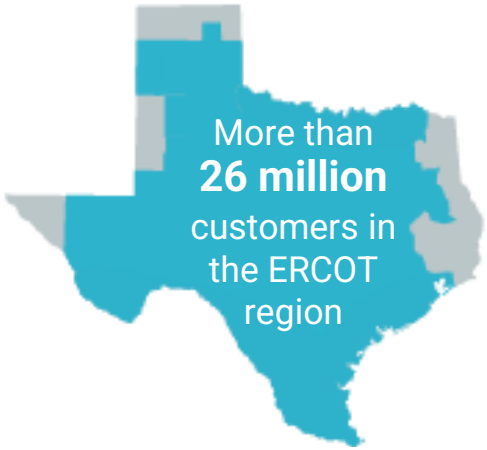
The interconnected electrical system serving most of Texas, with limited external connections

- 90% of Texas electric load; 75% of Texas land
- 85,464 MW peak, August 10, 2023
- More than 52,700 miles of transmission lines
- 1100+ 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

85,464 MW
Record peak demand
(August 10, 2023, 5-6 pm)

37,725 MW
of installed wind capacity

27,044 MW
Wind generation record
(May 29, 2022, 10 pm)

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

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

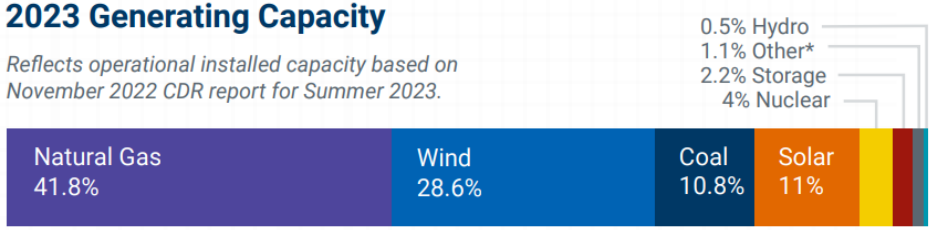
17,040 MW
of installed solar capacity

13,737 MW
Solar generation record
(Sept. 1, 2023, 11 am)

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

2023 Generating Capacity

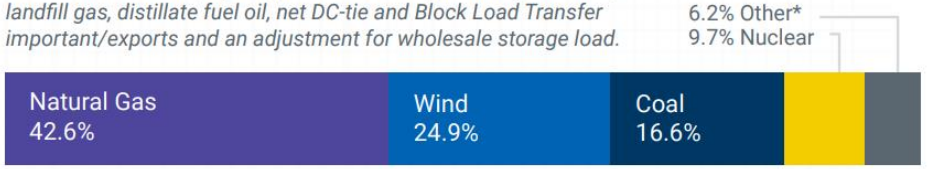
Reflects operational installed capacity based on November 2022 CDR report for Summer 2023.



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

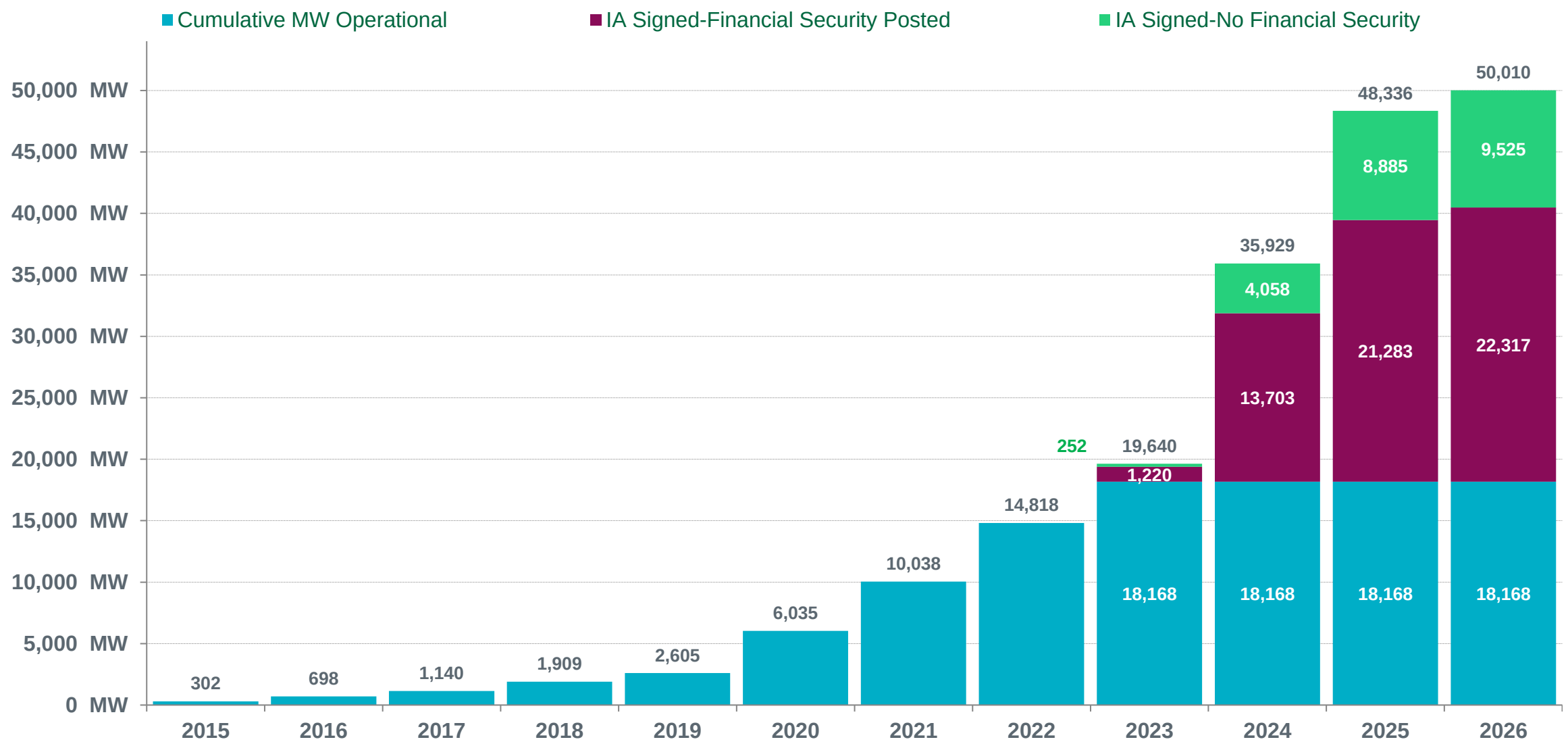
2022 Energy Use

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

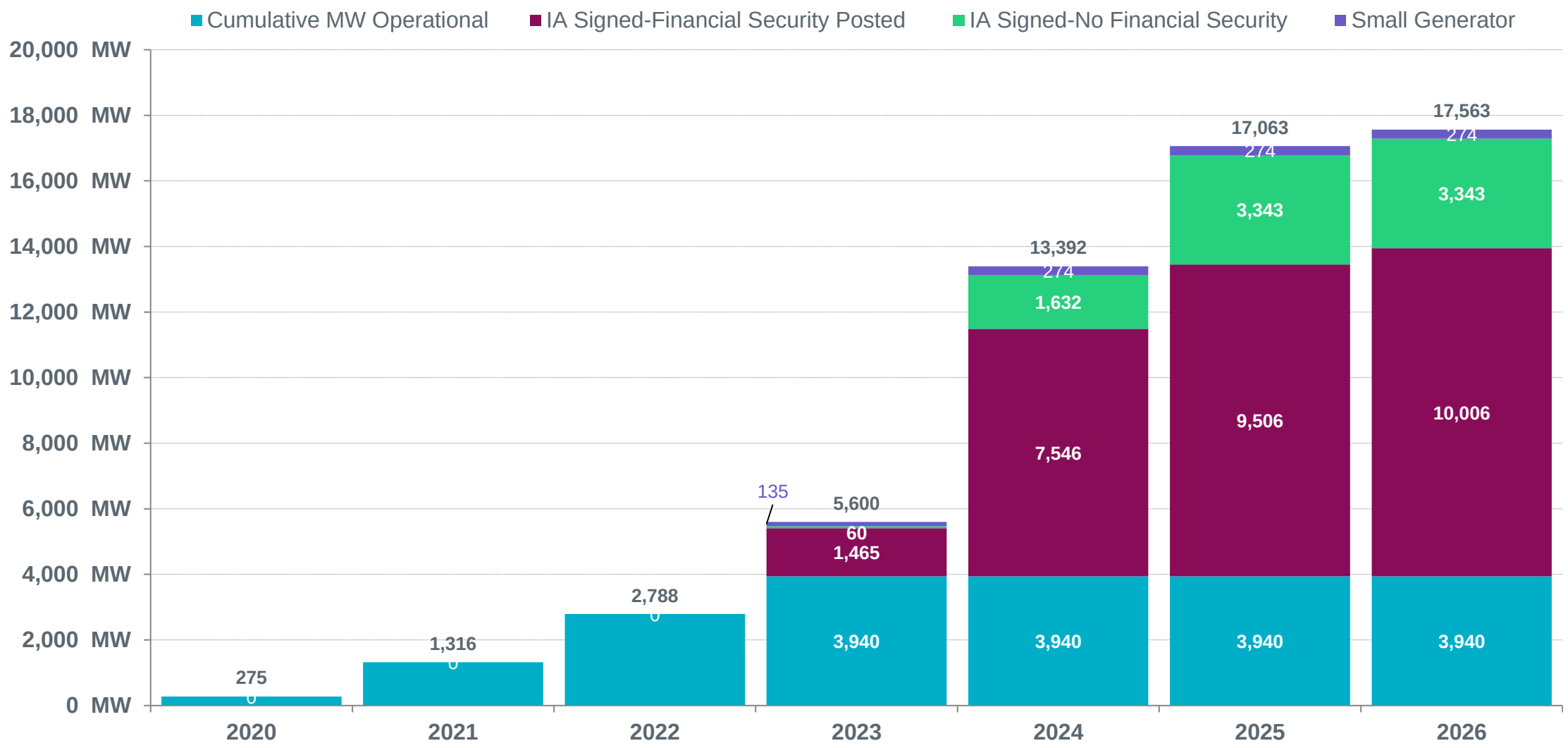


ERCOT Wind Additions by Year (as of Aug. 31, 2023)

ERCOT Solar Additions by Year (as of Aug. 31, 2023)



ERCOT Battery Additions by Year (as of Aug. 31, 2023)

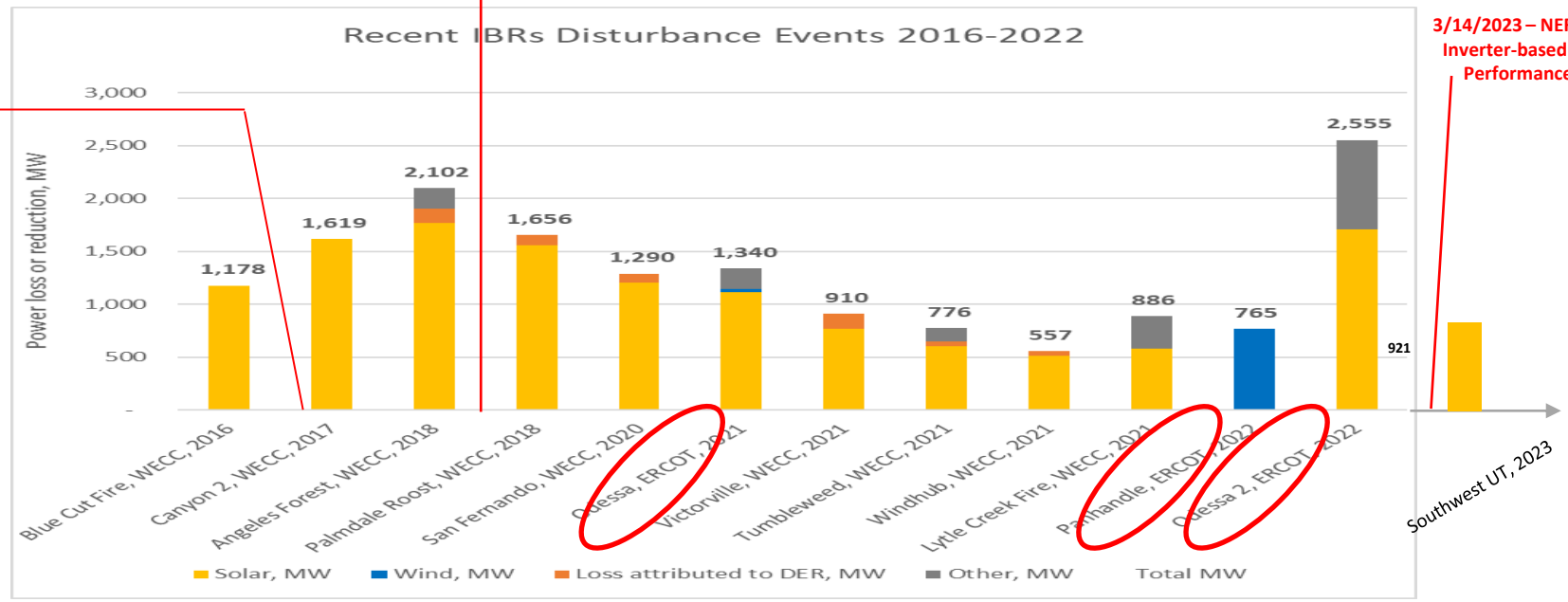


Recent IBR Events, Alerts and Guidance in North America

6/20/2017 – NERC Alert on Loss of Solar Resources during Transmission Disturbances due to Inverter Settings

5/1/2018 – NERC Alert on Loss of Solar Resources during Transmission Disturbances due to Inverter Settings #2

3/14/2023 – NERC Alert on Inverter-based Resource Performance Issues



December 2017 – Integrating Inverter-Based Resources into Low Short Circuit Strength Systems

September 2018 - Power Plant Model Verification for Inverter-Based Resources

September 2018 - BPS-Connected Inverter-based Resource Modeling and Studies

February 2019 - Inverter-Based Resource Performance Task Force (IRPTF) 024-2 Gaps Whitepaper

September 2019 - Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

April 2020 - SPP Inverter-Based Resource Integration Study – April 2020

May 2020 - BPS-Connected Inver-based Resource Performance

August 2020 - NERC-WECC report on Inverter-Based Resource Modeling

March 2021 - Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants

December 2021 - Grid Forming Technology White paper

April 2022 - EMT Models in NERC MOD, TPL, and FAC Standards

June 2022 - NERC IRPS – Inverter Based Resource Strategy

- Existing performance requirements and non-mandatory guidelines, alerts, and education have not been effective
- Detailed performance requirements, monitoring, and validation are necessary to support reliable transition to the IBR dominated power grid

Background and Objectives of GFM assessment

- Continued focus on improving Resources' capability and performance **AND** improvements on the transmission system are **BOTH** needed to maintain the reliable operations of the ERCOT grid.
  - Adoption of NERC reliability guidelines, IEEE 2800, NOGRR245
  - Recommendation of synchronous condensers (6*350MVA) to strengthen West Texas grid

- Additional improvements will be needed to support the continued growth of IBRs in the ERCOT grid. Increasing discussion of grid forming inverters (GFM) to improve the IBR performance and system support have been noted especially in other regions with high penetration of IBRs. For example, AEMO, UK, Hawaii,…etc.

- ERCOT planning and operations evaluated the potential application of GFM Energy Storage Resource (ESR) in ERCOT grid, and the preliminary observations and findings are included in this presentation.

Three scenarios were tested for GFM ESR impact

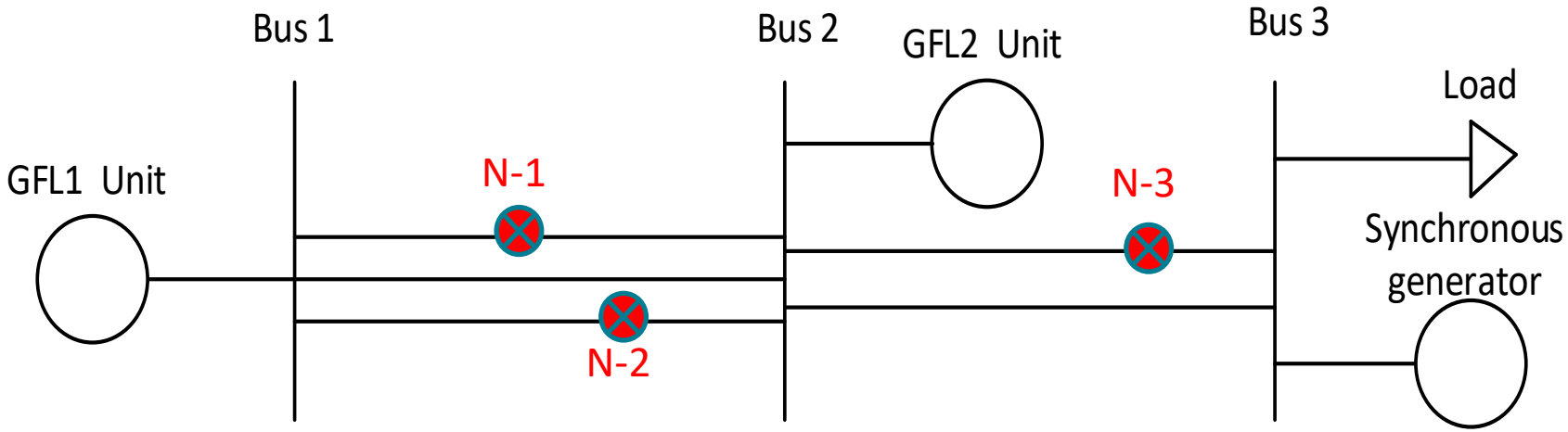
- ERCOT preliminary GFM ESR evaluation on three scenarios
  - Scenario 1: a weak grid condition (a simple test case in PSSE to prove the concept)
  - Scenario 2: West Texas grid (tested in PSSE)
  - Scenario 3: an actual ERCOT local area with identified stability constraints (tested in both PSSE and PSCAD)
- GFM ESR dynamic models used in these tests were supported by Pacific Northwest National Laboratory (PNNL) and Electric Power Research Institute (EPRI)

➢ Acknowledgment:
  - Dr. Wei Du from PNNL for providing GFM PSSE (REGFM_A1*) and PSCAD models
  - Dr. Deepak Ramasubramanian from EPRI for providing GFM PSSE and PSCAD models

*Beta version of REGFM_A1 has been developed in commercial tools PTI-PSS®E, GE-PSLF, PowerWorld Simulator and TSAT

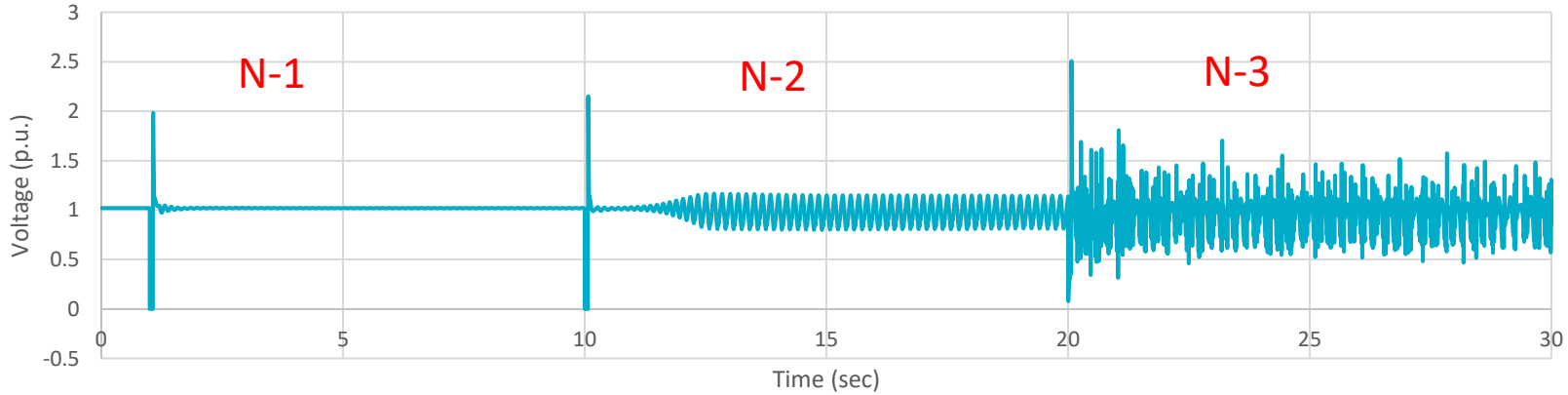
Scenario 1: Weak Grid Test Case Simulation (PSSE)

- A simple test case was developed to mimic known stability challenges in ERCOT



Unit	MVA
GFL1	300
GFL2	200
Syn Gen	488
Load	800

Bus 1 Voltage Plot

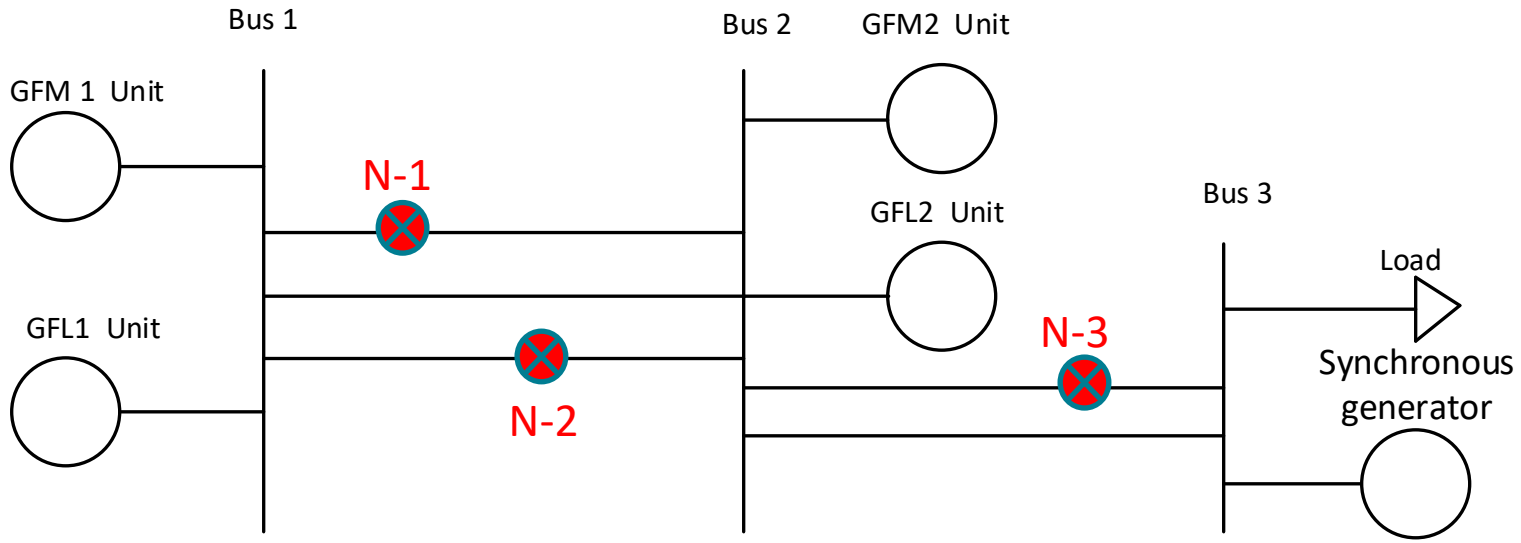


Grid Following (GFL) IBRs instability identified in a weak grid condition

Note: The test cases will be published at https://sites.google.com/view/weakgrid/home

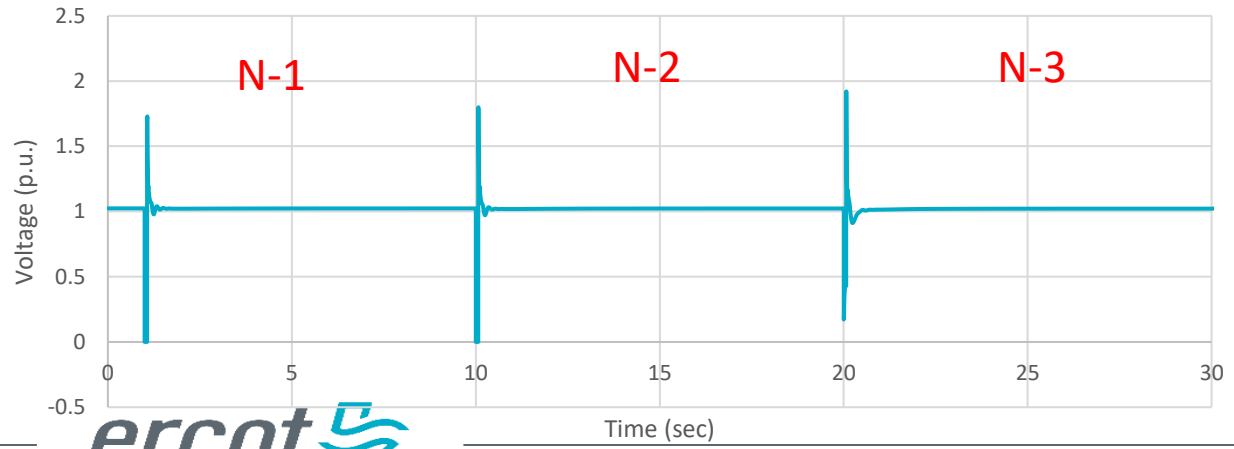
Scenario 1: Weak Grid Test Case Simulation (PSSE)

- Two GFM ESRs were added next to GFL1 and GFL2



Unit	MVA
GFL1	300
GFL 2	200
Syn Gen	488
Load	800
GFM 1	70
GFM 2	70

Bus 1 Voltage Plot



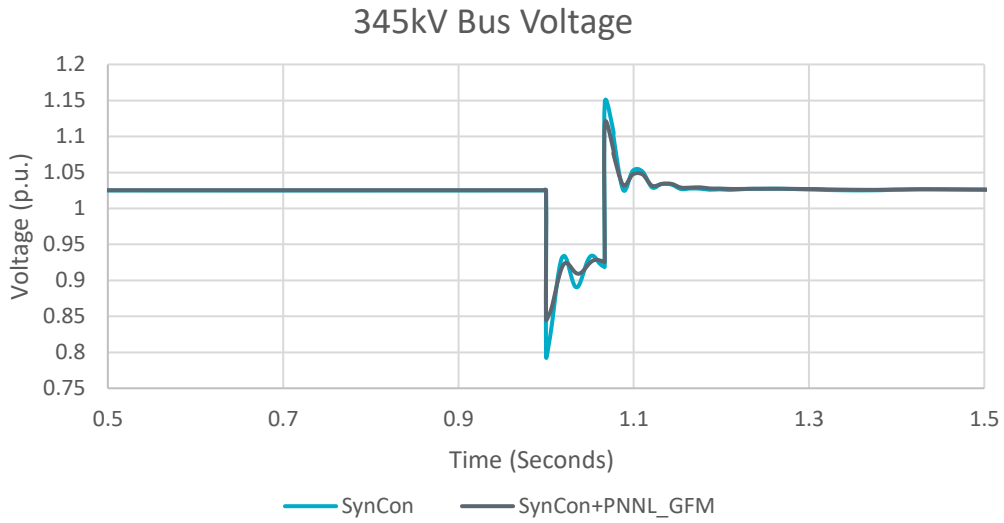
The addition of GFM ESR improves the overall system stability performance under weak grid conditions

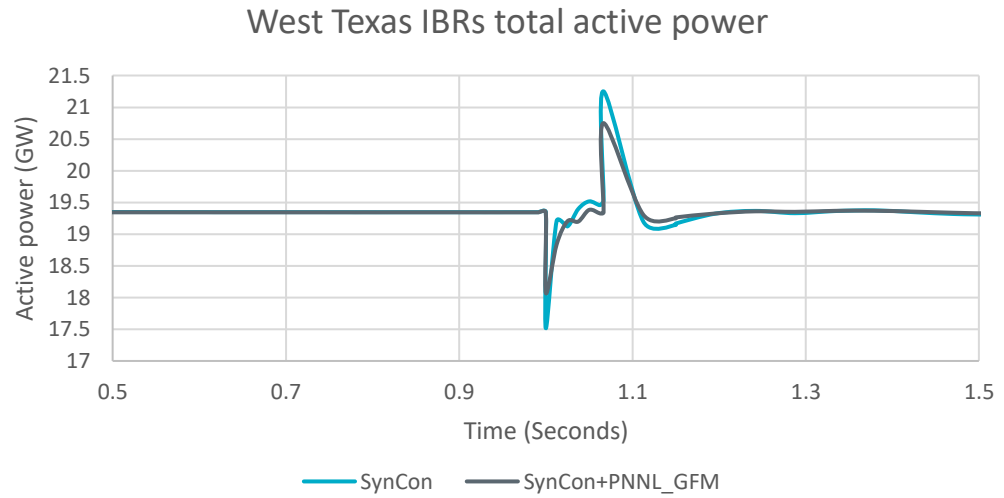
Scenario 2: West Texas Grid (PSSE)

- More than 35 GW IBRs (including ~2GW ESRs) are connected to West Texas transmission grid
- Six synchronous condensers are proposed to strengthen the West Texas grid to provide system security and resilience
- This scenario is to assess the impact if ~2GW ESRs are GFM
  - Generic GFM ESR models were used to evaluate the impact in this assessment
  - The ESR inverters maximum current capability were kept the same as the existing models
- Both GFM ESR models provided by PNNL and EPRI were tested and similar results were obtained

WTX System Strength with GFM (PSSE)

- The presence of the GFM ESRs did not reduce the dispatch stability limit
- GFM ESRs improved the system numerical performance
- Notable Observations:
  - Reduce both voltage dip and overshoot
  - Reduce affected IBRs in WTX, less active power temporary reduction and swing
  - Reduce angle jump

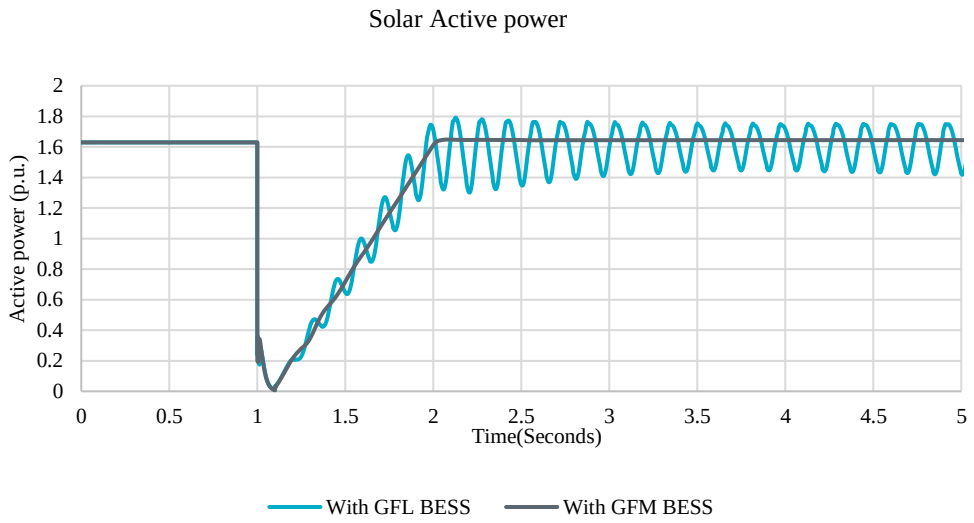


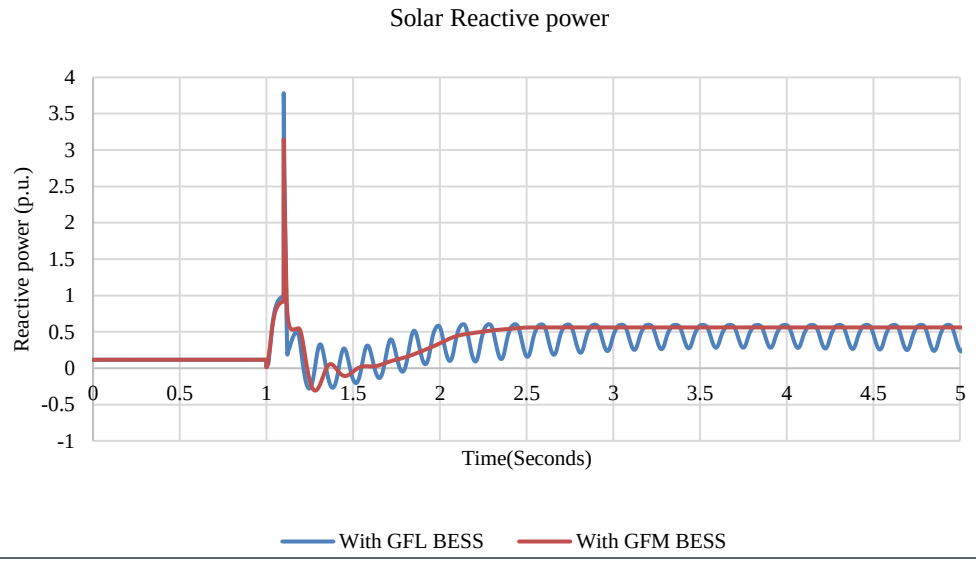


Scenario 3: Local area with identified instability (PSSE and PSCAD)

- A local area (138kV) in the ERCOT grid has been identified with stability issue due to weak grid challenges
  - Generation resources in this area include wind, solar, and ESR (all are GFL inverters)
  - Stability study indicated stability constraints under N-1 and N-1-1 based on original models provided by the developers and resource entities.
- A GFM ESR model was used to replace the original GFL model. The results in both PSSE and PSCAD tests show stable response for both N-1 and N-1-1 and no stability constraint is needed if the ESR is equipped with proper GFM capability

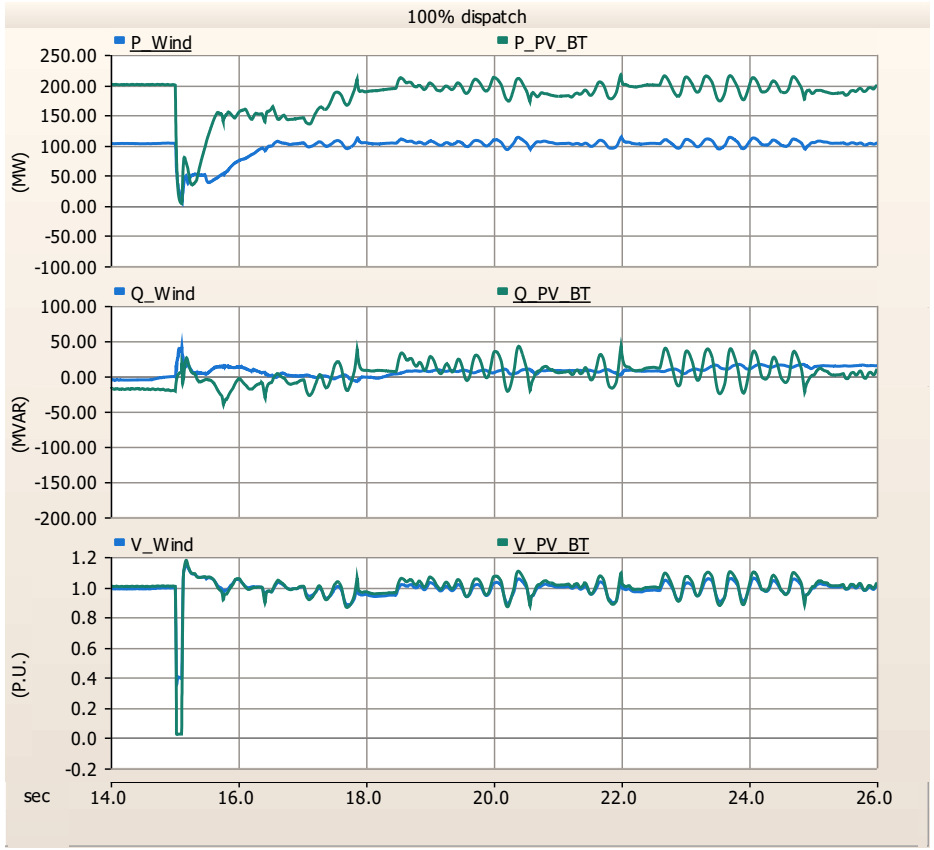
100% dispatch, N-1-1



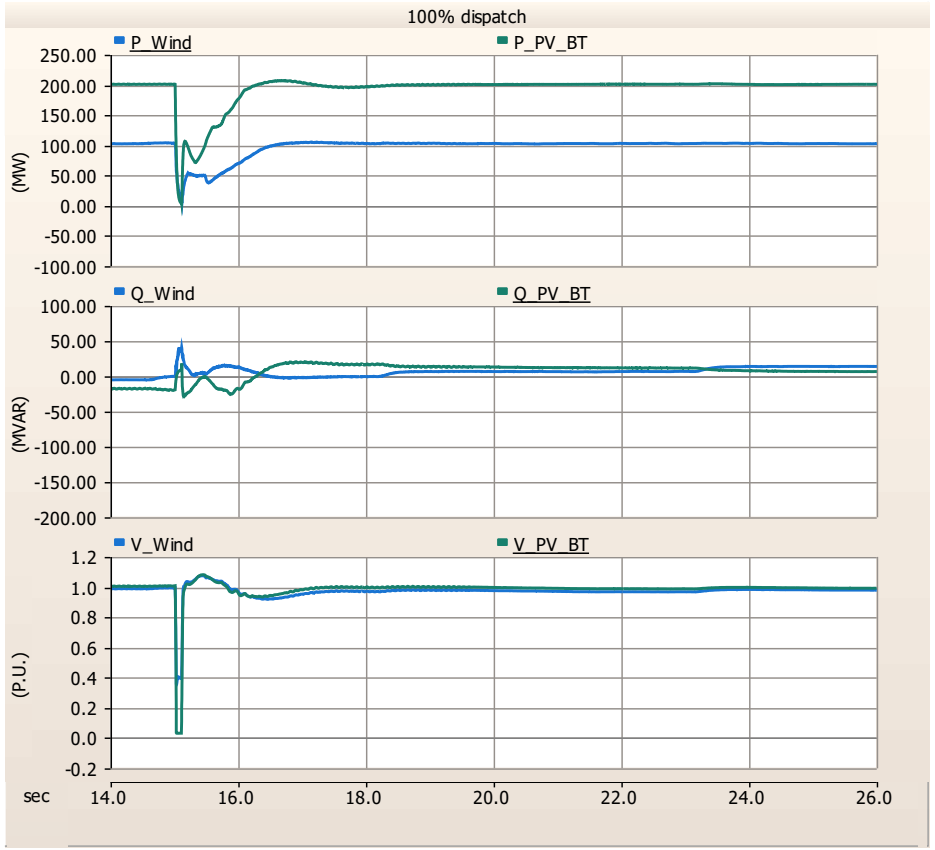


Scenario 3: Local area with identified instability (PSSE and PSCAD)

- PSCAD simulation results for 100% dispatch under N-1-1



ESR modeled as GFL (original model)



ESR modeled as GFM (EPRI VSM model)

Preliminary Findings and Next Steps

- ERCOT's preliminary assessment results indicate the GFM ESRs could be a viable option to improve system dynamic responses, but
  - cannot solve all the issues with GFM only
  - require headroom or energy buffer to provide adequate GFM support
  - still require proper control settings and coordination
- ERCOT is working on the GFM ESR requirements including but not limited to performance, models, studies, and verification.
  - Expect GFM ESR will be capable of meeting IEEE 2800 and existing ERCOT requirements
  - Expect GFM ESR will be required to meet additional performance requirements (an RFP about GFM performance requirement was released in Sep. 2023)
- ERCOT will continue provide regular updates to the stakeholders and comments are welcome to provide to
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  - Shun Hsien (Fred) Huang, Shuang@ercot.com