Integration of Inverter-Based Resources into ERCOT

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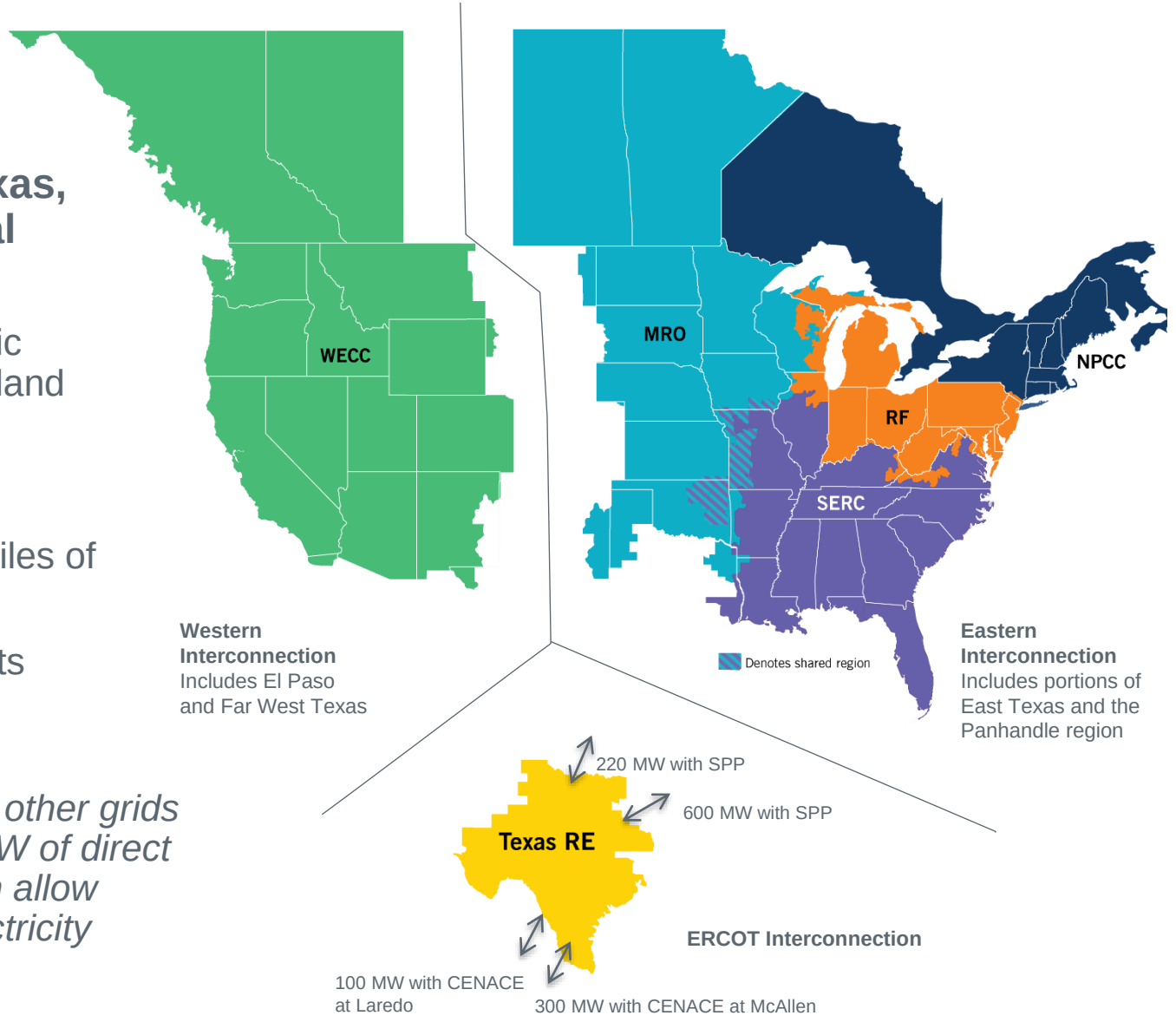
The ERCOT Region

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

- 90% of Texas electric load; 75% of Texas land
- 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

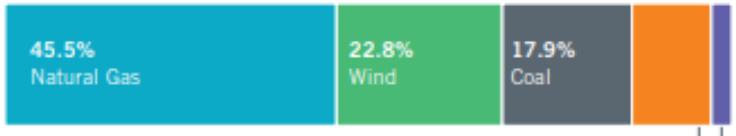


ERCOT Facts

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.

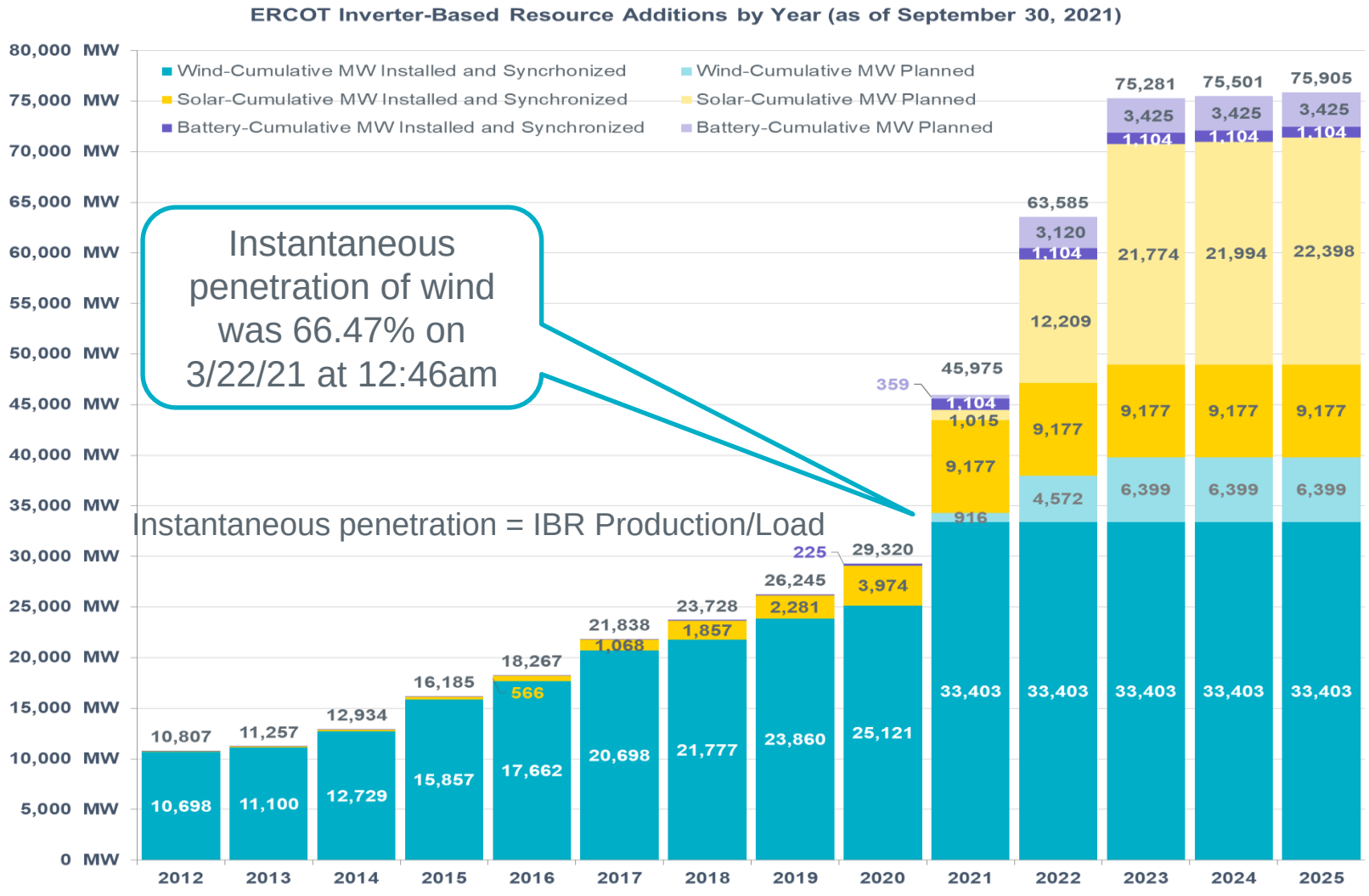
- 710+ generating units, excluding PUNs
- Transmission projects endorsed in 2020 total $1,071 million
- 46,500+ miles of high-voltage transmission

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

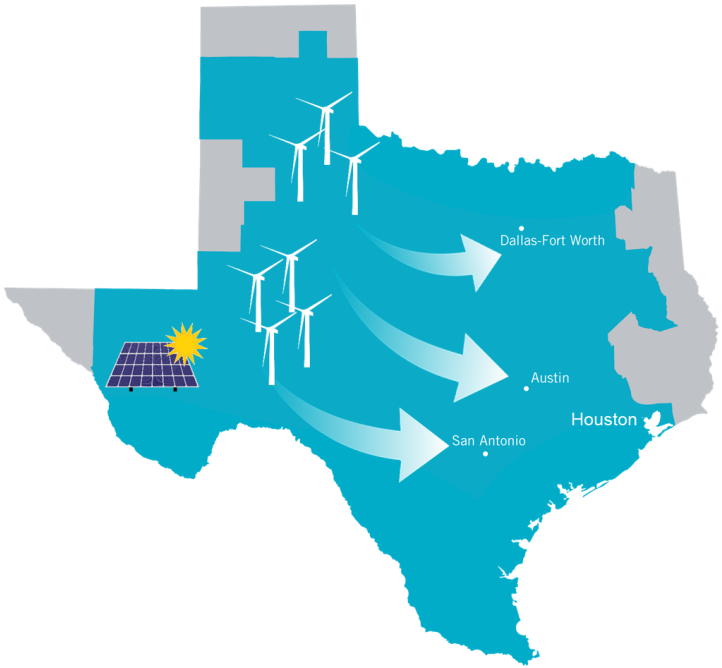
Note: Of the planned projects shown on the chart, only the ones that reached certain project milestones are included in the planning studies

Inverter-Based Resources in ERCOT

- > 45 GW IBRs are planning 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
- Similar issues are also manifesting themselves in South Texas.
- Increased number of stability-related constraints managed through Generic Transmission Constraints (GTC).

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

*As of Sept. 2021



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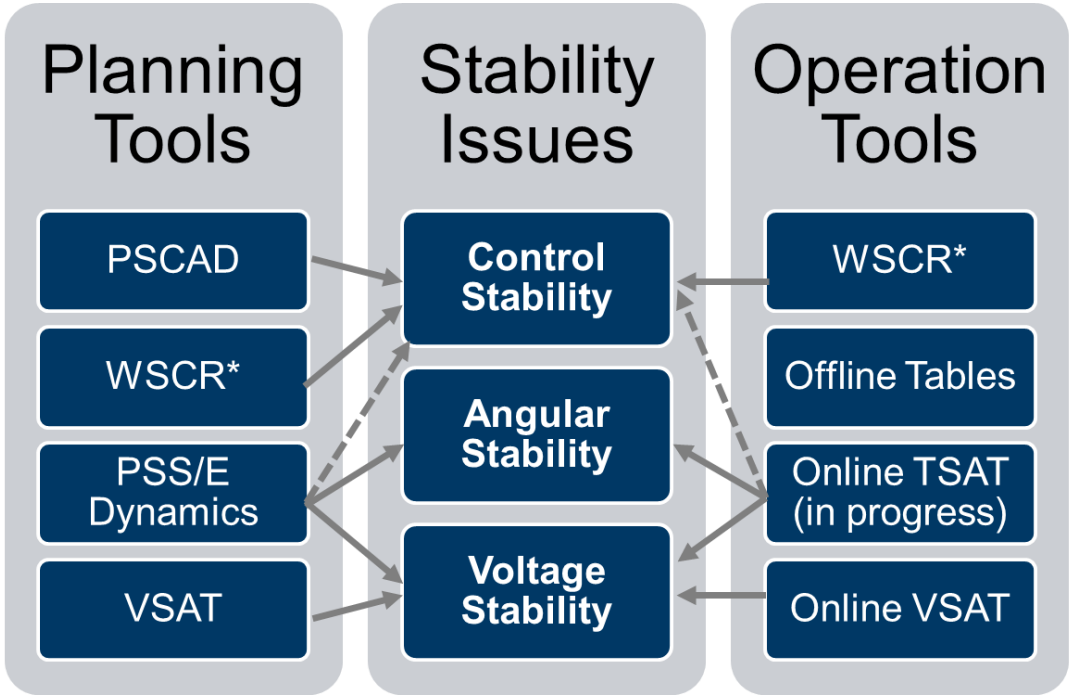
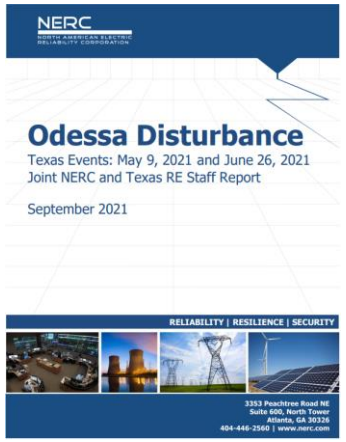
Stability Assessment and Tools

- With more IBRs
  - 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



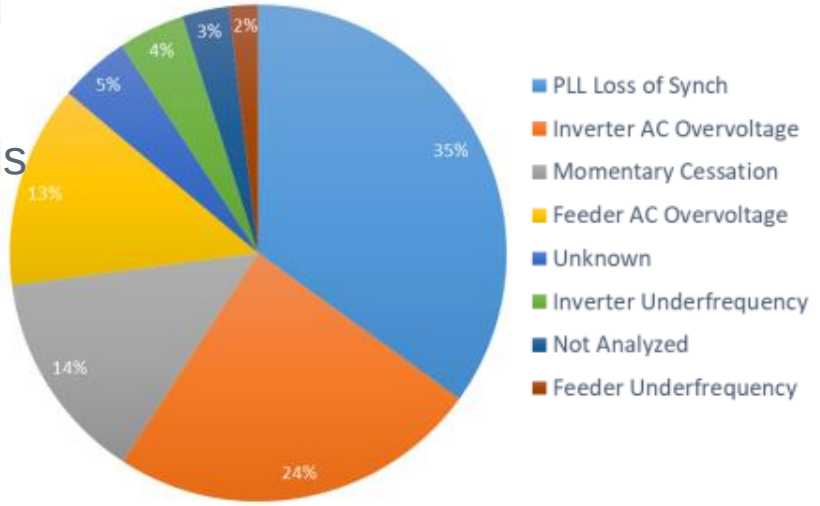
* WSCR (weighted short circuit ratio) is used to identify the system strength of an area with multiple IBRs. Detailed PSCAD studies are required to validate the adequacy of WSCR application and its threshold for weak grid identification.

Odessa disturbance

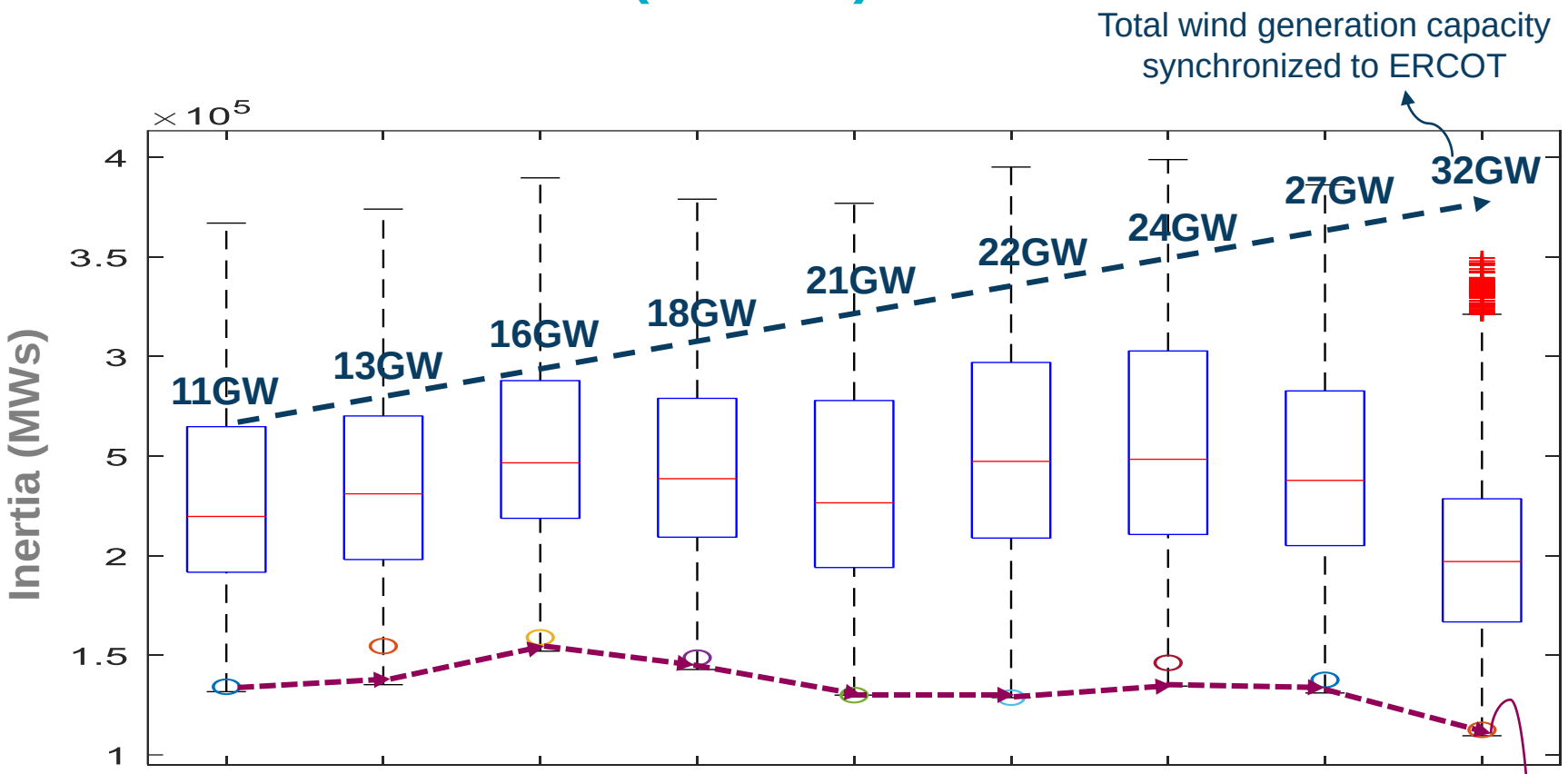


- On May 9, 2021, a single-line-to-ground fault occurred at a combined-cycle plant near Odessa, TX, cleared within 3 cycles.
- The fault caused voltages in the area to drop, but are generally within Voltage Ride-Through envelope.
- A number of transmission-connected IBRs (primarily solar PV) exhibited MW reductions (from few seconds to serval minutes) caused by the fault event.
- The preliminary review of the dynamic models provided by the Resource Entities indicated model deficiency and needs for model and process improvements.
- NERC Webinar on November 5th.

MW Reduction by Unit Type	
Combined Cycle Plant	192
Solar PV Plants	1,112
Wind Plants	36
Total	**1,340**



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 (the first stage of ERCOT UFLS setting).
- Monitoring of inertia in real-time and forecasting several hours ahead.
- If inertia is getting close to critical level (currently 100 GWs), 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 (Responsive Reserve Service) are procured.
- Faster frequency response is more effective than traditional governor response in low inertia conditions.
- Fast Frequency Response has been introduced (sub-product in RRS) to ensure faster and earlier response. This allows reduction of critical inertia level and reduces overall amount of frequency containment reserves.

ERCOT's Ancillary Services

New Framework, NPRR 863

Regulation Up

157 to 687 MW

Regulation Up

157 to 687 MW

Responsive Reserve Service (RRS)

- Fast Frequency Response (FFR)
- Load Resources on UFR
- Primary Frequency Response (PFR)

2,300 to 3,200 MW

ERCOT Contingency Reserve Service (ECRS)

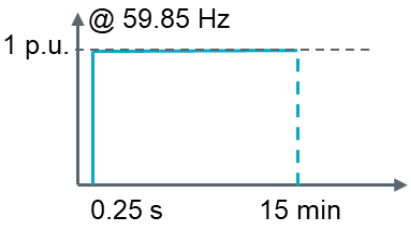
- 10 minute ramp
- Load Resources may or may not be on UFR

508 to 1,644 MW

Non-Spin

0 to 1,180 MW

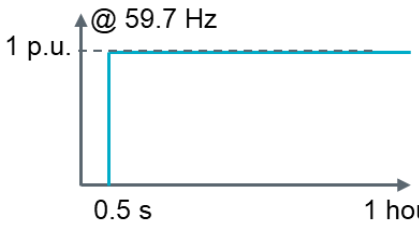
NEW



FFR

OR

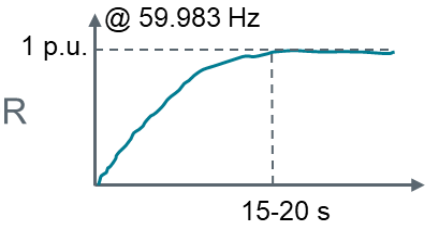
Unchanged



Load Resources w. UFR

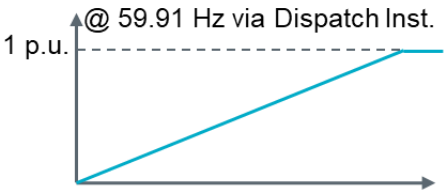
OR

Awarded MW
Perf.-Based



PFR

NEW



10-min ramp

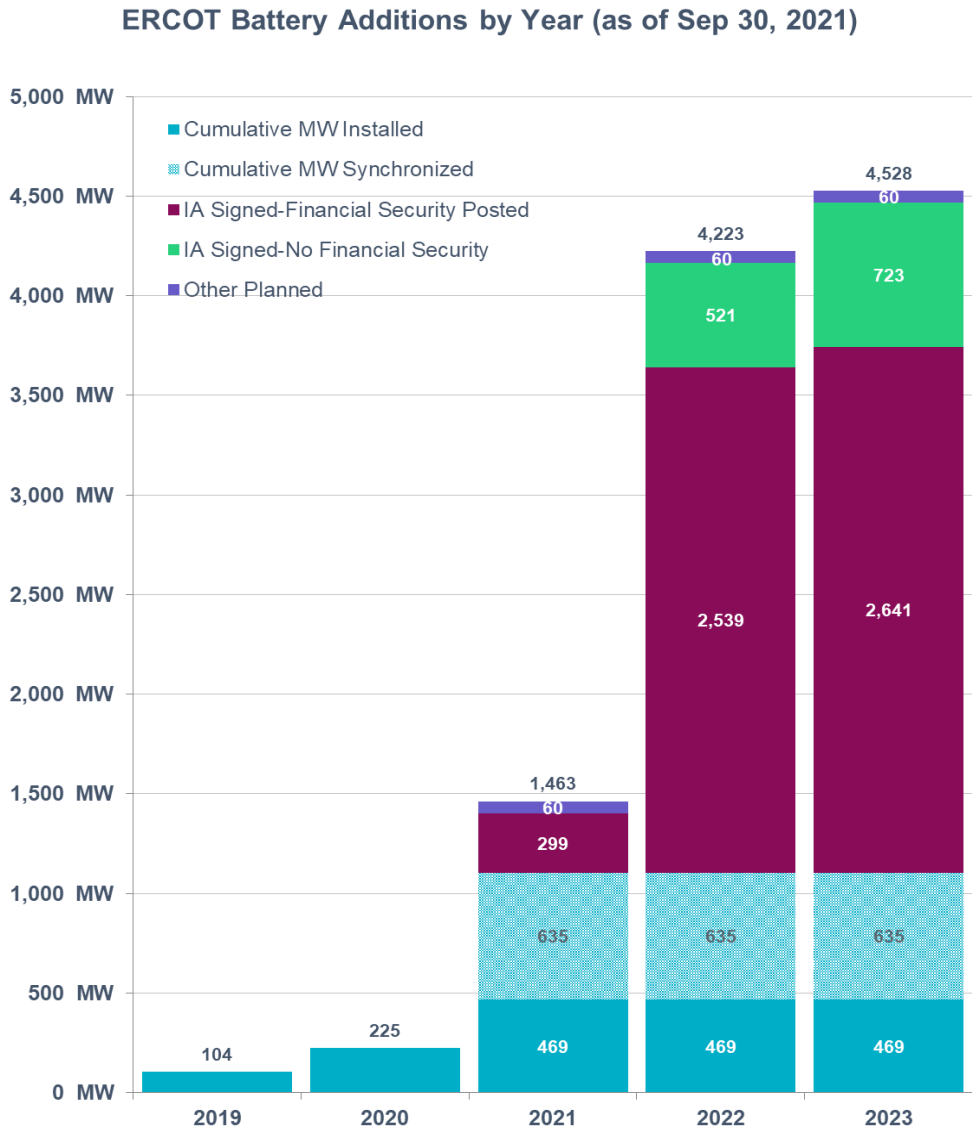
Overall A/S: 3,807 to 5,958 MW*

FFR implemented on 3/1/2020 and ECRS will be implemented in 01/2022

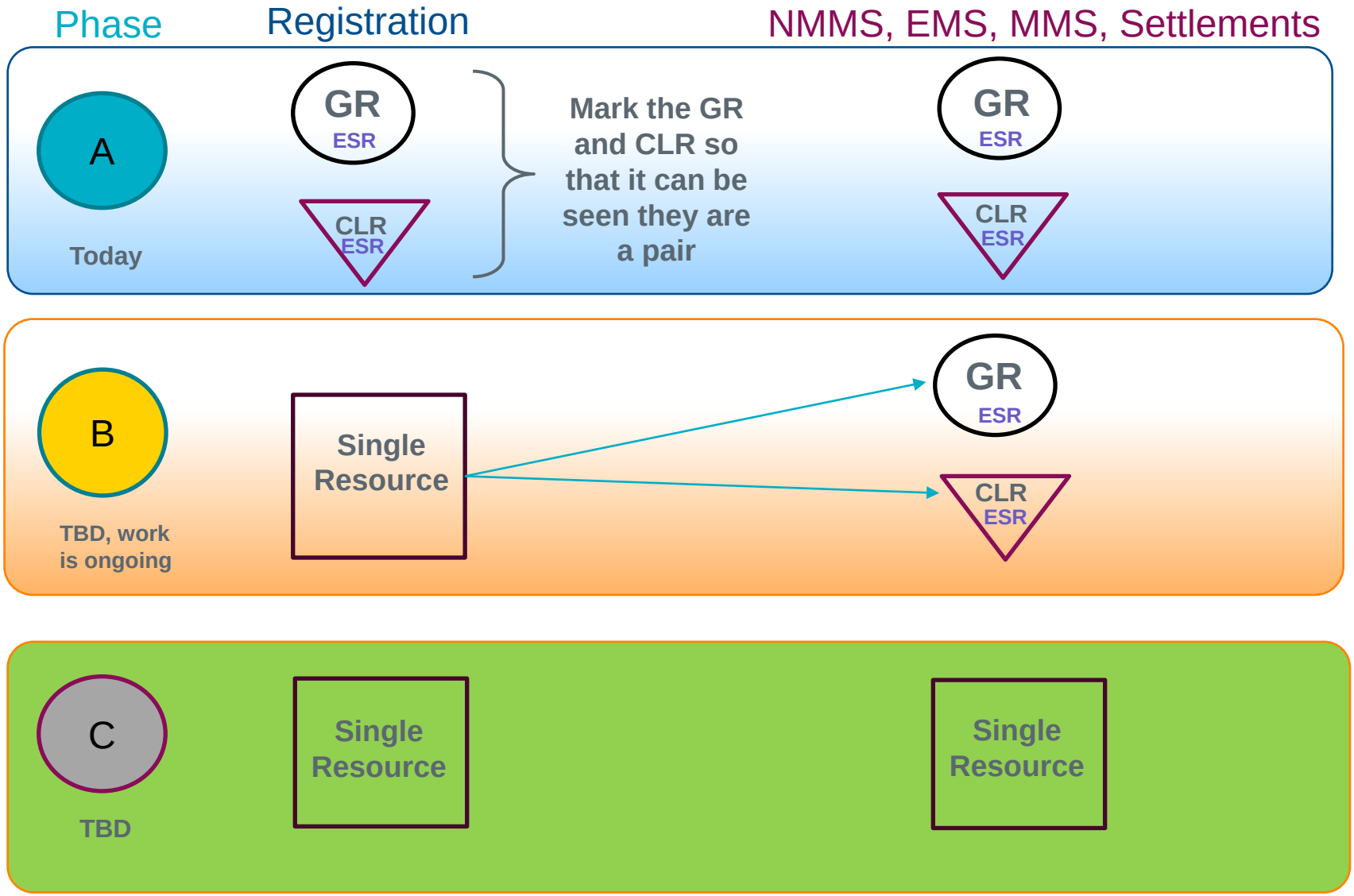
Integration of Battery Storage

Some of the drivers:

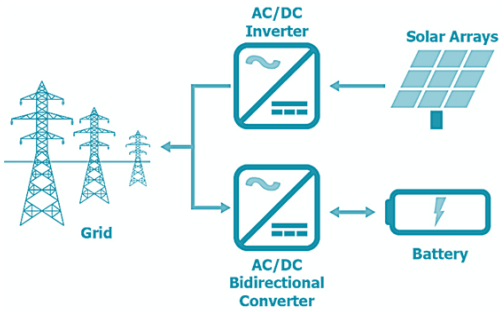
- Declining technology costs
- Federal incentives (for co-located with solar PV)
- Price spikes during scarcity conditions, i.e. opportunities for energy arbitrage
- Utility-scale energy storage in ERCOT can participate in energy market and any or all the existing Ancillary Services (after completing required qualification testing)



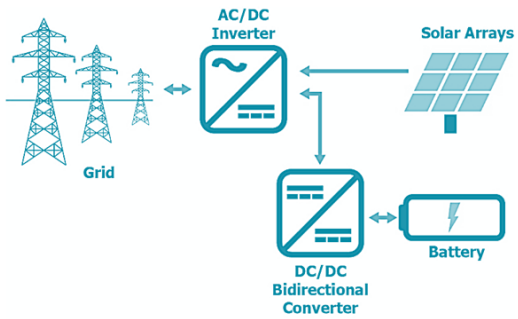
ERCOT Evolution for Battery Energy Storage Resources



Overview of Different Co-Located ("Hybrid") Resources

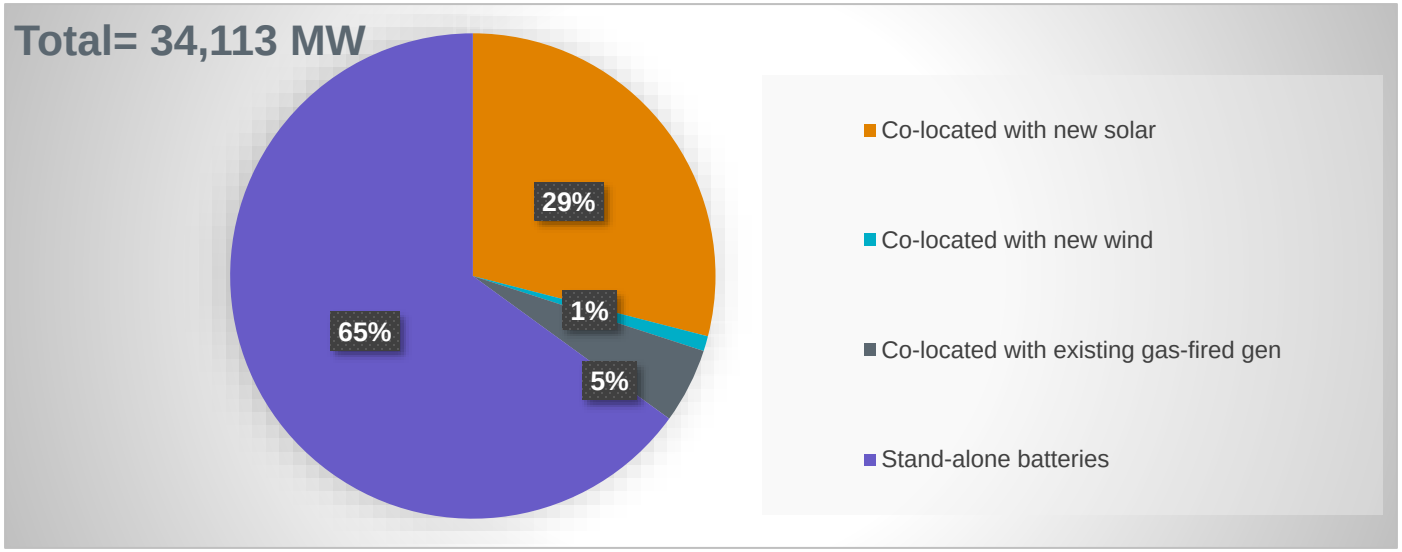


AC-Coupled Hybrid Plant



DC-Coupled Hybrid Plant

Battery storage projects in ERCOT interconnection queue with Full Interconnection Study started, September 2021



* Co-located means the same Point of Interconnection (POI)

Summary

- ERCOT successfully has integrated nearly 45 GW of IBRs and significant amount of IBRs is projected in near future
- Increasing number of stability-related transmission constraints due to high IBR concentration in areas remote from the load centers and synchronous generation
- Increasing complexity of simulation tools, models and model validation processes
- Increasing need for real-time simulation tools
- Inertia and frequency containment has not been an immediate concern and is being addressed through increased situational awareness and introduction of faster AS.
- Increased interest in development of Battery Storage requires a number of changes in ERCOT systems
- With rapidly growing interconnection queue more work lies ahead....

Thank you! Questions?

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