Item 4.7: System Operations Update – REVISED*

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Board of Directors Meeting

ERCOT Public
June 23-24, 2025

* 06/20/2025 Updates:
- Slide 7 updated
- Slides 12-14 added

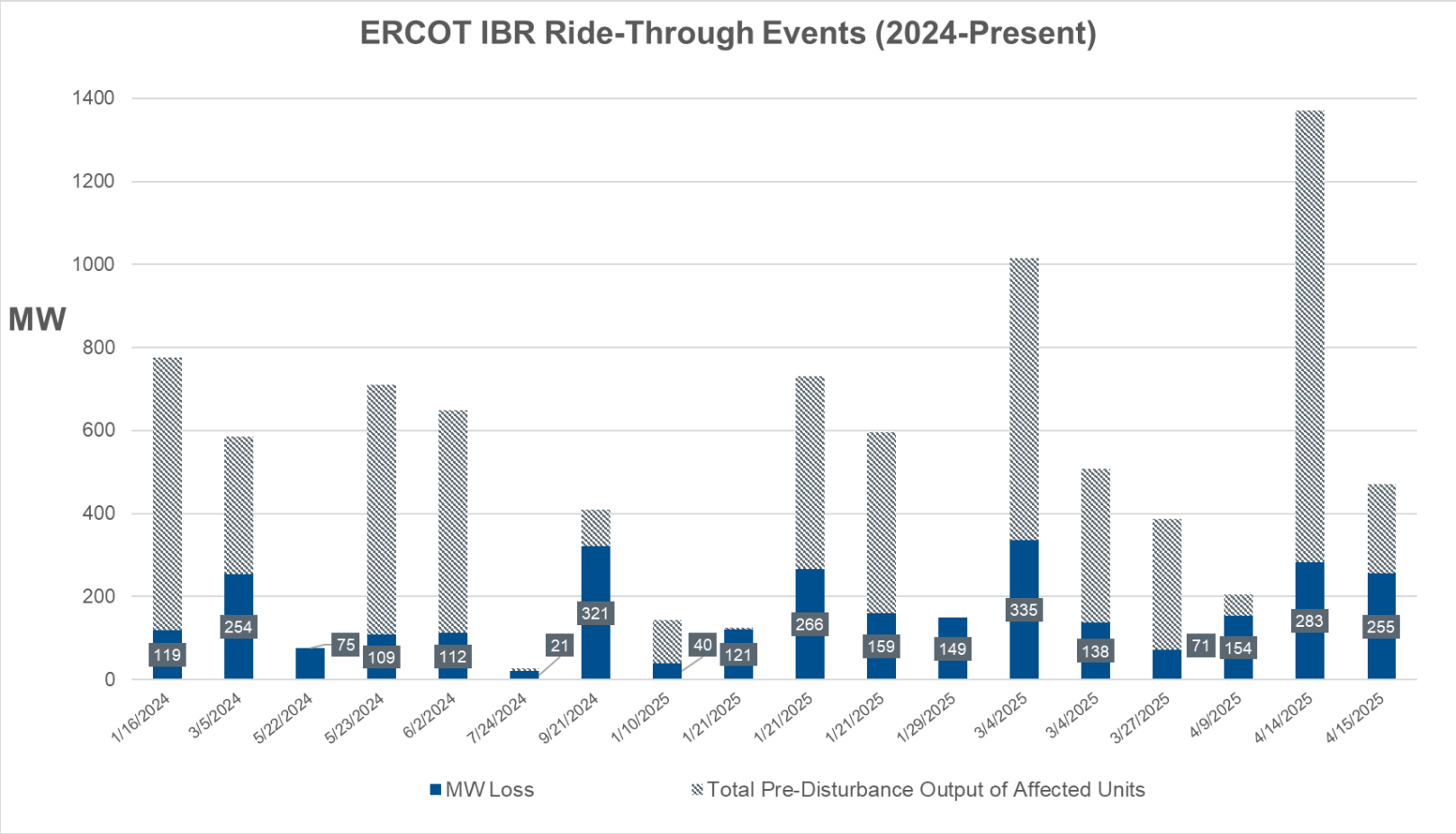
Overview

- **Purpose**
  - Provide an update on key operational metrics to the Board of Directors
  - Provide information on recent Ancillary Services performance
  - Provide information on hot topics
- **Voting Items / Requests**
  - No action is requested of the Board of Directors; for discussion only

- **Key Takeaways**
  - ERCOT continues to have IBR ride-through events, although the magnitude of events has remained below 500 MW.
  - Power electronic Large Load events continue to occur.
  - ERCOT is monitoring the facts coming out of Spain and Portugal following the blackout on April 28.
  - All key operational metrics are trending well, and all Ancillary Services are performing well.

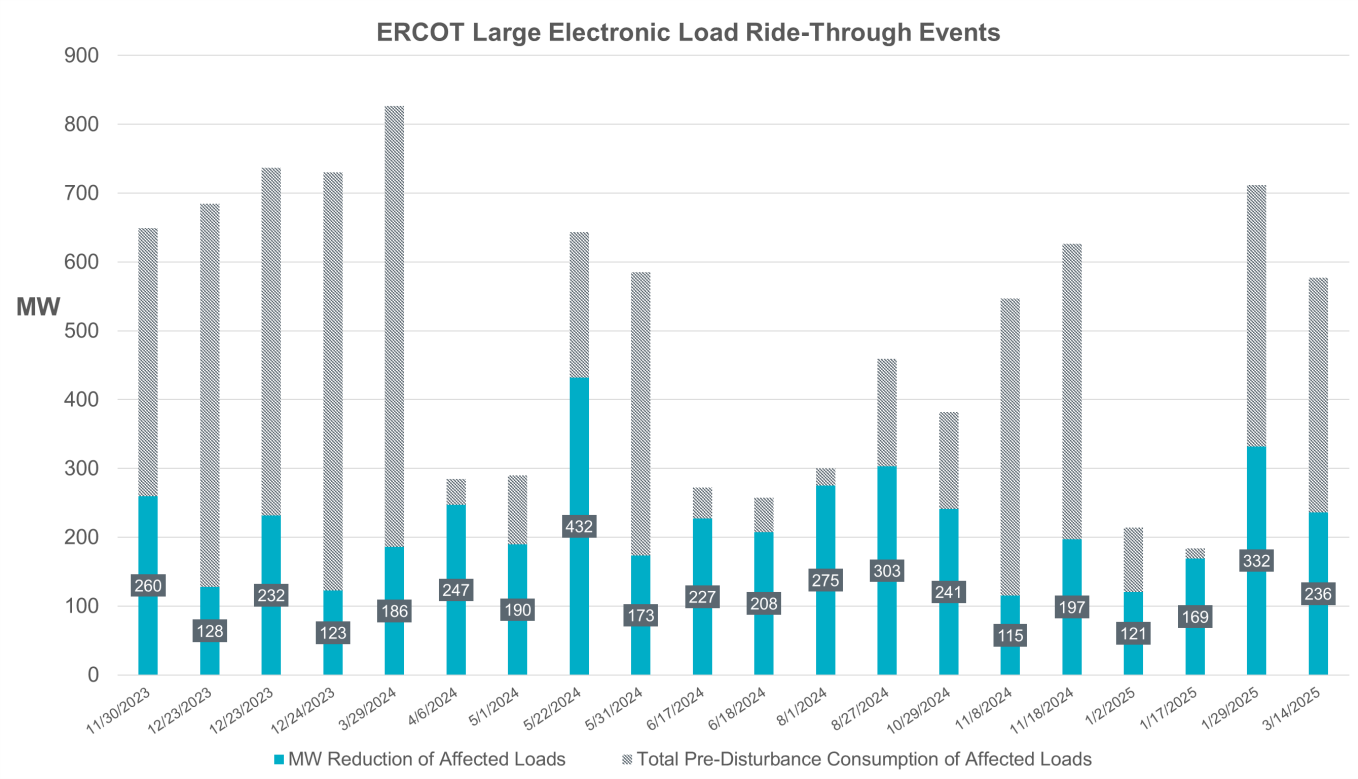
Inverter-Based Resource (IBR) and Large Electronic Load Ride-Through Events

IBR Ride-Through Events



Key Takeaway: ERCOT continues to have IBR ride-through events, although the magnitude of events has remained below 500 MW.

Large Electronic Load Ride-Through Events



Key Takeaway: Large Electronic Loads reduce consumption quickly when system faults occur in their area. The magnitude and frequency of these events will likely increase as more of these types of loads are connected to the system, especially when they are concentrated in an area.

This is an update with new events from the slide presented at April 2025 BOD.

April 28 Spain and Portugal Blackout Event

Disclaimers

- This presentation includes only information that is publicly available on the Spain and Portugal blackout event
- The Spanish grid operator, Red Electrica, posted a report on 6/18/25 and findings from that report have been added to this presentation on 6/20/25

ERCOT, Spain, & Portugal Comparison

ERCOT

- ~ 85,000 MW Peak Demand
- ~ 54,000 miles of high-voltage transmission (345, 138, & 69 kV)
- ~170,000 MW of installed capacity
- No synchronous connections

Spain and Portugal (Combined)

- ~ 50,000 MW Peak Demand
- ~ 31,000 miles of high-voltage transmission (400, 220, & 150 kV)
- ~ 150,000 MW of installed capacity
- Synchronous interconnections to France and Morocco (2,800 & 1,500 MW, respectively)

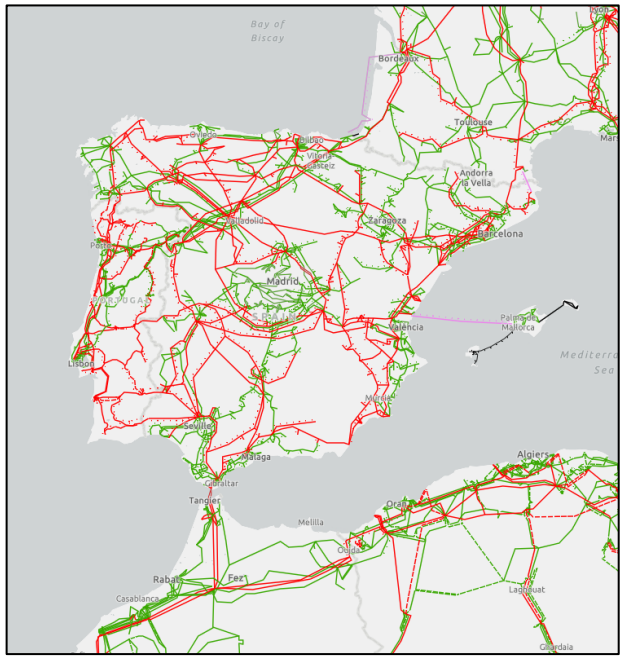
Energy Mix	ERCOT (2024)	Spain (2023)	Portugal (2023)
Natural Gas	44.2%	22.5%	21.3%
Oil	0.0%	3.3%	2.5%
Wind	24.2%	22.5%	26.9%
Coal	12.6%	1.6%	0.0%
Solar	10.4%	16.9%	11.2%
Nuclear	8.4%	19.9%	0.0%
Hydro	0.1%	10.9%	29.6%
Biofuels	0.1%	1.8%	7.1%
Other	-0.1%	0.7%	1.4%

Source: International Energy Agency (IEA)

April 28 Spain & Portugal Blackout

Known facts:

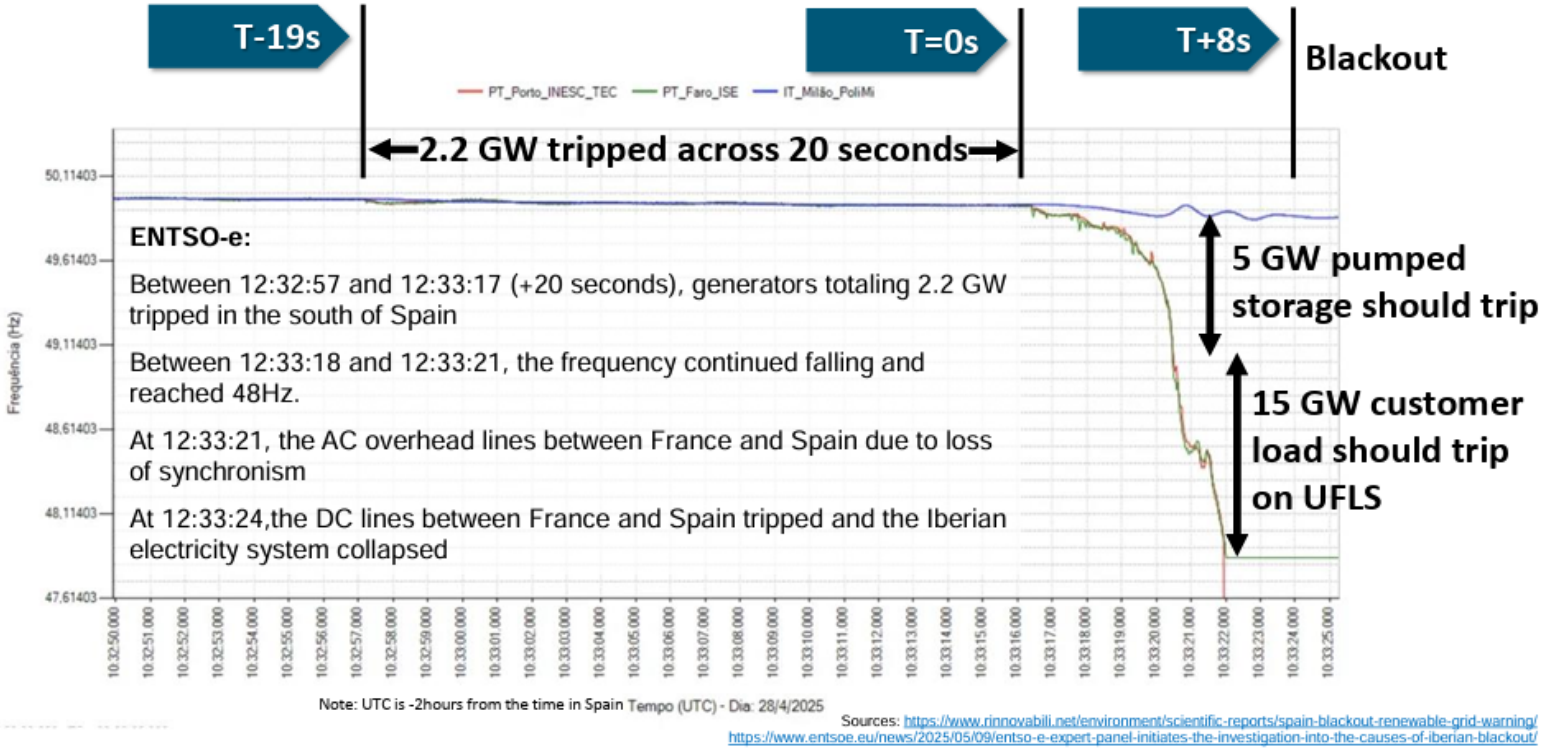
- Two loss of generation events within 1.5 seconds
  - Initial estimates are 2,200 MW in Southern Spain
- Instability resulting in separation from rest of European system
  - All six stages of Under-Frequency Load Shedding (UFLS) were activated but did not resolve the issue
  - Phase angle deviations led to loss of synchronism
- Further loss of generation and system collapse
- Relatively rapid Black Start implementation
  - Spanish load was fully restored in 23 hours
  - Portuguese load was fully restored in 12 hours



Key Takeaway: While the root cause of the Iberian blackout is still unknown, it appears to have been a fast-acting instability event.

April 28 Spain & Portugal Blackout

- Cause of generation outages currently unknown
- Frequency decreased to 48Hz (50Hz base)
- Automatic under-frequency load shedding was activated
- Loss of synchronism due to phase angle deviations



Sources: https://www.rinnovabili.net/environment/scientific-reports/spain-blackout-renewable-grid-warning/
https://www.entsoe.eu/news/2025/05/09/entso-e-expert-panel-initiates-the-investigation-into-the-causes-of-iberian-blackout/

April 28 Spain and Portugal Blackout Black Start

- Iberian Grid: Spain & Portugal
  - Synchronously connected with continental European (CE) system
- Restoration Process Initiated Minutes after event
    - Initial load restoration done through ties
      - France energizing from the North
      - Morocco energizing from the South
  - Hydro and Combined Cycle Gas Turbine (CCGT) Black Start Resources both in Spain & Portugal
    - CCGT: 2 failed attempts to energize the grid
  - Spanish load was fully restored in 23 hours
  - Portuguese load was fully restored in 12 hours

Key Takeaway: The rapid restoration of load can be attributed to Northern and Southern AC ties.

Summary based on 6/18/25 Red Electrica report

Event was due to a combination of factors, including:

- Oscillations
  - There was a forced oscillation due to a PV power plant's controls
  - The system adjustments made to dampen this oscillation raised system voltages
- Voltage management
  - Reactive power requirement of renewable generation is based on maintaining power factor not voltage, with reactive power requirement varying based on real power output
  - Units that were supposed to provide dynamic voltage control did not do so effectively
- Lack of ride-through
  - Some units, on both transmission and distribution systems, did not ride through high voltages

ERCOT Strategies Related to Red Eléctrica Findings

Findings	Spain	ERCOT
Oscillations	• Leading up to the event, oscillations were observed from a photovoltaic plant • Actions that were taken to mitigate the oscillation increased system voltage and reduced the system's voltage control flexibility	• Identify and implement Generic Transmission Constraints (GTCs) to maintain stable operations of impacted Resources • ERCOT synchronous Generation Resources (GRs) are required to install Power System Stabilizers to provide oscillation dampening support • ERCOT has some streaming PMUs and tools to diagnose real-time oscillations • ERCOT has ordered generators offline until they fix the source of their oscillations

ERCOT Strategies Related to Red Eléctrica Findings

Findings	Spain	ERCOT
Voltage Control	• Only conventional generators are required to comply with dynamic voltage control requirements • Other resource types, including renewables, are operated at constant power factor control • Some generation failed to comply with its voltage control obligations	• All GRs and Energy Storage Resources (ESR) are required to provide dynamic voltage support • ERCOT/VPWG routinely review and assess resources' voltage control performance • GR and ESR automatic voltage regulation (AVR) response to a change in voltage is tested every five years
Voltage Ride-Through	• Some generators tripped without meeting ride through requirements due to insufficient margin (set protection at the ride through profile) or without enough time delay	• GRs and ESRs are required to meet voltage and frequency ride through requirements. These are minimum operational requirements, not protection set-points • NOGRR245 reinforces IBR ride-through capability for existing units and improves capability for future units

(Added)

Initial Lessons Learned for ERCOT

- ERCOT has several existing processes in place and initiatives underway that would:
  - Prevent or lessen the magnitude and number of large power imbalances
  - Mitigate the impact of a large imbalance if it were to occur
  - Recover from the effects of a collapse due to a large imbalance
- The following slides list those processes and initiatives for reference; won't cover some of these today because they are subjects of a different presentation later in the meeting

Preventing Large Power Imbalances

ERCOT has implemented many processes over the last decade to mitigate the simultaneous loss of multiple generation sites

- Identification of Generic Transmission Constraints (GTCs) limit the output from units in an area to the amount that would be stable following a fault on the system
  - Identifying these situations has required increased study capability and personnel, more accurate dynamic models of the generators, etc.
  - Online stability studies to allow identification and quantification of stability issues rather than depending on offline studies
- NOGRR 245 to reinforce IBR ride-through capability for existing units and improve that capability for future units – to limit the number of generators that trip due to a single fault
- Project to install synchronous condensers at key locations across West Texas to limit the number of generators that are affected by a single fault
- Improved event analysis and data collection from smaller events such as IBR ride-through failures and generation/load oscillations

Preventing Large Power Imbalances

ERCOT has been working on additional initiatives to reduce the potential for loss of generation and large loads

- Current proposal to require grid-forming capability for all future Energy Storage Resources (NOGRR272/PGRR121)
- Current proposal to establish planning criteria to avoid the amount of load lost for any single contingency (PGRR122)
- ERCOT is investigating ride-through capabilities and requirements for large electronic loads

Mitigating the Impact of Large Power Imbalances

- ERCOT procures enough frequency-responsive Ancillary Services (Responsive Reserve Service (RRS)) to withstand the simultaneous loss of two largest units and keep the frequency above 59.3 Hz
  - Procure enough ERCOT Contingency Reserve Service to restore RRS within 15 minutes to prepare for another loss
  - This also protects against smaller outages or simultaneous outages of multiple units up to this magnitude (~2800MW)
  - The amount of RRS that is needed to protect against this generation loss varies based on the inertia on the system; so more RRS is procured when inertia is expected to be lower

Mitigating Large Power Imbalances – UFLS "Safety Net"

ERCOT implemented an Under-Frequency Loadshed Scheme (UFLS) program reduce up to 25% of system load automatically to serve as a safety net for larger generation losses

- For many years, this UFLS program included 3 stages; after winter storm Uri, this was adjusted to 5 stages over the same frequency range
- An "anti-stall" system is also being added to restore frequency if frequency stays below 59.5 Hz for an extended period

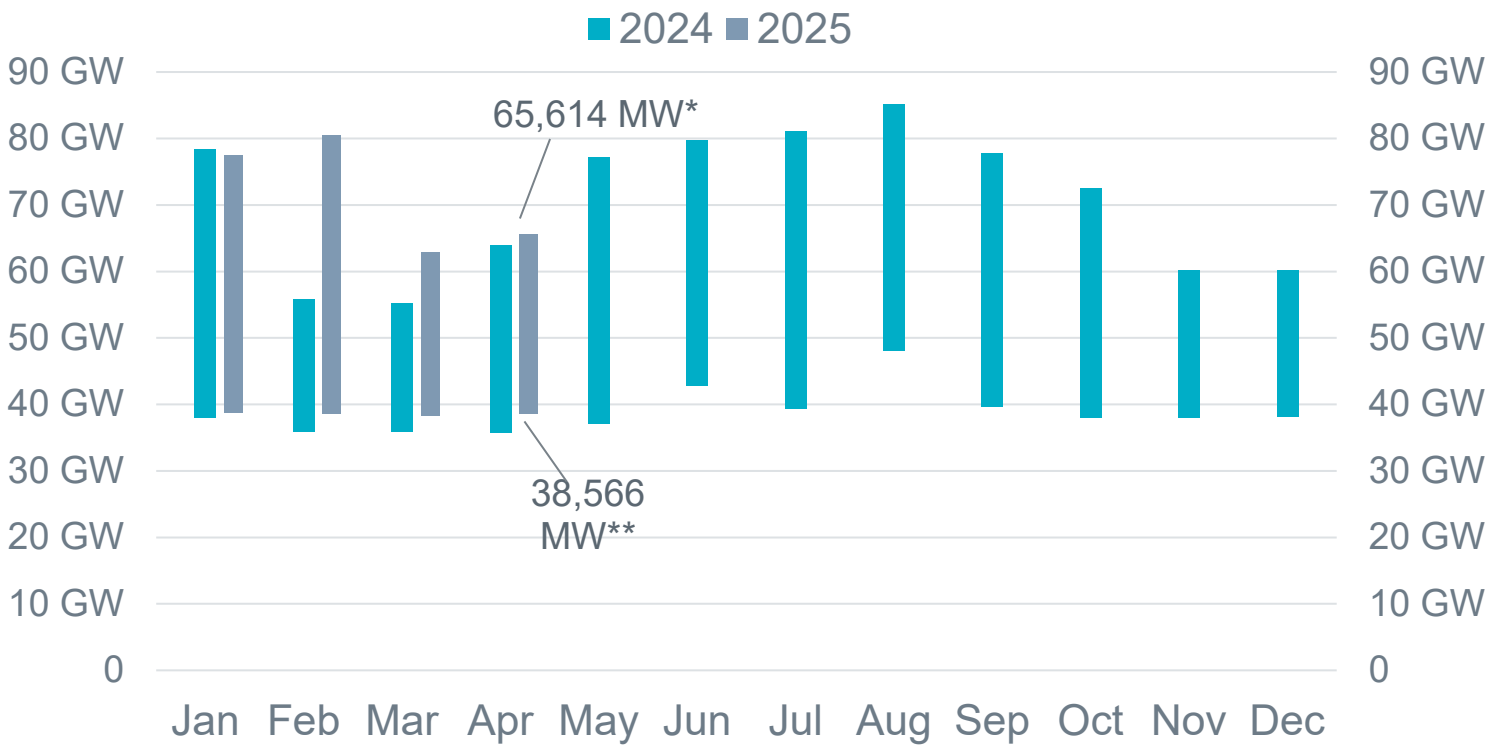
Frequency Threshold	Minimum Requirement	Delay to Trip
59.3 Hz	At least 5% of the TO Load	At least six cycles but no more than 30 cycles
59.1 Hz	A total of at least 10% of the TO Load	At least six cycles but no more than 30 cycles
58.9 Hz	A total of at least 15% of the TO Load	At least six cycles but no more than 30 cycles
58.7 Hz	A total of at least 20% of the TO Load	At least six cycles but no more than 30 cycles
58.5 Hz	A total of at least 25% of the TO Load	At least six cycles but no more than 30 cycles

Recovering: Black Start Improvements

- If a blackout affects all or a large portion of a power system, special tools and procedures (Black Start) are used to re-energize the area
- ERCOT conducts annual Black Start Training with required Market Participants
  - Simulates a blackout event
  - Participants utilize Black Start tools and procedures to simulate the restoration of the grid
  - Next Black Start Training will be in October 2025
- ERCOT is actively reviewing the use of *temporary* synchronous ties to facilitate Black Start
  - Following Winter Storm Uri, ERCOT worked with Texas A&M to determine potential locations where temporary synchronous ties could form a Black Start "peninsula" to more quickly restore ERCOT load and generation following a blackout
  - The Iberian event emphasized the benefit of this initiative

Appendix
Operational Metrics and Ancillary Services Performance

Demand



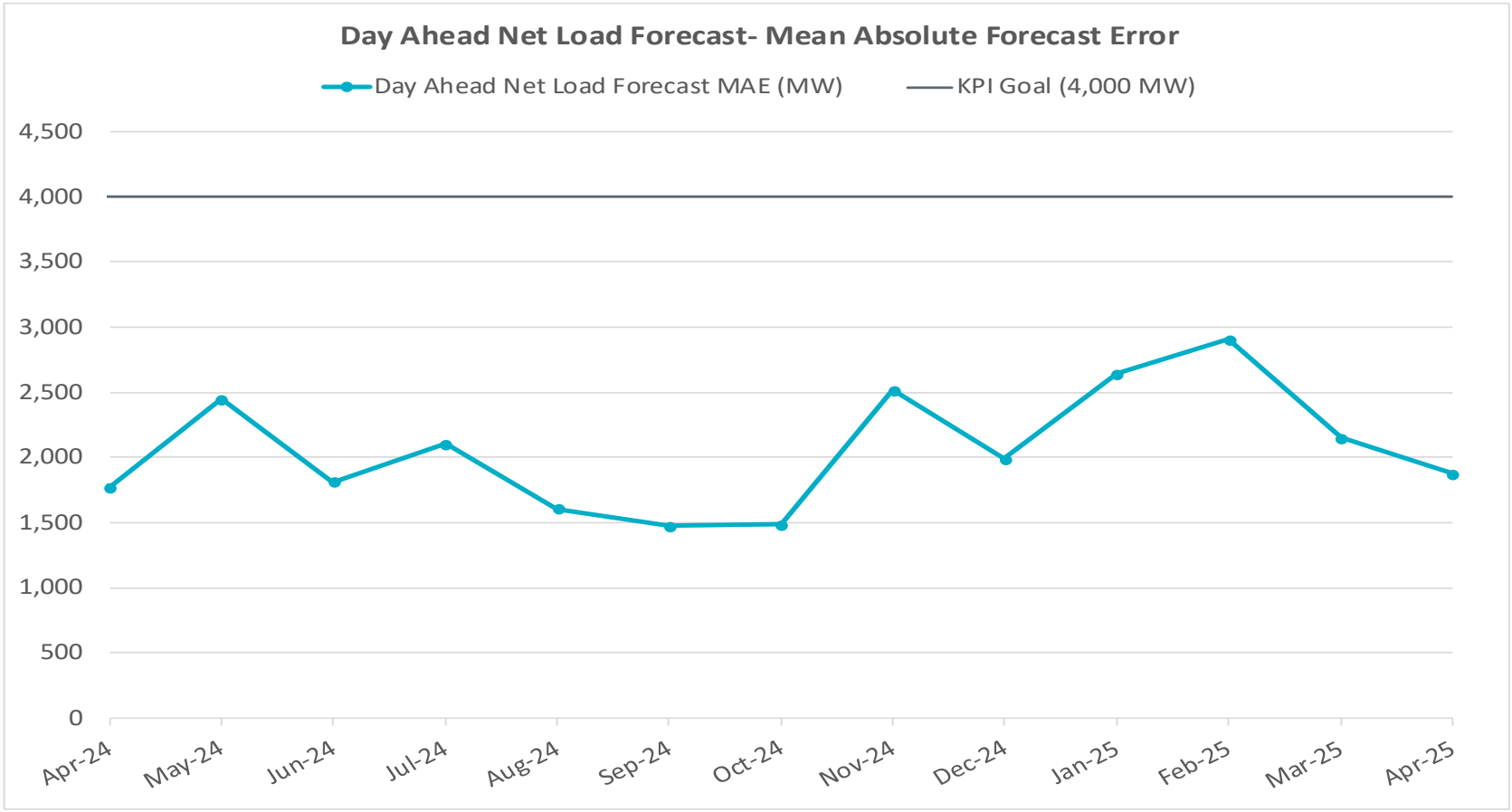
*Based on the maximum net system hourly value from April release of Demand and Energy 2025 report.

**Based on the minimum net system 15-minute interval value from April release of Demand and Energy 2025 report.

Data for latest two months are based on preliminary settlements.

Key Takeaway: ERCOT set a new record of 65,614 MW* for the month of April on 4/14/2025. This is 1,617 MW more than the April 2024 demand of 63,997 MW on 4/30/2024.

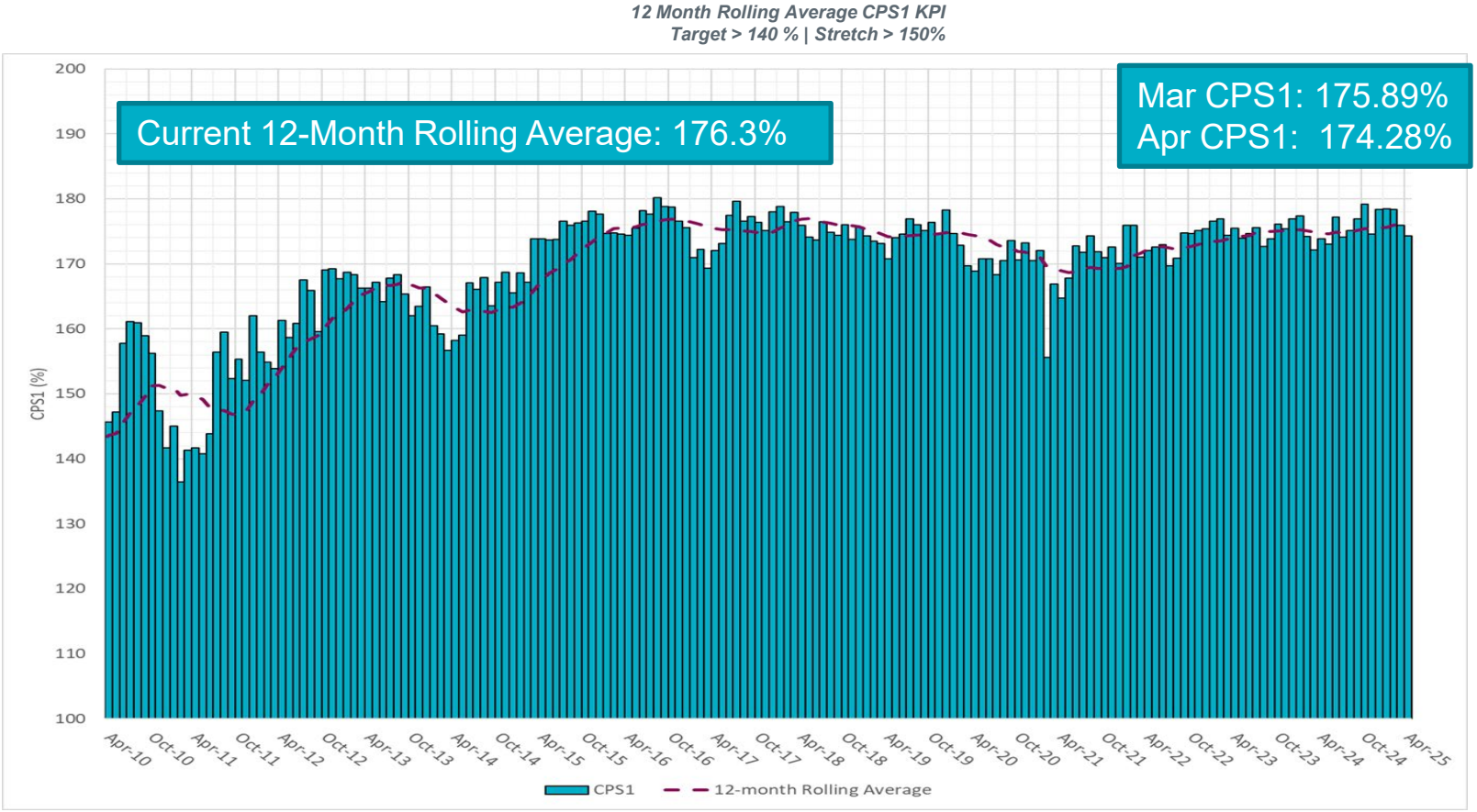
Forecast Performance



Key Takeaway: Day Ahead Net Load Forecast Mean Absolute Forecast Error has met the target and has been trending well.

Frequency Control

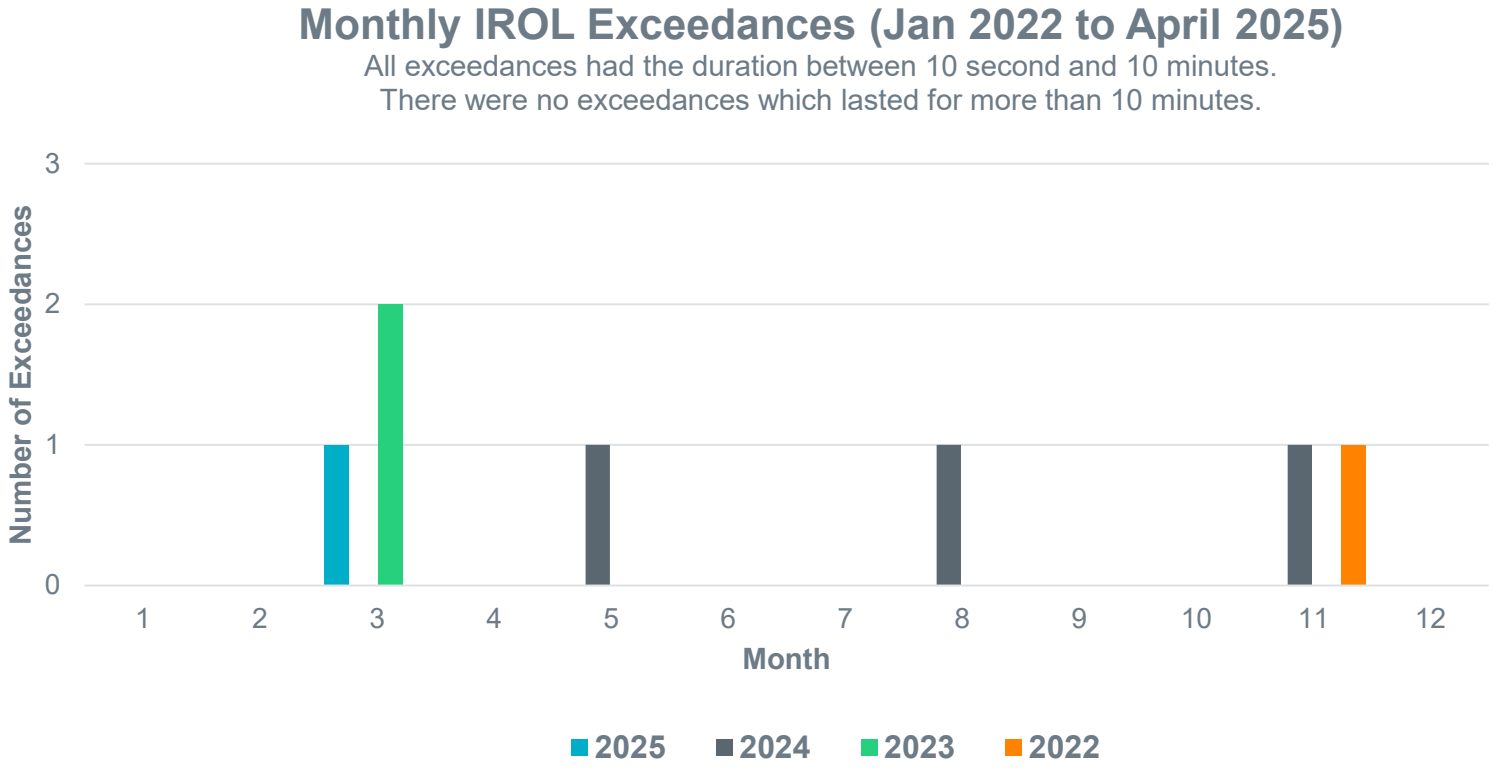
- Control Performance Standard 1 (CPS-1) is a measure of the frequency control on a power system, pursuant to NERC Standard BAL-001. The 12-month rolling-average of this measure is required to stay above 100%.



Key Takeaway: Frequency control has been performing extremely well.

Transmission Limit Control

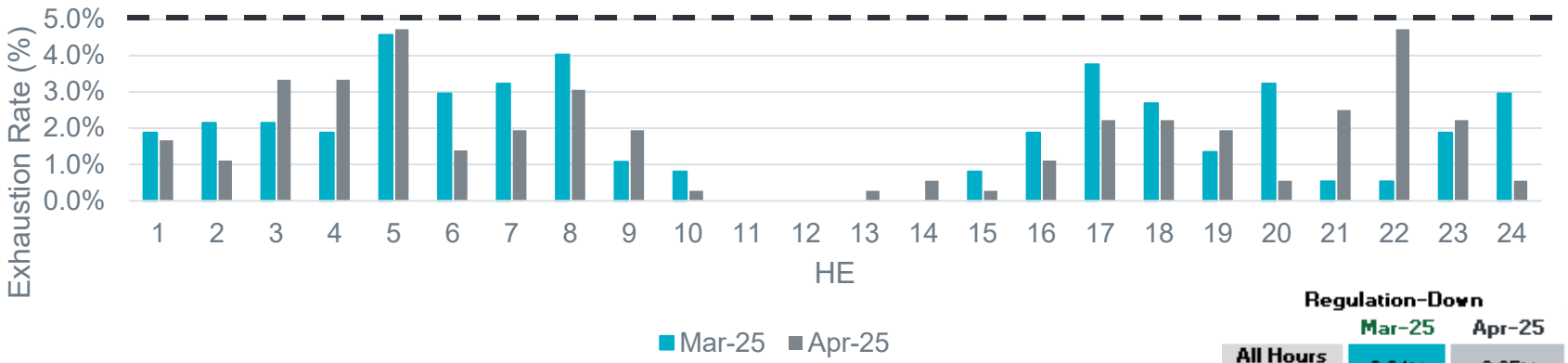
- The most-recent Interconnection Reliability Operating Limit (IROL) exceedance occurred in March 2025.



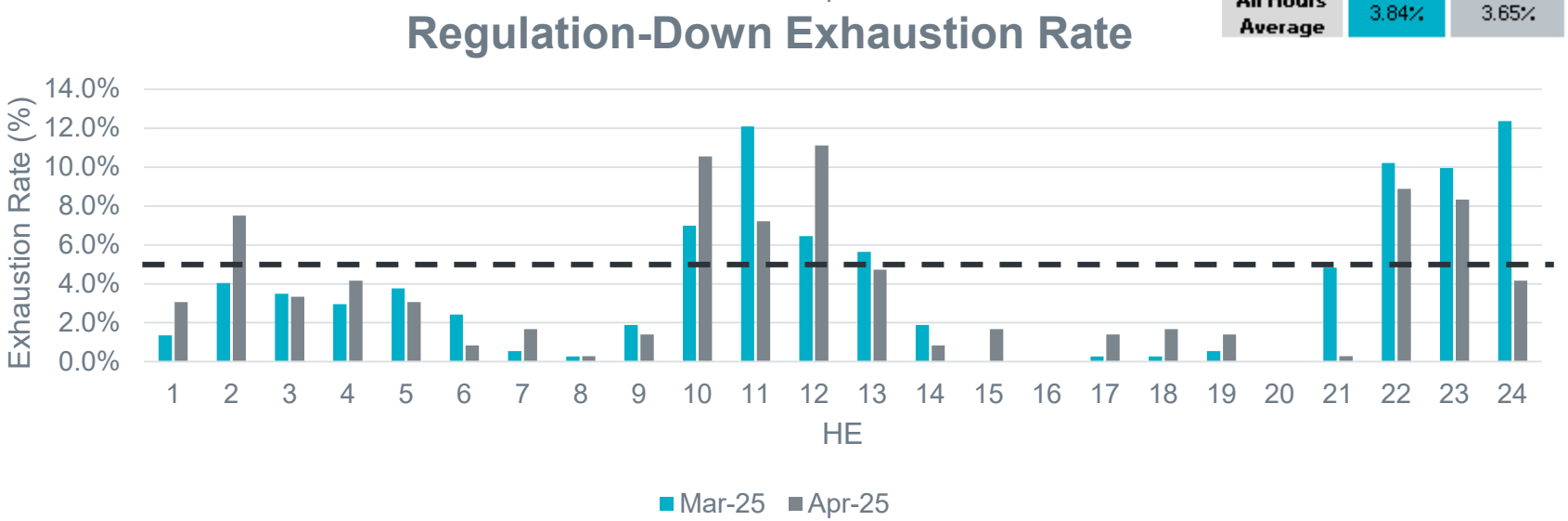
Key Takeaway: Panhandle IROL exceeded for approximately 2 minutes on March 28, 2025.

Regulation Service Deployments for Mar-Apr 2025

Regulation-Up	Mar-25	Apr-25
All Hours Average	1.85%	1.75%



Regulation-Down	Mar-25	Apr-25
All Hours Average	3.84%	3.65%



Exhaustion Rate = % of 5 min intervals when all available Reg is less than 5 MW

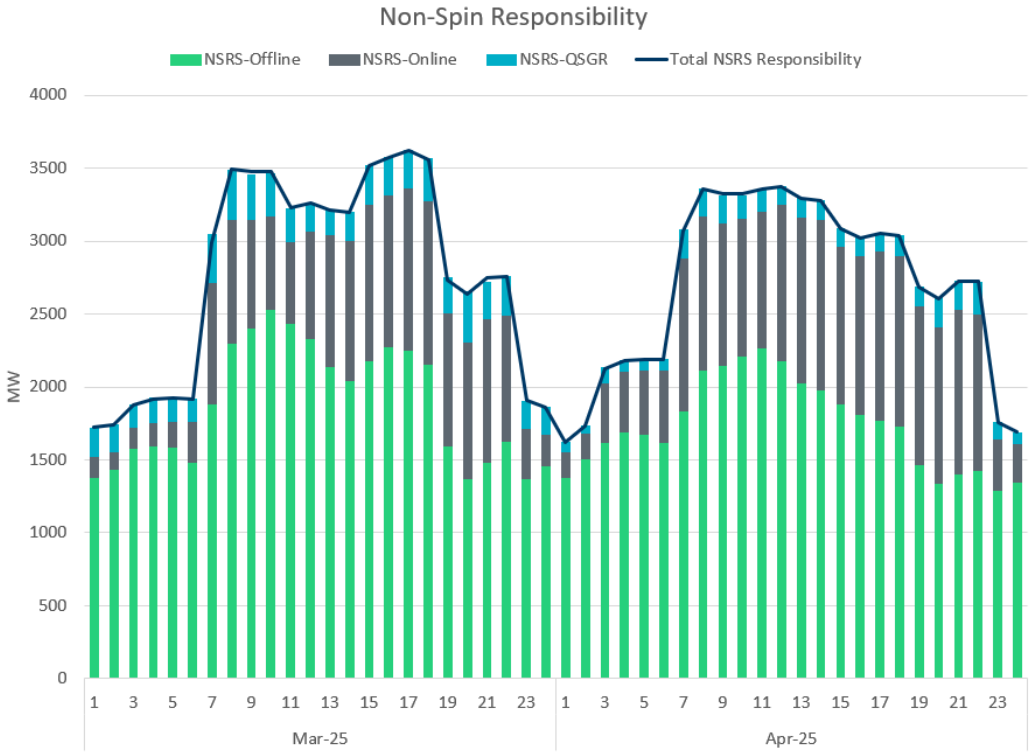
Key Takeaway: Average Regulation Up and Down exhaustion rates were similar in 2024.

Non-Spinning Reserve Service (Non-Spin) Deployments for Mar-Apr 2025

From March to April 2025, there were 7 event that resulted in deployment of offline Non-Spin.

During this time, an average of ~32% of Non-Spin was provided using online capacity and by Quick Start Generation Resources. This type of Non-Spin is always available to SCED to dispatch (with an offer floor of $75) and no operator action is needed to deploy this capacity.

Deployment Start Time	Deployment Duration	Max Deployment (MW)
3/1/2025 16:57	01:23:10	1375
3/2/2025 17:43	04:41:48	2021
3/5/2025 17:36	01:38:12	696.3
3/10/2025 18:46	01:25:56	1929.3
4/7/2025 18:46	01:13:28	1408.8
4/11/2025 18:37	01:32:14	1393
4/21/2025 19:05	01:21:09	1321.4

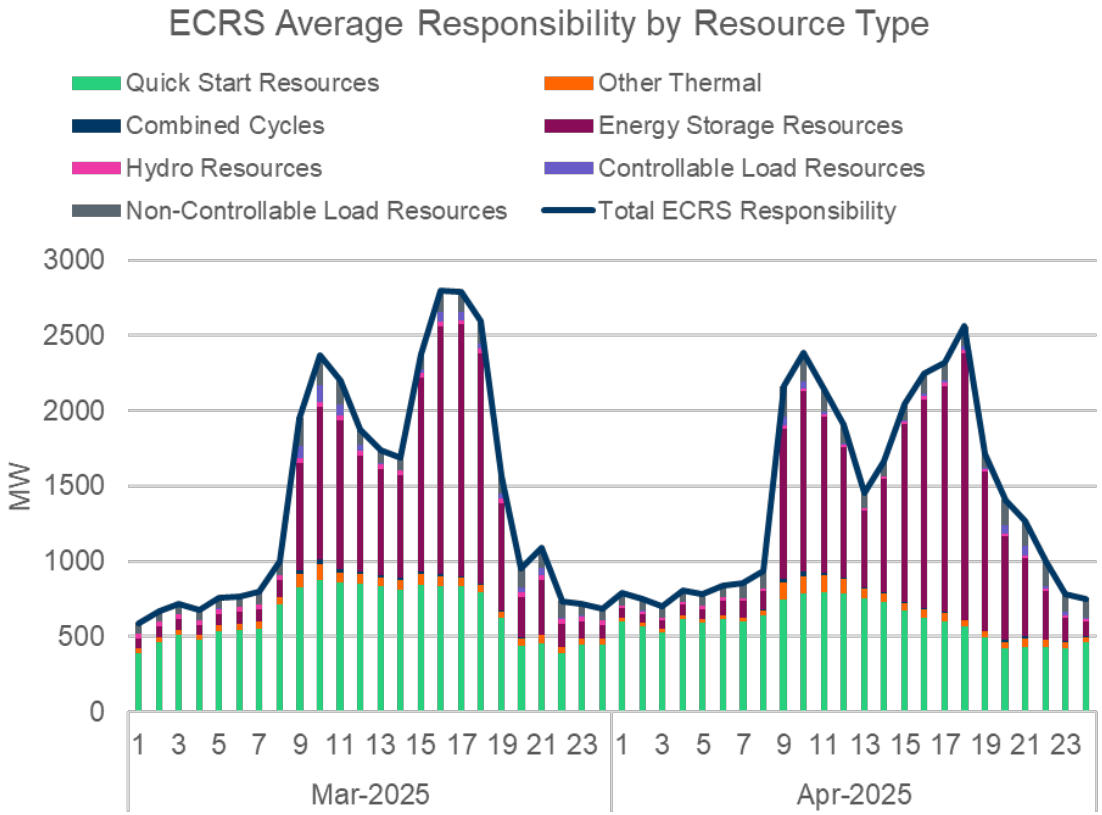


Key Takeaway: All recent Non-Spin deployments were to meet 30-minute ramping needs. Non-Spin performed well in all deployments.

ERCOT Contingency Reserve Service (ECRS) Release for Mar-Apr 2025

From March to April 2025, there was 1 event that resulted in the release of SCED dispatchable ECRS.

Deployment Start Time	Deployment Duration	Maximum SCED Dispatchable MW Released	Reason
4/7/2025 06:45	00:40:32	688	Release due to SCED UnderGen



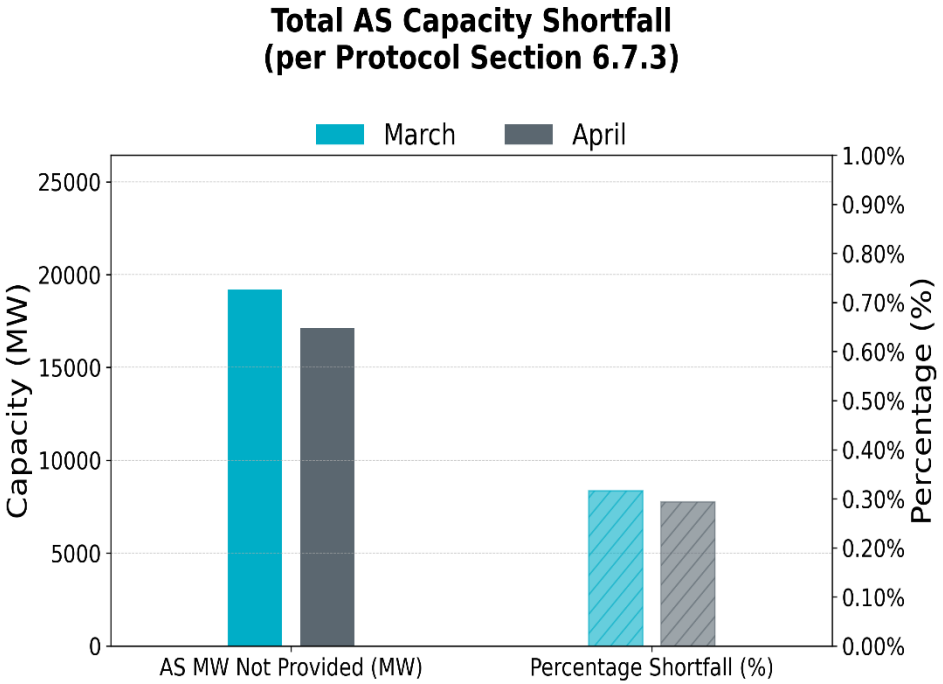
Key Takeaway: ECRS Performed well in one deployment and helped recover from the event that triggered deployment.

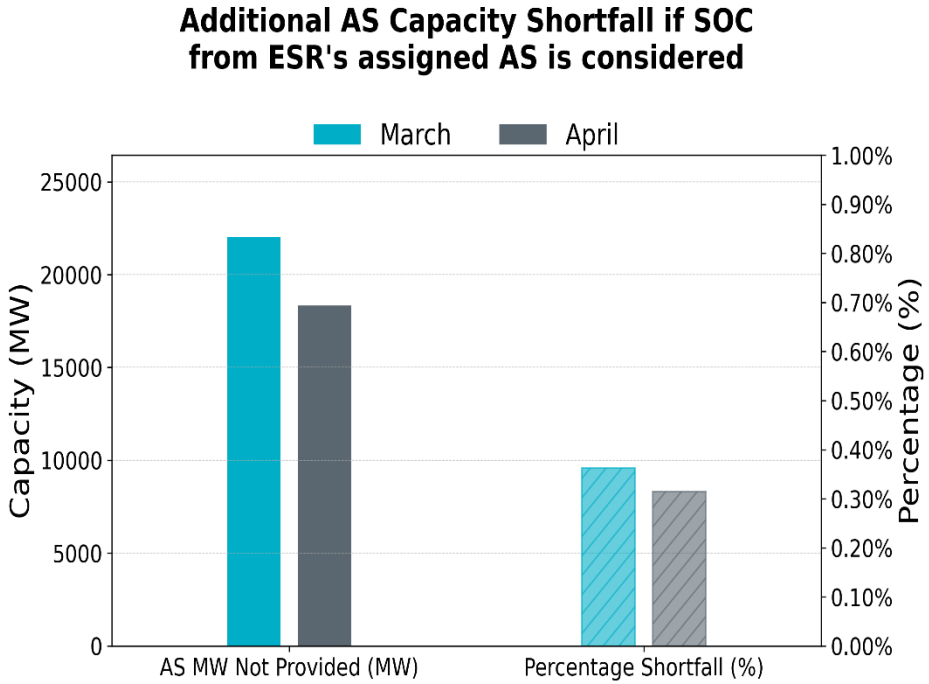
Responsive Reserve Service (RRS) Released for Mar-Apr 2025

- From March to April 2025, there was no manual release of RRS.
- With the implementation of ECRS, RRS capacity autonomously deploys when frequency exceeds the frequency dead-band. RRS may be manually released to SCED during scarcity events when additional capacity is needed.

Key Takeaway: There was no manual RRS release from Mar-Apr 2025.

AS MW Shortfall Analysis for Mar-Apr 2025





Key Takeaway: A (small) portion of the procured AS is not being assigned to resources (regardless of technology type) by QSEs and is not available in Real Time. The magnitude of AS capacity unavailable in Real Time increases further if SOC from ESRs that are assigned AS is considered.

****Capacity data (MW) is plotted on primary y-axis and percentage shortfall (%) is plotted with a pattern format on secondary y-axis. Percentages in both graphs are based on total AS procured.*