



ERCOT'S OPERATIONAL EXPERIENCE WITH BATTERY ENERGY STORAGE

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G-PST/ESIG WEBINAR SERIES

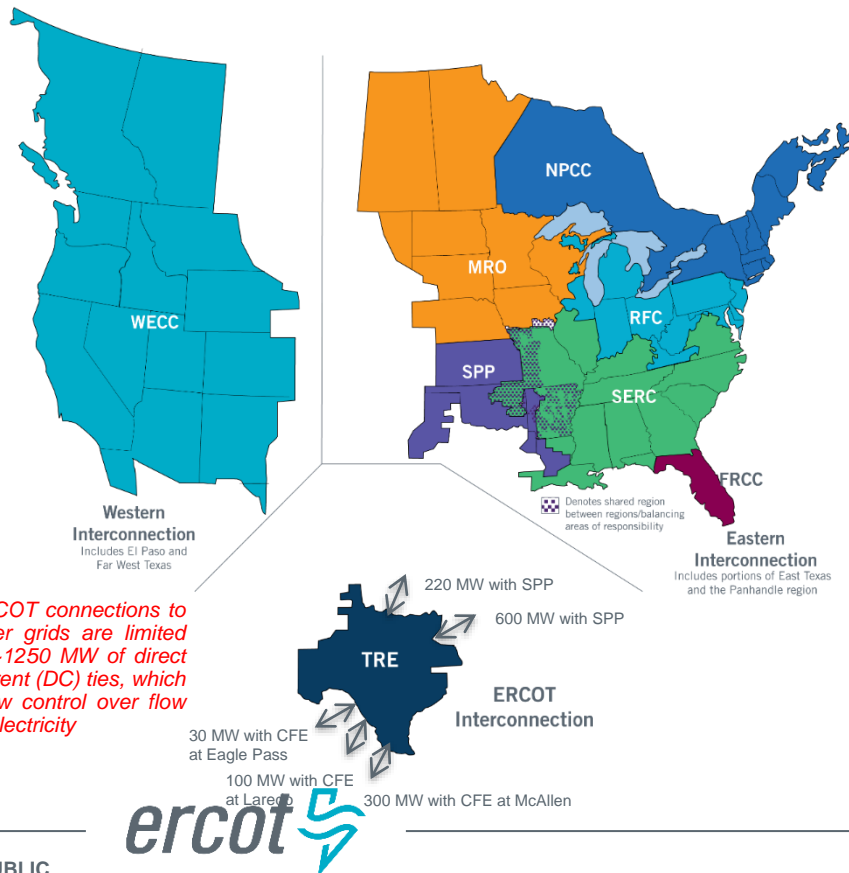
Outline

- Introduction to ERCOT
- Overview of ERCOT's Current Resource Mix
- Energy Storage Resource (ESR) Current and Future Capacity Outlook
- Modeling of ESRs in ERCOT systems
- ESR Participation in Energy and Ancillary Services during recent events
- ESR Operational Challenges and Future Changes that are being considered.

Introduction to ERCOT Region & Company

ERCOT Region

- The interconnected electrical system serving most of Texas, with limited external connections
 - 90% of Texas electric load; 75% of Texas land
 - More than 52,700 miles of transmission lines
 - 570+ generation units



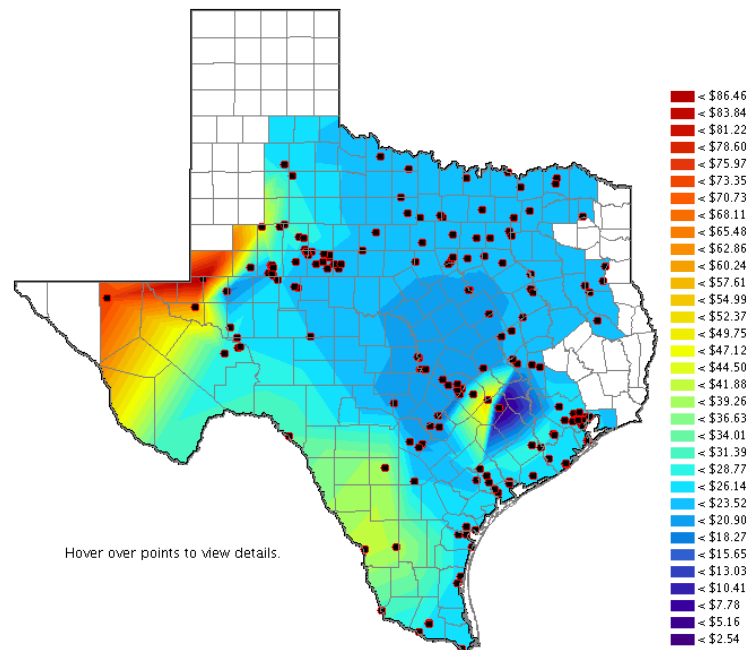
ERCOT Inc.

- The Texas Legislature restructured the Texas electric market in 1999 and assigned ERCOT four primary responsibilities under PURA Section 39.151:
 - Maintain system reliability
 - Facilitate competitive wholesale market
 - Ensure open access to transmission
 - Facilitate competitive retail market
- ERCOT is regulated by the Texas Public Utility Commission (PUC) with oversight by the Texas Legislature.
- Must balance consumer demand in the ERCOT region (load) and the power supplied by companies that generate electricity (generation) while maintaining system frequency of 60 Hz.
- Performs financial settlement for the competitive bulk wholesale power market and administers retail switching for approximately 8 million premises in competitive choice areas

ERCOT is not a market participant and does not own generation or transmission/distribution wires.

Energy Market Construct

- Energy-only market; \$5,000 price cap with operating reserve scarcity adder
- Generator self-commitment; ERCOT makes residual reliability commitments if needed
- Voluntary Day-Ahead Market (DAM); Ancillary Services procured and co-optimized with energy in DAM
- All generators (including renewables) submit offers for generation output
- Real-Time Market clears every five minutes, using generation with the lowest offers to serve the load, subject to unit operational and transmission constraints
- All generators (including renewables), other than some small distributed generators, receive output level instructions and Locational Marginal Prices.



Ancillary Services

- Load and generation are constantly changing, due to:
 - Daily load patterns
 - Instantaneous load variation
 - Changes in variable generation output
 - Generators tripping offline
- Ancillary Services are procured in the Day-Ahead Market to ensure extra capacity is available to address variability that cannot be covered by the five-minute energy market.
- Minimum quantities of each type of ancillary service are reviewed annually and can be increased during the year as required.

Ancillary Service Products

- **Regulation Service (Reg)**
 - Reserved capacity that is deployed every 4 seconds to balance supply and demand and maintain frequency close to 60Hz between 5-minute SCED runs.
- **Responsive Reserve Service (RRS)**
 - Reserved capacity that is procured to respond to low frequency events typically triggered by generating unit trips.
- **ERCOT Contingency Reserve Service (ECRS) – in development**
 - Capacity that can respond in 10 minutes to recover frequency, cover forecast errors or ramps and replace deployed reserves. 2 hour duration requirement.
- **Non-Spin Reserve Service**
 - Capacity that can be started in 30 minutes to cover forecast errors, ramps or forced outages and replace deployed reserves until additional resources can be committed. 4 hour duration requirement.

Records (as of March 31, 2023)

Peak Demand Record: 80,148 MW

- Jul. 20, 2022, 4-5 p.m.

Weekend Peak Demand Record: 77,359 MW*

- Sunday Jul. 9, 2022, 5-6 p.m.

Winter Peak Demand Record: 74,525 MW

- Dec. 23, 2022, 7-8 a.m.

Renewable Generation Records (instantaneous)

- Output: 30,595 MW
 - Jun 13, 2022, 2:55 p.m.
- Penetration (load served): 71.30%
 - Apr. 10, 2022 09:05 a.m.
 - Total MW Served = 26,451 MW
 - System Inertia ~121 GW·s

Wind Generation Records (instantaneous)

- Output: 27,044 MW
 - May 29, 2022, 10:36 p.m.
- Penetration (load served): 69.15%
 - Apr. 10, 2022 01:43 a.m.
 - Total MW Served = 23,968 MW
 - System Inertia ~122 GW·s

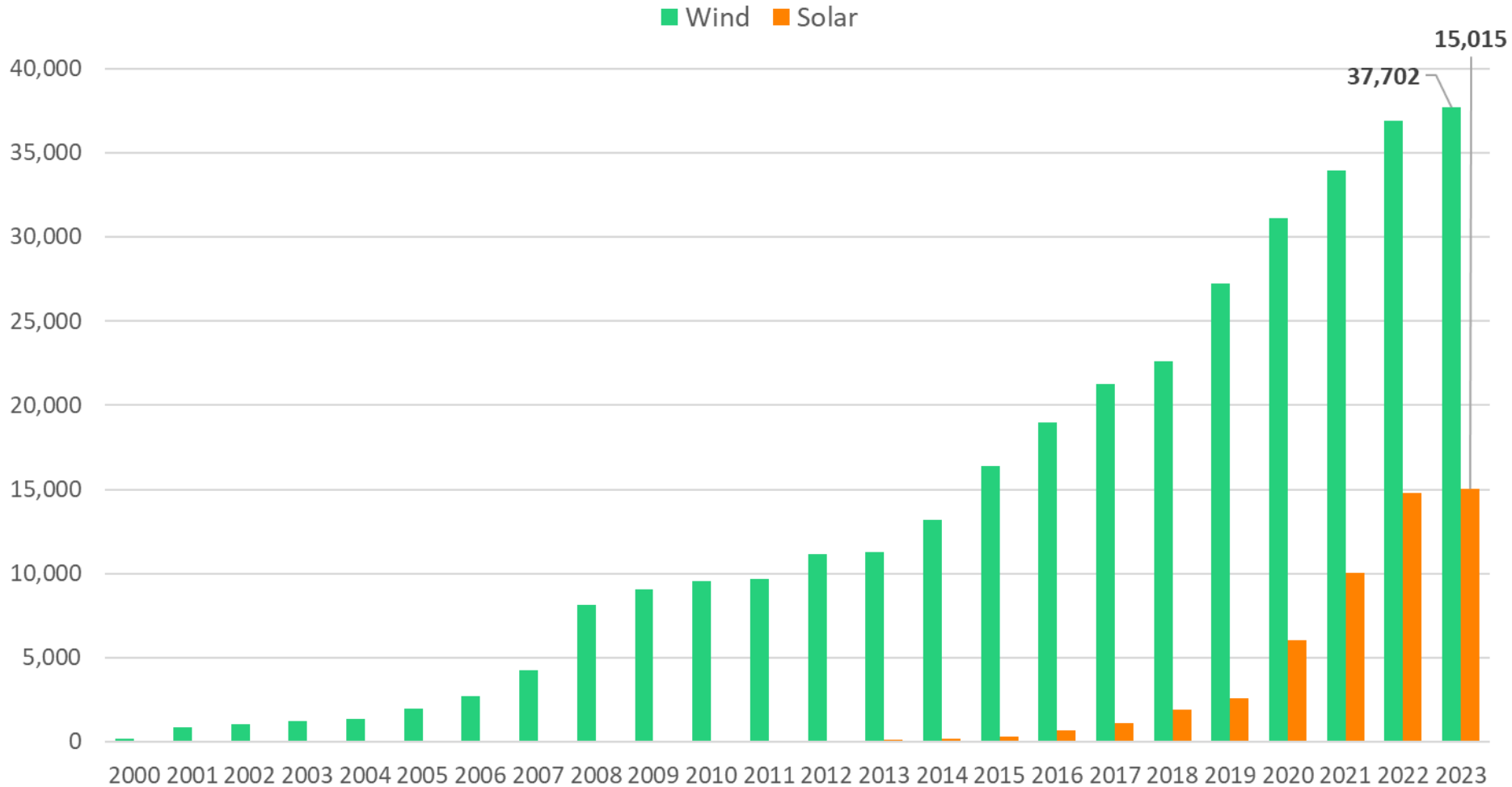
Solar Generation Records (instantaneous)

- Output: 11,937 MW
 - March 25, 2022, 2:25 p.m.
- Penetration (load served): 29.77%
 - Mar. 4, 2023 11:19 a.m.
 - Total MW Served = 11,887 MW

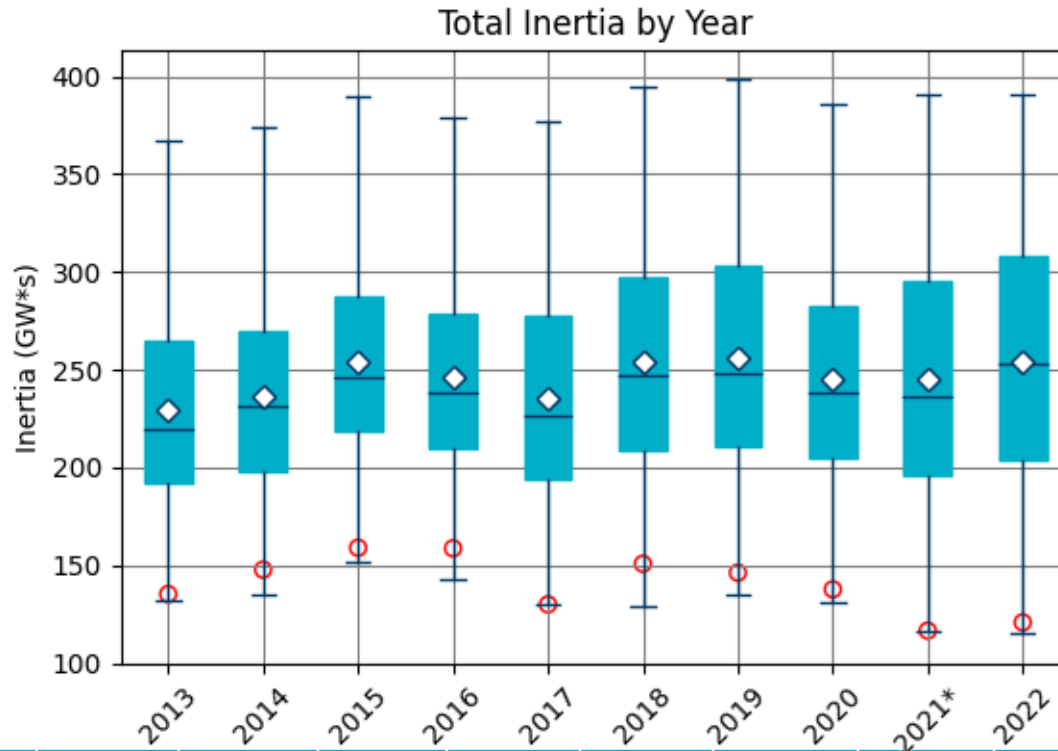
**New records are preliminary, subject to change in final settlement*

Wind, Solar Additions By Year (As Of Feb 28, 2023)

ERCOT Wind, Solar Additions by Year (As Of Feb 28, 2023)

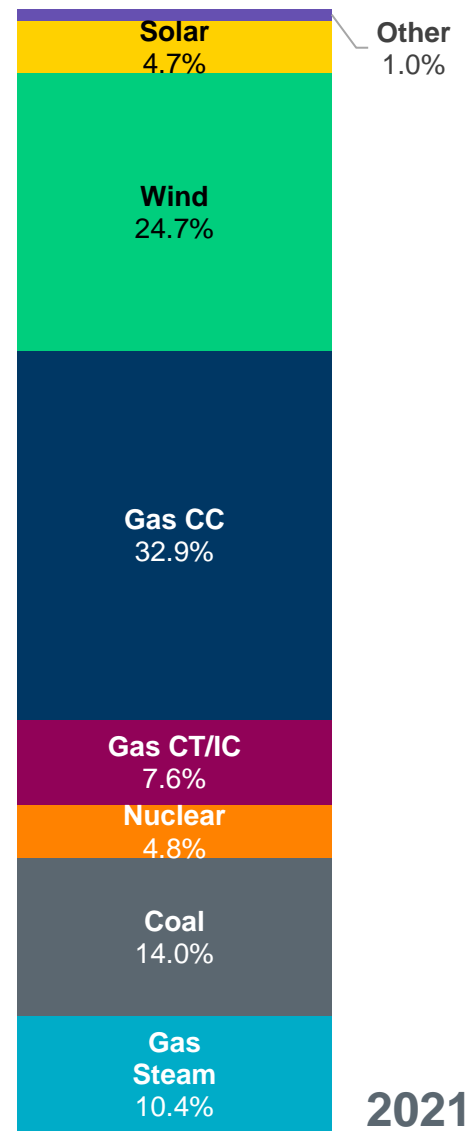
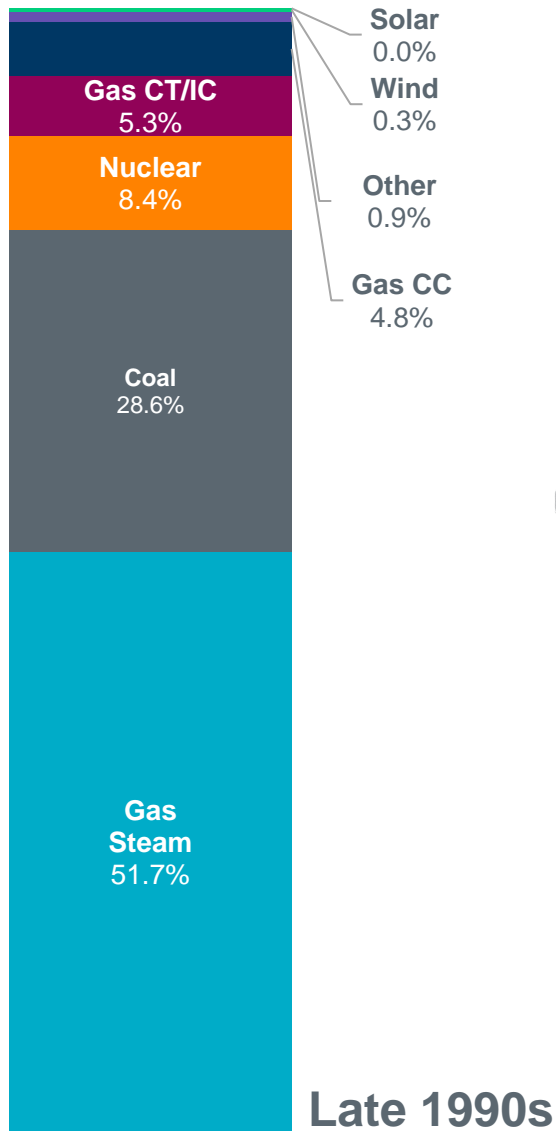


ERCOT Inertia 2013-2022



Date and Time	2013 3/10 3:00 AM	2014 3/30 3:00 AM	2015 11/25 2:00 AM	2016 4/10 2:00 AM	2017 10/27 4:00 AM	2018 11/03 3:30 AM	2019 3/27 1:00 AM	2020 05/01 2:00 AM	2021 03/22 1:00 AM	2022 03/21 2:00 AM
Min synch. Inertia (GW*s)	132	135	152	143	130	128.8	134.5	131.1	116.6*	115.0
System load at minimum synch. Inertia (MW)	24,726	24,540	27,190	27,831	28,425	28,397	29,883	30,679	31,767	33,784
Non-synch. Gen. in % of System Load	31	34	42	47	54	53	50	57	66	65

Changing Resource Capacity Mix



Other
1.0%

Capacity totals are based on Real Power Ratings (RTG_MW) for generating units. "Other" is comprised of Biomass, Hydro and Storage.

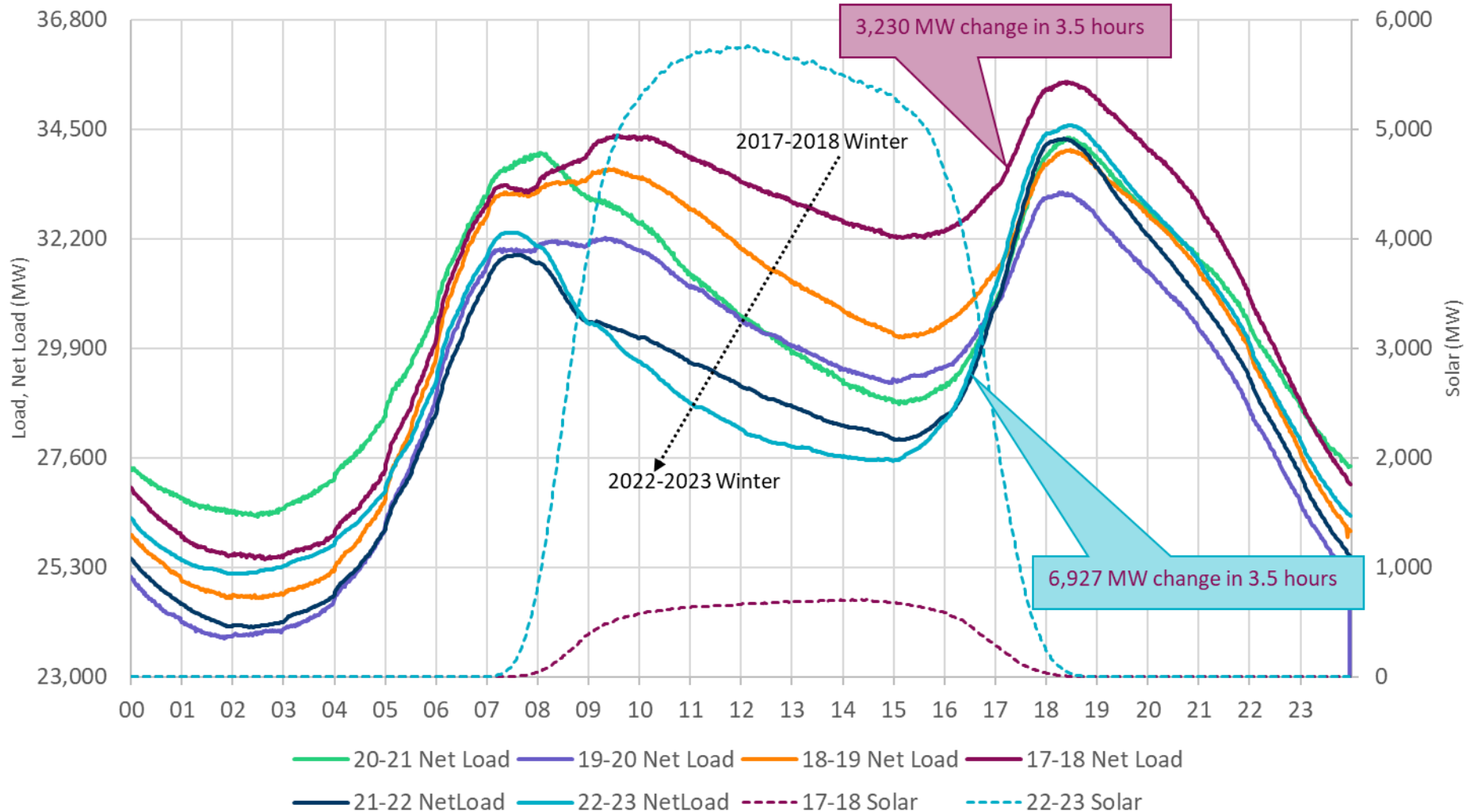
Totals include Distribution Generation Resources (DGRs) but do not include Settlement Only Distribution Generators (SODGs), Private-Use Networks (PUNs) or Synchronized planned projects.

The percentages do not include capacity from synchronized planned projects.

Data as of September 10, 2021

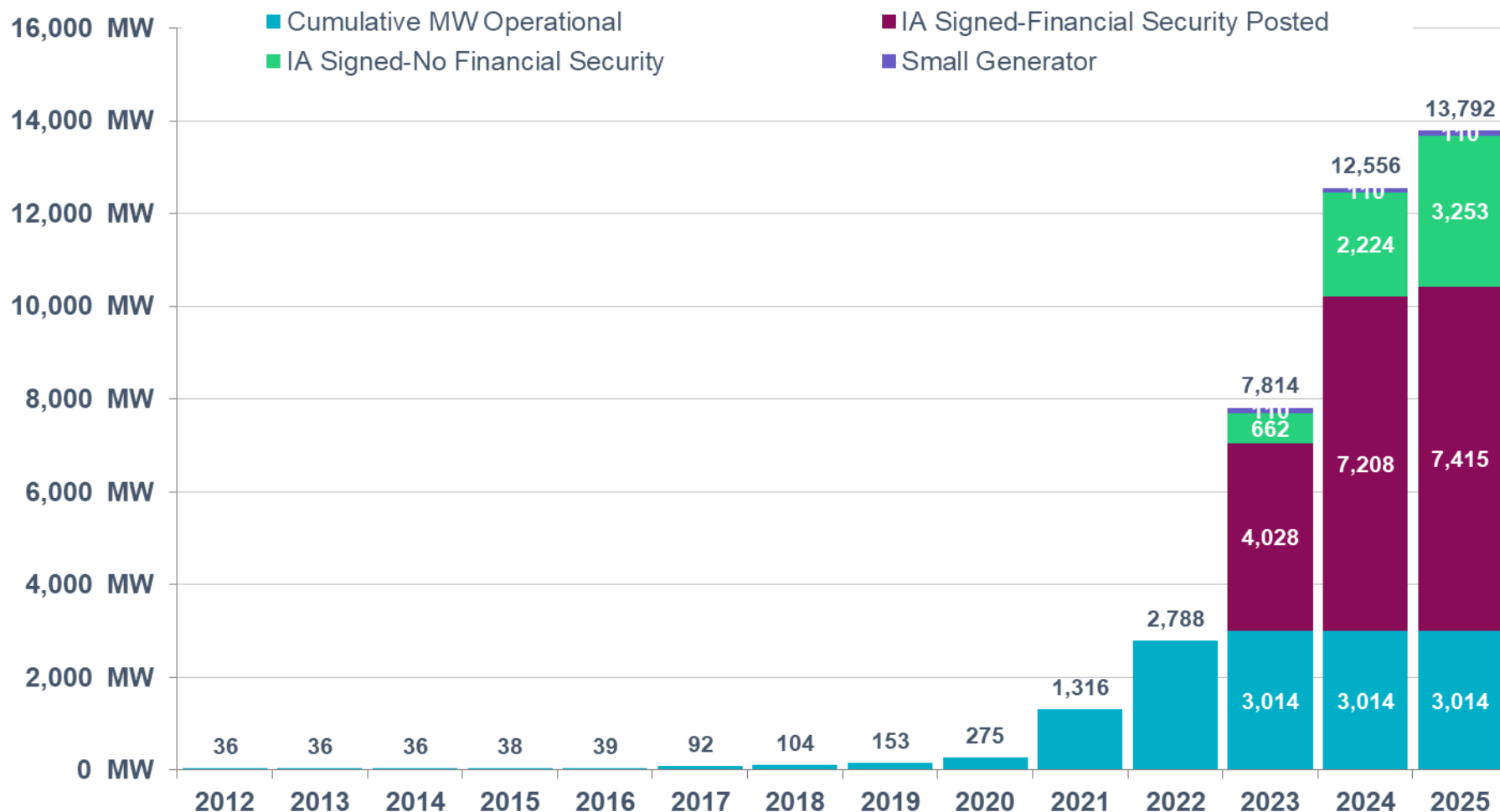
Net Load Profile Changes in last 6 Winters

Winter Net Load, Solar Profile



Battery Additions by Year (As of Feb 28, 2023)

ERCOT Battery Additions by Year (as of Feb 28, 2023)



Generation Interconnection Requests (As of Mar 31, 2023)

Fuel Type/ Technology Type	Screening Studies and Full Interconnection Studies with Completed IA (MW)	Grand Total In Progress (MW)
Combined Cycle	670	3,632
Combustion Turbine	1,058	7,025
Steam Turbine	14	694
ICE (Internal Combustion Engine)	149	868
Wind	8,096	25,742
Solar	22,479	127,765
Compressed Air Storage	0	324
Battery	7,893	96,356
Other (including Biomass)	0	2,288
Total	40,359	264,694

91,493 MW includes requests of 284 MW of distribution connected but does not include requests of x,xxx MW of “Self-Limiting Facility”.

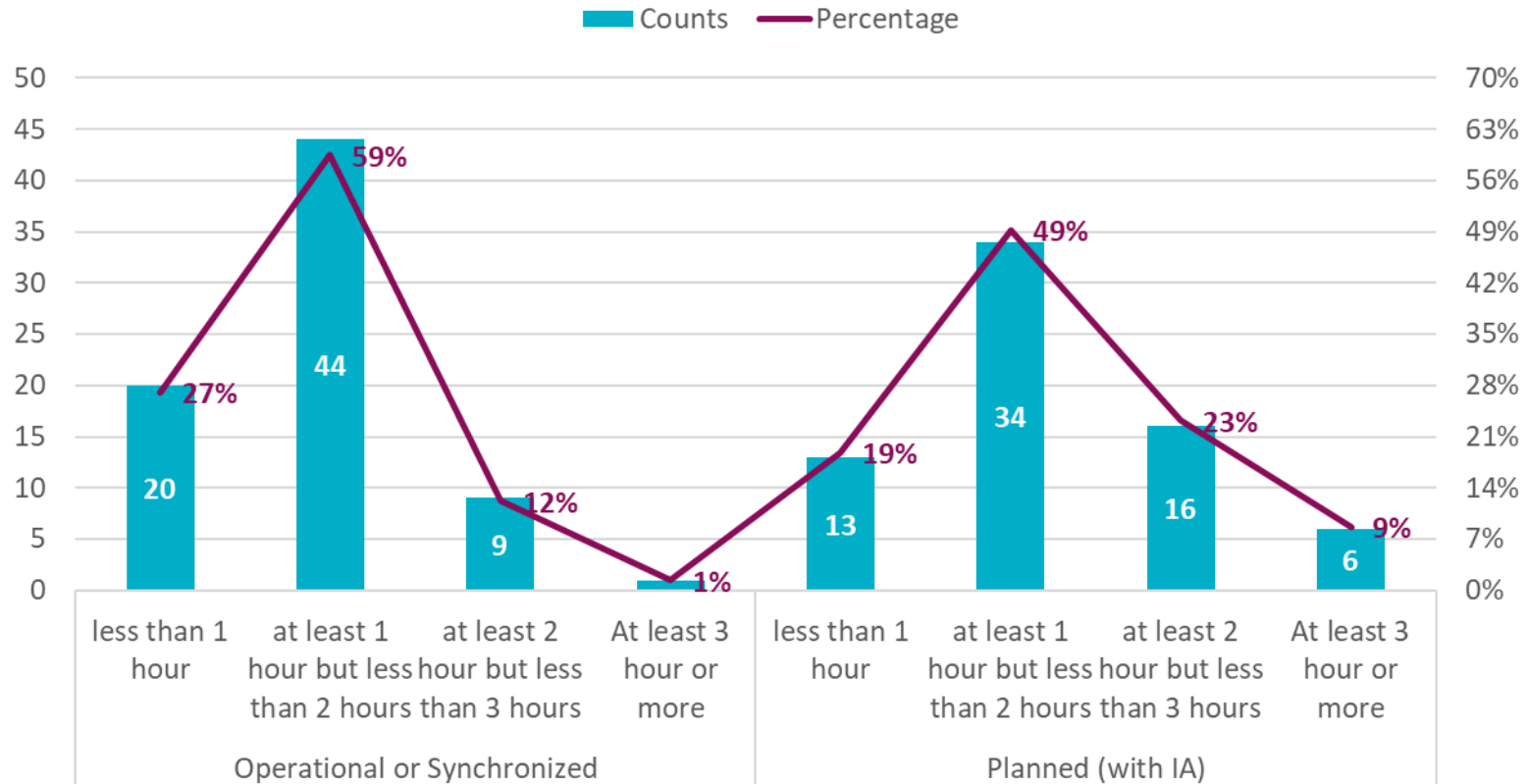
SS = Security Screening Study
FIS = Full Interconnection Study
IA = Interconnection Agreement

Report Run Date Battery Qty

Dec 1, 2022: 78,746 MW
Dec 1, 2021: 46,946 MW
Dec 1, 2020: 21,404 MW
Dec 1, 2019: 7,214 MW
Dec 1, 2018: 2,048 MW
Dec 1, 2017: 0 MW

Duration of Battery Installations (As Of Feb 28, 2023)

ESR Duration Distribution (As Of Feb 28, 2023)



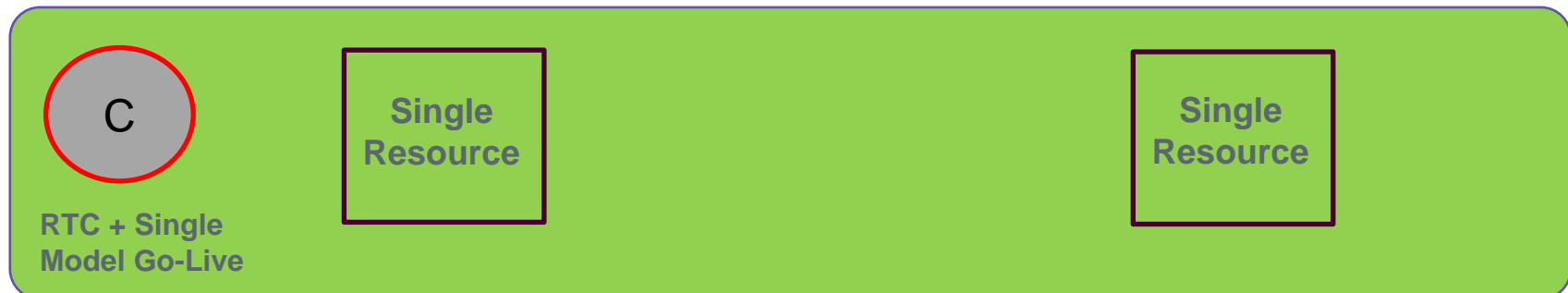
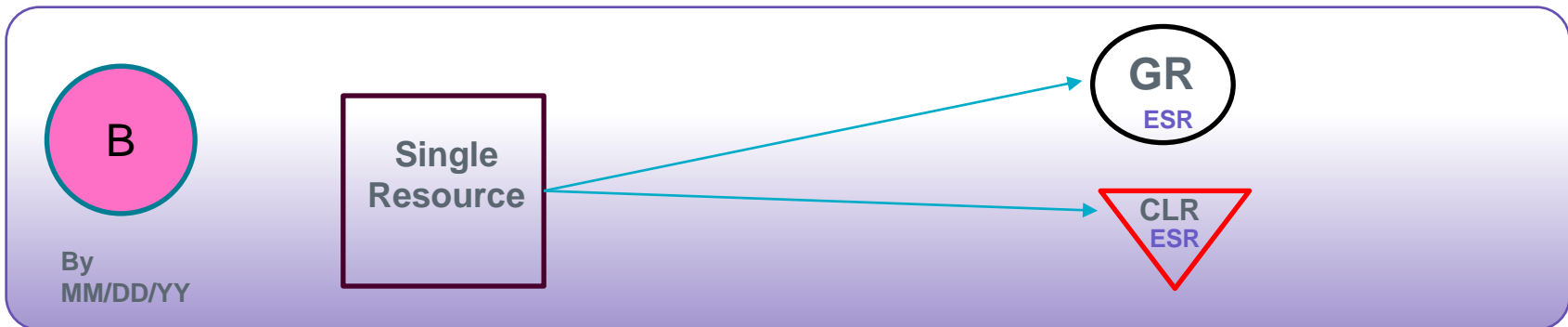
- Based on RFI Received and EIA-860 Information
- Includes Distribution connected ESRs
- 74 Operational or Synchronized ESRs and 69 Planned.

ERCOT Evolution for Battery Energy Storage Resources

Phase

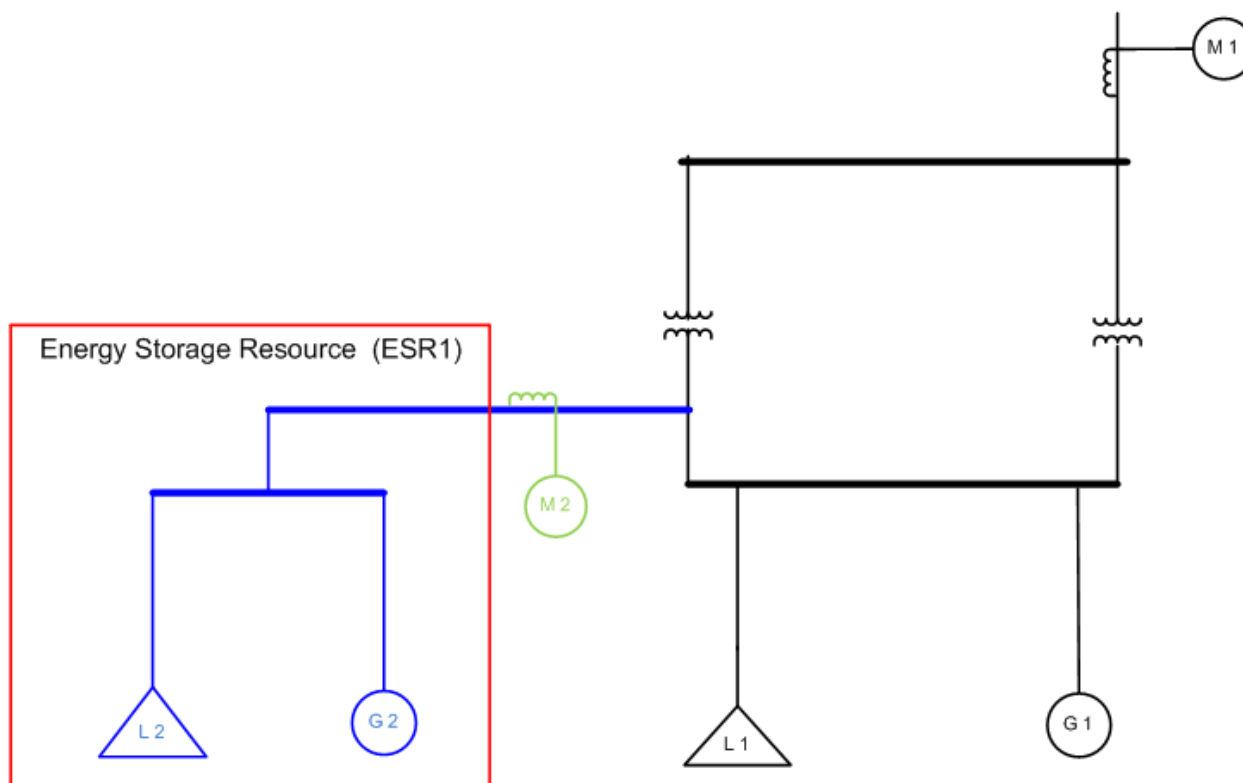
Registration
(RARF or RIOO)

CIM, EMS, MMS and Settlements



Energy Storage Resources (ESRs): Current Approach Combo Model

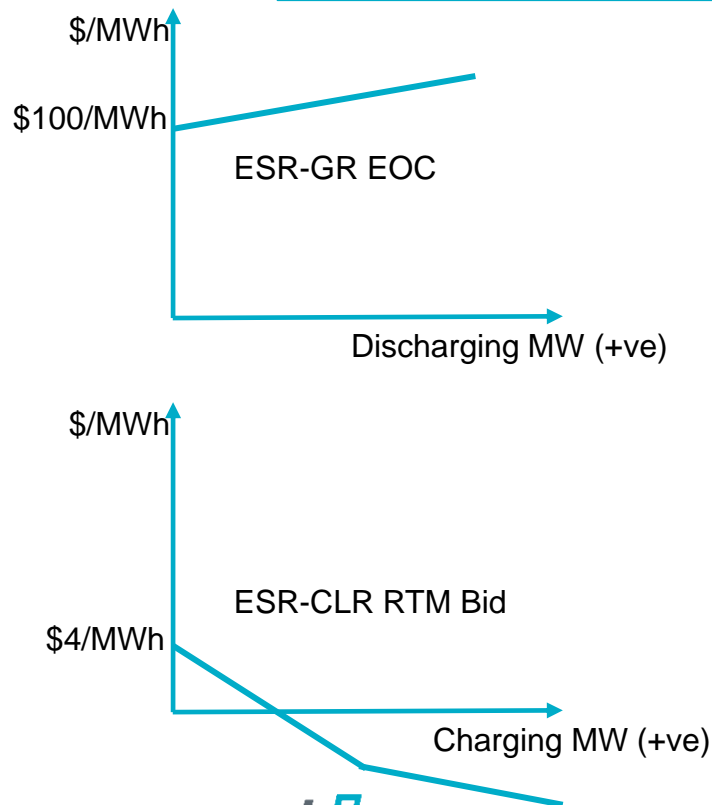
- ERCOT models the discharging capability of an ESR as a Generation Resource and the charging capability as a Controllable Load Resource.
- Each Resource receives independent Base Points and Ancillary Service deployments, which can lead to performance monitoring issues.



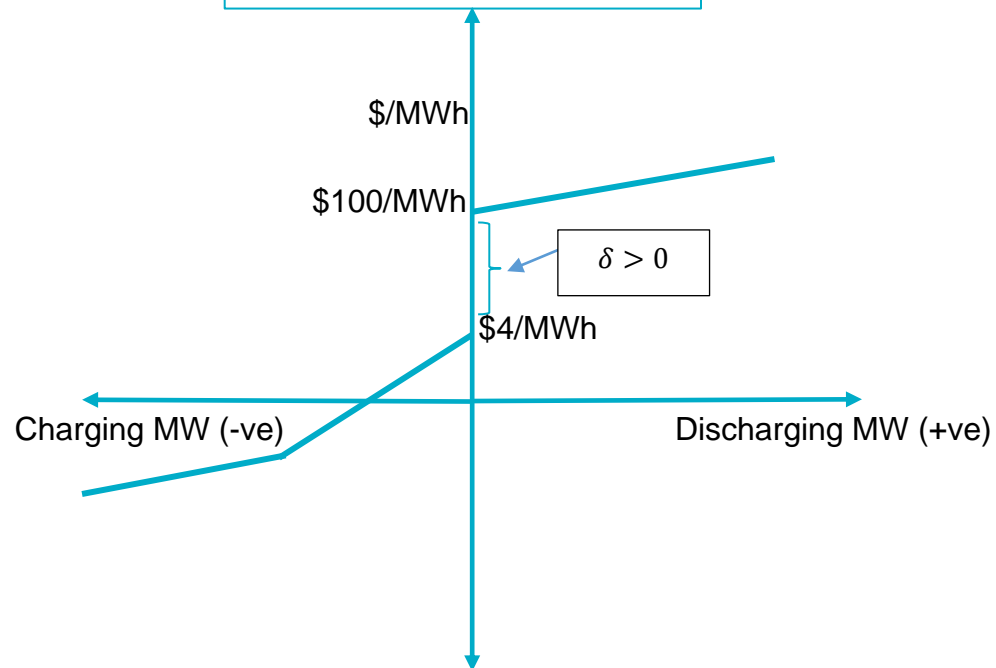
Future Single Model: Energy Incremental Cost Curve

- Single Cost curve shall be monotonically increasing from maximum charging MW (negative) to maximum discharging MW.
- The maximum price on the charging curve is less than the minimum price on the discharging curve i.e. $\delta > 0$

Combo ESR Model



Single ESR Model



Future Single Model for ESR

ESR Telemetry

Resource Status (ON, ONOS, ON TEST, ONEMR, ONHOLD, OUT)

Gross MW

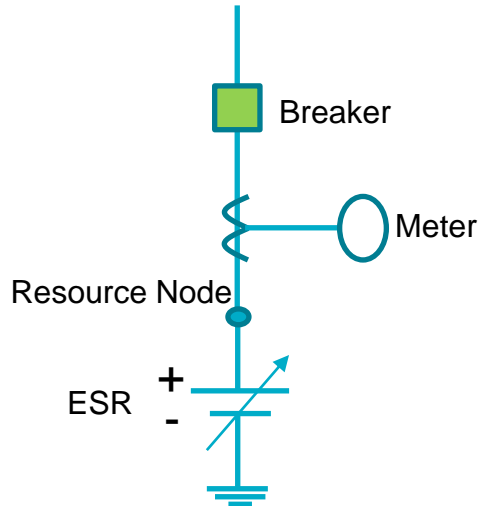
Gross MVar

Net MW

Net MVar

HSL

LSL (can be negative)



ESR State Of Charge (SOC) Telemetry

SOC (MWhr)

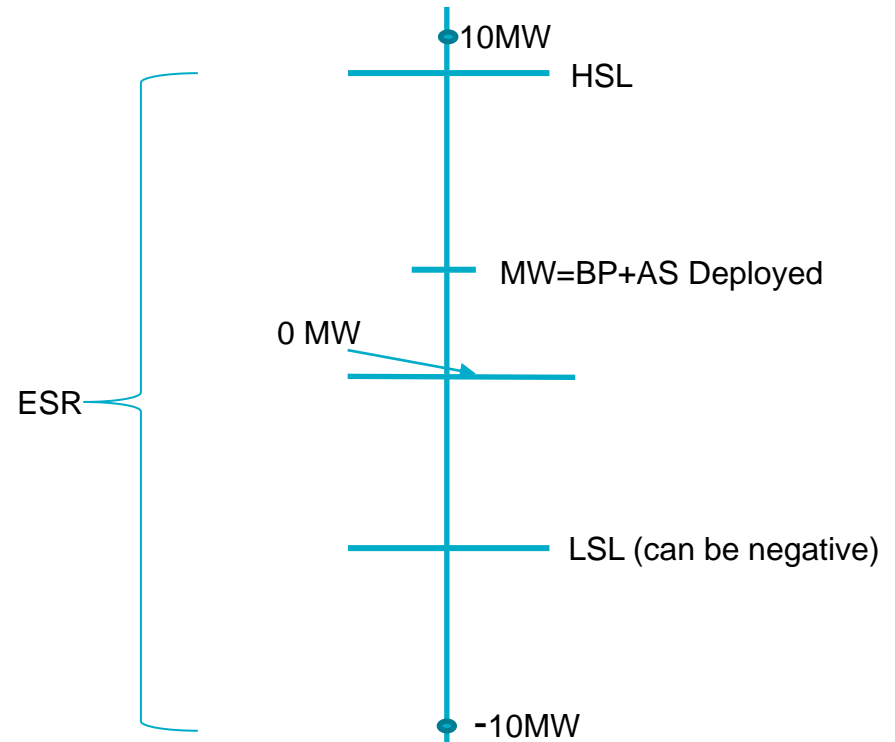
MaxLimitSOC (MWhr)

MinLimitSOC (MWhr)

MaxDisRate (MW)

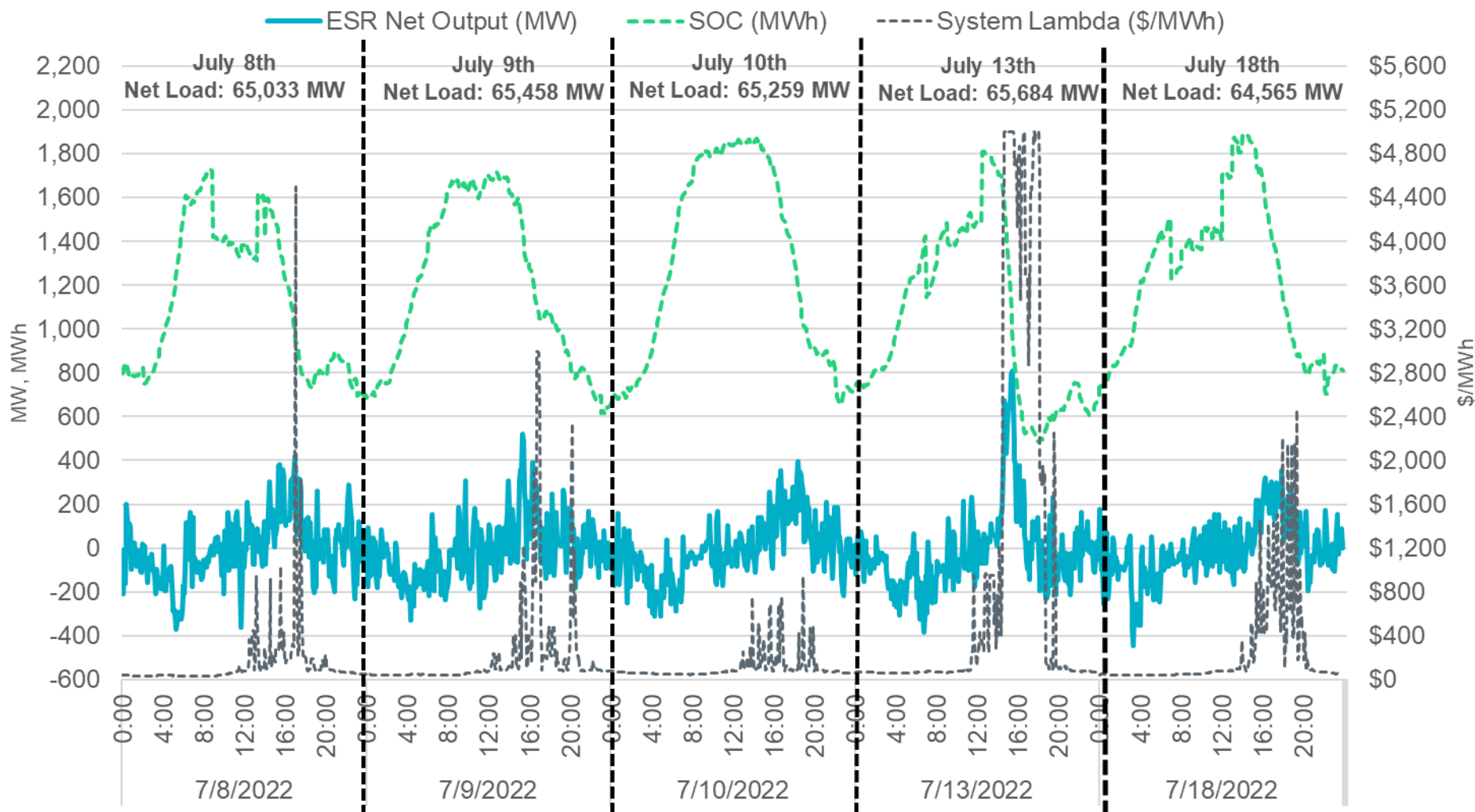
MaxChgRate (MW)

QSE responsibility for managing State of Charge by changing ESR (HSL,LSL) telemetry



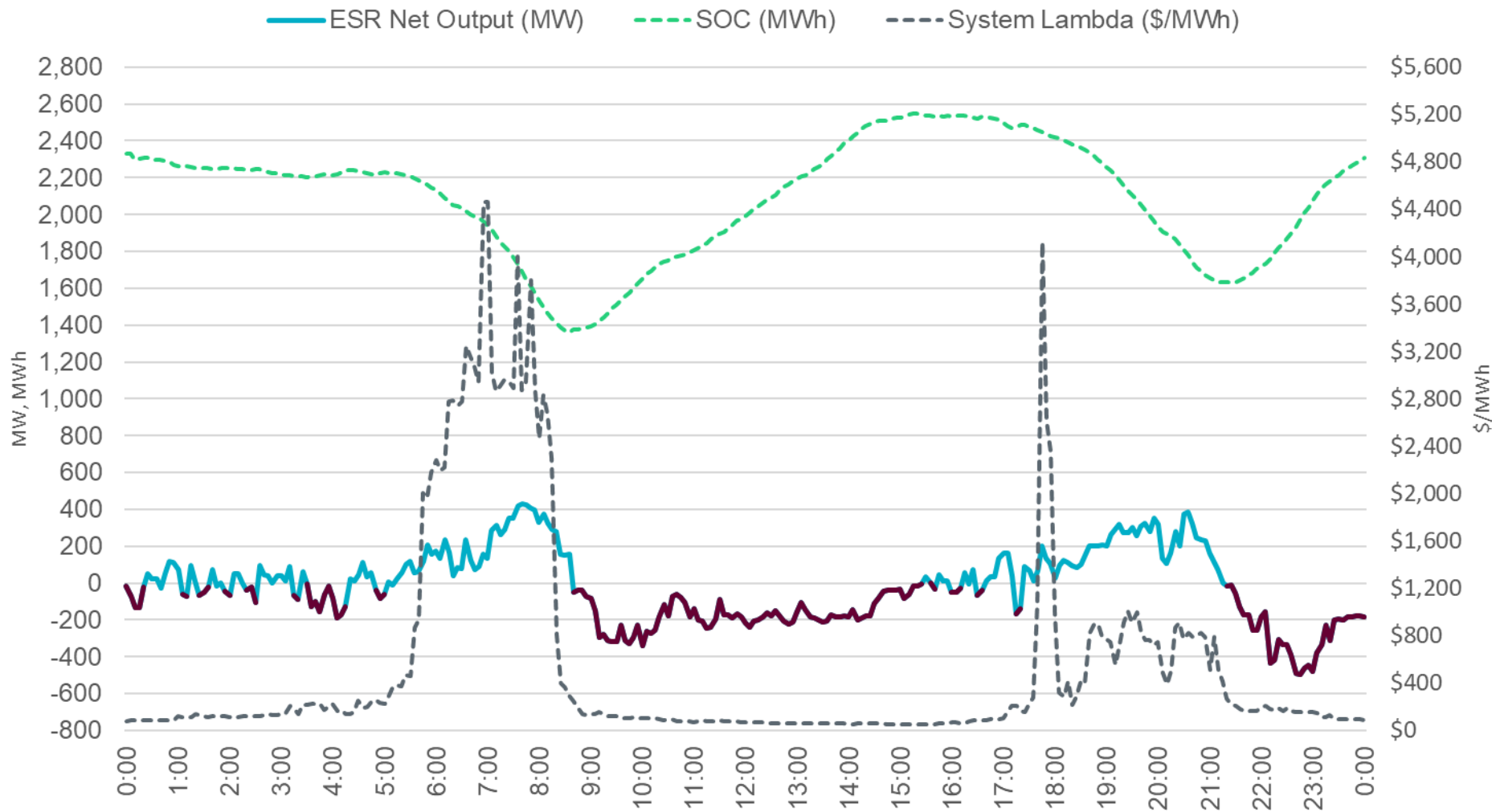
ESR Performance on Top 5 Net Load Days in Summer 2022

Energy Storage Resource Net Output on July 8th-10th, 13th, and 18th 2022



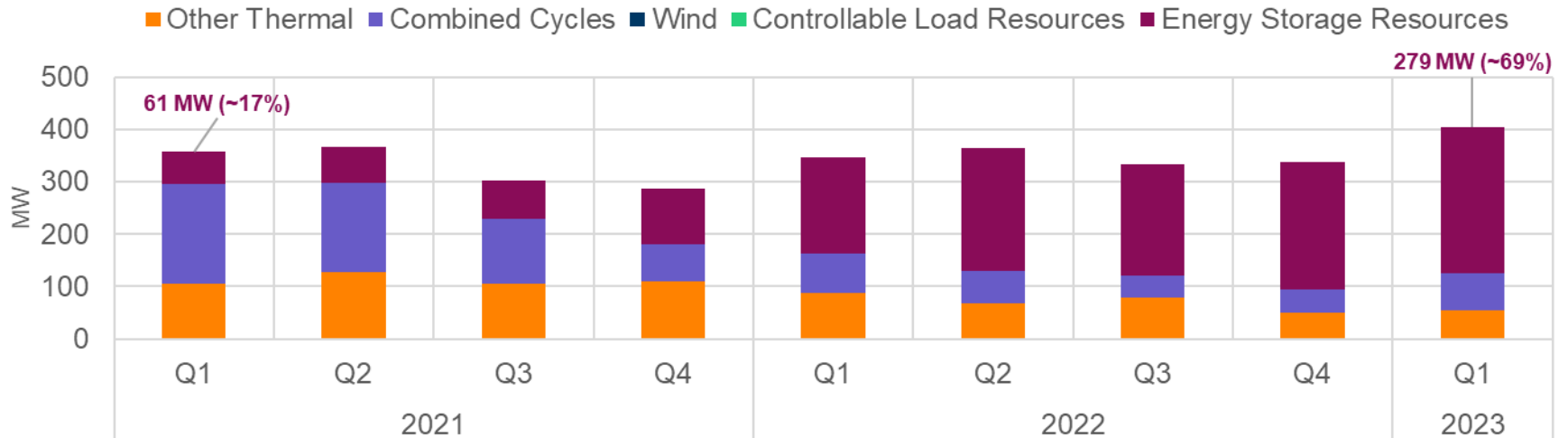
ESR Performance During Winter Storm Elliott

Energy Storage Resource Net Output During Winter Storm Elliott Dec 23, 2022

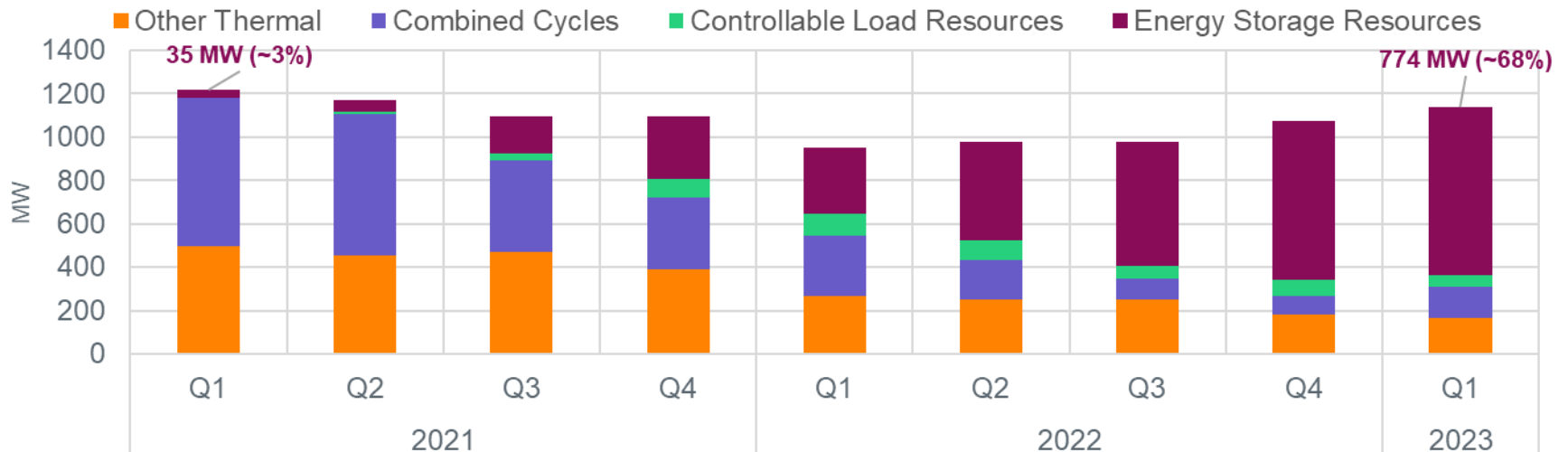


ESR Participation in Ancillary Services

Average Regulation Up Responsibility by Resource Type

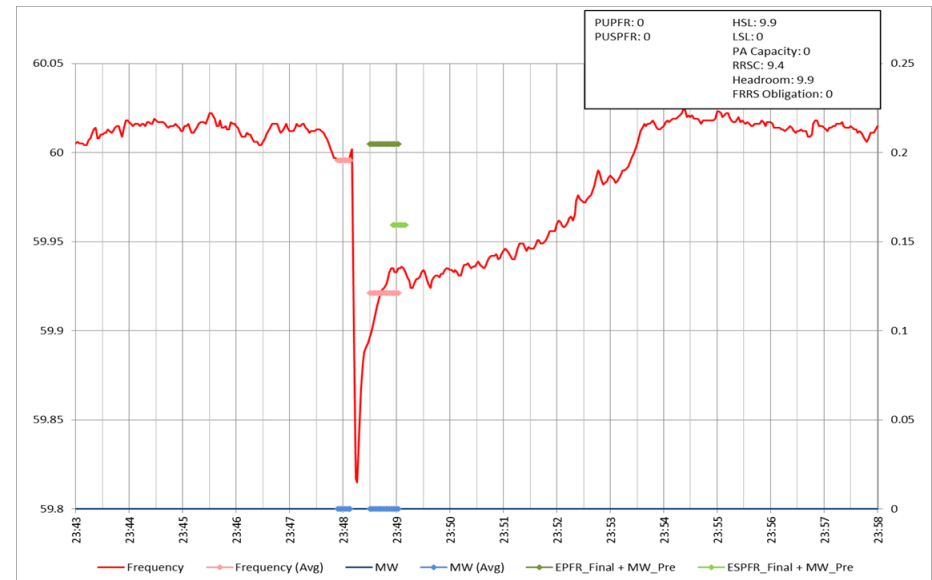


Avg. Responsive Reserve Service (RRS) from Primary Frequency Response (PFR)



Challenges: Lack of RRS-PFR Response

- ERCOT rules allow non-thermal resources like ESRs (which may have a 1% or lower governor droop setting) to provide up to 100% of their capability as RRS-PFR.
- Due to various reason (incorrect logic implementation, insufficient headroom for RRS responsibility, wrong telemetry data, etc.) some ESRs have failed to deliver the required RRS-PFR response when needed.
- Non-thermal Resources such as ESR's, data-center-load, etc. are already carrying upto 73% of ERCOT's total RRS-PFR requirement. As more such Resources become operational, this number will likely grow further.



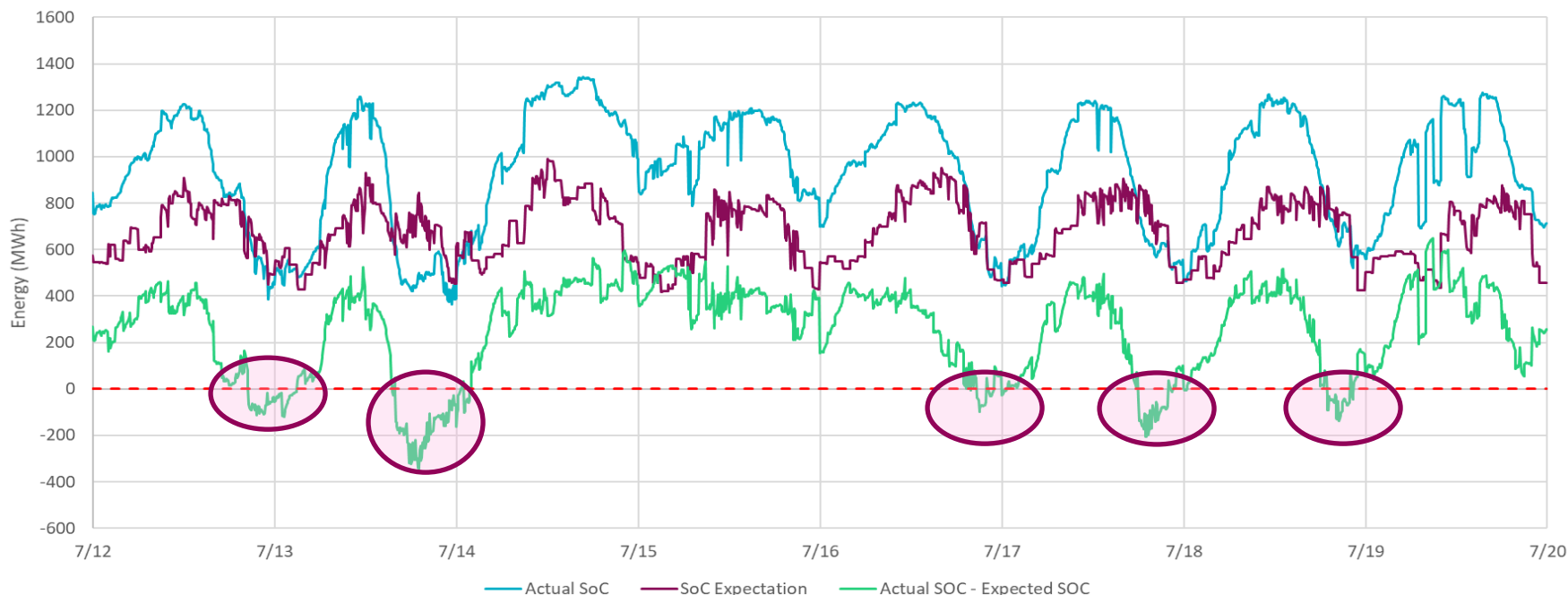
As installed capacities of non-thermal Resources grow, there is a concern that the inherent diversity in the fleet of resources providing RRS-PFR may diminish and potentially too much RRS-PFR may be carried by a single resource/facility. The potential risk of such a setup is that there maybe operating conditions wherein failure to provide RRS-PFR may result in violating NERC standards.

Since late 2021 ERCOT has commissioned a study to investigate whether there are reliability reasons to establish one or more types of limits on Resources providing RRS-PFR limit per Resource, group, and/or at system level for different technologies or the limit on the number of Resources providing RRS-PFR. Recommendations from the study will be discussed in a [workshop on April 6, 2023](#).

Challenges: Insufficient State Of Charge (SOC) for Up AS Obligation

- With the steady growth in the amount of up Ancillary Services that ESRs have been carrying, ERCOT has been monitoring if ESRs are reserving sufficient amount of SOC for the up AS obligation being carried on the injection side. ERCOT has identified several cases where the expected SOC wasn't met.
- Below is an example from the week of July 12th that demonstrates SOC performance on ESRs that were carrying up AS

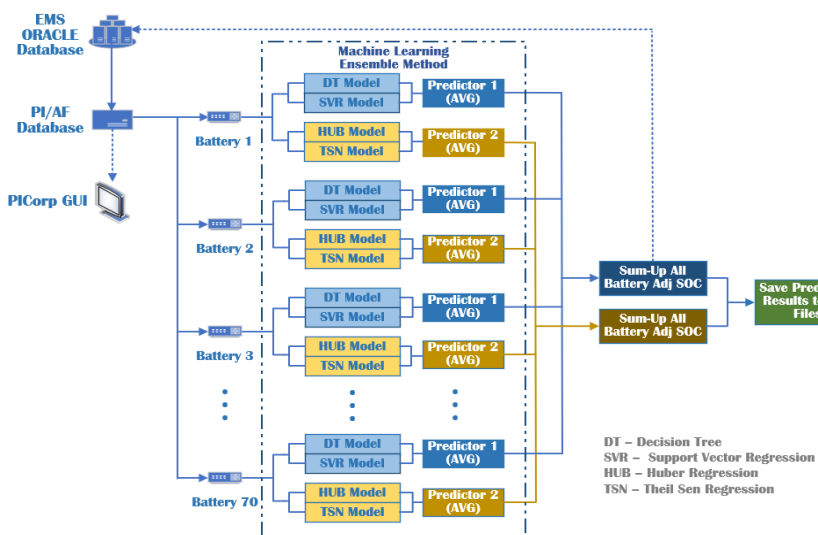
Aggregate State of Charge for ESRs Carrying Ancillary Services



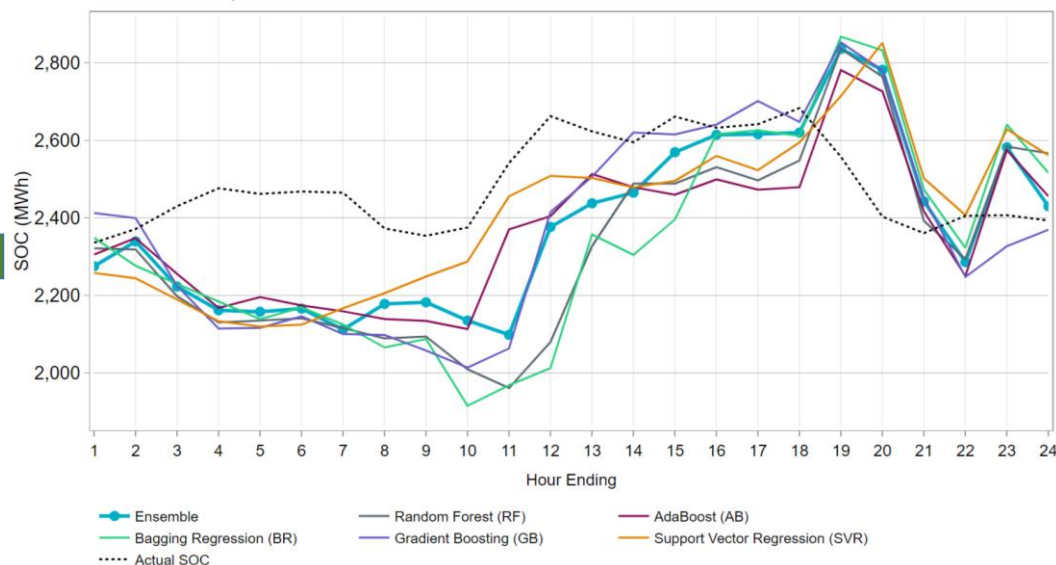
Since late 2022, ERCOT has been working on identifying changes that can be made to model ESR State of Charge in ERCOT tools and studies (primarily Unit Commitment related) both in current setup and with Real Time Co-optimization.

ESR State of Charge Forecasts

- As the fleet of ESRs within ERCOT's footprint grows, there is an increasing need to better account for ESR capability within ERCOT's near-term studies and Resource Adequacy assessments.
- To this end, ERCOT is working on an initiative to build a State-of-Charge forecasts (5-min granularity for next 2 hours and hourly granularity for the next 168 hours) using Machine Learning models.

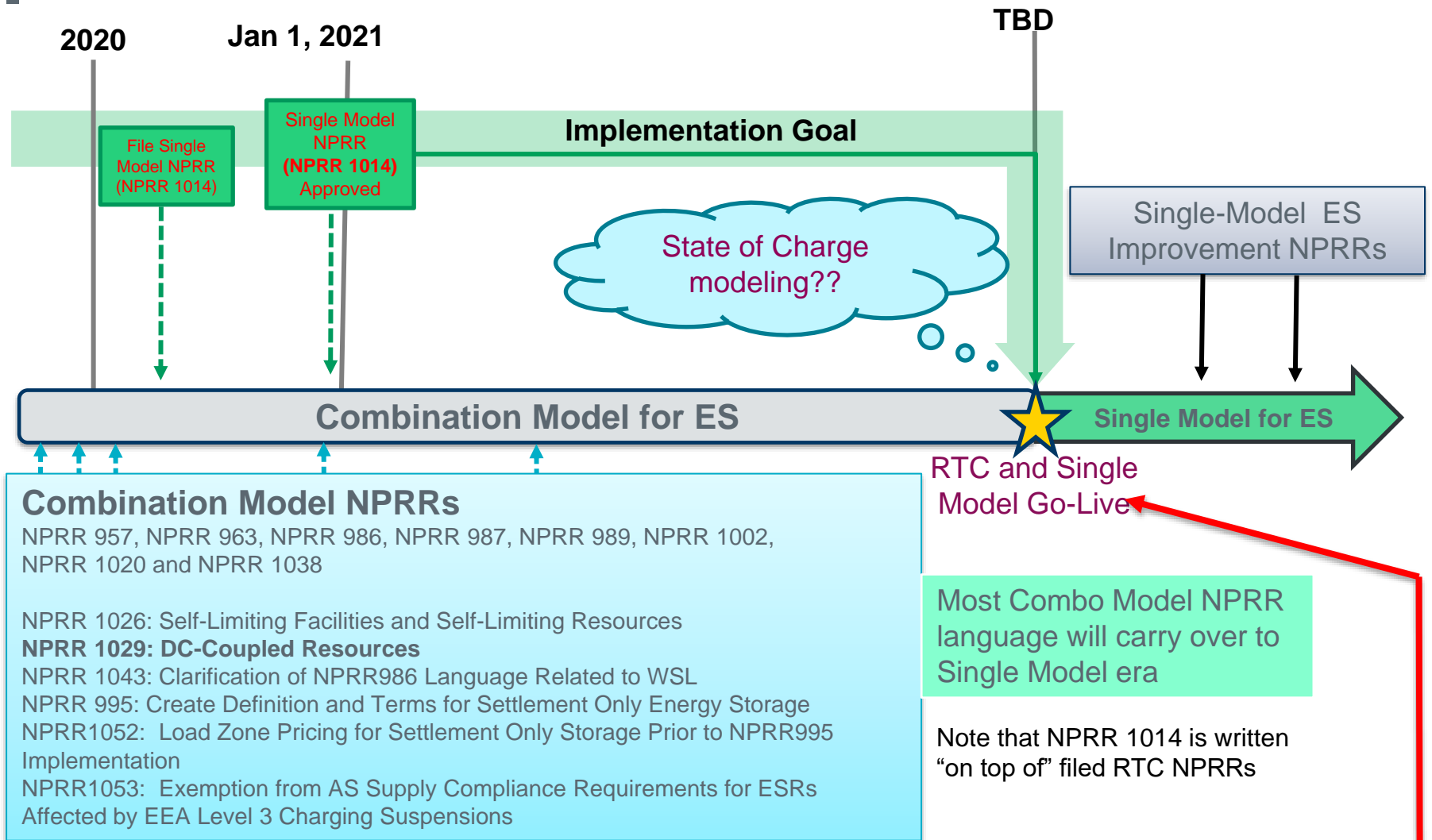


System-Wide SOC Forecast Performance on 04/03/2023 from Latest Forecast



Models	Advantages
Decision Tree (DT)	Reliable performance for all types of data problems
Support Vector Regression (SVR)	Robust linear regression and highly insensitive to outliers
Huber Regression (HUB)	
Theil Sen Regression (TSN)	

Energy Storage Roadmap – In Development



****Timing of RTC and Single Model Implementation TBD (and after EMS Upgrade)

Key Takeaways

- ERCOT is an islanded electrical grid in North America with a high penetration of utility scale wind and solar resources.
- ERCOT currently has ~3,014 MW of short duration, mostly transmission connected ESRs in its footprint. Short duration ESRs make up a significant portion of ERCOT's interconnection queue also.
- Currently operational ESRs are actively participating in ERCOT's Energy and Ancillary Service markets. ESRs are providing nearly 68% of ERCOT's Regulation Up and Responsive Reserve Service from Primary Frequency Response. As the volume of ESRs within ERCOT's footprint increases, ERCOT expects the share of A/S from ESRs to increase further.
- ERCOT has been actively monitoring performance of ESRs during events. ERCOT has seen performance issues in some cases. ERCOT is working with equipment operators to fix issues. Lack of performance may increase reliability risk and hence where appropriate ERCOT is working on identifying systemic ways to mitigate the risk.
- ERCOT's current Energy and Market Management Systems do not model ESRs and a "combination" of a Generation and Load Resource are being used as a substitute. Also ERCOT current studies do not model State-of-Charge (SOC) of ESRs. As the fleet of ESRs grows, it is becoming increasingly important for ERCOT to improve the modeling and accounting of ESRs in its systems and studies. ERCOT is actively working on identifying improvements for the both current and future (i.e. along with RTC) systems.

Discussion and Questions

