



WIND AND SOLAR FORECASTING PRACTICES AT ERCOT

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G-PST FSO SEMINAR #5
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OUTLINE

- Introduction to ERCOT
- Key features of ERCOT's Renewable Generation integration approach
- Summary of ERCOT's Ancillary Services aka Operational Reserves to cover risks
- Overview of tools that have been developed to monitor Renewable operations

Records (as of July 10, 2022)

Peak Demand Record: 78,501 megawatts (MW)

- Jul. 8, 2022, 4-5 p.m.

Weekend Peak Demand Record: 74,917 MW

- Sunday Jun. 12, 2022, 5-6 p.m.

Winter Peak Demand Record: 69,150 MW

- Feb. 14, 2021, 6-7 p.m.

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 by Wind = 23,968 MW
 - System Inertia ~122 GW·s

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

Recent Monthly Peak Demand Records

2021

- February: 69,812 MW (February 14, 6-7 p.m.)
- June: 70,257 MW (June 23, 4-5 p.m.)
- September: 72,339 MW (Sept. 1, 4-5 p.m.)*

2020

- April: 55,292 MW (April 8, 4-5 p.m.)
- July: 74,344 MW (July 13, 4-5 p.m.)

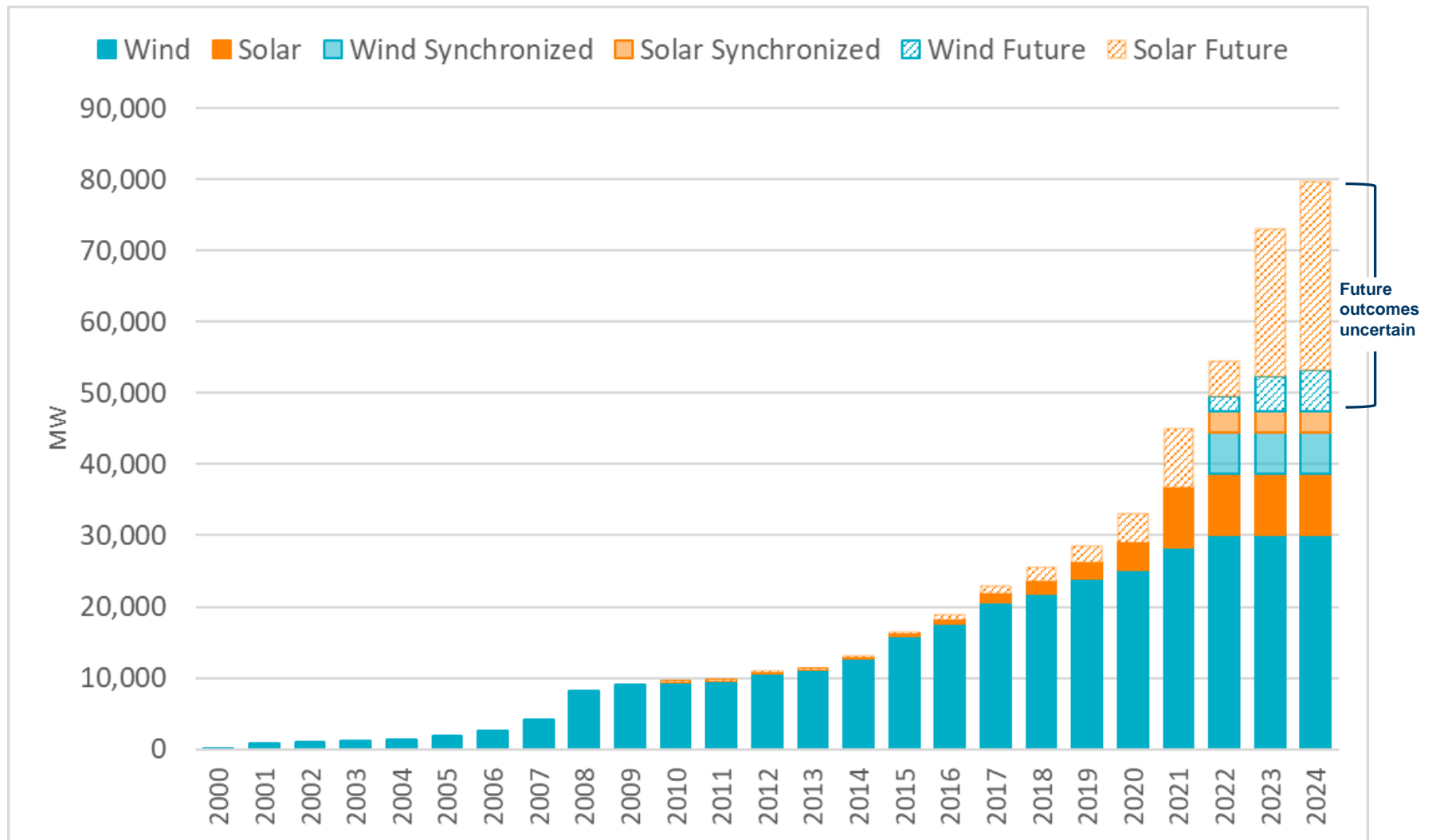
2019

- March: 60,756 MW (March 5, 7-8 a.m.)
- August: 74,820 MW (Aug. 12, 4-5 p.m.)
- October: 65,304 MW (Oct. 2, 4-5 p.m.)
- November 56,446 MW (Nov. 12, 7-8 a.m.)

2018

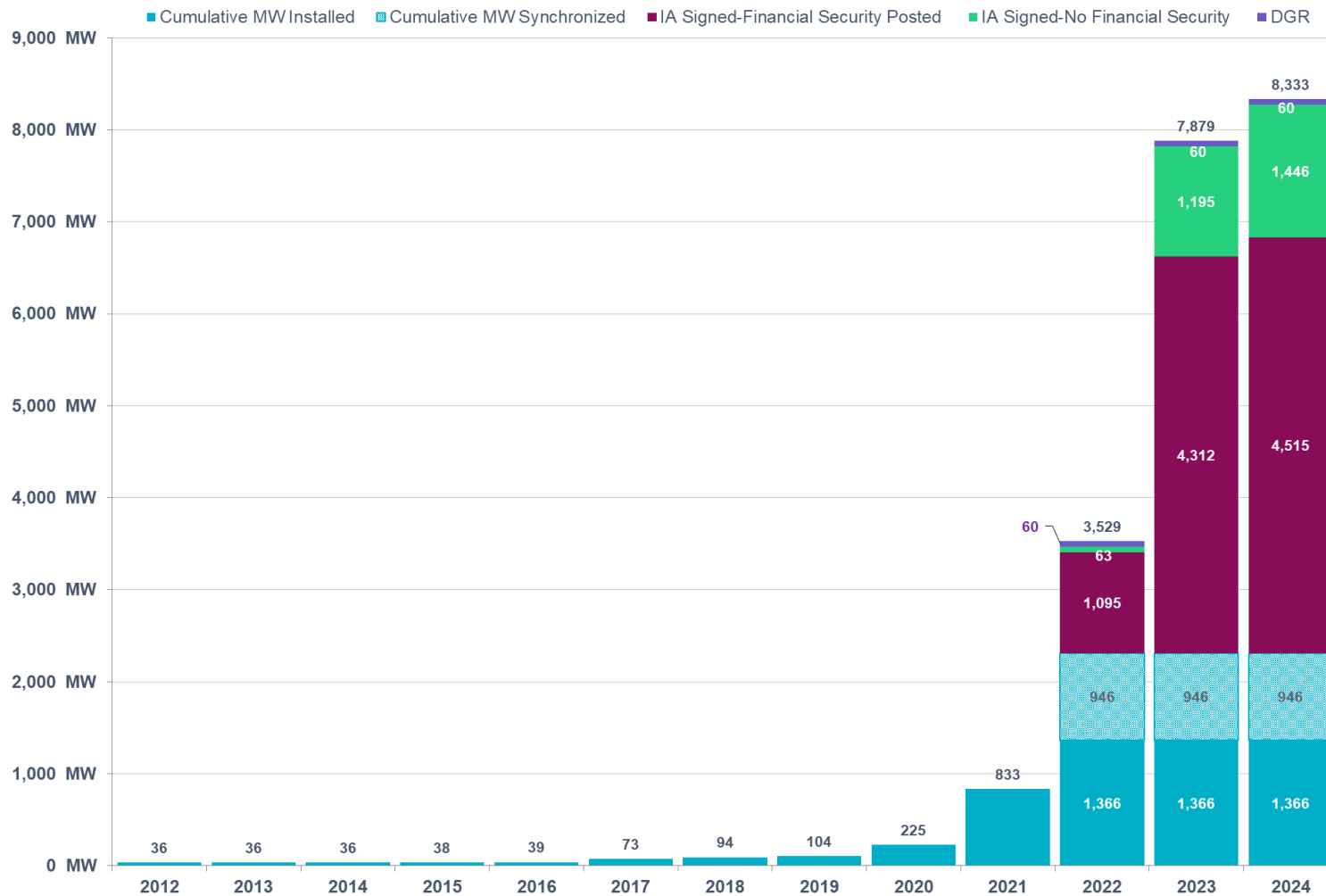
- January: 65,915 MW (Jan. 17, 7-8 a.m.)
- May: 67,265 MW (May 29, 4-5 p.m.)

Wind and Solar Additions by Year (As Of May 2022)



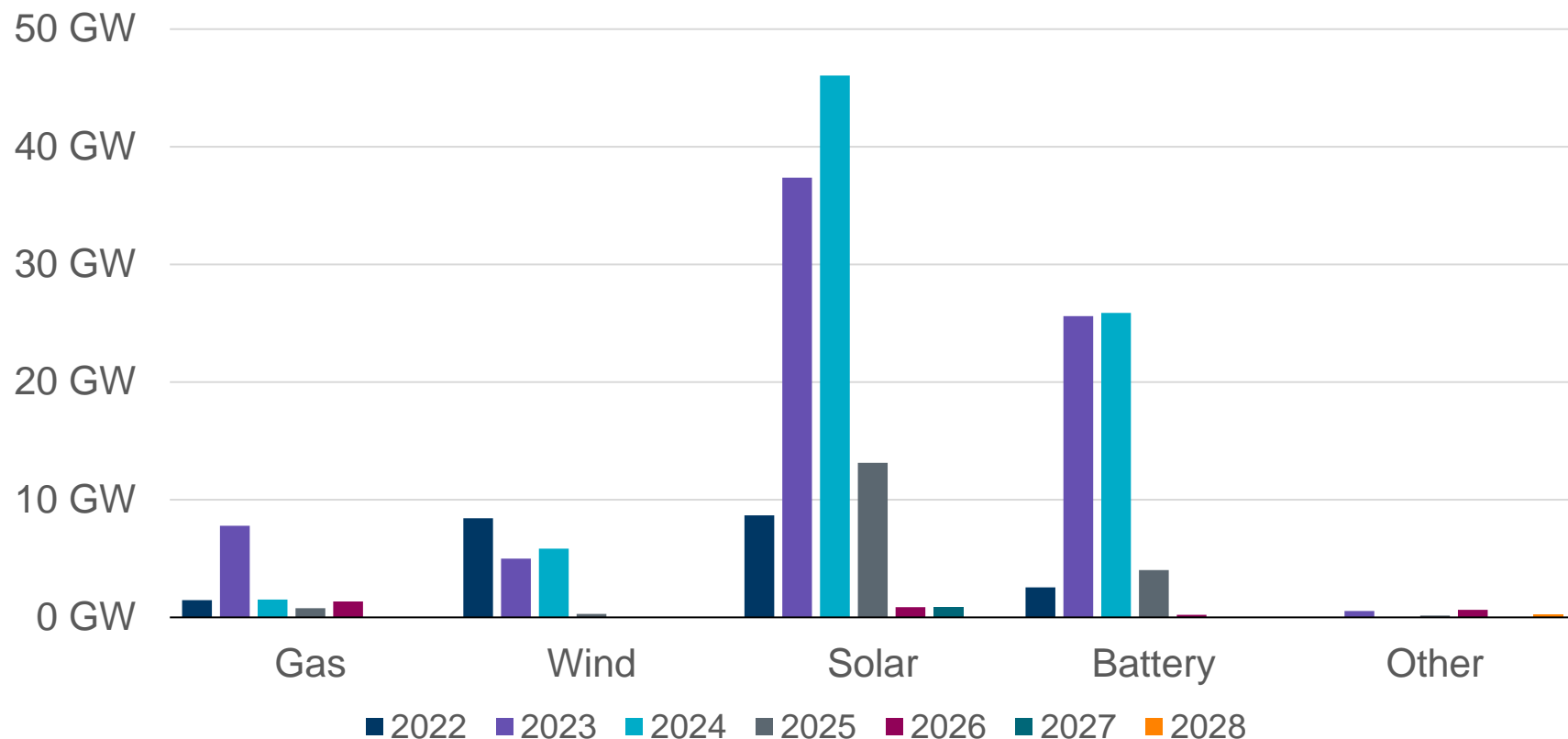
Energy Storage Resource Additions by Year (As Of Jun 2022)

ERCOT Battery Additions by Year (as of Jun 30, 2022)



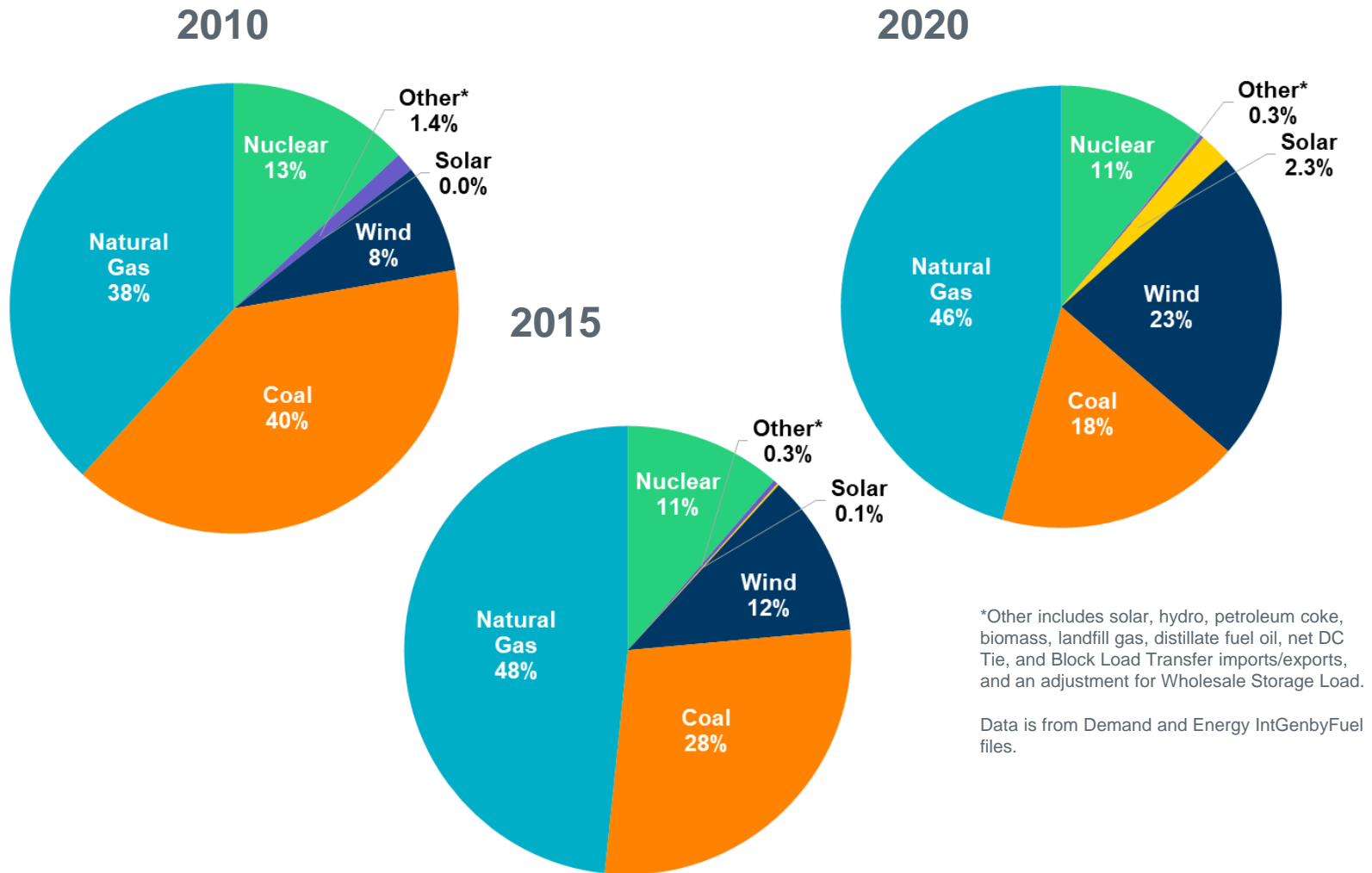
Interconnection Queue Capacity by Fuel Type

Queue totals: Solar 107 GW (53.7%), Wind 20 GW (9.8%), Gas 13 GW (6.5%), Battery 58 GW (29.3%)
(Excludes capacity associated with Projects designated as Inactive per Planning Guide Section 5.7.6)

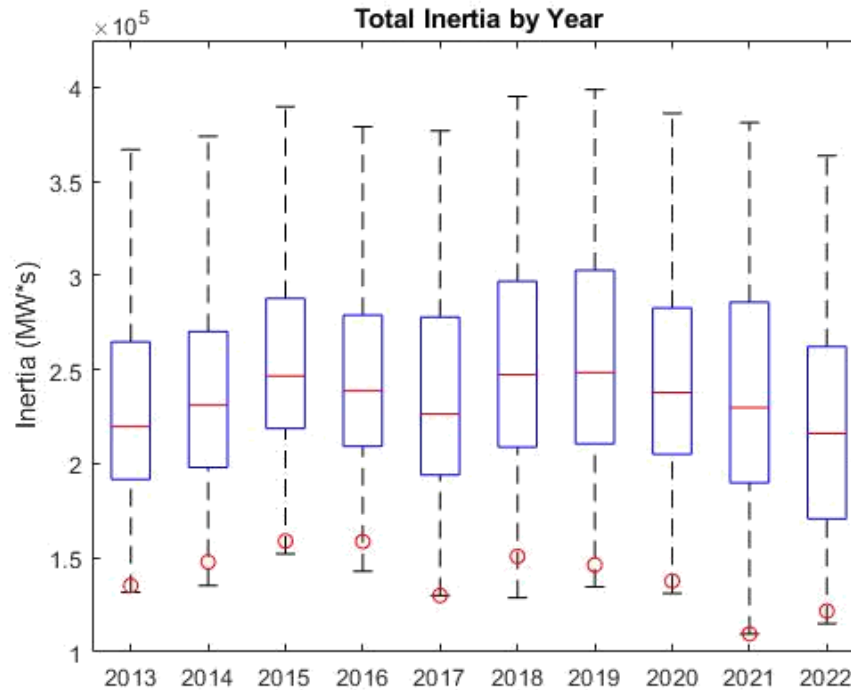


A break-out by zone can be found in the monthly Generator Interconnection Status (GIS) reports available on the ERCOT Resource Adequacy Page: <http://www.ercot.com/gridinfo/resource>

ERCOT Annual Energy Mix Evolution



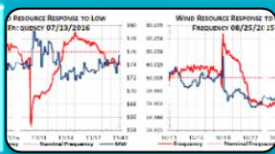
ERCOT Inertia 2013-2022*



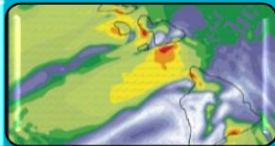
Date and Time	2013 3/10 3:00 AM	2014 3/30 3:00 AM	2015 11/25 2:00 AM	2016 4/10 2:00 AM	2017 10/27 4:00 AM	2018 11/03 3:30 AM	2019 3/27 1:00 AM	2020 05/01 2:00 AM	2021 03/22 1:00 AM	2022 03/21 2:00 AM
Min synch. Inertia (GW*s)	132	135	152	143	130	128.8	134.5	131.1	109.6*	115.0
System load at minimum synch. 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

* Using updated inertia constants, re-calculated 2021 min = **116.6 GW*s**

Key Features that further Renewable Integration



Robust Grid Code



Including Renewable Forecast in studies

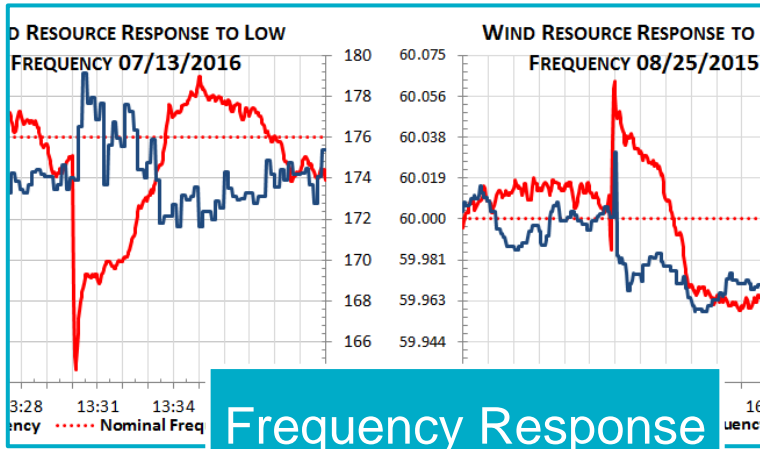


Continually refining Ancillary Services

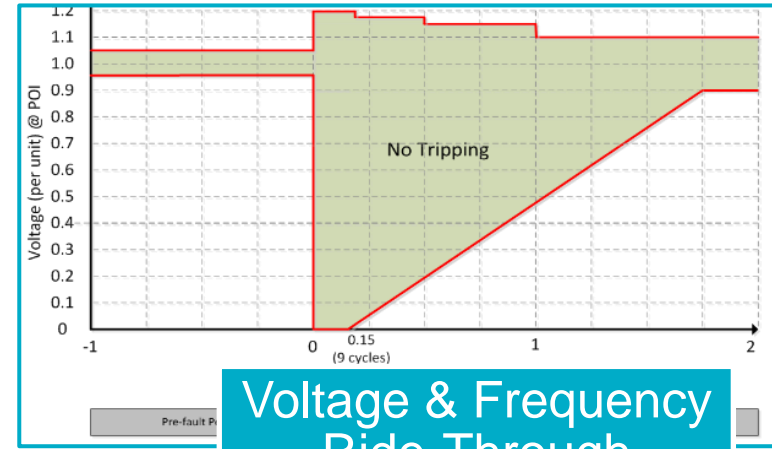


“Precise” Real Time Operations

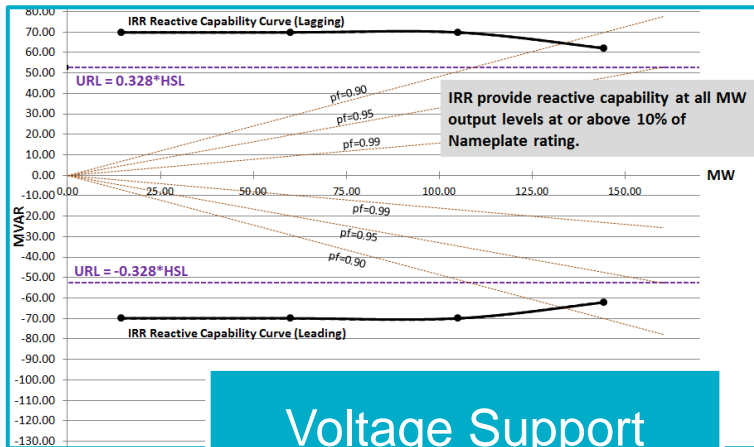
Grid Code for Renewable Resources



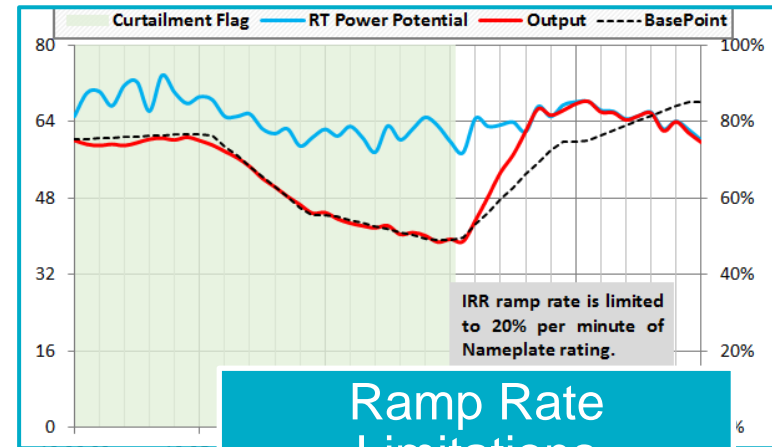
Frequency Response



Voltage & Frequency Ride-Through



Voltage Support



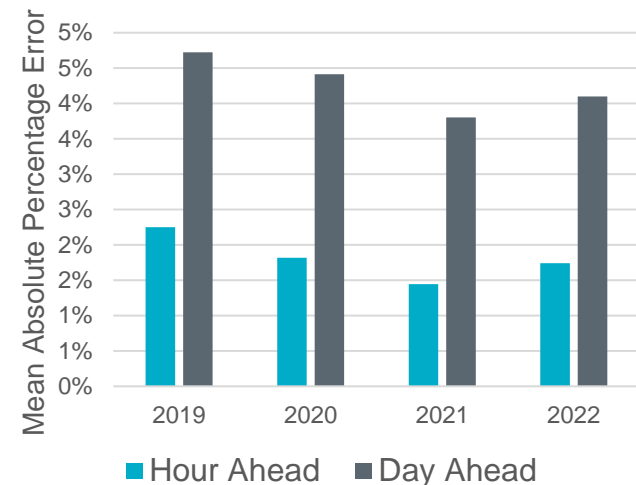
Ramp Rate Limitations

Wind and Solar Forecast

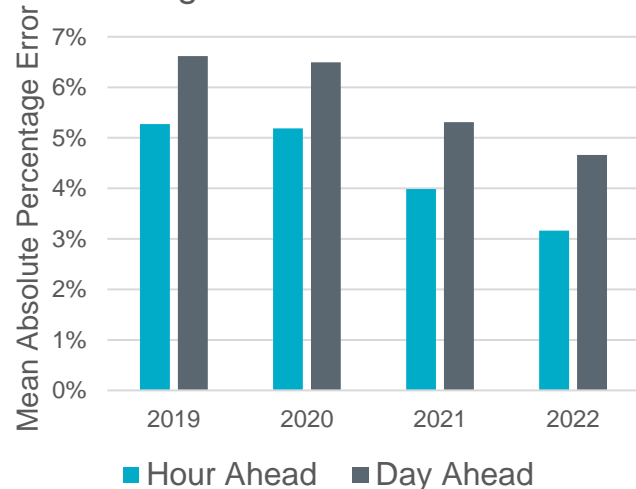
- ERCOT implemented a centralized forecast for wind in 2009 and for solar in 2016. In 2017, ERCOT contracted a second provider for wind forecasts. In 2022, ERCOT contracted a second provider for solar forecasts.
- ERCOT receives an
 - **“Hourly” Forecast** for each wind and solar resource and **Extreme Event Forecast** for each wind resource for next 168-hr at hourly resolution, updated hourly
 - **Intra-hour Forecast** for system level wind and solar potential for next 2-hr, at 5-min resolution, updated every 5-min
- Primary Inputs,
 - Site geo-location, Met tower geo-location,
 - Wind Speed and Temperature Operational limits
 - Telemetered site-specific data
 - Scheduled outages & de-rates
 - Generic power curves
 - Weather variables like wind speed/direction, irradiance, cloud cover

*In the graphs below, 2022 represents the average forecast error between 01/01/2022 and 06/23/2022

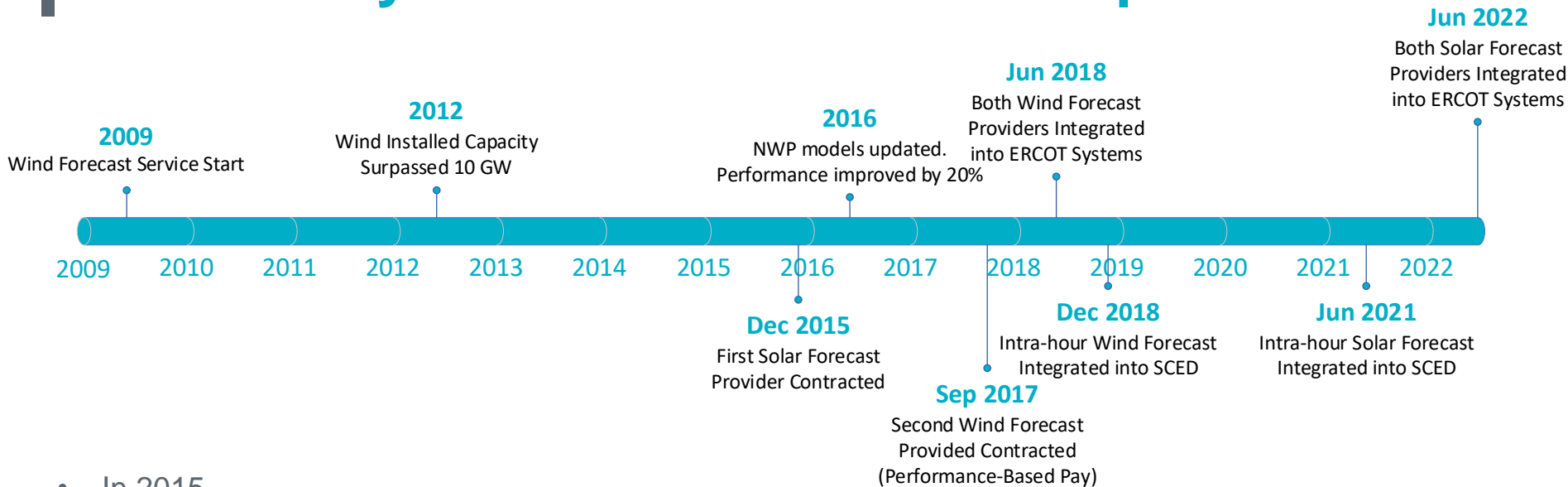
Average Wind Forecast Error



Average Solar Forecast Error



Noteworthy Renewable Forecast Improvements

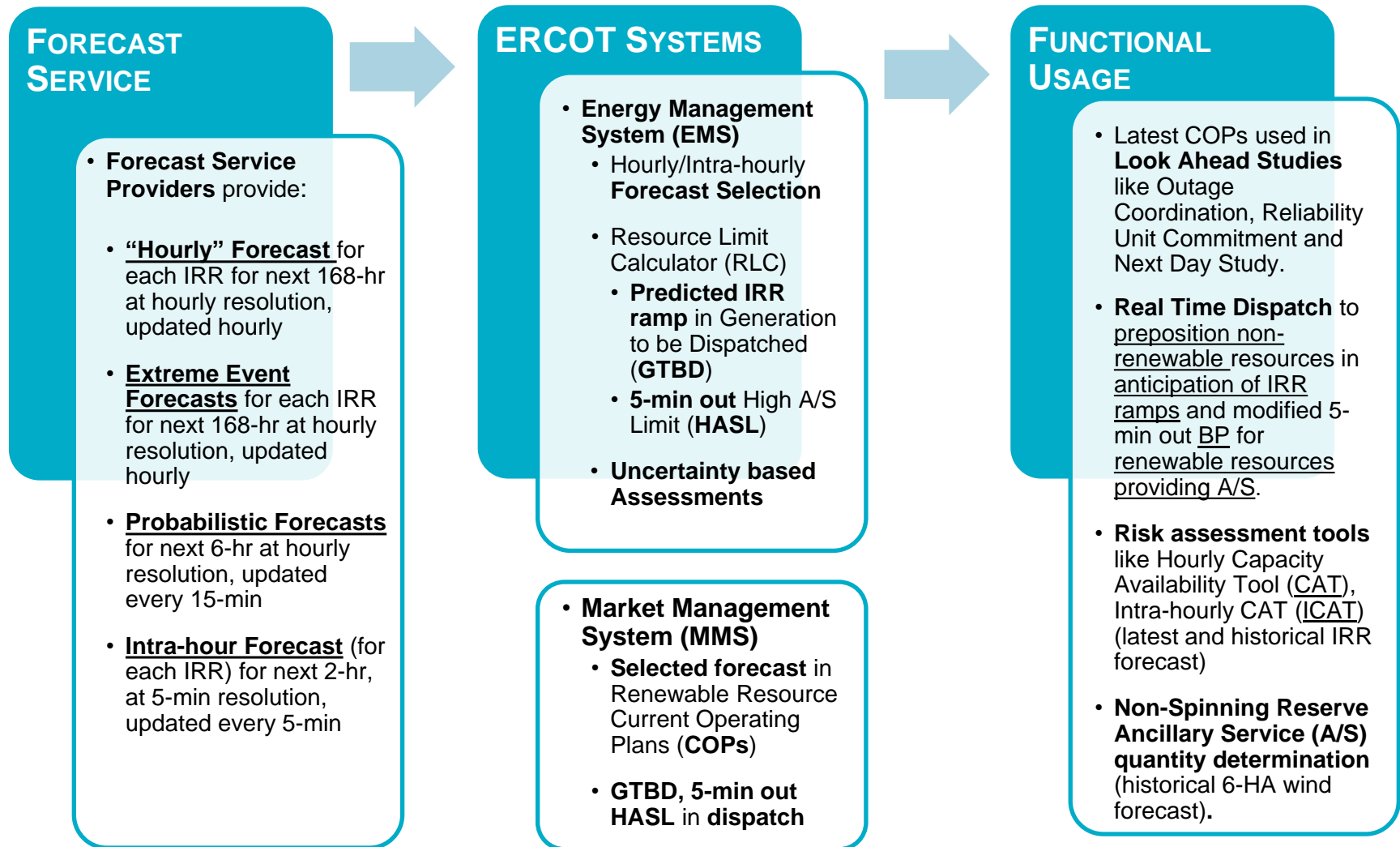


- In 2015,
 - Capability to **manually override wind forecast** was acquired. This allowed manual changes to wind forecast when the meteorological conditions are not captured by the forecasting process. 2022
- In 2017,
 - **Reliability Risk Desk** was added in the Control Room.
 - ERCOT started **automatically updating Wind and Solar Current Operating Plans (COPs)** with the most recent forecast. This change ensured that the most recent wind and solar forecast was used in all **Look Ahead Studies** like Outage Coordination, Reliability Unit Commitment and Next Day Study.
- In 2018,
 - **Hourly and Extreme Weather Wind Forecasts** from both vendors were incorporated into ERCOT's EMS. As a part of this implementation, System Operators in the Reliability Risk Desk were given the ability to **"select" active wind forecast** that will be used in Wind COPs.

Noteworthy Renewable Forecast Improvements

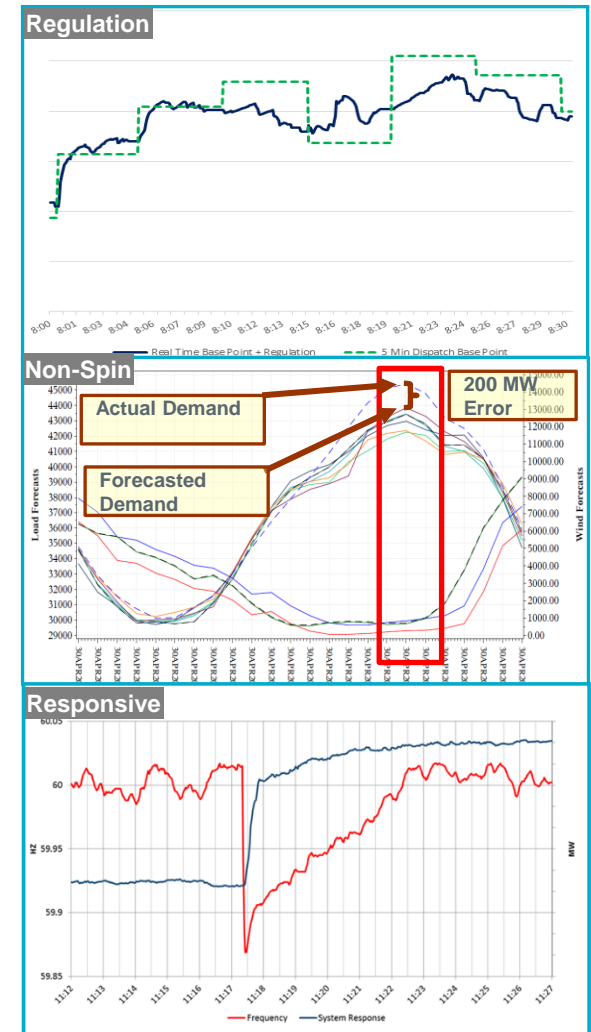
- In 2018,
 - Hourly and Extreme Weather Wind Forecasts from both vendors were incorporated into ERCOT's EMS. As a part of this implementation, System Operators in the Reliability Risk Desk were given the ability to “**select**” **active wind forecast** that will be used in Wind COPs.
 - Intra-hour wind forecast was integrated into the Security Constrained Economic Dispatch process. This allowed ability to **preposition non-renewable resources in response to an expected wind ramp**.
- In 2021,
 - Intra-hour solar forecast will be integrated into the Security Constrained Economic Dispatch process. This will allow for the ability to **preposition non-renewable resources in response to an expected solar ramp**.
 - Capability to manually override solar forecast was acquired.
- In 2022 [ONGOING],
 - Second vendor for solar forecasting was integrated into EMS system and studies.
 - Implemented a Forecast Presentation Platform (FPP) to source all renewable forecasts related Real Time operations

IRR Forecast Usage at ERCOT



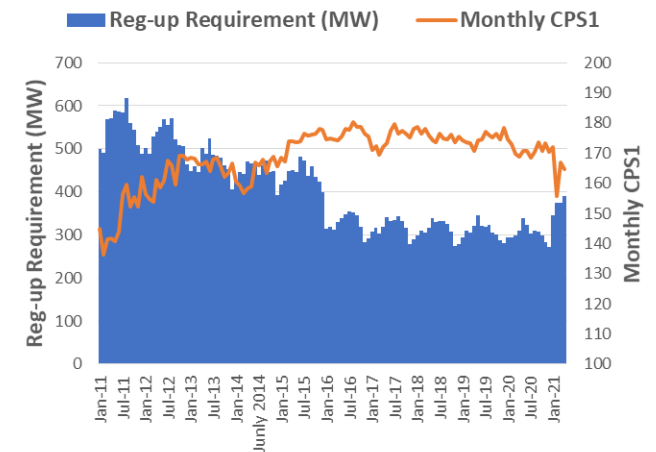
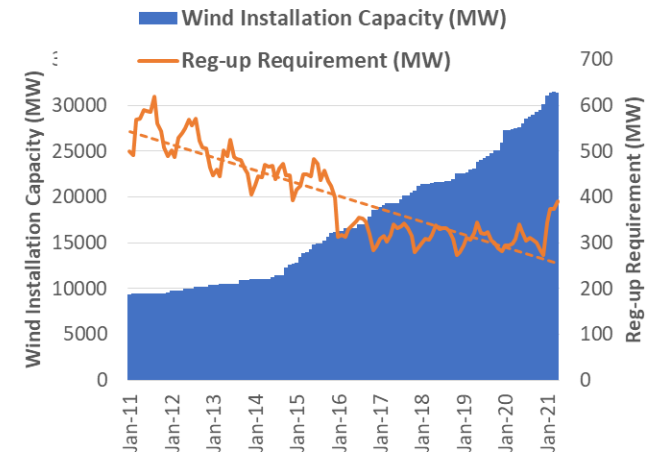
Ancillary Services i.e. Operational Reserves

- Ancillary Service are procured to ensure sufficient resource capacity is on-line, or able to be brought on-line in a timely manner, to balance the variability that cannot be covered by the 5-minute energy market.
- Three types of reserves
 - Regulation Service
 - Non-Spin Service
 - Responsive Reserve Service
- With changing generation mix, ERCOT and its stakeholders continue to focus on the design of these services able to provide resources that can maintain system reliability by responding quickly to sudden changes in load and generation output.
 - While the types of Ancillary Services have stayed the same, over the years ERCOT has tweaked the methodology for computing the reserve requirements continuously, to adapt to the evolving needs of the ERCOT grid and to become more efficient in responding to the additional operational risks.
- ERCOT is in the process of implementing a 10-min Ancillary Service named ERCOT Contingency Reserve Service (ECRS) that will help recover frequency following large trips and short-term net load ramps.



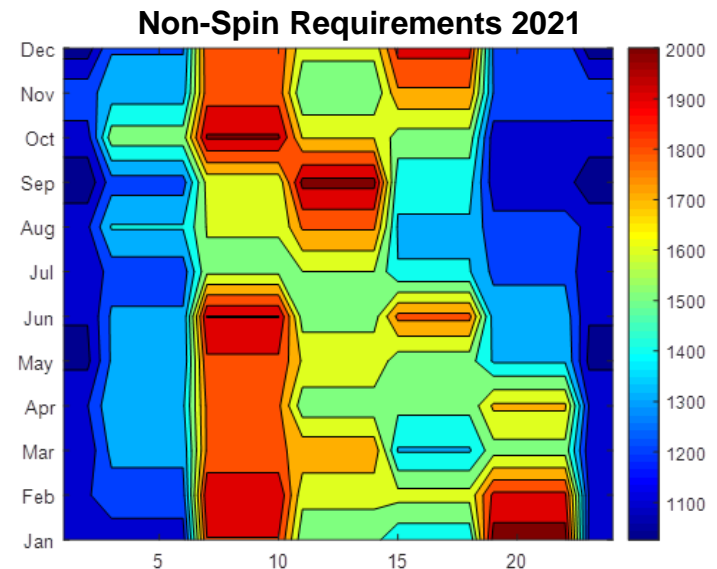
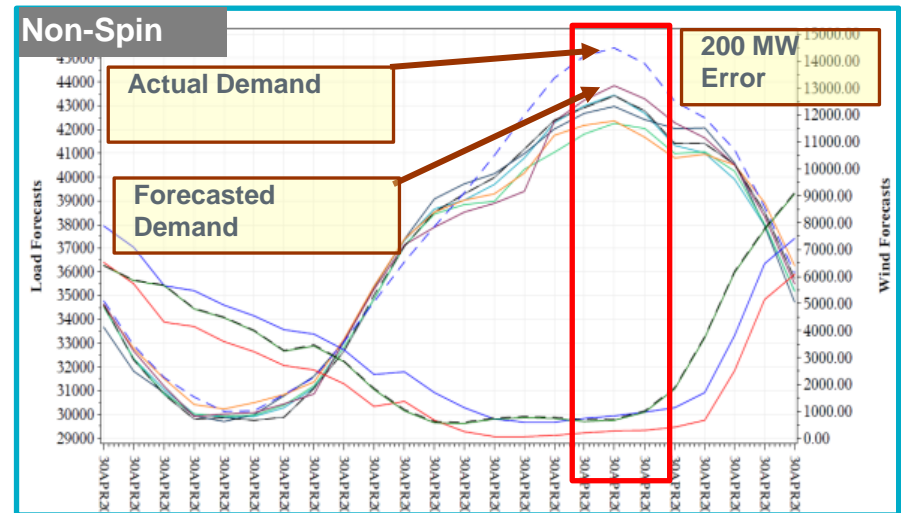
Regulation Up and Down Operational Reserve

- Regulation Service is deployed every 4 seconds to maintain frequency (i.e. maintain supply & demand balance) between 5-min dispatch intervals.
- This service is typically provided by supply side resources such as Generation Resources and energy storage resources.
- CPS1 is performance metric used to gauge efficacy of procured Regulation reserves.
- Regulation requirements are calculated to cover 95th percentile of deployed regulation or 5-min net load variability observed in previous two years.
 - Adjustments are also included to account for additional variability from expected growth in Wind & Solar capacity.



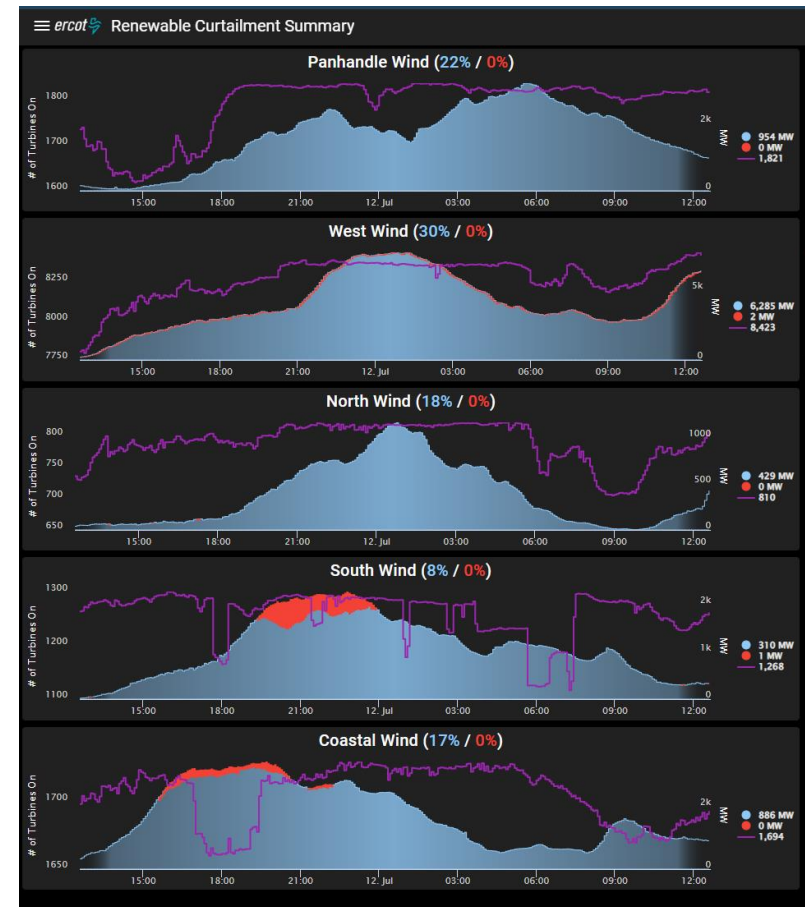
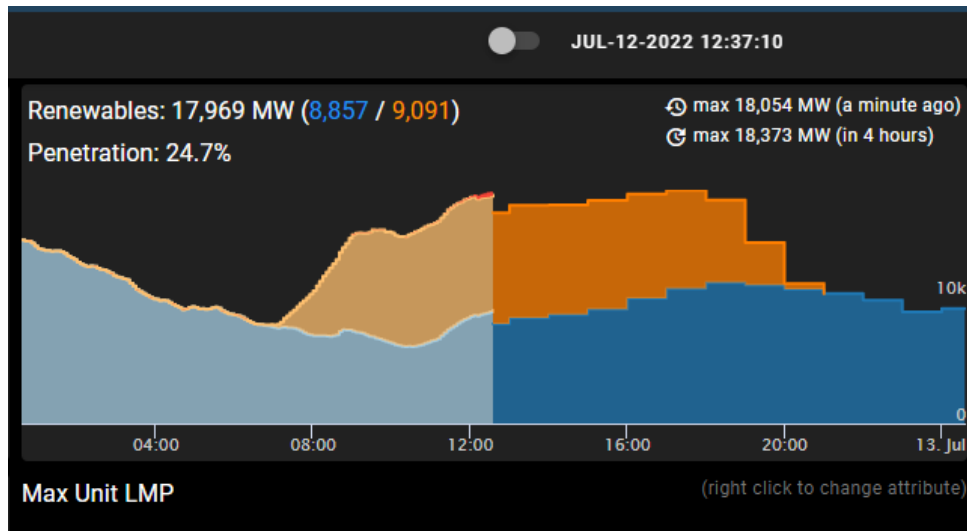
Non-Spin Operational Reserve

- Non-Spin Reserve is capacity that can be started in 30 minutes to cover net load forecast errors (NLFE) or net load ramps.
 - Non-spin methodology focuses on 6 Hour Ahead net load under forecast errors and intra-day Forced Outages.
 - Larger protection against net load forecast error is used in hours with higher risk of net load up ramps.
 - Adjustments are also included to account for increases in wind & solar over forecast errors as installed wind and solar capacities grow within the year.

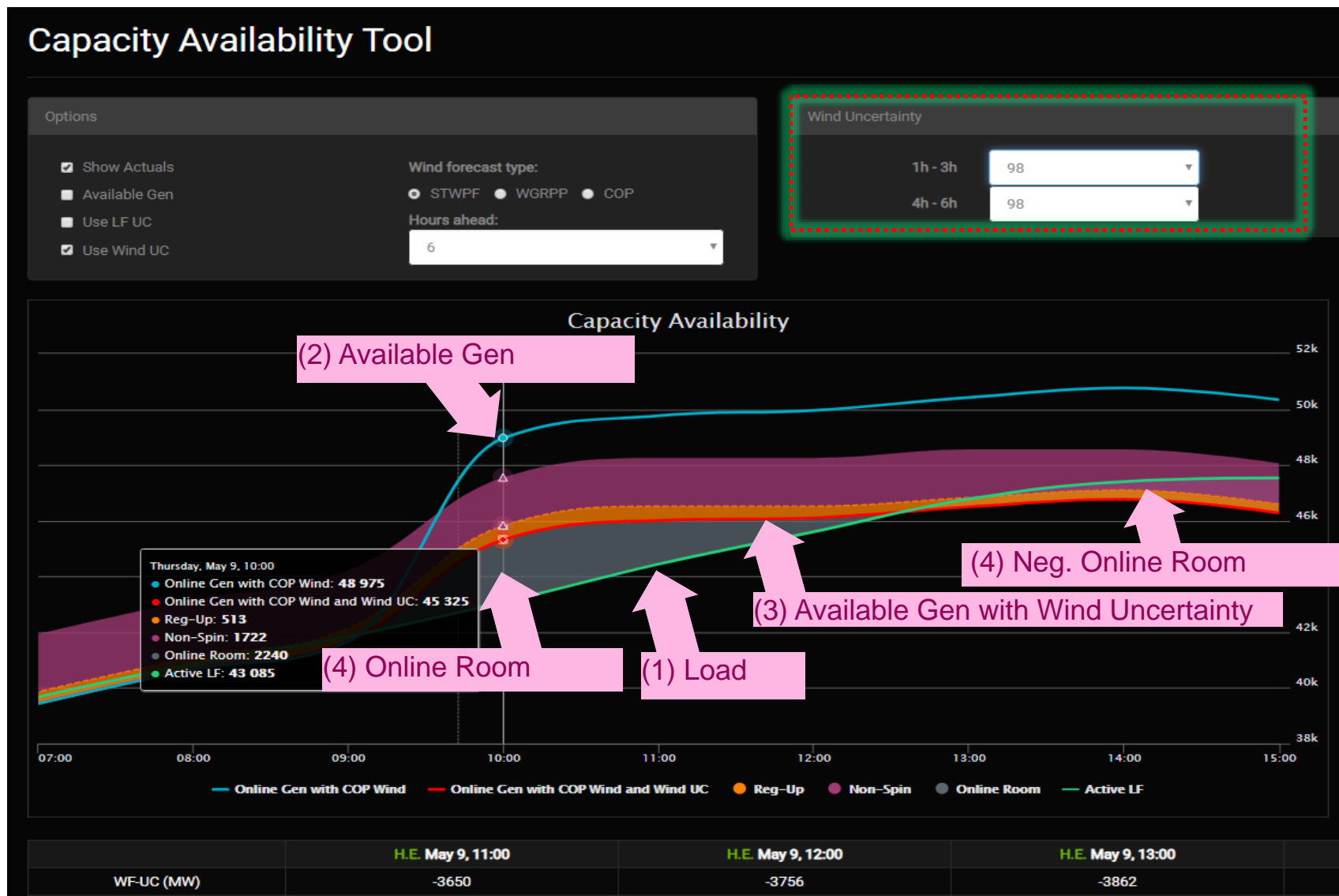


Monitoring Tools for Renewable generation

- Over the years several tools have been developed to
 - monitor operations of the wind and solar resources integrated into ERCOT grid,
 - make changes to renewable forecasts used in real time dispatch and future studies,
 - conduct analysis on impacts of changes in wind and solar generation to grid reliability.

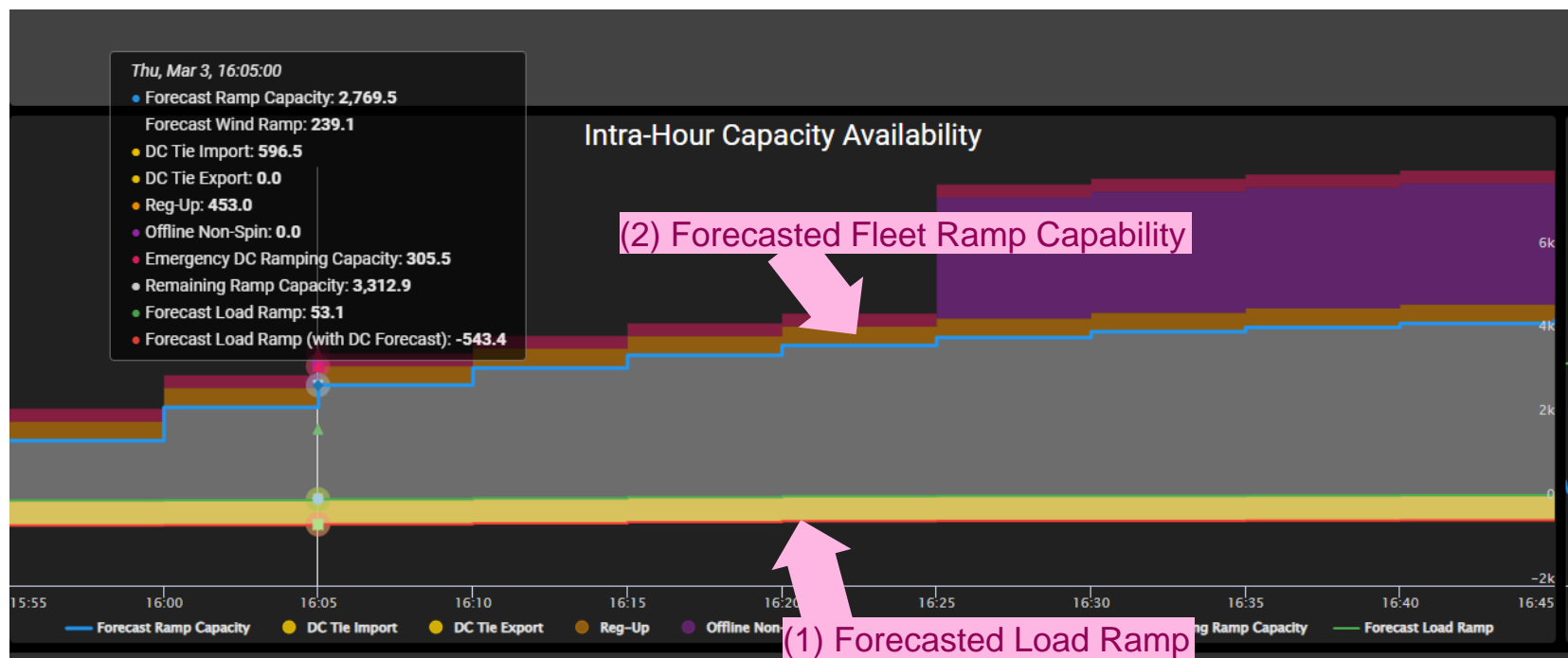


Capacity Availability Tool – “What If” Assessment for next 6 hours



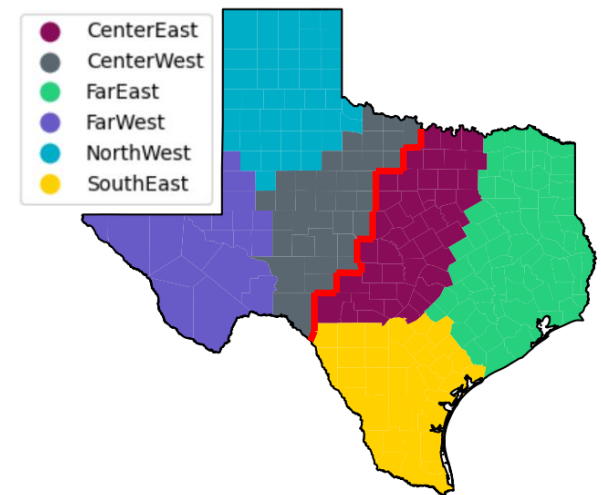
Intra-Hour Capacity Availability Tool – “What If” Assessment for next 2 hours

- Currently implementing a tool that will monitor forecasted net load ramp in the next two hours and the available ramping capability of the thermal fleet to cover these.



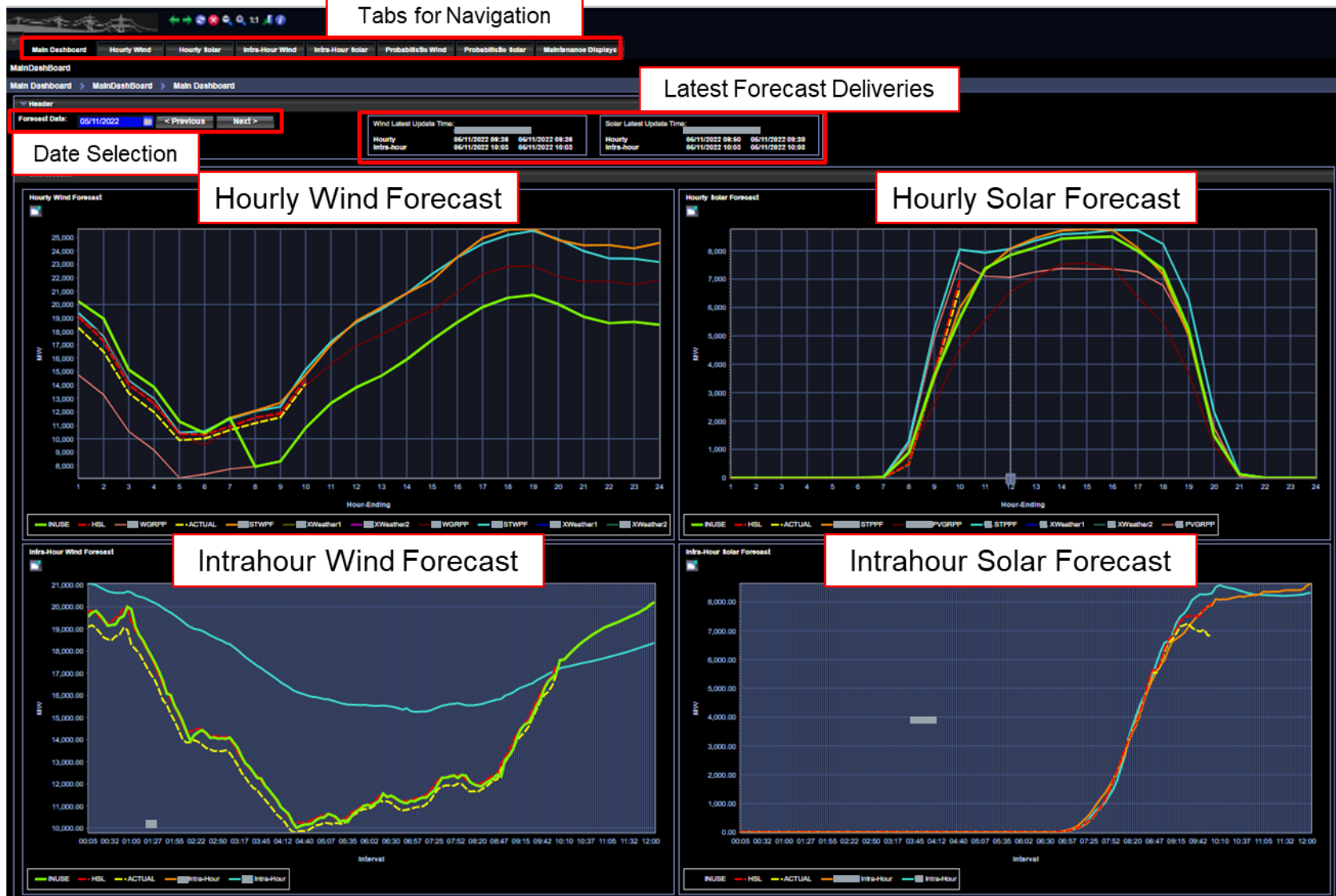
Forecast Presentation Platform – Background + Overview

- The EMS was not designed to host forecasting data making it difficult for developers to add new forecasts and features.
- The Forecast Presentation Platform (FPP) is a new application, separate from the EMS, which will host all IRR forecast data and allow operators to view forecast data and select the desired forecast across all available vendor models.
- Enhancements resulting from this project
 - First release (June, 2022)
 - Resource-level forecast graphs and tables
 - Available selection of 80th percentile forecast
 - Integration of new second solar forecast vendor
 - Implementation of six new solar regions
 - Second Release (August, 2022)
 - Available selection of blended forecast model. Allows operators to define a forecast by applying weights to various forecast models.
 - In-house forecast override capability
 - Probabilistic forecast displays
 - Ability to define custom aggregations of resources



1. V1F4 and V2F4 are 80th percentile forecasts
2. B1 is a blended forecast
3. O2 is a manual override

FPP Main Dashboard



Hourly Forecast Region-Level Graph



Hourly Region-Level Forecast Table

DefaultSourceForDay

DATE

FORECAST_SELECT

05/11/2022

Select Active Forecast Model, by day

Data in the table will update based on selected date and aggregation

Wind

Export table data to Excel

Select active forecast model, by hour

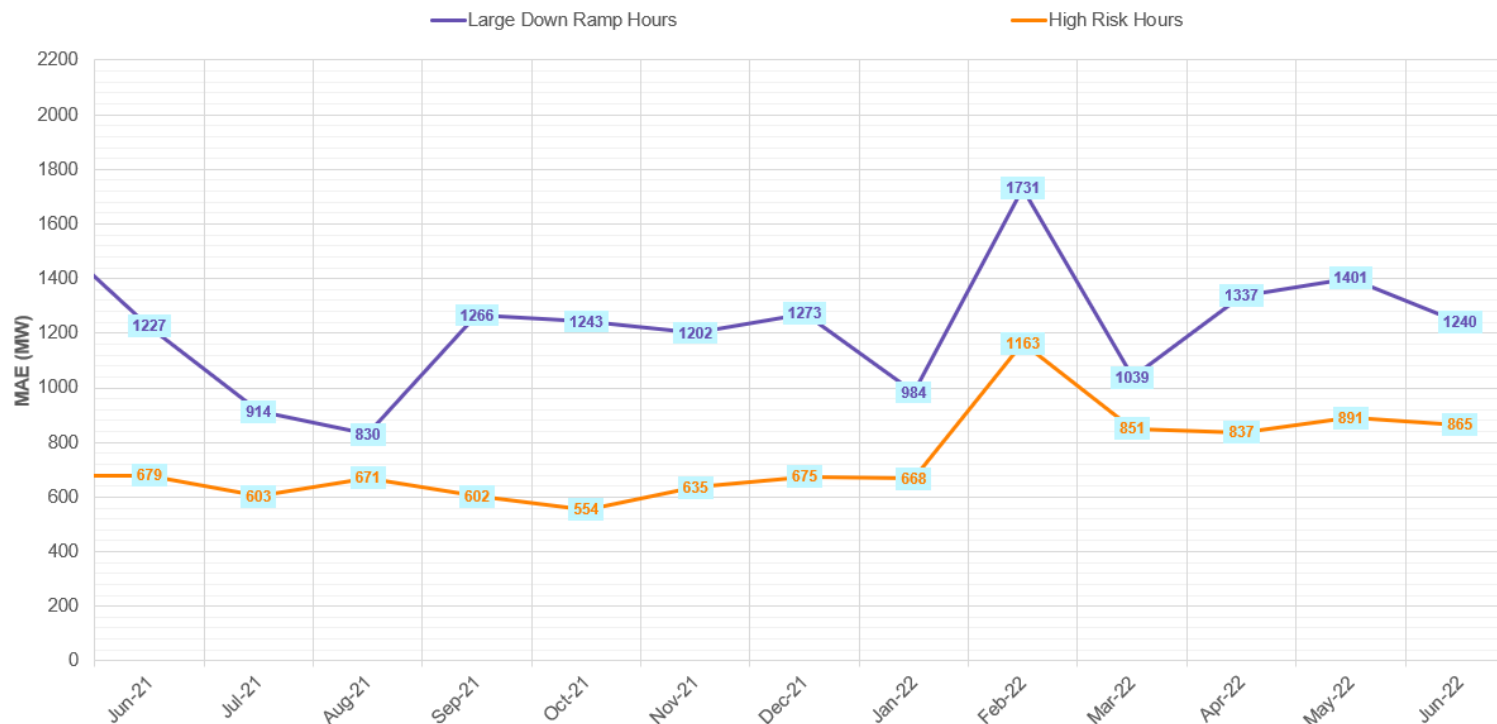
Data for all available forecast models are shown

Hour-Ending	INUSE	HSL	HSL Viol	MW	STWPF	XWeather1	XWeather2	WGRPP	STWPF	XWeather1	XWeather2	WGRPP
01	20,241.8	19,132.6	●	18,284.0	20,241.8	20,241.8	20,241.8	18,850.8	19,386.9	19,386.9	19,386.9	14,769.3
02	18,945.0	17,252.0	●	16,487.9	18,945.0	18,945.0	18,945.0	17,808.5	17,662.4	17,662.4	17,662.4	13,287.3
03	15,138.0	14,001.4	●	13,396.9	15,138.0	15,138.0	15,138.0	14,229.1	14,334.5	14,334.5	14,334.5	10,538.1
04	13,844.3	12,613.5	●	11,980.7	13,844.3	13,844.3	13,844.3	12,875.0	12,963.0	12,963.0	12,963.0	9,149.1
05	11,289.9	10,379.5	●	9,888.4	11,289.9	11,289.9	11,289.9	10,219.9	10,449.9	10,449.9	10,449.9	7,095.3
06	10,419.9	10,291.8	●	10,021.5	10,419.9	10,419.9	10,419.9	9,515.5	10,568.4	10,568.4	10,568.4	7,359.9
07	11,552.4	10,913.6	●	10,647.0	11,552.4	11,552.4	11,552.4	10,748.3	11,463.7	11,463.7	11,463.7	7,750.0
08	7,929.2	11,569.1	●	11,159.0	12,081.7	12,081.7	12,081.7	11,201.6	12,044.8	12,044.8	12,044.8	7,929.2
09	8,324.8	11,906.5	●	11,594.1	12,674.9	12,674.9	12,674.9	11,817.0	12,389.2	12,389.2	12,389.2	8,324.8
10	10,810.7	14,460.4	●	14,105.2	14,771.0	14,771.0	14,771.0	13,970.0	15,161.1	15,161.1	15,161.1	10,810.7
11	12,653.2				17,015.9	17,015.9	17,015.9	15,545.2	17,236.6	17,236.6	17,236.6	12,653.2
12	13,827.6				18,764.1	18,764.1	18,764.1	16,919.9	18,656.8	18,656.8	18,656.8	13,827.6
13	14,700.6				19,791.0	19,791.0	19,791.0	17,755.8	19,650.4	19,650.4	19,650.4	14,700.6
14	15,911.0				20,834.9	20,834.9	20,834.9	18,732.1	20,831.9	20,831.9	20,831.9	15,911.0
15	17,358.0				21,799.5	21,799.5	21,799.5	19,535.5	22,273.7	22,273.7	22,273.7	17,358.0
16					23,522.2	23,522.2	23,522.2	20,927.5	23,494.8	23,494.8	23,494.8	18,670.6
17					24,944.4	24,944.4	24,944.4	22,251.2	24,525.3	24,525.3	24,525.3	19,811.8
18					25,571.0	25,571.0	25,571.0	22,825.8	25,178.5	25,178.5	25,178.5	20,498.8
19					25,619.9	25,619.9	25,619.9	22,854.3	25,484.5	25,484.5	25,484.5	20,709.2
20					24,790.2	24,790.2	24,790.2	22,081.6	24,863.6	24,863.6	24,863.6	20,019.3
21					24,406.4	24,406.4	24,406.4	21,699.6	23,978.9	23,978.9	23,978.9	19,082.4
22	18,610.9				24,430.3	24,430.3	24,430.3	21,721.3	23,434.3	23,434.3	23,434.3	18,610.9
23	18,701.8				24,191.9	24,191.9	24,191.9	21,486.6	23,411.6	23,411.6	23,411.6	18,701.8
24	18,489.8				24,580.5	24,580.5	24,580.5	21,806.8	23,150.9	23,150.9	23,150.9	18,489.8

Indicates whether forecast error for latest forecast has exceeded a configurable threshold

Performance based payment structure for Renewable Forecasts

Hour-Ahead Mean Absolute Error (MAE) During Large Down Ramp (> 2000 MW)
and High Risk Hours*



- ERCOT's performance-based payment structure for Wind and Solar Forecasts incentivizes improvements in forecast performance during hours that are of more importance to operational reliability. This approach is a paradigm shift from the "traditional" methodology of measuring forecast performance as a singular monthly average percentage based metric. In 2018 and 2019, ERCOT implemented a pay for performance scheme for both wind forecast vendors.
- In 2022, a pay for performance scheme for solar forecast vendor will be implemented. The following improvements were made, based on lessons learned from the wind forecast implementation.
 - Boolean yes/no award thresholds were changed to sliding-scale continuous thresholds.
 - Added a metric which considers reliable delivery of forecasts
 - Added metrics regarding the 6 hour-ahead time horizon due to its importance to operations.

Net Load Variability Evaluation

- Since July 12, 2021, ERCOT has been monitoring the weather forecast near Real Time and in some instances has procured up to an additional 1,000 MW of Non-Spin during periods* that were identified as having an increased potential of high forecast variability that may cause a higher net load during these hours.
- Beginning Sep 1, 2021, ERCOT has updated the [Forecast Variability report](#) for the Current Day + 2 to include separate variability assessments for peak and off-peak hours.
 - Below is a break-down of the criteria for classifying the variability of the load, wind, solar and net load forecast that is currently being used in the report.

Potential Error in MW				
	Load Under Forecast	Wind Over Forecast	Solar Over Forecast	Netload Under Forecast
High	>3000	>3000	>2000	>4000
Medium	1000-3000	1500-3000	1000-2000	2000-4000
Low	<1000	<1500	<1000	<2000

- Using this process ERCOT procured additional Non-Spin on 9 days each in 2021 and 2022
 - 2021: Jul 29, Aug 1, Aug 2, Aug 14, Aug 27, Aug 29, Aug 30, Sep 3, Sep 4
 - 2022: Jan. 2, Jan. 3, Jan. 20, Feb. 3, Feb. 4, May 22, May 23, May 24, Jun 1

Renewable ramp in Real Time Dispatch to preposition thermal resources

ERCOT Area Details

Generation to be Dispatched (GTBD):

```
72292.12 = 72263.59 -
( 0.00 * 10 * 89.50 *
( 60.02 -
60.00 -
0.00 )) -
0.00 * (
55.02 )) +
1.00 * ( 5.00 *
-18.34 ))
+ 0.20000 * 269.76
- 0.50000 * -250.00
- 1.00000 * 5 * 20.15
+ 0.50000 * 5 * 0.00
- 1.00000 * 5 * -8.40

GTBD = sum (Output MW) -
(K1 * 10 * System Load Frequency Bias *
(System Actual Frequency -
System Scheduled Frequency -
System Frequency Offset)) -
K2 * (net non-conforming load -
net filtered non-conforming load) +
K3 * (nominal SCED execution interval in minutes *
Predicted load ramp rate) (Using STLFF)
+ K4 * Regulation Deployed
- K5 * Integral ACE
- K6 * 5 * Predicted Wind Ramp Rate (Using IHWF)
+ K7 * 5 * Predicted DC Tie Ramp Rate
- K8 * 5 * Predicted Solar Ramp Rate (Using STPPF)
```

Regulation Rolling Average and Integral ACE Detail >>

Intra-Hour Wind Forecast (IHWF) Details >>

Intra-Hour Solar Forecast (IHPPF) Details >>

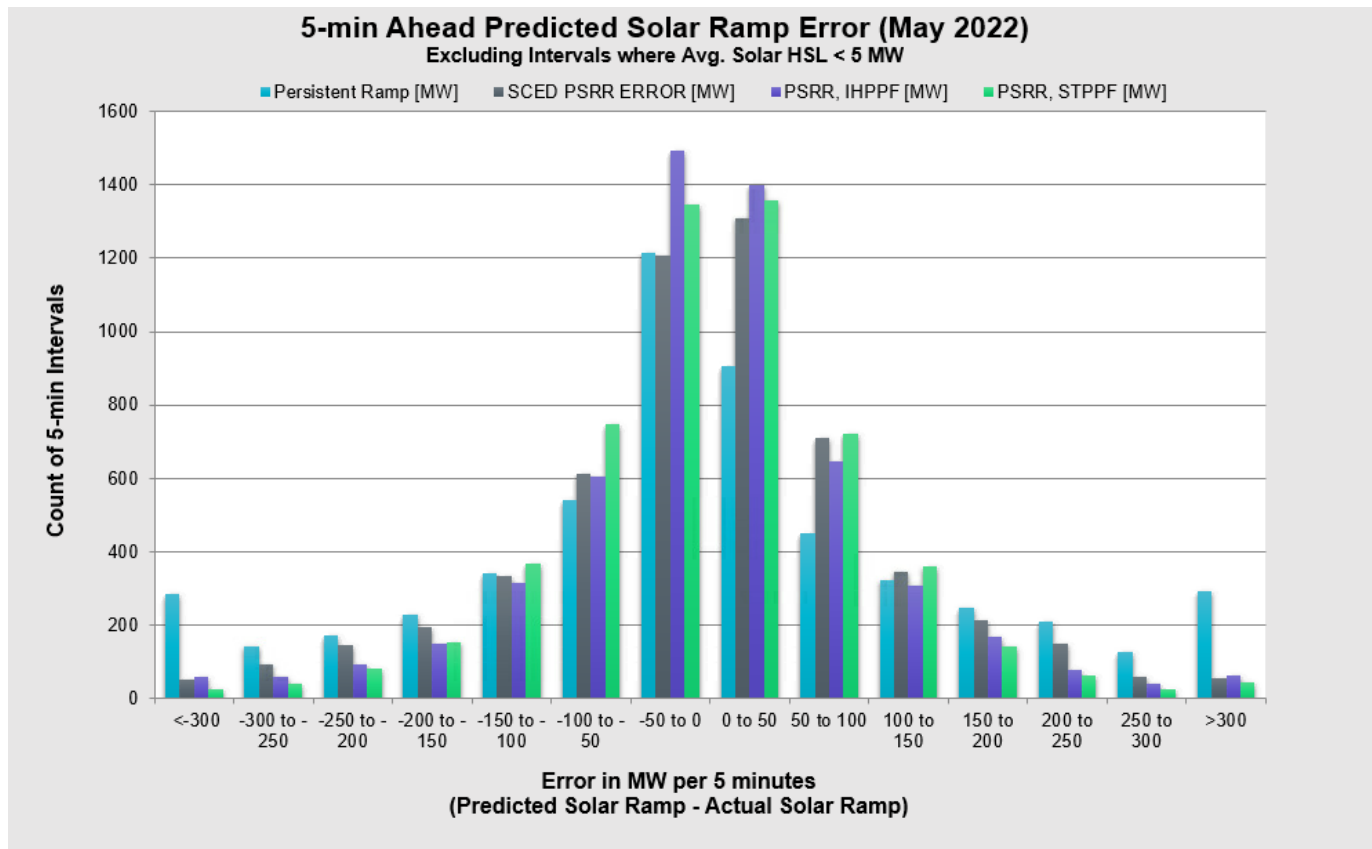
Predicted DC Tie Ramp (PDCTRR) Details >>

OK

PWRR Max/Min Threshold(MW): 30 PSRR Max/Min Threshold (MW/min): 30

Predicted Solar Ramp Rate (PSRR) Error (May 2022)

Performance Metric	Persistence Ramp*	SCED PSRR	PSRR, IHPPF	PSRR, STPPF
Monthly MAE (MW per 5 minutes)	120	82	72	70
Monthly MAE when 5-Min. Solar Ramp > 100 MW	229	117	88	87



Emerging Challenge

- Inverter Based Resources are expected to and required to be able to ride through without tripping or reduction in capability for normal system disturbances that fall within predetermined criteria.
- However, some Inverter Based Resources (IBRs) have in recent years demonstrated performance after disturbances that, if left unaddressed, will negatively affect reliability of the BES.
- ERCOT is actively engaged in analysis of these events to understand the underlying issues and identify actions that will mitigate these.

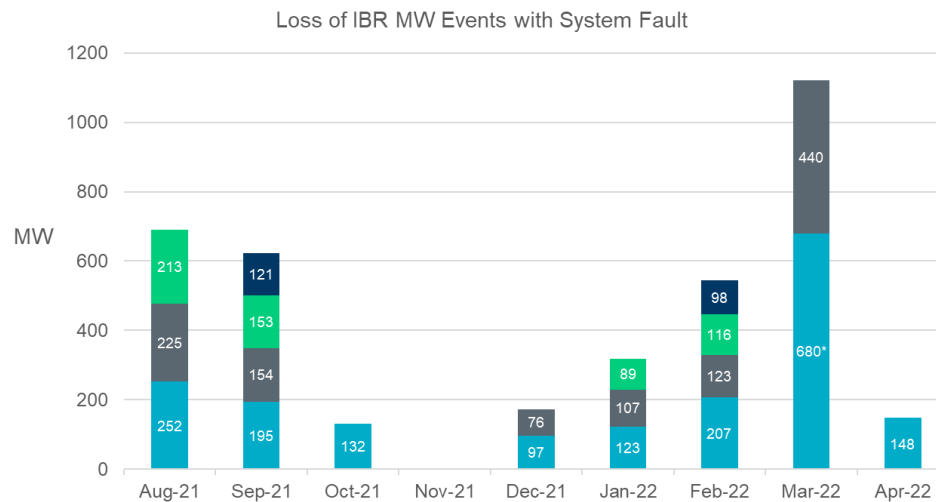
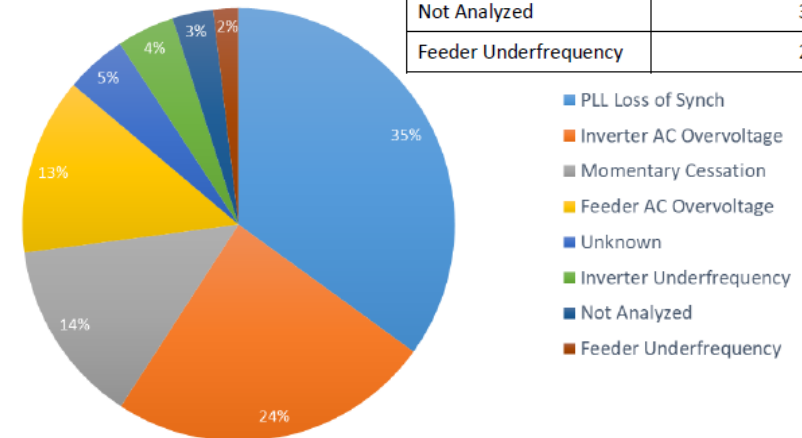


Table 1.1: Causes of Reduction	
Cause of Reduction	Reduction [MW]
PLL Loss of Synchronism	389
Inverter AC Overvoltage	269
Momentary Cessation	153
Feeder AC Overvoltage	147
Unknown	51
Inverter Underfrequency	48
Not Analyzed	34
Feeder Underfrequency	21



Charts and tables from NERC Event Report for Odessa Disturbance - https://www.nerc.com/pa/rm/ea/Documents/Odessa_Disturbance_Report.pdf

APPENDIX

Pay for Performance – Wind Vendors

“MUST MEET” Requirements

Day Ahead MAPE < xx%
Hour Ahead MAPE < xx%

Failure to meet these metrics
results in
no performance payment

“MUST MEET” 5 minute accuracy

- Beats persistence ramp for > 50% of intervals
- Monthly MAE < Persistence ramp MAE

Performance Metric #1 MAPE Evaluation

Horizons Evaluated: DA , HA

Performance Metric #2 MAE Evaluation

Horizons Evaluated: DA , HA

Performance Metric #3 Scoring Metric

Each hour is categorized and scored
Ramping Hours
High Risk Hours

Performance Metric #4 5 minute accuracy

- Beats Persistence for X% of intervals
- Beats Persistence for X% of ramping intervals
- Improvement upon persistence ramp MAE

Pay for Performance – Solar Vendors

Only consider intervals: System-wide MW > 5 MW (For solar vendors only)

“MUST MEET” Requirements

Day Ahead MAPE < xx%
Hour Ahead MAPE < xx%

Failure to meet these metrics
results in
no performance payment

“MUST MEET” 5 minute accuracy

- Beats persistence ramp for > 50% of intervals
- Monthly MAE < Persistence ramp MAE

Performance Metric #1 MAPE Evaluation

Horizons Evaluated: DA , 6HA , HA

Performance Metric #2 MAE Evaluation

Horizons Evaluated: DA , 6HA , HA

Performance Metric #3 Scoring Metric

Each hour is categorized and scored
Ramping Hours
High Risk Hours

Performance Metric #4 5 minute accuracy

- Beats Persistence for X% of intervals
- Beats Persistence for X% of ramping intervals
- Improvement upon persistence ramp MAE

Reliability Metric – Missed deliveries (For solar vendors only)

Intrahour Forecast Missed Deliveries
Hourly Forecast Missed Deliveries