Real-Time Reserve Requirements

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Reserve Design

30 Min. Reserves – Updated

Used to ensure sufficient supply is available to manage net-load forecast uncertainty and to serve net-load in the next 30 minutes. Also to ensure sufficient reserves to backfill 10-minute contingency reserves and support system recovery following an event.

10 Min Ramp/Uncertainty Reserves – Up and Down Reserves

Used to ensure sufficient supply is available to manage net-load forecast uncertainty and to serve net-load in the 10 minutes following the target interval.

Primary Reserves (PR)

Synchronized Reserves (SR)

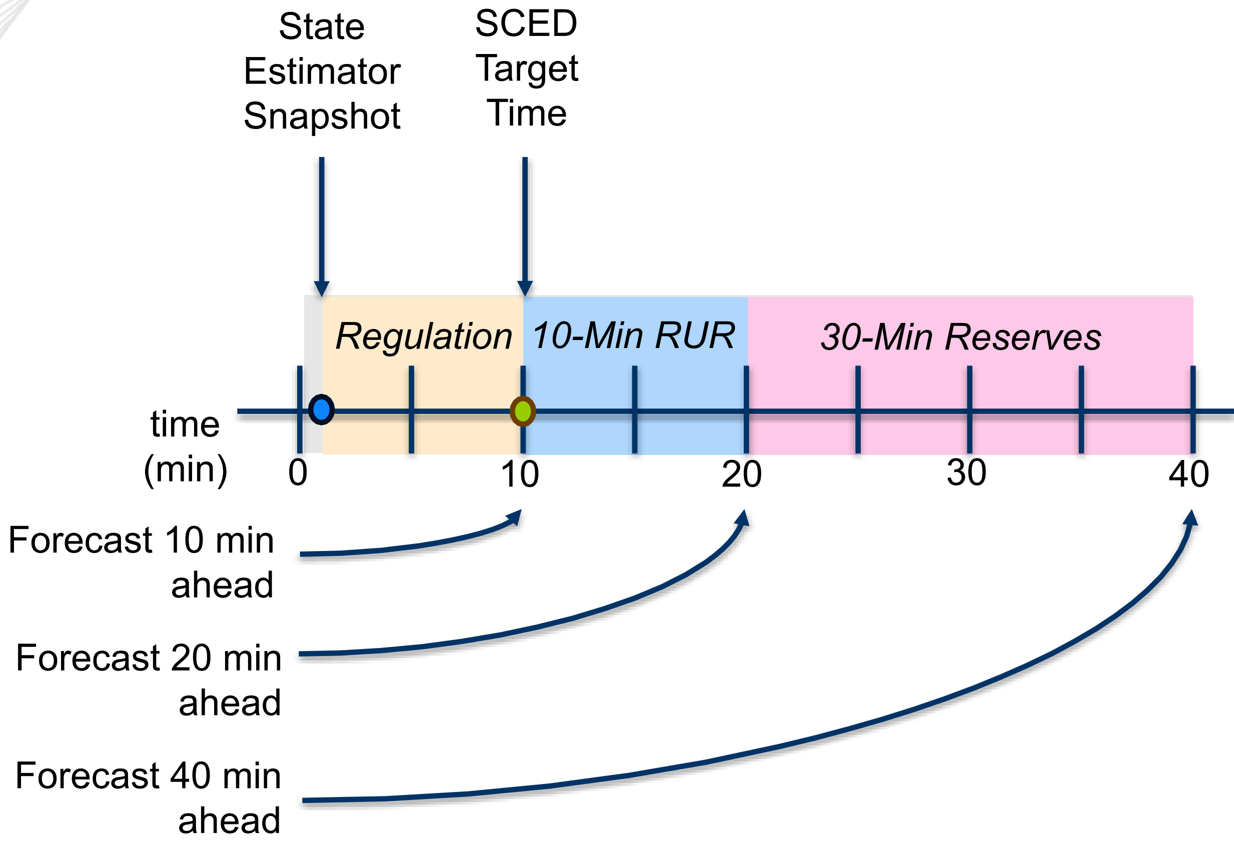
Used to manage the risk of losing the largest unit and to meet NERC reliability requirements.

Reserve Deployment and Forecast Timing

Reserves to manage net-load forecast error and expected net-load ramp would be "deployed" economically as energy after the target interval in which they are procured.

The ramp/uncertainty components of the reserve requirements provide the dispatch flexibility to supply our expectation of future energy demand, recognizing some uncertainty around that expectation.

This framing informs the forecast lookahead windows that would drive those requirement definitions: 20 minutes ahead for 10-minute reserves and 40 minutes ahead for 30-minute reserves.



A Note on Bi-Directional Reserves

- PJM believes that the market design should support bi-directional reserve procurement for the 10-Minute Ramping/Uncertainty product to address future flexibility needs.

- However, for simplicity, this presentation focuses on “up” reserves, or reserves that are needed to manage under-forecasted load, over-forecasted wind/solar generation or expected net-load ramp up. Similar approaches could be applied to quantify “down ramping” needs in the opposite direction.

Calculating the Uncertainty Component of Real-Time Reserves

Two approaches were considered to calculate the net-load forecast uncertainty.

1. Using historical net-load forecast uncertainty and defining the distribution in terms of the MW delta values directly.

2. Using percent uncertainty numbers to define the distribution of uncertainty, where these percent values would then be multiplied by the applicable forecast to the get the MW requirement for each interval. This is more akin to the DASR approach we take in day-ahead.

Uncertainty Quantification Approach 1: Using Historical Net-Load Forecast Uncertainty MW Values

Net-Load Forecast Definition

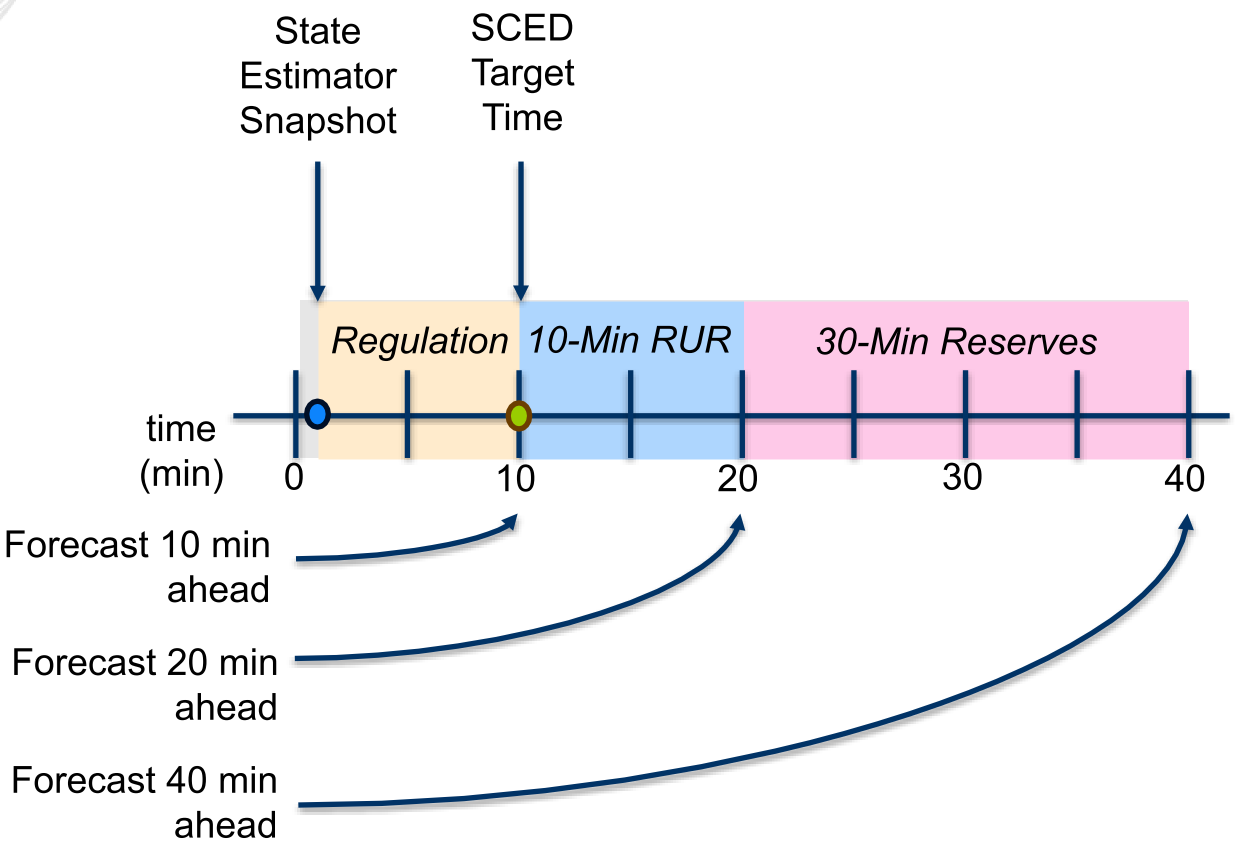
For this work, the Net-Load Forecast is defined as:

Net-Load Forecast = Forecasted Load – Forecasted Solar Generation – Forecasted Wind Generation

Net-Load Forecast Uncertainty Calculation

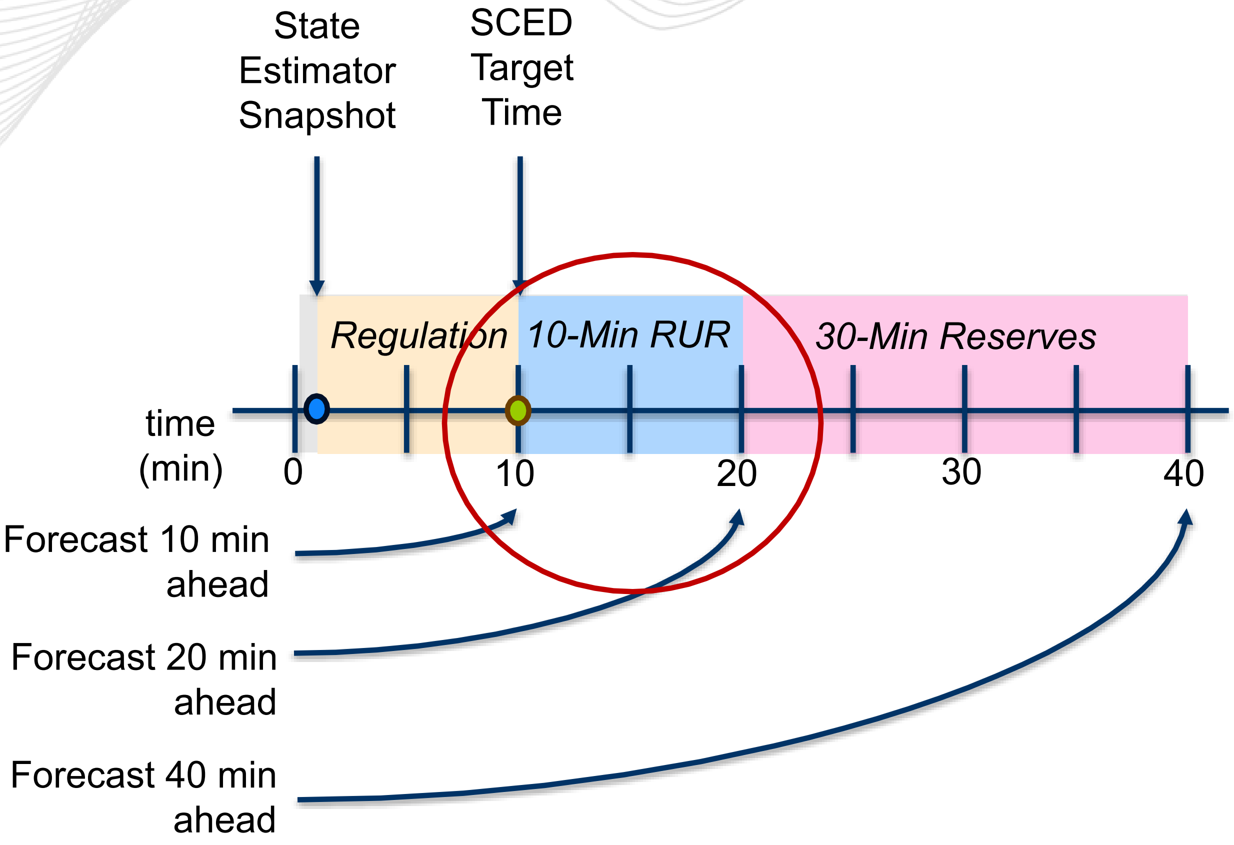
- For every interval, the net-load forecast uncertainty is calculated as the difference between the net-load forecast at the beginning of the uncertainty window and the net-load forecast at the end of the uncertainty window.

- The intent is therefore to capture how much uncertainty exists – and resolves – during the relevant window. Uncertainty that resolves beyond the effective uncertainty window could be addressed by a longer lead time reserve product. Uncertainty that resolves before the effective window would need to be addressed by a faster product.



10-Min RUR Net-Load Uncertainty

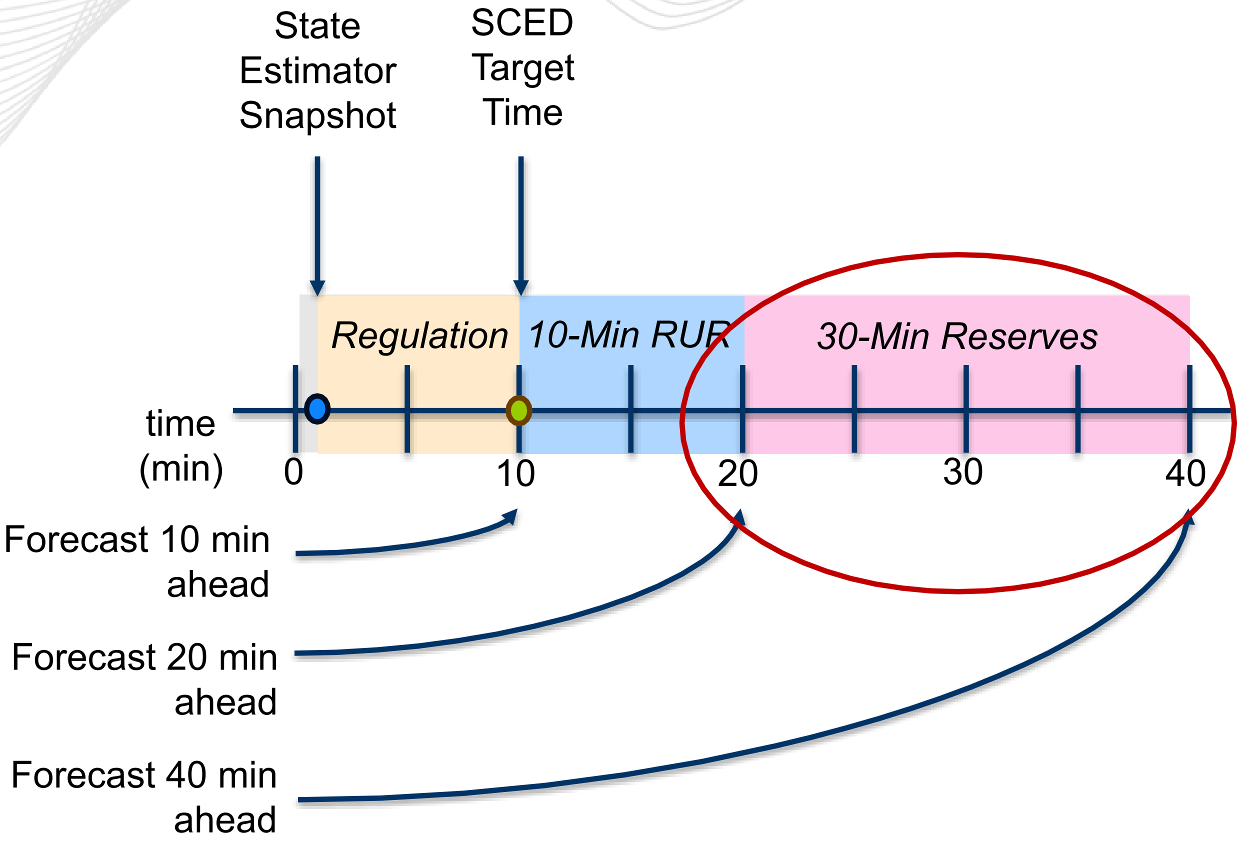
- The net-load forecast uncertainty for the 10-Min RUR product would therefore be calculated by looking at the difference between the net-load forecast 20 minutes ahead of the effective time and the net-load forecast 10 minutes ahead of the effective time.
- The uncertainty component of the 10-Min RUR product would therefore be designed to manage the net-load forecast uncertainty in the 10 minutes beyond the target time in the economic dispatch software.



10-Min RUR Net-Load Uncertainty = Net-Load Forecast$_{t+20}$ - Net-Load Forecast$_{t+10}$

30-Min RUR Net-Load Uncertainty

- The net-load forecast uncertainty for the 30-Min Reserve product would be calculated by looking at the difference between the net-load forecast 40 minutes ahead of the effective time and the net-load forecast 20 minutes ahead of the effective time.
- The uncertainty component of the 30-Min Reserve product would therefore be designed to manage the net-load forecast uncertainty in the 20 minutes beyond the uncertainty window managed by the 10-Min RUR product.



$$\text{30-Min RUR Net-Load Uncertainty} = \text{Net-Load Forecast}_{t+40} - \text{Net-Load Forecast}_{t+20}$$

Data Used in the Analysis

- One year of data covering the 2024-2025 Delivery Year (June 1, 2024 – May 31, 2025)
- Data capture every five-minute snapshot within the delivery year, resulting in 105,120 observations.
- To account for seasonality, the data were grouped by season and time of day.
- The seasons were defined as follows:

Season	Months
Winter	Dec – Feb
Spring	Mar - May
Summer	June - Aug
Fall	Sept - Nov

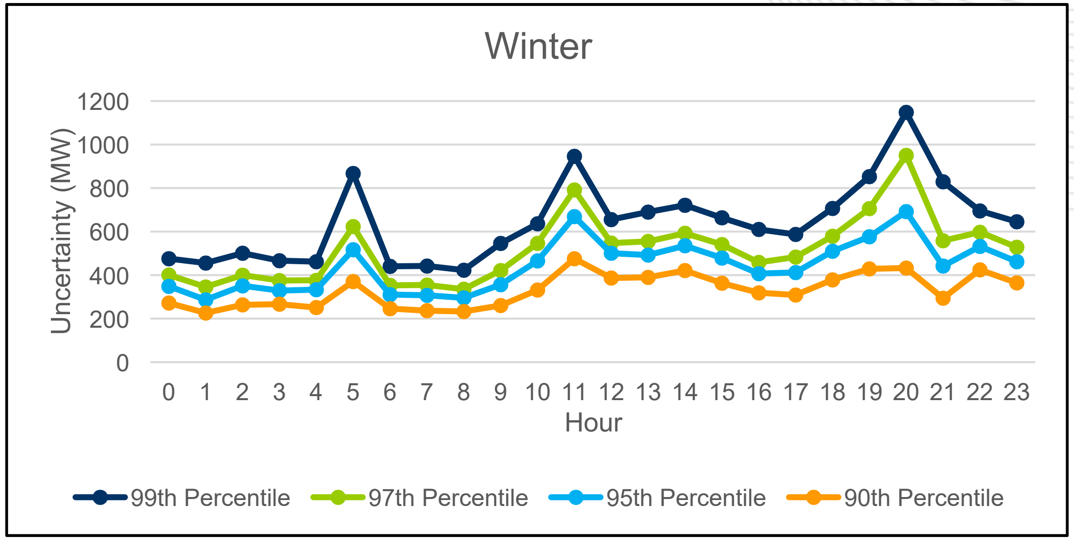
Temporal Classification

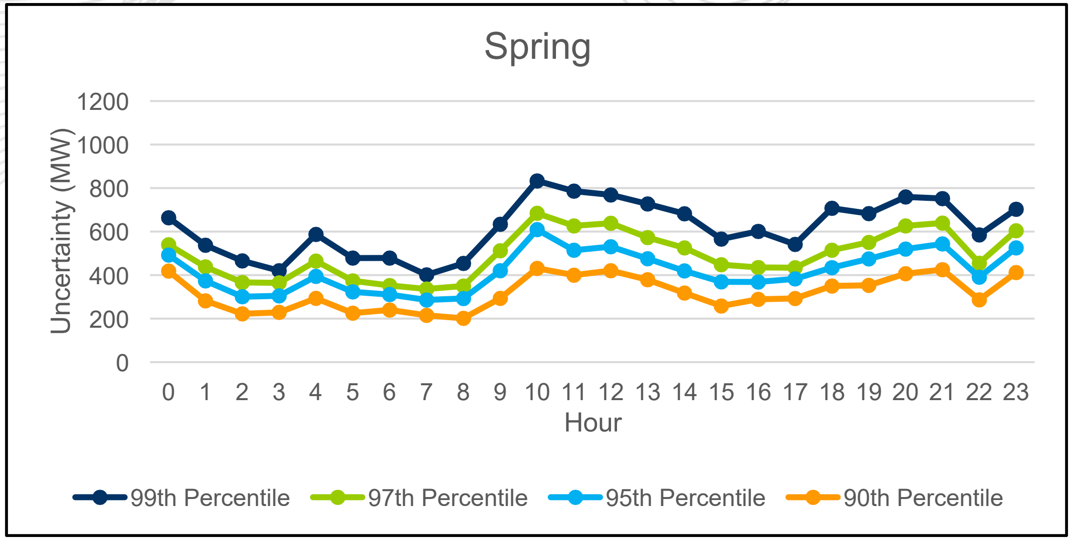
To account for the differences in net-load forecast uncertainty at different times of day, two approaches were explored:

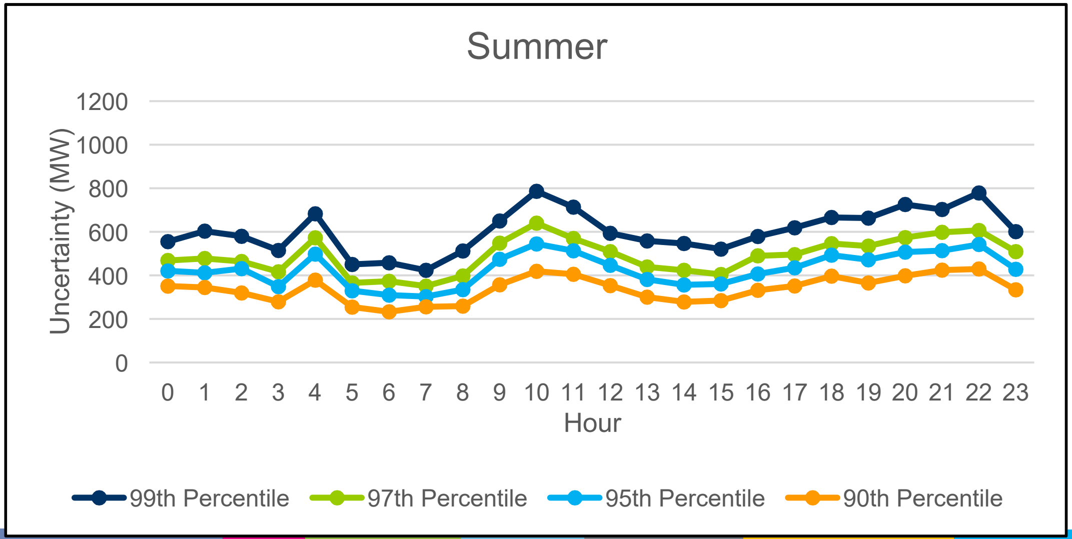
1. Using hourly data where each hour is considered separately
2. Bucketing the data into larger groups of hours representing different times of day, where the buckets used are as follows:

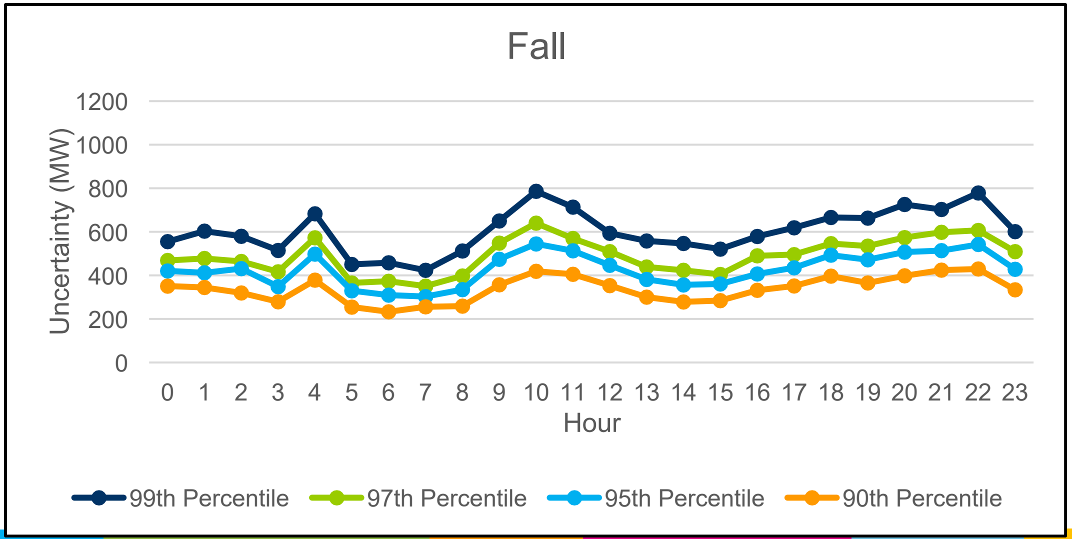
Hours in the Time Block	Time of Day
Hours 0 to 4	Overnight
Hours 5 to 9	Early Morning
Hours 10 to 14	Mid-morning/Early afternoon
Hours 15 to 19	Late afternoon/Early evening
Hours 20 to 23	Evening

Net-Load Forecast Uncertainty by Hour and Season for 10-Min Ramp/Uncertainty Reserve Product

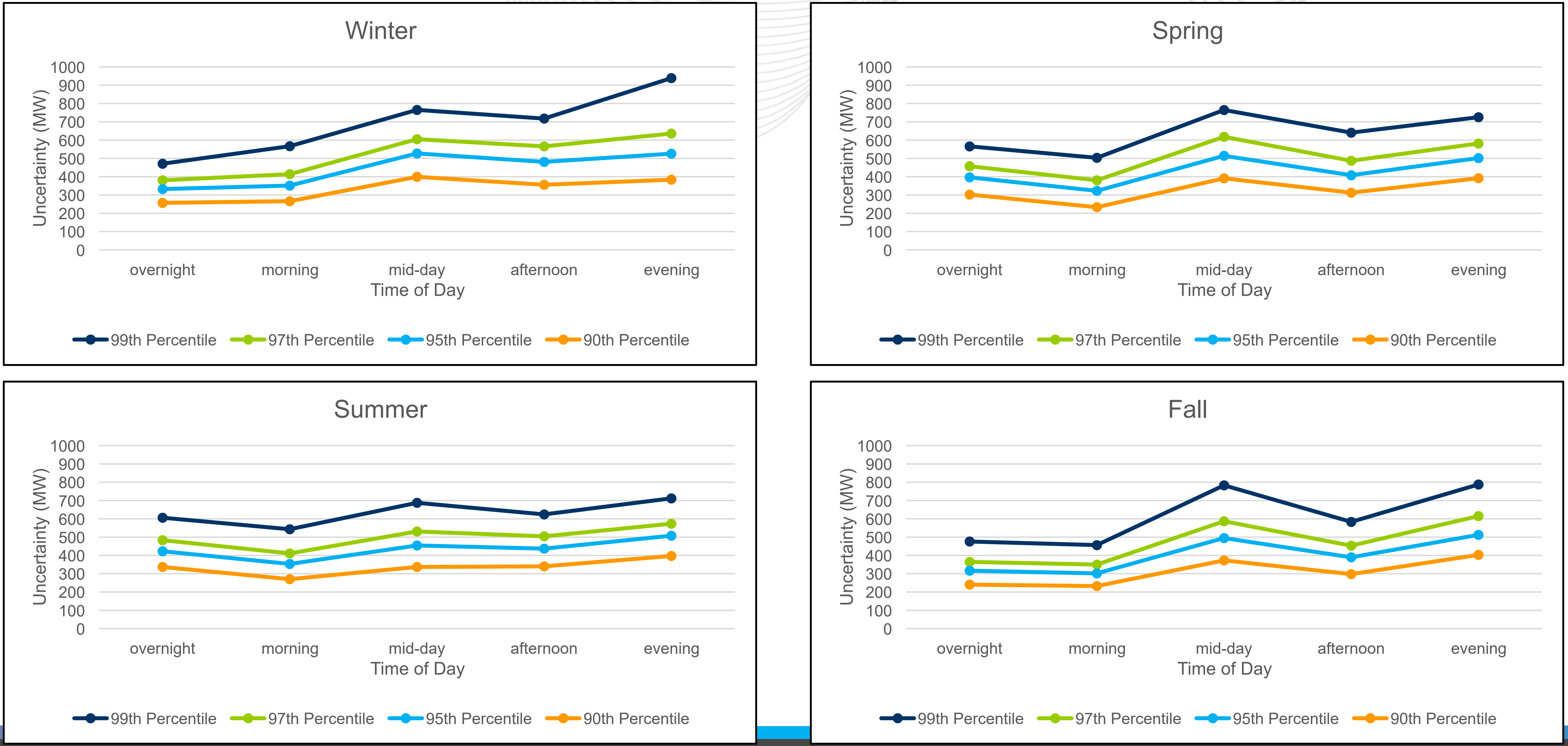




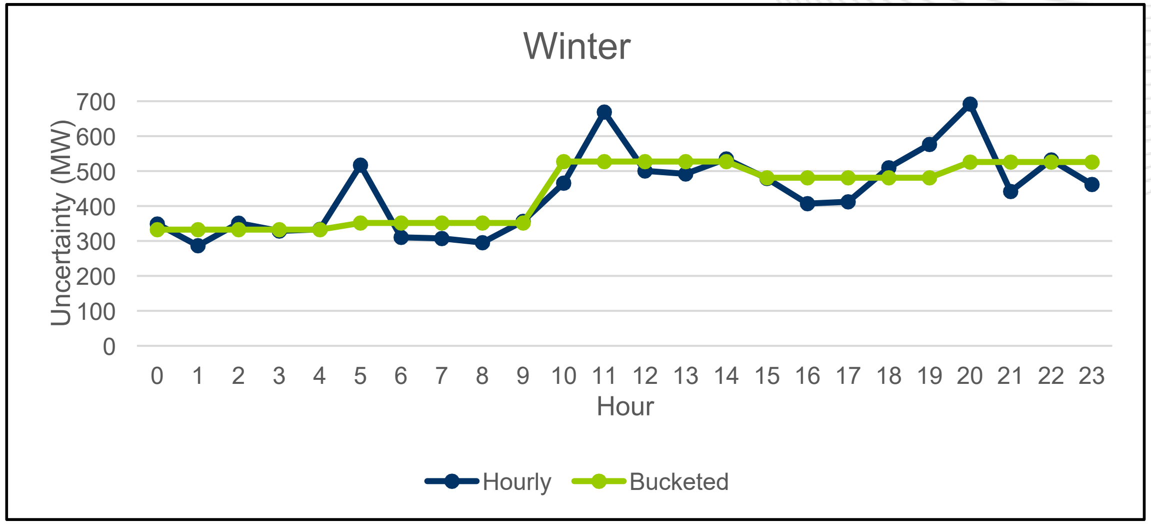


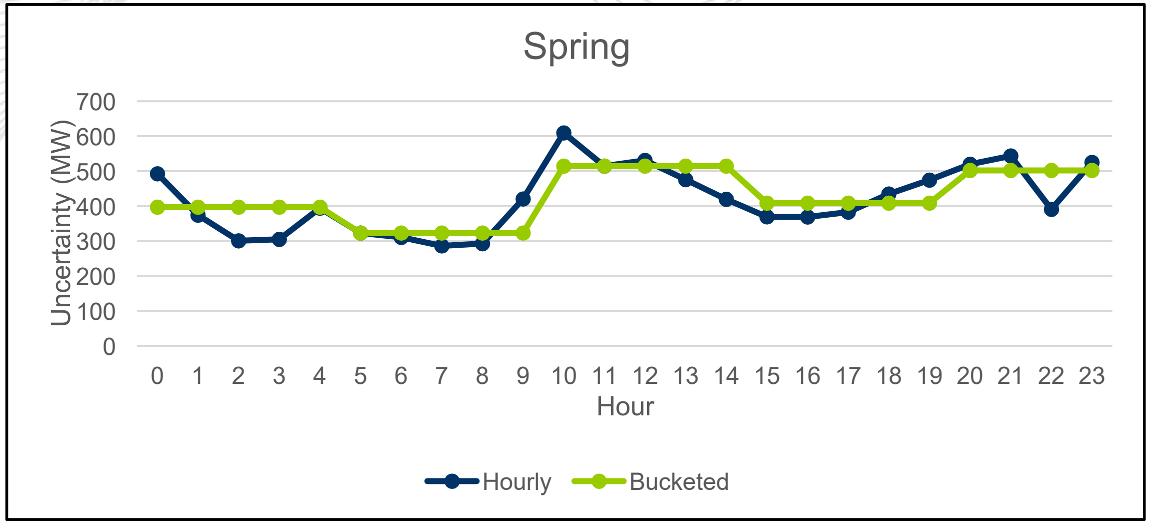


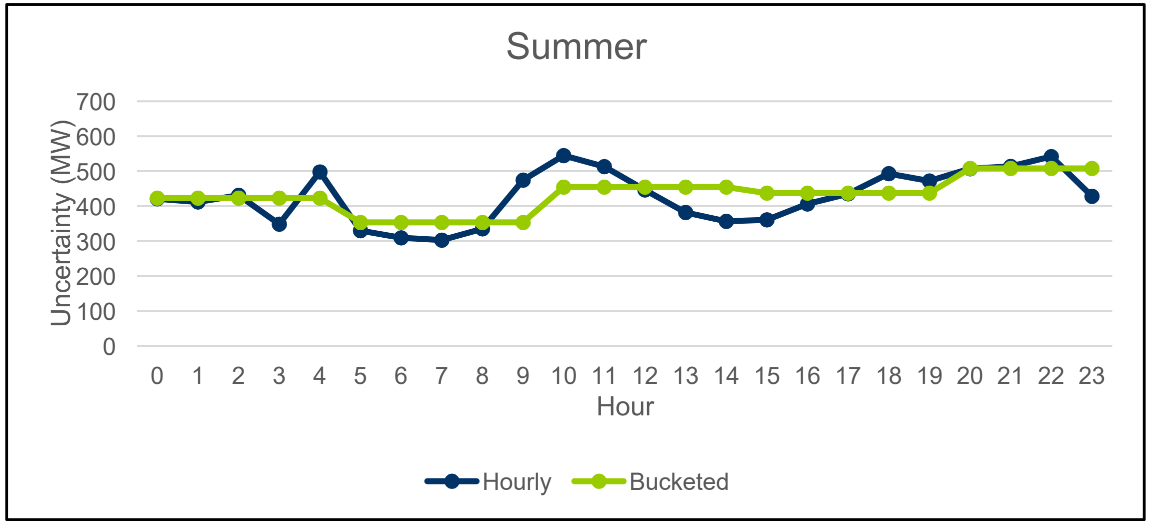
Net-Load Forecast Uncertainty by Hour Bucket and Season for 10-Min Ramp/Uncertainty Reserve Product

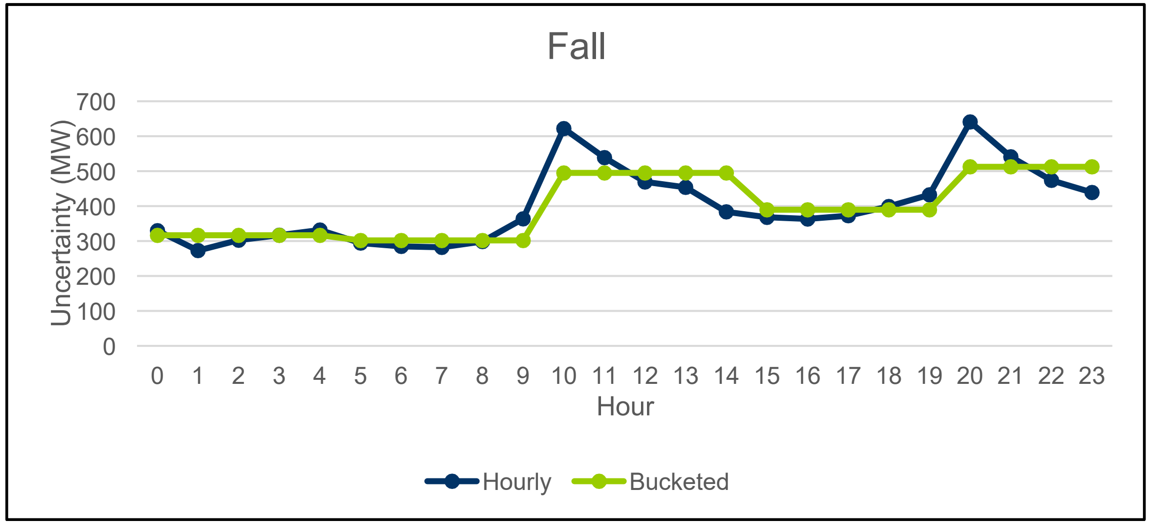


Comparison of Hourly and Hour Block Uncertainty Values for 95th Percentile 10-Min RUR Net-Load Uncertainty

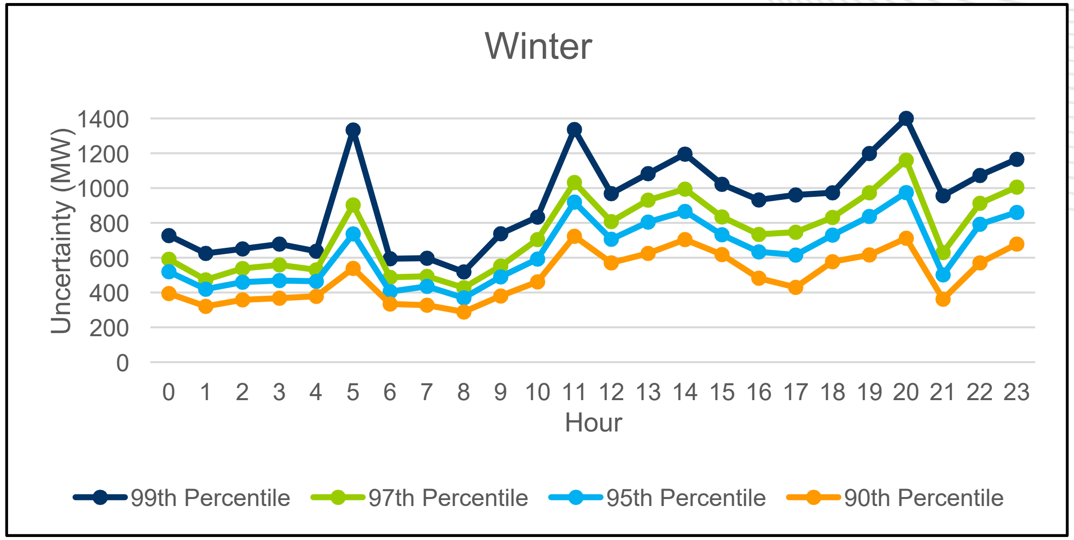


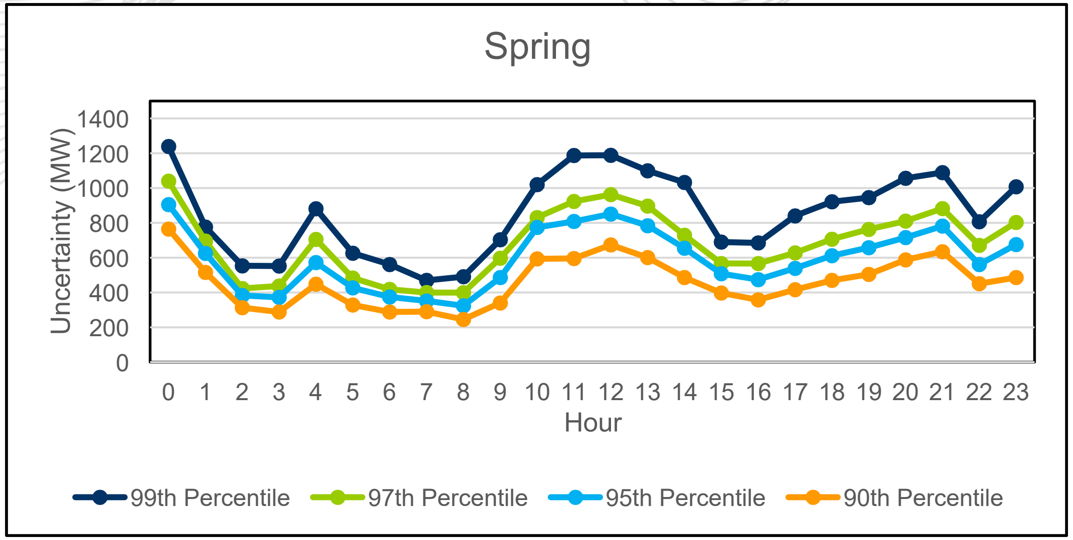


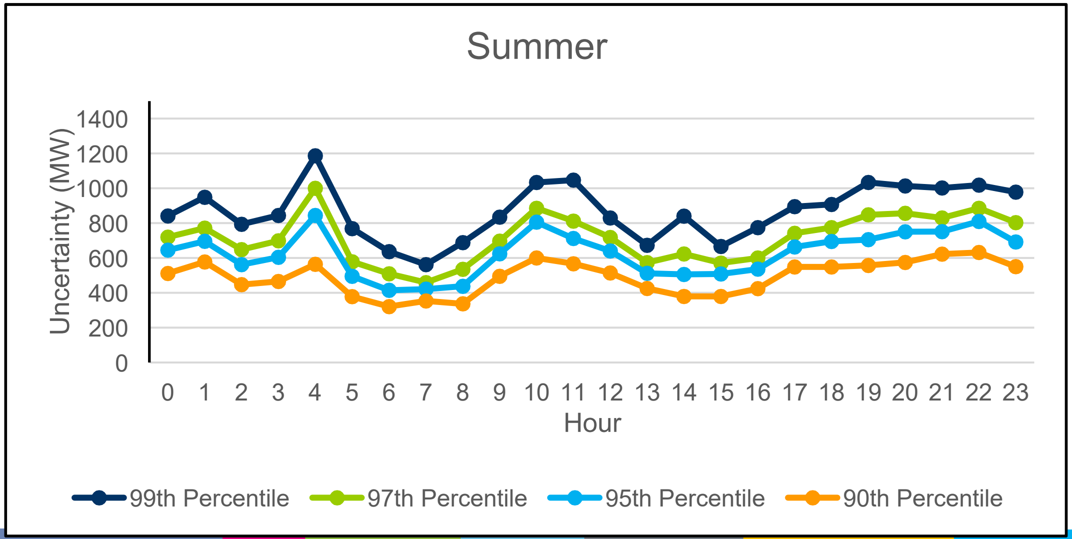


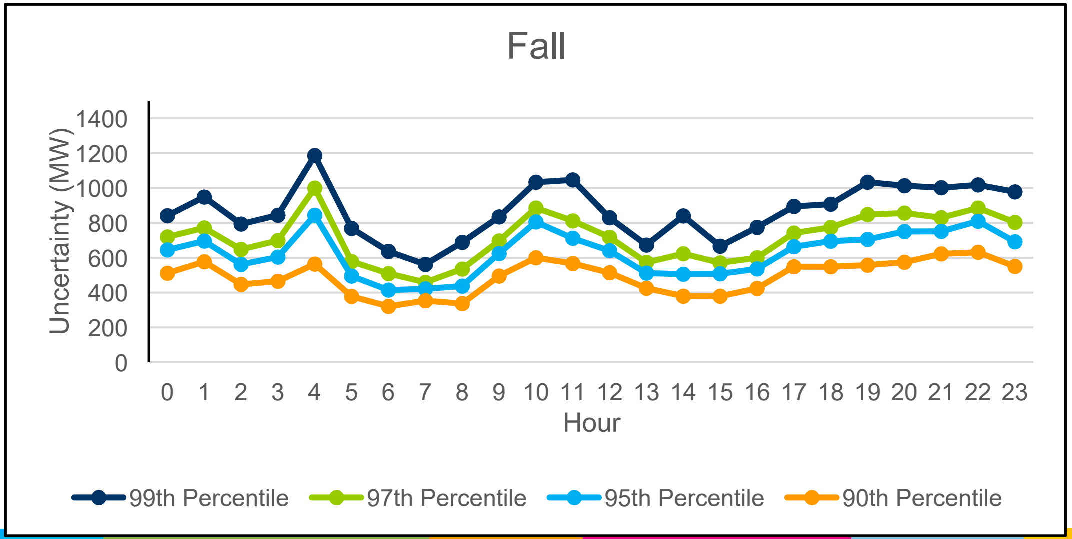


Net-Load Forecast Uncertainty by Hour and Season for 30-Min Reserve Product

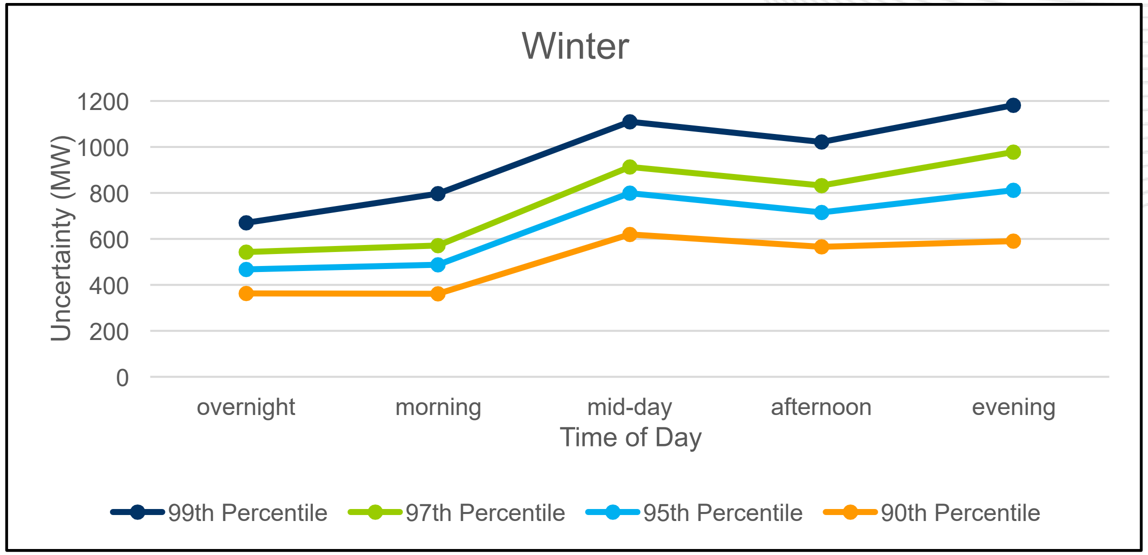


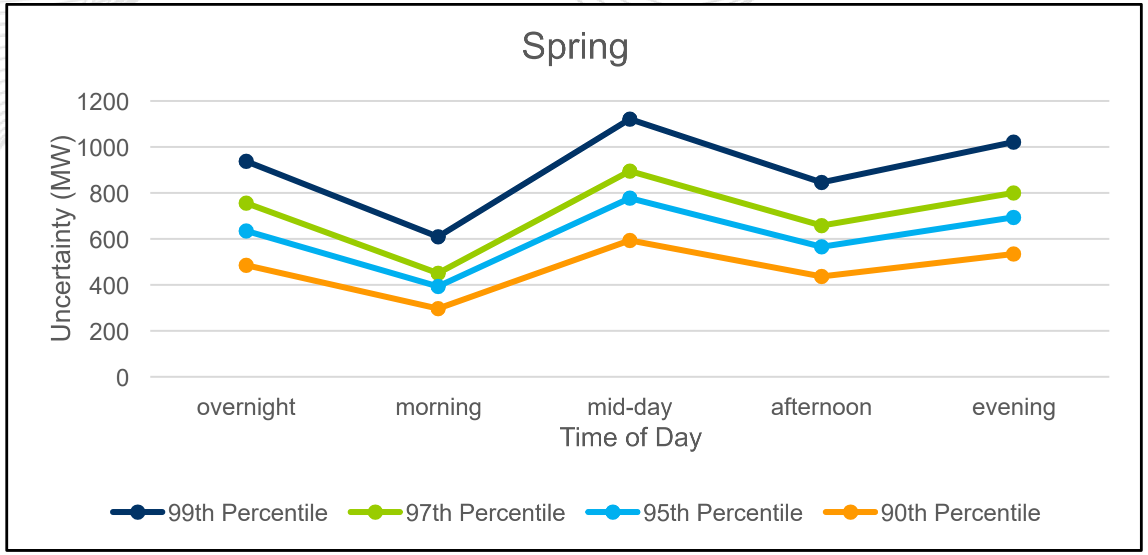


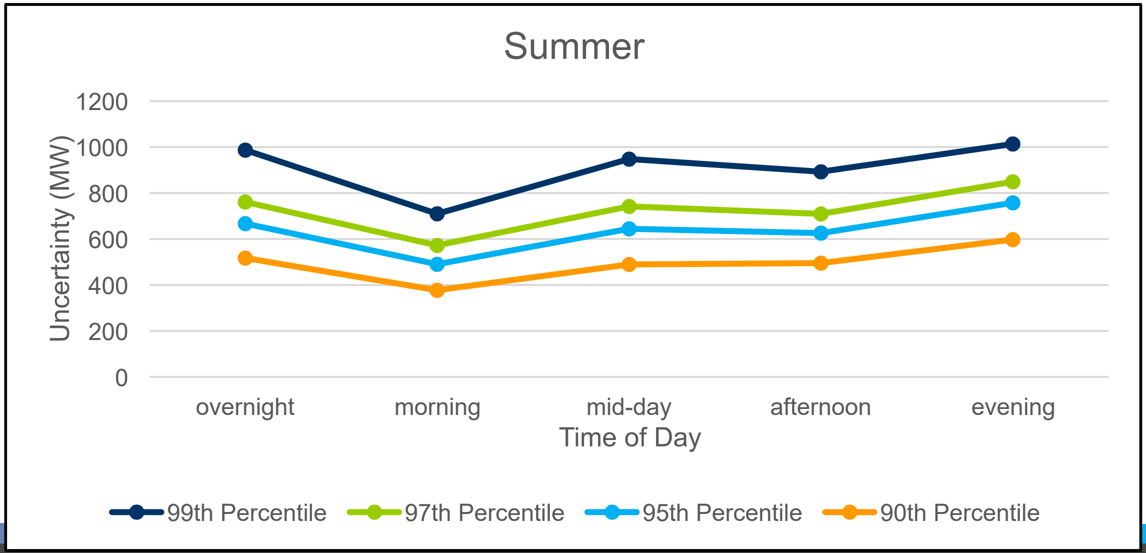


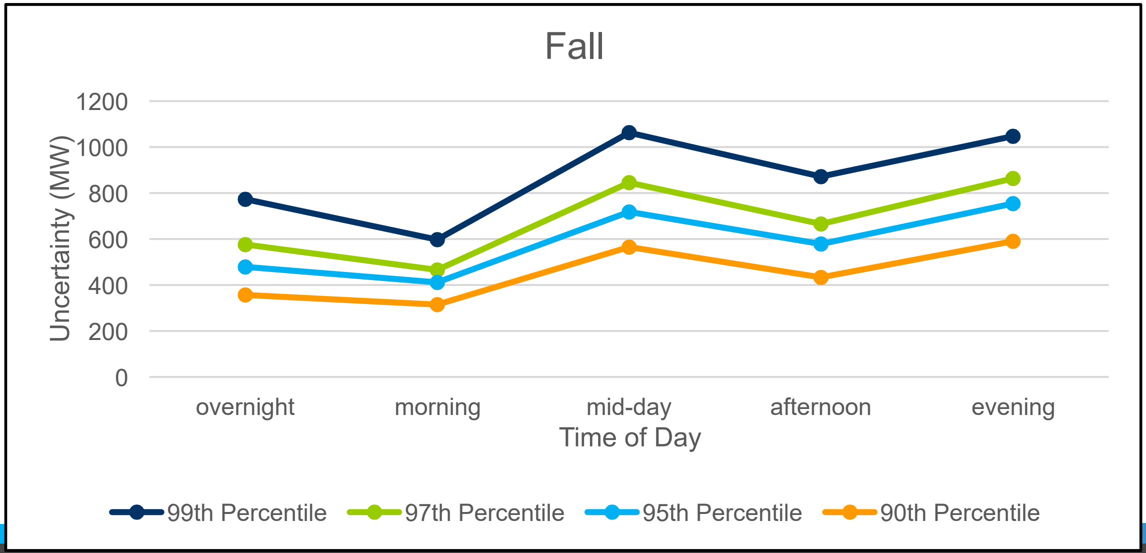


Net-Load Forecast Uncertainty by Hour Bucket and Season for 30-Min Reserve Product

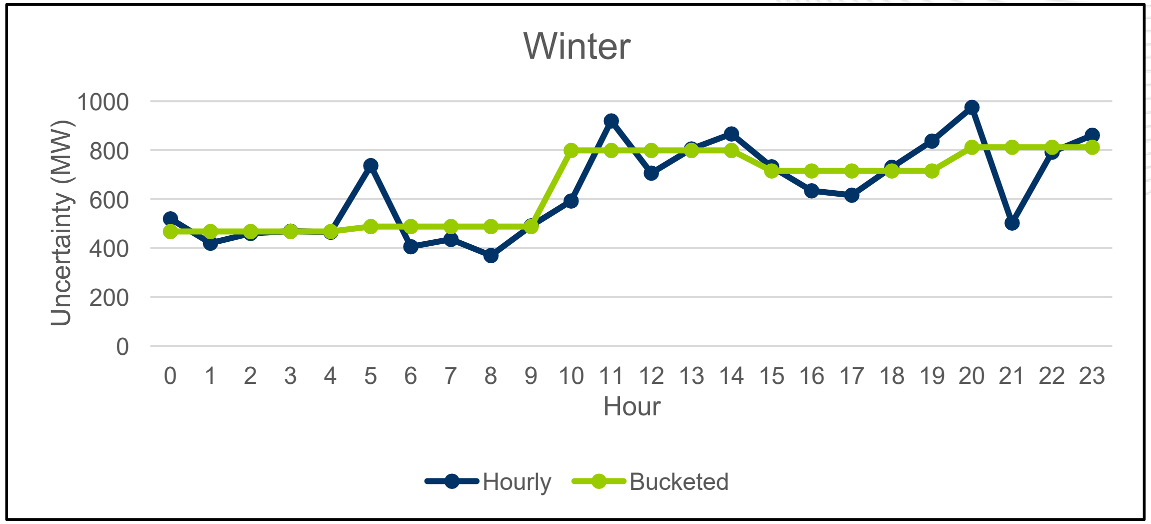


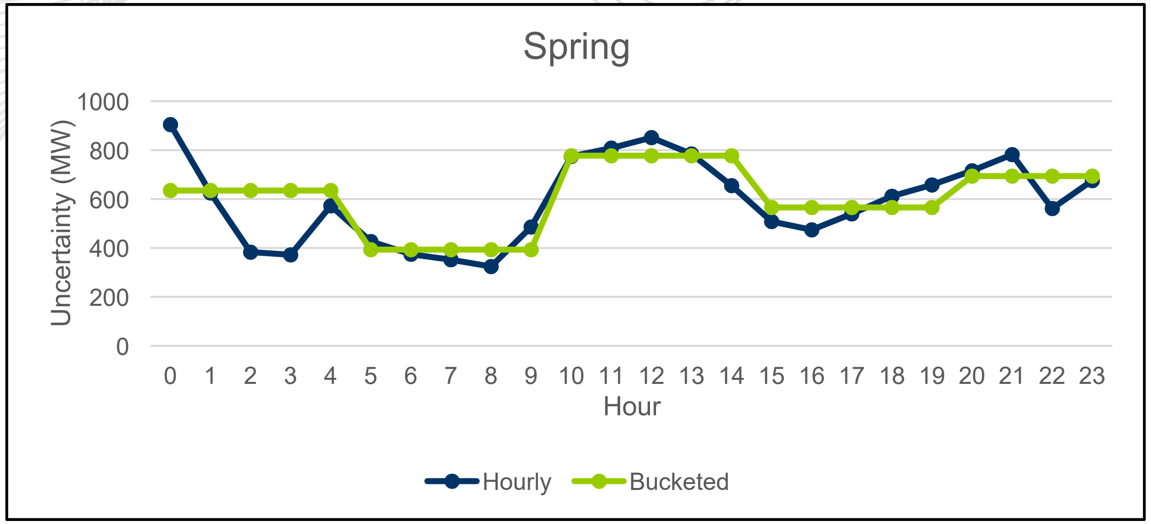


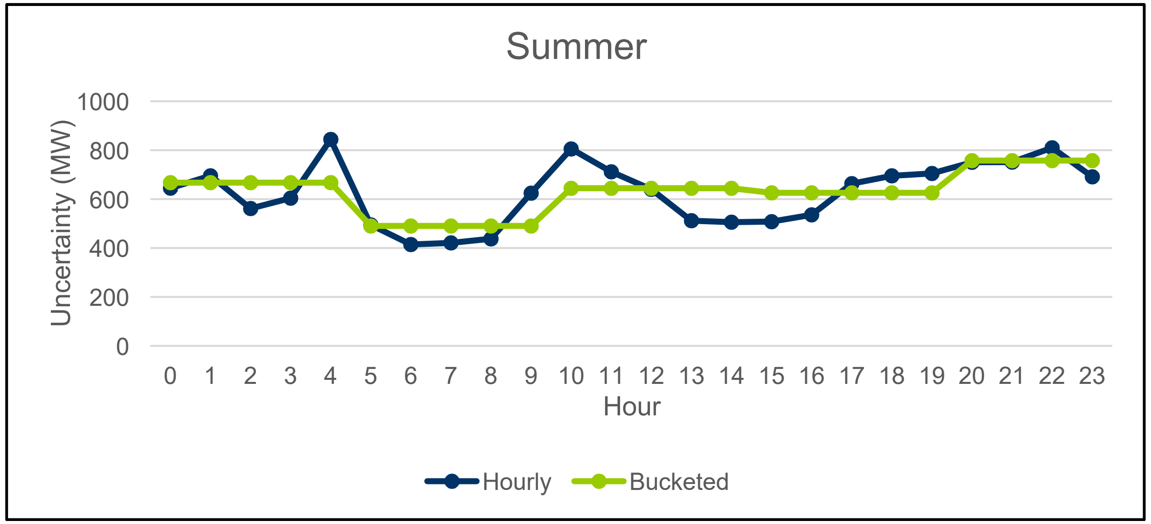


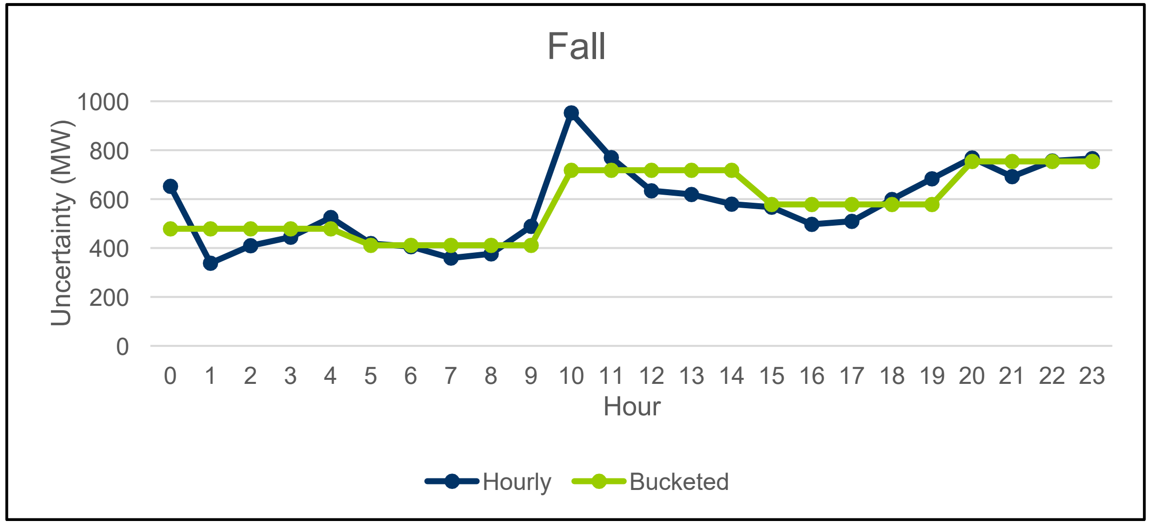


Comparison of Hourly and Hour Block Uncertainty Values for 95th Percentile 30-Min Reserve Net-Load Uncertainty









Comparison of the Hourly vs. Hour Bucket Approaches

- Analysis of the net-load uncertainty data from the 2024/2025 Delivery Year, does show some variation hourly that is not captured when the data is bucketed into time-of-day blocks.

- However, there is a trade-off between increasing the temporal granularity and reducing the number of observations in the data set for each MW quantity. If some of the variation we observe hourly is a function of the increased influence of outliers in the data pool, that may not be more indicative of future uncertainty.

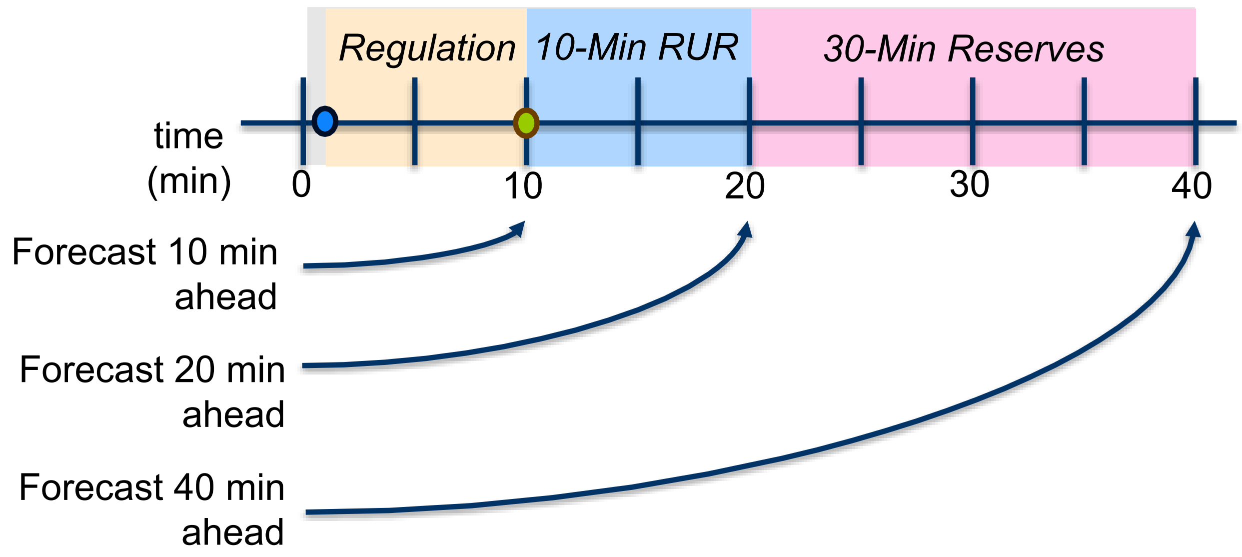
- Concerns about the size of the data set could be mitigated by using more years of data (i.e., going back beyond the last Delivery Year.) However, given the current and anticipated growth in wind and solar participation in the PJM energy market, going back further in time may decrease the predictive value of the analysis.

Uncertainty Quantification Approach 2: Using Historical Load, Solar and Wind Percent Uncertainty Values

Percent Forecast Uncertainty Calculation

% Forecast Uncertainty = Δ Forecast Over the Uncertainty Window / Forecast at the Lookahead Time

- For the 10-Min RUR product, the uncertainty would be equal the difference between the 20-minute ahead forecast and the 10-minute ahead forecast divided by the 20-minute ahead forecast.
- For the 30-Min Reserve product, the uncertainty would be equal to the difference between the 40-minute ahead forecast and the 20-minute ahead forecast, divided by the 40-minute ahead forecast.



Percent Forecast Uncertainty Calculation for Net-Load Uncertainty

- The percent forecast uncertainty calculation would be done separately for load, wind and solar, providing separate % forecast uncertainty values for each.

- The calculation to derive the Δ forecast over the uncertainty window (or the difference in the forecast at one lookahead time vs. the other) would be reversed for load vs. wind and solar so that we have a consistent sign convention for under- vs. over-forecasted total net-load (i.e., to account for the fact that over-forecasted generation is directionally the same as under-forecasted load).

- These % forecast uncertainty values would then be applied to the relevant real-time forecast to get MW values to inform the reserve requirements.

Requirement Definition Using Percent Uncertainty Values

Like the Day-Ahead Scheduling Reserve methodology, the uncertainty component of the real-time reserve requirements would be based on the relevant forecast and the % uncertainty distribution of that forecast based on historical analysis. This would be done dynamically for each interval using the most current forecast information available.

Reserve Requirement Uncertainty Component =
% Load Forecast Uncertainty x Forecasted Load +
% Solar Forecast Uncertainty x Forecasted Solar +
% Wind Forecast Uncertainty x Forecasted Wind

Data Used in the Analysis

- One year of data covering the 2024-2025 Delivery Year
- Data for every five-minute snapshot, resulting in 105,120 observations
- Like the approach taken in the DASR calculation, the data were filtered to not consider observations where the actual wind and solar production was below a threshold relative to the maximum production in the year. The goal of this is to filter out times when relatively small MW differences in the forecast have an outsized impact on the % uncertainty numbers.
- For this analysis, any times when the actual solar and wind production was less than 50% of the annual maximum production were filtered out of the data set.
- This also removes times when solar production is 0 MW because the sun is not shining.

Load, Wind and Solar Percent Uncertainty Values

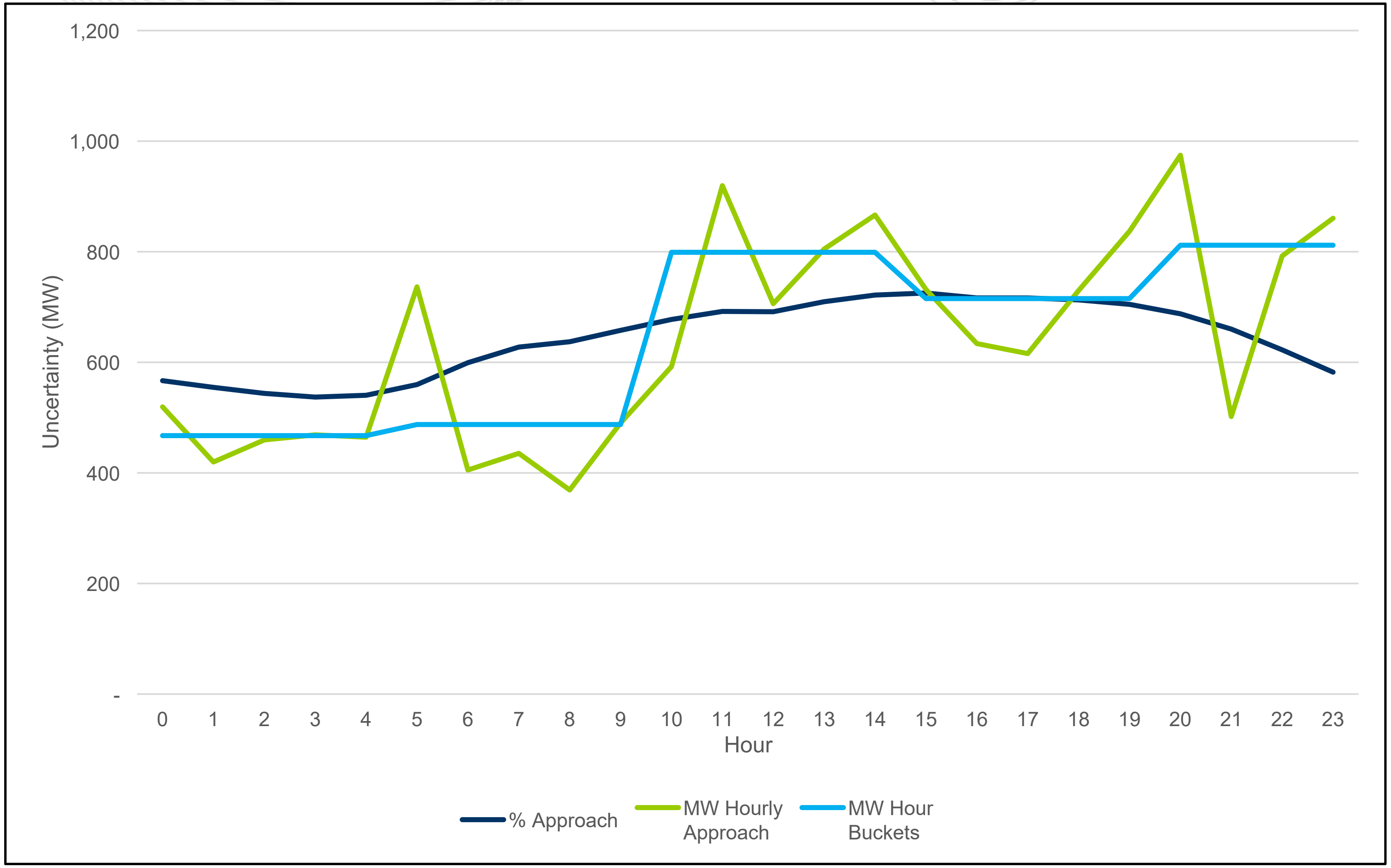
	10-Min Ramp/Uncertainty Reserve			30-Min Reserve		
Percentile	Load	Solar	Wind	Load	Solar	Wind
99th	0.6%	5.8%	3.3%	0.9%	7.3%	4.9%
97th	0.5%	3.9%	2.4%	0.7%	5.1%	3.4%
95th	0.4%	3.1%	1.9%	0.6%	4.0%	2.7%
90th	0.3%	2.0%	1.3%	0.4%	2.7%	1.8%

Comparison of 10-Min RUR Uncertainty Values for December 10, 2024

Hour	% Approach (MW)	MW Hourly Approach (MW)	MW Hour Buckets (MW)
0	381	349	332
1	373	286	332
2	366	351	332
3	361	329	332
4	363	333	332
5	376	517	352
6	402	310	352
7	421	307	352
8	428	295	352
9	444	356	352
10	460	465	527
11	472	669	527
12	472	501	527
13	485	492	527
14	493	535	527
15	495	479	481
16	485	407	481
17	483	412	481
18	480	510	481
19	474	576	481
20	463	692	526
21	444	442	526
22	419	532	526
23	391	462	526

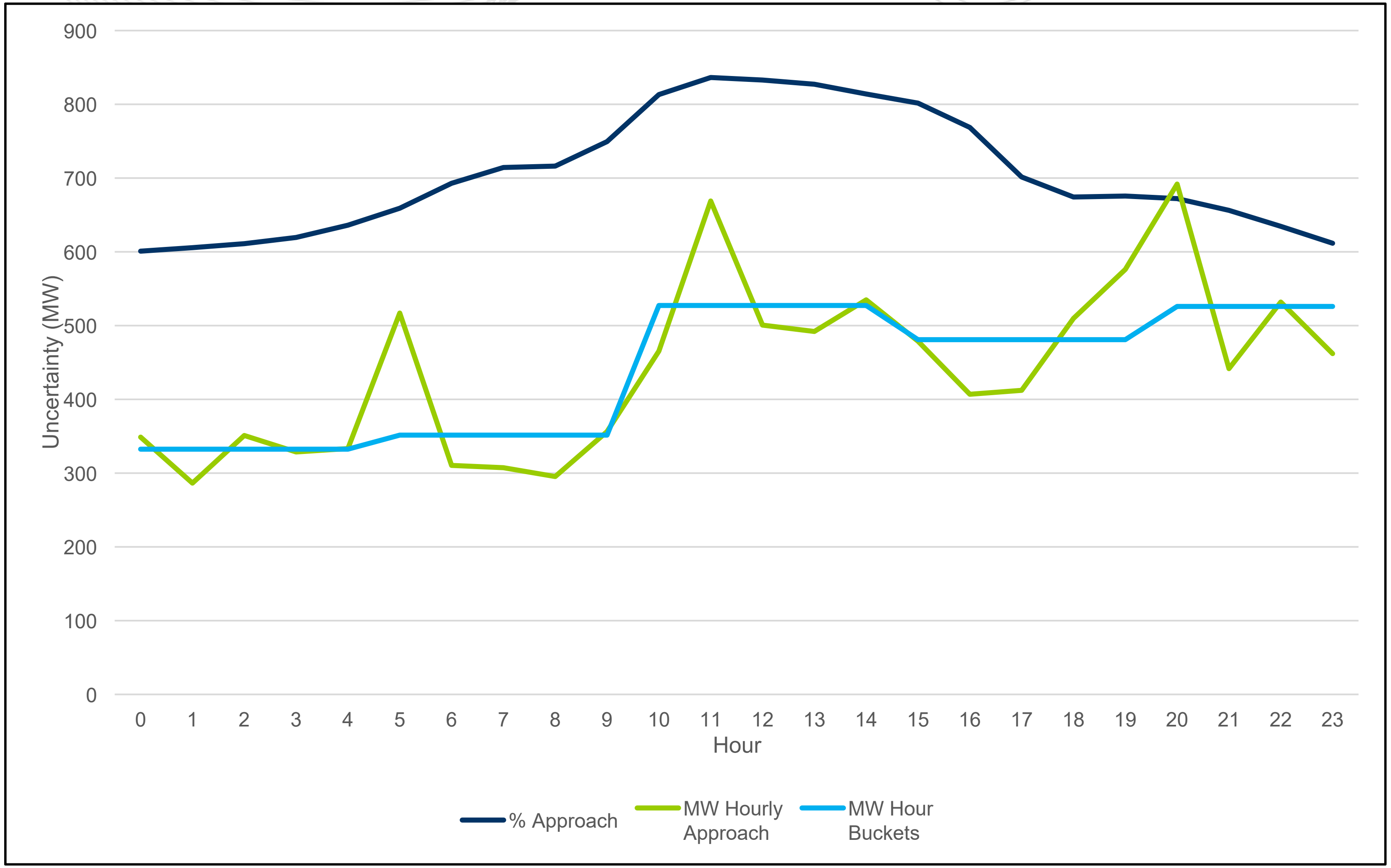
Comparison of 30-Minute Reserve Uncertainty Values for December 10, 2024

Hour	% Approach (MW)	MW Hourly Approach (MW)	MW Hour Buckets (MW)
0	567	519	467
1	555	420	467
2	544	460	467
3	537	469	467
4	540	465	467
5	560	736	488
6	599	405	488
7	628	435	488
8	637	369	488
9	658	490	488
10	678	592	799
11	692	920	799
12	691	706	799
13	710	805	799
14	722	866	799
15	725	732	715
16	722	634	715
17	718	616	715
18	712	730	715
19	705	837	715
20	688	975	812
21	660	502	812
22	623	792	812
23	582	861	812



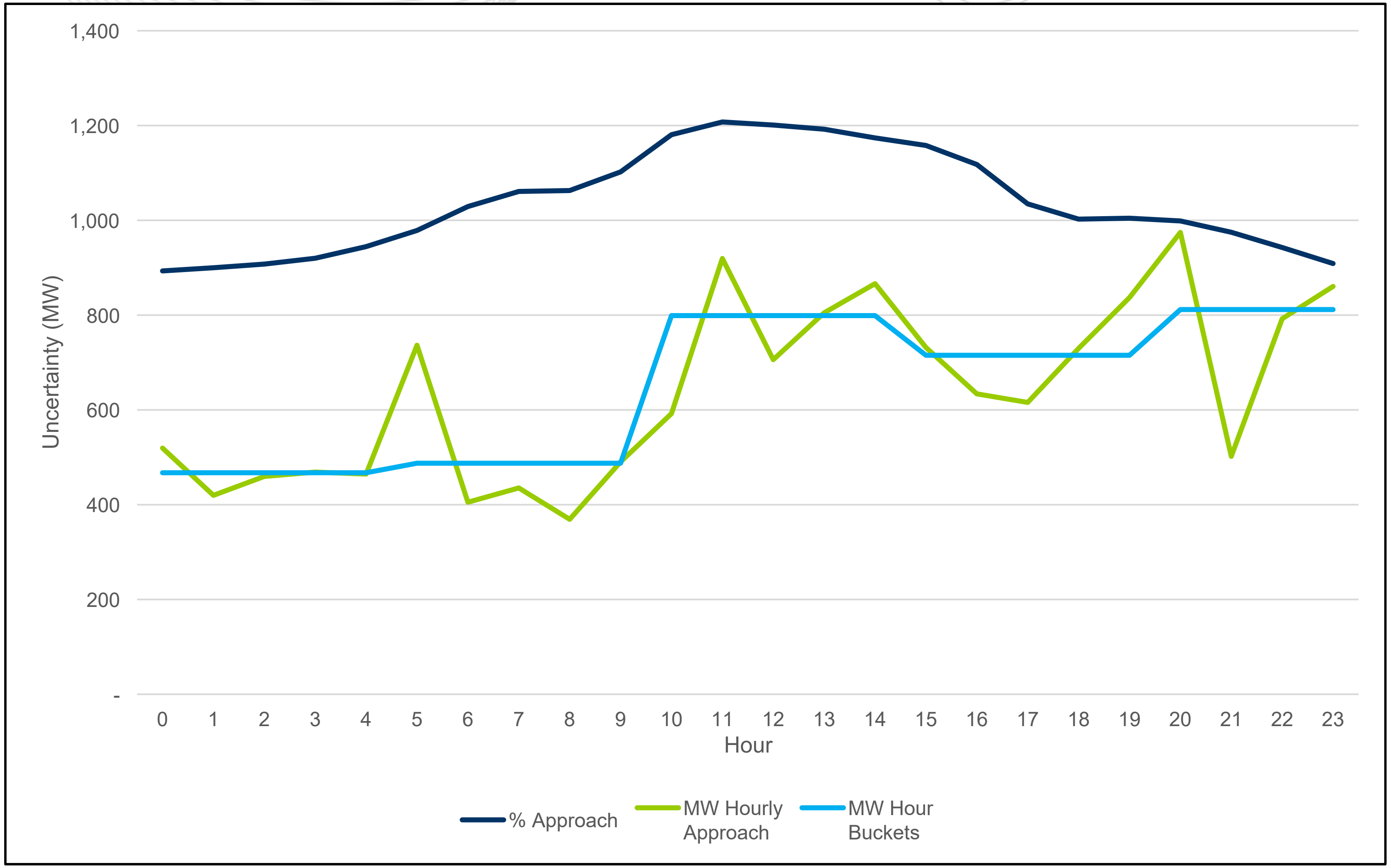
Comparison of 10-Min RUR Uncertainty Values for January 22, 2025

Hour	% Approach (MW)	MW Hourly Approach (MW)	MW Hour Buckets (MW)
0	601	349	332
1	606	286	332
2	611	351	332
3	619	329	332
4	636	333	332
5	659	517	352
6	693	310	352
7	714	307	352
8	716	295	352
9	749	356	352
10	813	465	527
11	836	669	527
12	833	501	527
13	827	492	527
14	814	535	527
15	802	479	481
16	769	407	481
17	701	412	481
18	674	510	481
19	676	576	481
20	672	692	526
21	656	442	526
22	635	532	526
23	612	462	526



Comparison of 30-Minute Reserve Uncertainty Values for January 22, 2025

Hour	% Approach (MW)	MW Hourly Approach (MW)	MW Hour Buckets (MW)
0	893	519	467
1	900	420	467
2	908	460	467
3	920	469	467
4	945	465	467
5	979	736	488
6	1,029	405	488
7	1,061	435	488
8	1,063	369	488
9	1,102	490	488
10	1,181	592	799
11	1,208	920	799
12	1,201	706	799
13	1,192	805	799
14	1,174	866	799
15	1,158	732	715
16	1,118	634	715
17	1,035	616	715
18	1,003	730	715
19	1,004	837	715
20	999	975	812
21	975	502	812
22	943	792	812
23	909	861	812



Comparison of the Percent Uncertainty vs. the MW Uncertainty Approaches

- An advantage of the percent uncertainty approach is that it incorporates actual forecast data in the reserve analysis, meaning that on days when there is more load and more wind and solar participation, the reserve requirements scale accordingly. This may also allow the reserve requirements to stay more current with actual levels of wind and solar on the system.

- The advantage of the net-load MW value approaches is that they do not separate the load, solar and wind uncertainty values and treat them separately. Looking at net-load forecast values holistically may do a better job of capturing any correlations (positive or negative) between the relative levels of uncertainty across these forecasts.

- It may ultimately be worth exploring a third approach, along the lines of the approach that CAISO has taken in recent years, where PJM would develop a quantile regression model using historical data to calculate more predictive requirements based on forecast information.

Net-Load Ramping Component of Reserve Requirements

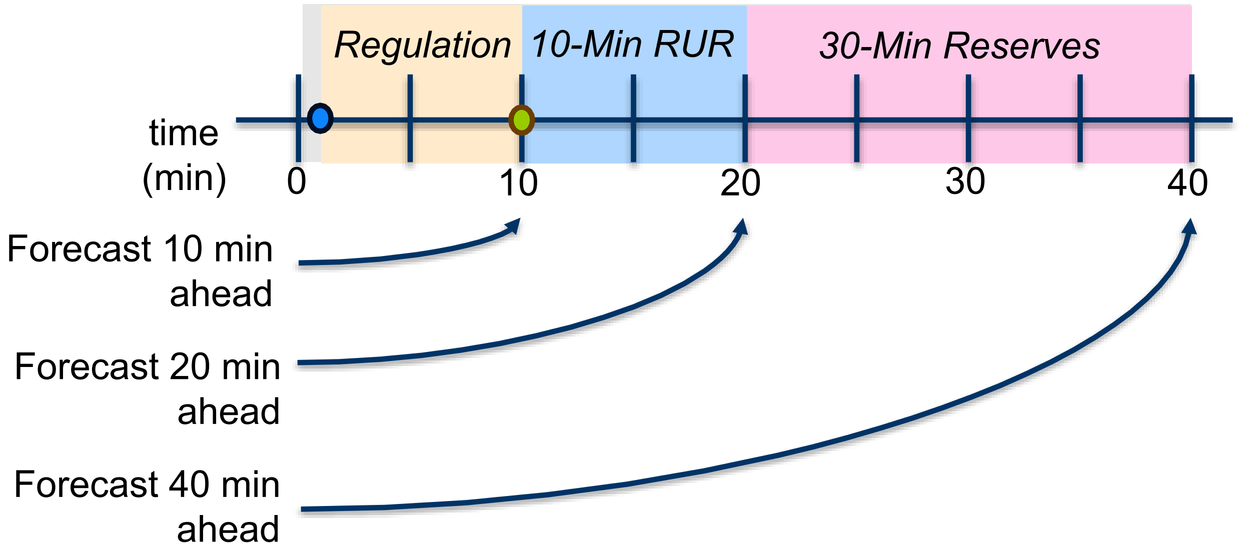
Rationale

- Procuring reserves to manage the expected net-load ramp supports the objective of ensuring that PJM maintains sufficient flexibility to serve future demand, recognizing some uncertainty, and avoids reserve shortages that could compromise reliability.
- If uncertainty reserves are procured without accounting for net-load ramping needs, those reserves may be dispatched for expected ramp, leaving the system short of the reserves intended to mitigate the risk of net-load forecast error.
- Failing to account for periods where net-load ramp is creating tight operating conditions could lead an under-representation of risk during times when the reserves are most critical.
- PJM is therefore proposing to consider a more targeted representation of uncertainty (i.e., 30 minutes ahead rather than 2 hours ahead for the 30-Min product) but align this with a market design that accounts for both net-load forecast uncertainty and expected ramp in the 10-Min RUR and 30-Min Reserve products.

Expected Ramp Lookahead Calculation

Expected Ramp = Forecast at the end of the ramping period – Forecast at the beginning of the period

- For the 10-Min RUR product, the expected ramp would be equal to the 20-minute ahead forecast minus the 10-minute ahead forecast.
- For the 30-Min Reserve product, the expected ramp would be equal to the 40-minute ahead forecast minus the 20-minute ahead forecast.



Secondary Reserves for System Recovery

30-Min Reserves

- The secondary reserve component of the 30-Min Reserve Requirement would be based on the largest active contingency on the system.
- This is to ensure that PJM has sufficient replacement MWs available on the system to backfill its contingency reserves in the case of an event.
- This quantity would therefore be set based on the resources committed to the system, and which unit loss represents the most severe single contingency. The methodology for identifying the size of this contingency would be the same for 30-Min Reserves as for Synchronized Reserves.*

Note: *any performance adjustment to the Synchronized Reserve Requirement to account for SR resource performance would not be applied to the 30-Min Reserve Requirement.*

Online vs. Offline Reserves

Online Portion of the 30-Minute Reserve Requirement

- As previously discussed, all reserves procured to manage 10-minute ramping and uncertainty flexibility needs would need to be online and dispatchable by SCED in the next target interval.

- For 30-Minute Reserves procured to backfill PJM's contingency reserves, these reserves would be called upon when needed and could therefore perform this service from an online or offline state.

- However, given the updated definition of the 30-Minute Reserve uncertainty component (20 to 40 minutes following the target time) and the inclusion of the expected ramping component, these reserves would need to be able to follow a more linear ramping pattern to provide this service. These 30-Min Reserves would therefore need to be online and able to follow a SCED dispatch signal.

- PJM is therefore proposing to introduce an online component of its 30-Minute Reserve Requirement to cover the portion of reserves procured to manage net-load forecast uncertainty and expected net-load ramp.

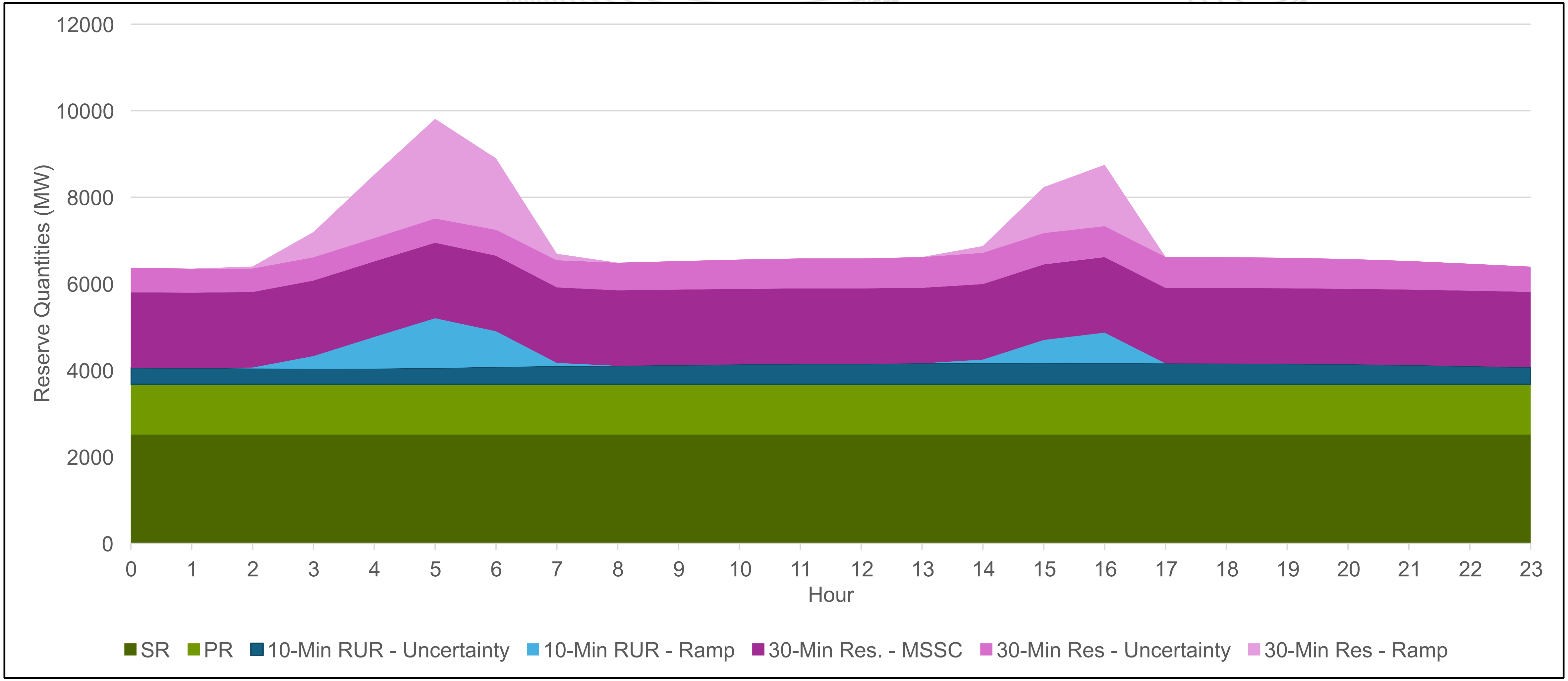
Full Real-Time Requirements for a Set of Example Days

Data Used in these Examples

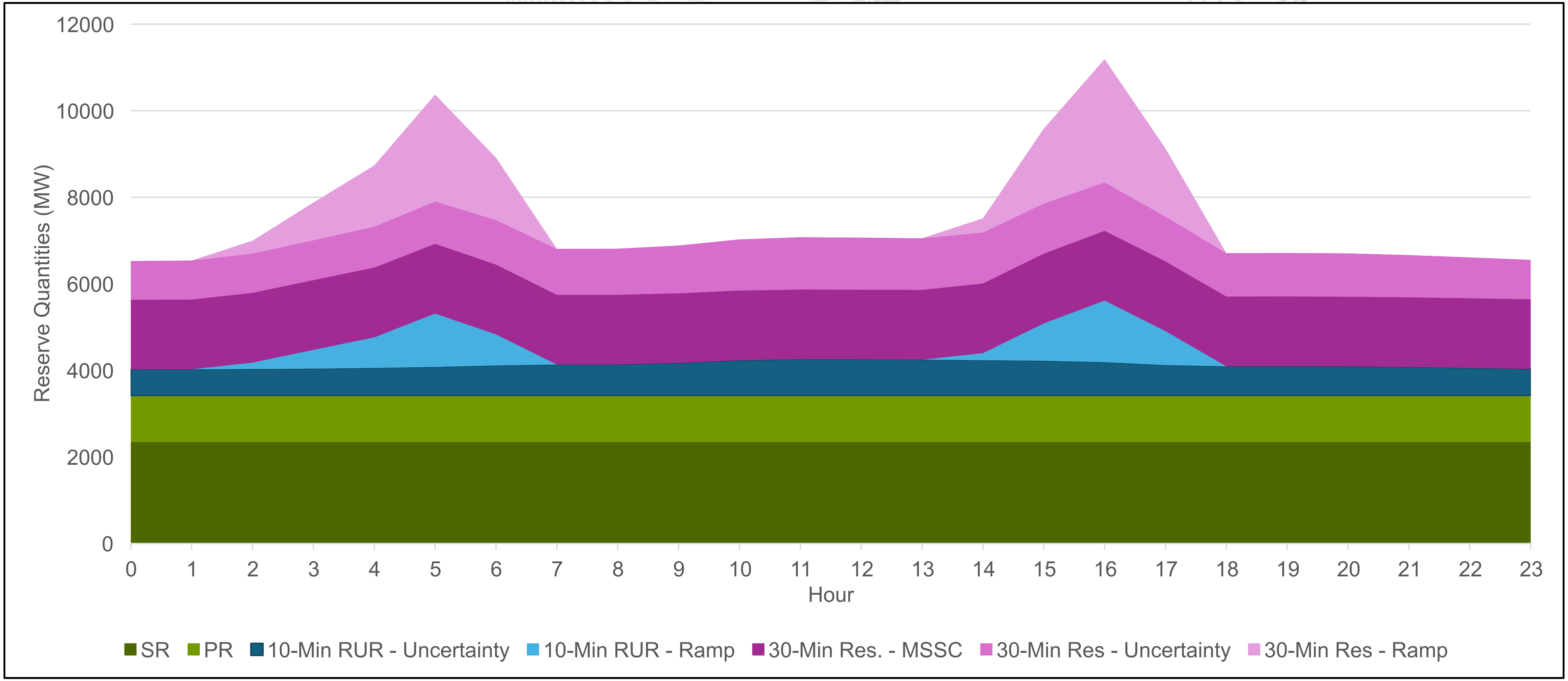
Disclaimer: *The values shown on the following slides are intended as exemplar reserve quantities to facilitate understanding and discussion and do not represent a finalized market design or proposal.*

- Hourly forecast data for each example day
- Expected ramp was interpolated from these hourly data
  - Hourly ramp values were divided by six for 10-minute ramp and by three for the following 20-minutes of ramp to inform 10-Min RUR and 30-Min Reserve expected ramp numbers
- The percent forecast uncertainty approach was used to calculate hourly uncertainty reserve quantities
- Actual SR, PR and MSSC numbers from the Day-Ahead Market clearing were used for each day

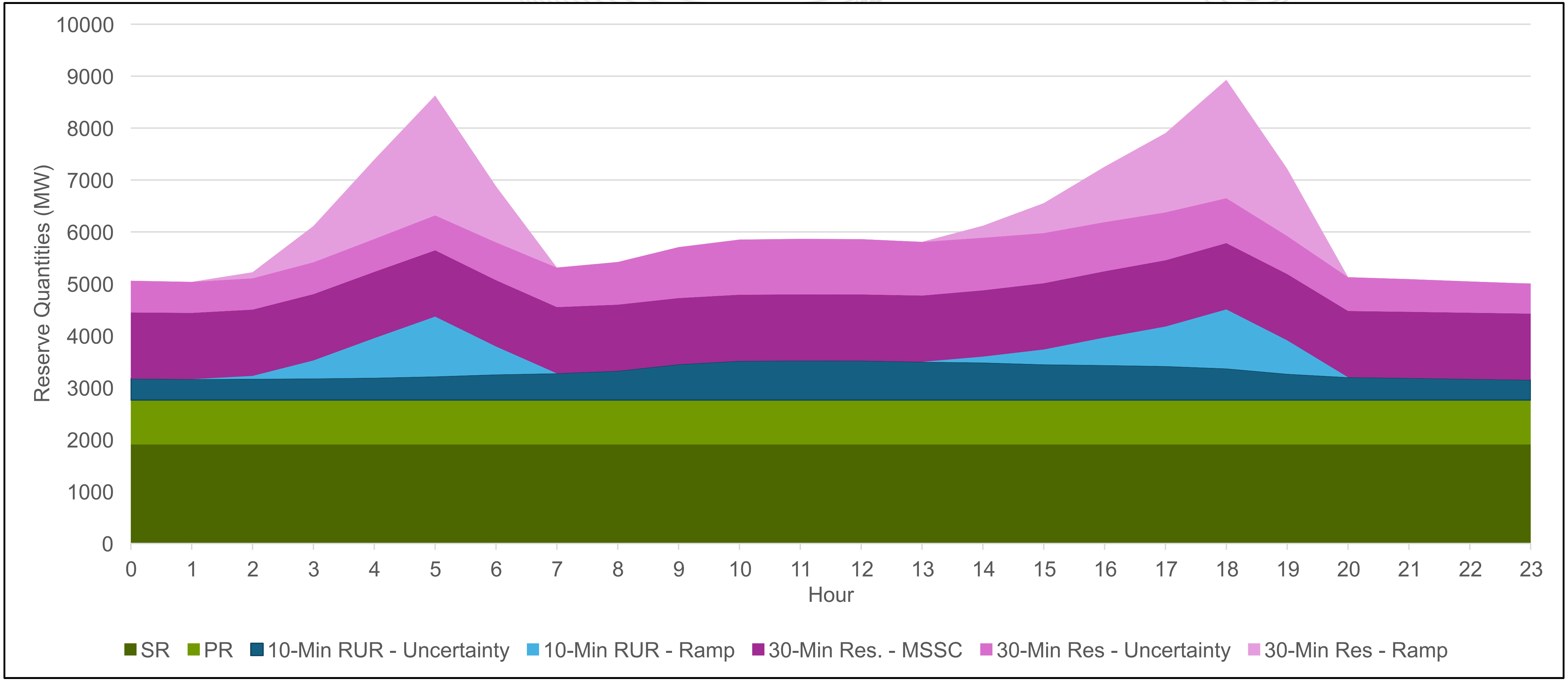
December 10, 2024



January 22, 2025



April 9, 2025



10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Reserve Quantities (MW)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
SR
PR
10-Min RUR - Uncertainty
10-Min RUR - Ramp
30-Min Res. - MSSC
30-Min Res - Uncertainty
30-Min Res - Ramp

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Acronyms

Acronym	Term & Definition
SR	**Synchronized Reserves** are reserves provided by resources that are synchronized to the grid and can respond within 10 minutes.
PR	**Primary Reserves** are reserves provided by resources that are either synchronized or not synchronized to the grid and can respond within 10 minutes.
RUR	**Ramping/Uncertainty Reserves** are reserves that would be procured to manage forecasted ramp and uncertainty operational flexibility needs.
MW	A **Megawatt** is a unit of power equaling one million watts (1 MW = 1,000,000 watts) or one thousand kilowatts (1 MW = 1,000 KW).


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