Introduction

PJM system operation is facing increased uncertainty due to higher renewable penetration, which – coupled with increasing net-load ramping events – can lead to reliability challenges. To ensure grid reliability, PJM is proposing three new ramping/uncertainty reserve services so that PJM's markets can proactively provision the reserves necessary to manage these challenges. PJM is proposing to two 10-Min Ramp/Uncertainty services, one for up reserves and one for down (10-Min RUR Up and 10-Min RUR Down), and one new 30-Min Ramp/Uncertainty Reserve service in the up direction only (30-Min RUR). The uncertainty component of procurement targets for these new reserve services would be based on a historical analysis of PJM's real-time operational data. This document is intended to outline this analysis.

Forecast Uncertainty

In the context of this analysis and quantification approach, forecast uncertainty is defined as the amount that a forecast changes between the time when the forecast is used to make a decision and the time when that decision effectively has an impact. To illustrate this, assume the uncertainty being quantified is to inform procurement of a 10-minute ramp and uncertainty reserve service, which is intended to address net-load ramp and net-load forecast uncertainty in the 10 minutes beyond the next target energy dispatch point. Figure 1 shows the timeline for calculating and sending out dispatch instructions to resources, which effectively instruct resources to be at a certain dispatch point at time T. These energy dispatch and reserve instructions are based on information available (and the forecasts evaluated) at time T-10.

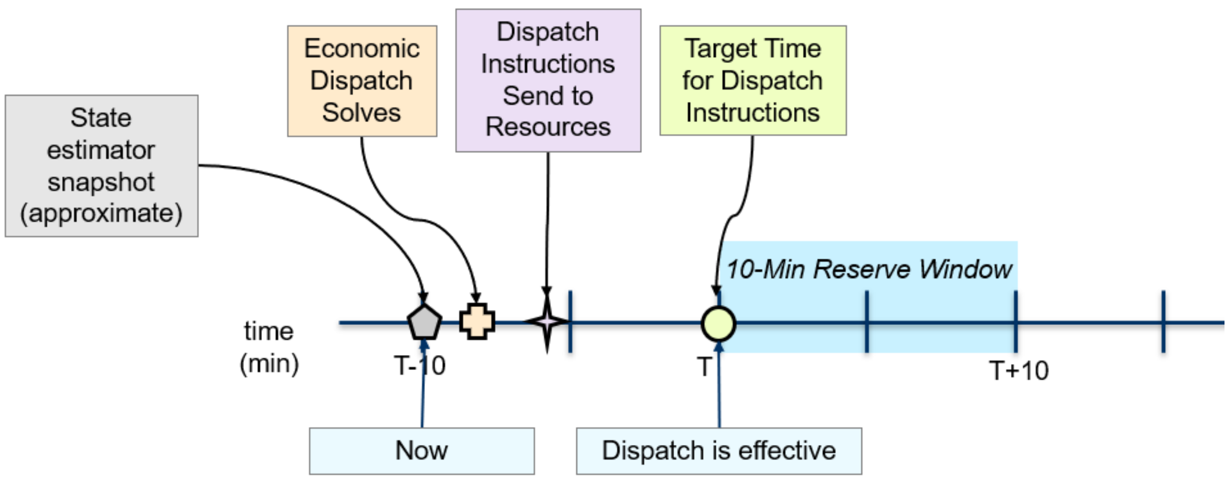

Figure 1: Forecast and dispatch timing.

A 10-minute ramp/uncertainty reserve service is intended to ensure that enough flexibility is available to meet net-load in the 10 minutes after the target time. Based on the timeline above, consider that the goal is therefore to reliably serve net-load at time T+10. The uncertainty component that needs to be addressed in the reserve procurement is therefore how much the forecast could change between when it is evaluated now, at T-10 when energy dispatch decisions are determined for time T, and when it is evaluated again at time T, when dispatch decisions will be determined for time T+10. This can be calculated as a percentage of the forecast at the lookahead time, T+10. This is represented mathematically by

$$\Delta F_{\%,T+10} = \frac{F_{T+10\ @\,T} - F_{T+10\,@\,T-10}}{F_{T+10\,@\,T-10}}$$

Where:

- $\Delta F_{\%,T+10}$ is the percent change in the forecast for effective time T+10
- $F_{T+10\ @\,T}$ is the forecast for effective time T+10 as evaluated at T
- $F_{T+10\ @\,T-10}$ is the forecast for effective time T+10 as evaluated at T-10

For the 30-Min RUR uncertainty, the methodology is very similar, except that the forecasts used are for the forward interval 30 minutes after the target time, T, and the change in forecast is from that evaluated at T-10 and T+10. This ensures that the quantified 30-minute only accounts for the uncertainty not already captured for the 10-minute uncertainty calculation.

$$\Delta F_{\%,T+30} = \frac{F_{T+30\ @\,T+10} - F_{T+30\,@\,T-10}}{F_{T+30\,@\,T-10}}$$

Where:

- $\Delta F_{\%,T+30}$ is the percent change in the forecast for effective time T+30
- $F_{T+30\ @\,T+10}$ is the forecast for effective time T+30 as evaluated at T+10
- $F_{T+30\ @\,T-10}$ is the forecast for effective time T+30 as evaluated at T-10

As explained in the following section, the total net-load uncertainty is assumed to be a function of three independent uncertainty components: (i) load, (ii) wind generation, and (iii) solar generation. Let $\Delta F^{L}_{\%,T+10}, \Delta F^{W}_{\%,T+10}, \&\ \Delta F^{S}_{\%,T+10}$ denote the percent change in load forecast, wind forecast, and solar forecast for time $T+10$, respectively.

To quantify forecast uncertainty, these percent change values are calculated for every 5-minute interval in a year to get an uncertainty distribution for that year. Let H denote the indexing set of historical observations for the specific year. The reserve requirements are set to cover the 95th percentile of the forecast changes $\Delta F^{L}_{\%,T+10}, \Delta F^{W}_{\%,T+10}, \&\ \Delta F^{S}_{\%,T+10},\ \ \forall\ T \in H. LFU_{\%}, WFU_{\%},\ \&\ SFU_{\%}$ denote the 95th percentiles of the forecast changes for the dataset H. These values are set as follows:

1. For load, sort $\{\Delta F^{L}_{\%,T+10}: T \in H\}$ in ascending order. For $X \in \{W, S\}$, sort $\{-\Delta F^{X}_{\%,T+10}: T \in H\}$ in ascending order. We make the sign reversal between load and renewable generation forecast deviations because the 95th percentile point for the sorted load array should represent load under-forecast, while the 95th percentile entries for the renewable arrays should indicate renewable over-forecast, for the forecast made at $T-10$.
2. For each $X \in \{L, W, S\}$, denote the entries of the sorted arrays as $\{f^{X}_{0}, f^{X}_{1},\ \ldots f^{X}_{N-1}\}$.
3. Then, N indicates the cardinality of H.
4. Set the 95th percentile index as $R \coloneqq \lfloor 0.95 \times N \rfloor$

5. The 95th percentile of the percentage forecast changes for load, wind, and solar are then, respectively

$LFU_{\%} = f_R^L$

$WFU_{\%} = f_R^W$

$SFU_{\%} = f_R^S$

Net-Load Forecast Uncertainty and Requirement Calculation

PJM does not forecast net-load. Behind the meter solar generation is included in PJM's load forecast, but in front of the meter wind and solar generation, which are both considered part of the net-load that drives PJM's ramping and uncertainty reserve needs, are forecasted separately. Therefore, PJM proposes to calculate percent uncertainty values for wind, solar and load separately, and then use these values to inform PJM's ramping and uncertainty reserves procurement. This aligns with the methodology used for setting PJM's Day-Ahead Scheduling Reserve quantities, as discussed in Operation Uncertainty Quantification. It also has the advantage of allowing PJM's reserve targets to scale as more wind and solar shows up in the forecast. This helps to ensure that even though the uncertainty analysis used to set the reserve quantities is based on historical data, the procurement targets each day will increase if more wind and solar are forecasted than PJM had on its system in the previous year. The uncertainty component of the ramp and uncertainty reserve quantities would be set based on multiplying the percent forecast uncertainty values by each relevant forecast for the forward time. Again assuming a 10-minute uncertainty procurement, this would be given mathematically as

$$Unc_T^{10} = LF_{T+10} \times LFU_{\%} + WF_{T+10} \times WFU_{\%} + SF_{T+10} \times SFU_{\%}$$

Where:

- Unc_T^{10} is the uncertainty component of the 10-Minute Ramp/Uncertainty Reserve requirement for time T
- LF_{T+10} is the load forecast for effective time T+10
- $LFU_{\%}$ is the percent load forecast uncertainty calculated based on an analysis of the prior year
- WF_{T+10} is the wind forecast for effective time T+10
- $WFU_{\%}$ is the percent wind forecast uncertainty calculated based on an analysis of the prior year
- SF_{T+10} is the solar forecast for effective time T+10
- $SFU_{\%}$ is the percent solar forecast uncertainty calculated based on an analysis of the prior year

The same uncertainty requirement is used for both 10-Min RUR up and down services, since the net-load uncertainty distribution is approximately symmetric.

For the 30-Min product, the percent uncertainties $LFU_{\%}, WFU_{\%},\ \&\ SFU_{\%}$ would be set based on $\Delta F_{\%,T+30}$ instead of $\Delta F_{\%,T+10}$. The 30-Min uncertainty for SCED target T is then given by:

$$Unc_T^{30} = LF_{T+30} \times LFU_{\%} + WF_{T+30} \times WFU_{\%} + SF_{T+30} \times SFU_{\%}$$

Illustrative Values from the 2024/2025 Delivery Year

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
- Similar to the approach taken in the uncertainty quantities for the Day-Ahead Scheduling Reserves, 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.

Table 1 provides illustrative percent uncertainty values from the 2024/2025 Delivery year for both the 10-Min Ramp/Uncertainty Reserve and 30-Min Ramp/Uncertainty Reserve services. While 99th, 97th, 95th and 90th percentile quantities are provided to demonstrate the percent uncertainty quantities for different points at the higher end of the uncertainty distribution, the 95th percentile values are highlighted, as PJM proposes to use these values to inform the uncertainty component of the 10-Min RUR and 30-Min RUR services moving forward.

Table 1: Illustrative percent uncertainty values from Delivery Year 2024/2025 for the load, solar and wind forecasts. 99th, 97th, 95th and 90th percentile uncertainty values are given.

	10-Min Ramp/Uncertainty Reserve			30-Min Ramp/Uncertainty 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%**