

Demand Curves for 10-Minute Ramping and Uncertainty Reserves

Emily Barrett

Joel Mathias

Reserve Certainty Senior Task Force

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New and Existing Reserve Products Cleared in the Real-Time Market

30-Min Reserves – Updated

Addresses net-load ramping, net-load forecast uncertainty and the need for replacement reserves for system recovery.

Online 30-Min Reserves

Addresses net-load ramping and net-load forecast uncertainty

10-Min Ramp/Uncertainty Reserves – Up and Down Reserves

Addresses net-load ramping and net-load forecast uncertainty

Primary Reserves (PR) (10-minute reserves) – 150% SR

Contingency reserves and ACE recovery

Synchronized Reserves (SR) (10-minute reserves) – 100% MSSC*

Contingency reserves and ACE recovery



The focus of this presentation is on Demand Curves for the 10-Min RUR Product.

30-Min Reserves – Updated

Addresses net-load ramping, net-load forecast uncertainty and the need for replacement reserves for system recovery.

30-Min Spinning Reserves

Addresses net-load ramping and net-load forecast uncertainty

10-Min Ramp/Uncertainty Reserves – Up and Down Reserves

Addresses net-load ramping and net-load forecast uncertainty

Primary Reserves (PR) (10-minute reserves) – 150% SR

Contingency reserves and ACE recovery

Synchronized Reserves (SR) (10-minute reserves) – 100% MSSC*

Contingency reserves and ACE recovery

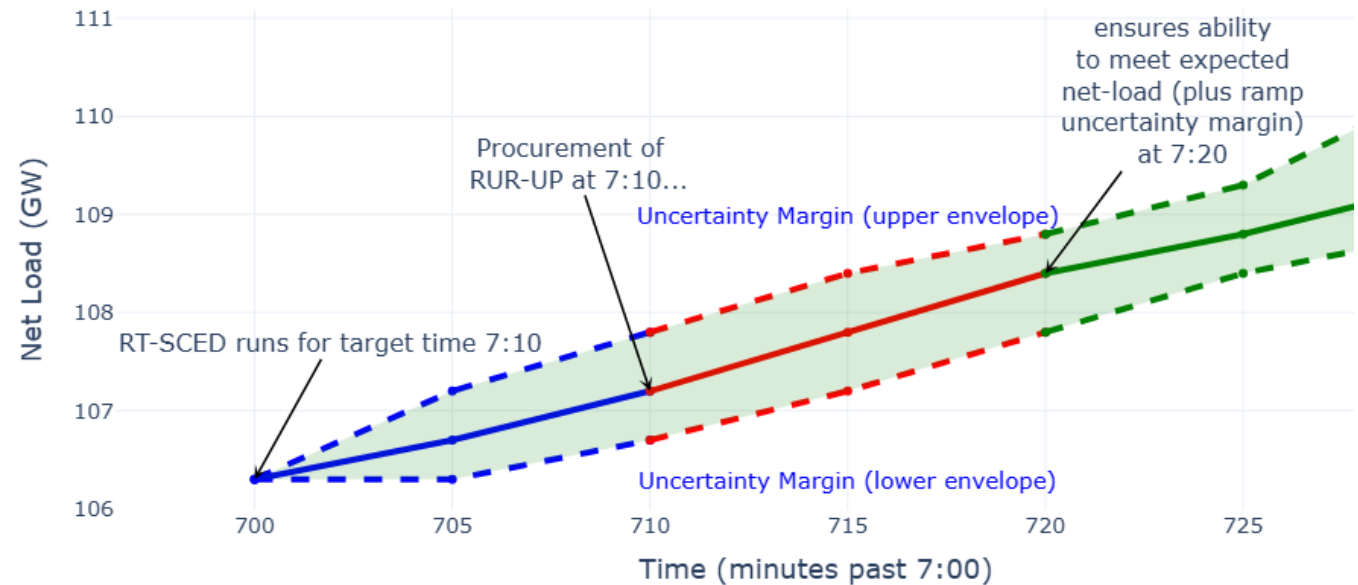
**10 Min Ramp/
Uncertainty Reserves**



**10-Min Net-Load Ramp +
10-Minute Uncertainty**

10-Min Net-Load Ramp

- The expected ramp component of the requirement ensures that we have sufficient flexibility to follow the forecasted net-load ramp. This is the red solid line from 7:10 to 7:20 in the figure to the right.

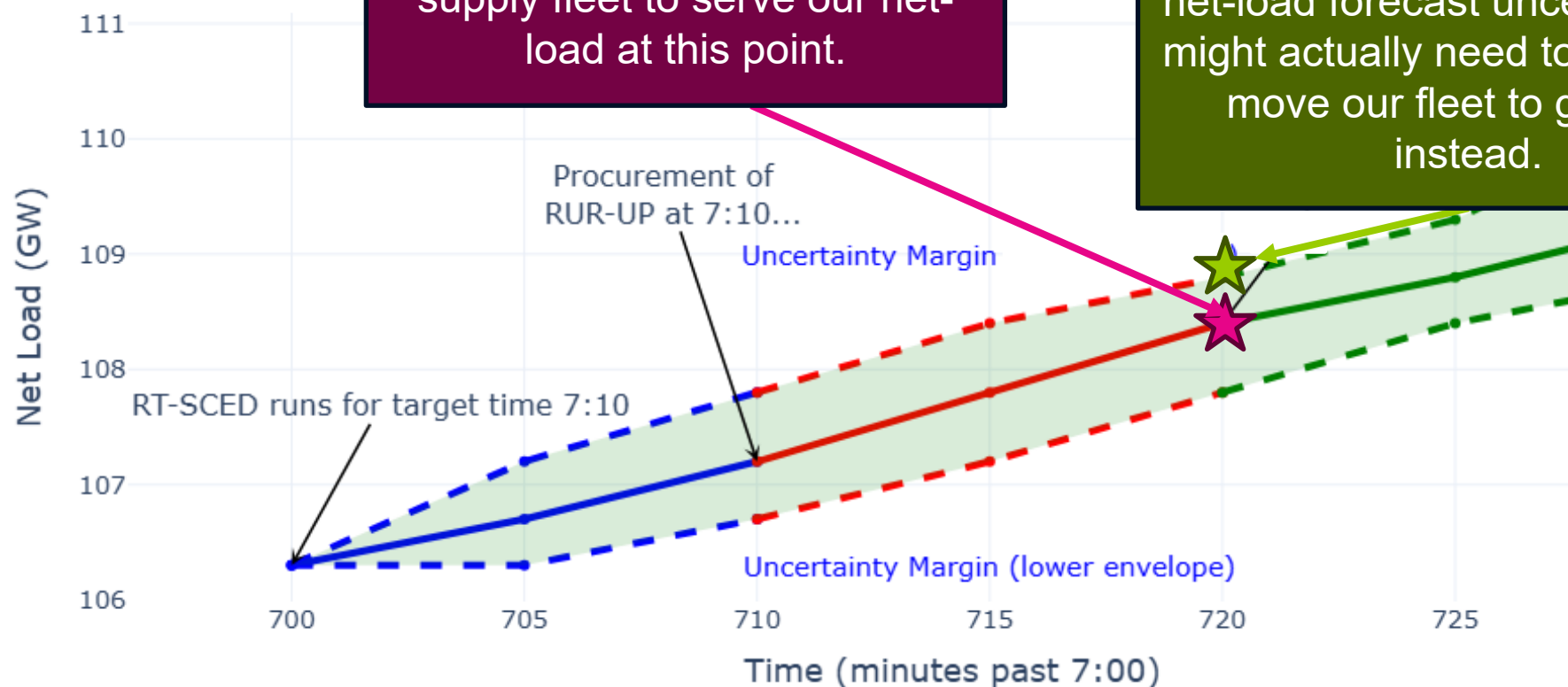


10-Min Uncertainty

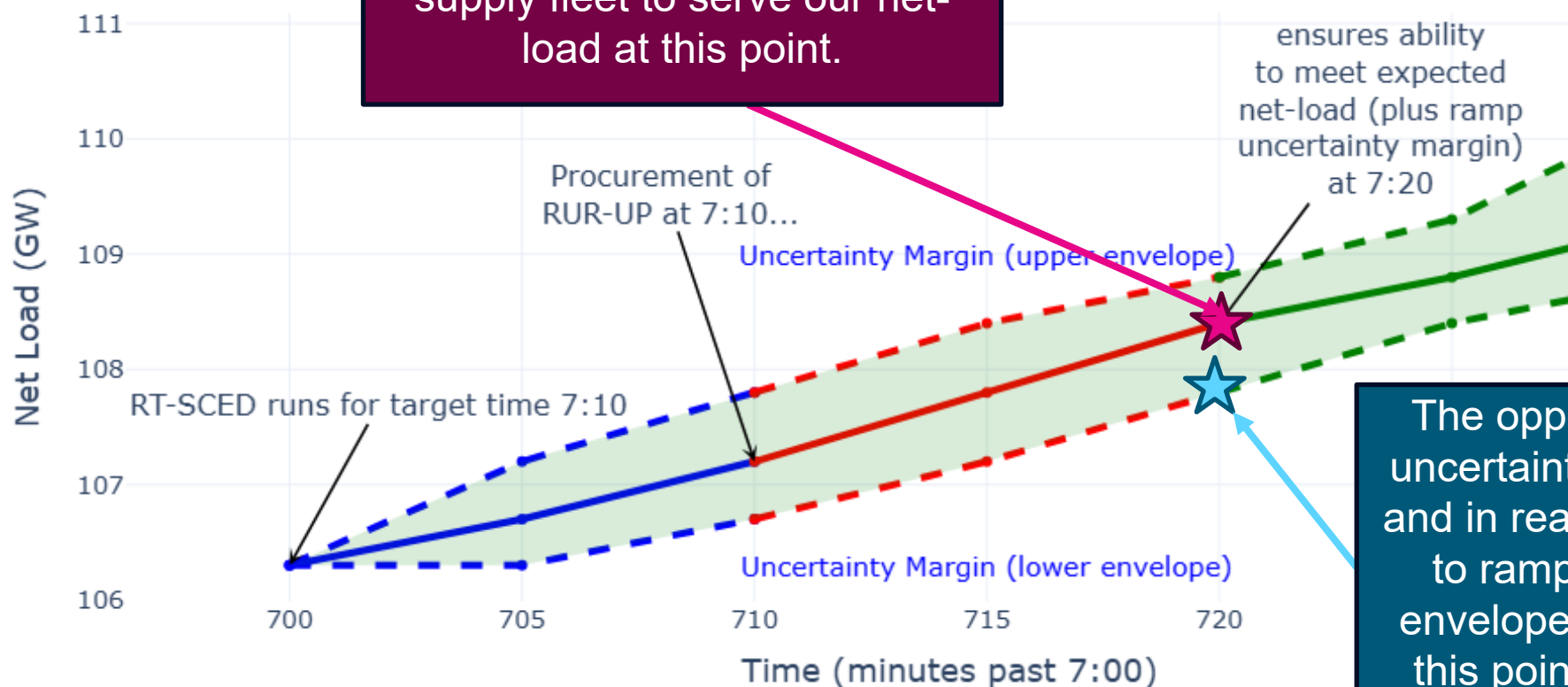
- The uncertainty component recognizes that we have some net-load forecast uncertainty around that expected ramp, represented by the envelope around the net-load forecast annotated by green shading and the dotted red line from 7:10 to 7:20.

The expected ramp component accounts for the fact that we *expect* to need to move our supply fleet to serve our net-load at this point.

The uncertainty component recognizes that, because of our net-load forecast uncertainty, we might actually need to be able to move our fleet to get here instead.



The expected ramp component accounts for the fact that we *expect* to need to move our supply fleet to serve our net-load at this point.



The opposite is true, too. The uncertainty is in both directions, and in reality, we might not need to ramp up to the top of the envelope, but in fact just get to this point at the bottom of the envelope.



The ORDC shape provides a market mechanism to represent the interaction between these two components of the 10-Min RUR Requirement and how the procured reserves address the need to position the system to meet future net-load.



The shape of the *uncertainty* portion of the 10-Min RUR products would be based on an uncertainty analysis of PJM's historical net-load forecast uncertainty.



This *uncertainty* exists around PJM's *expected* forecast, similar to the envelope around the load curve in the previous graphical examples.



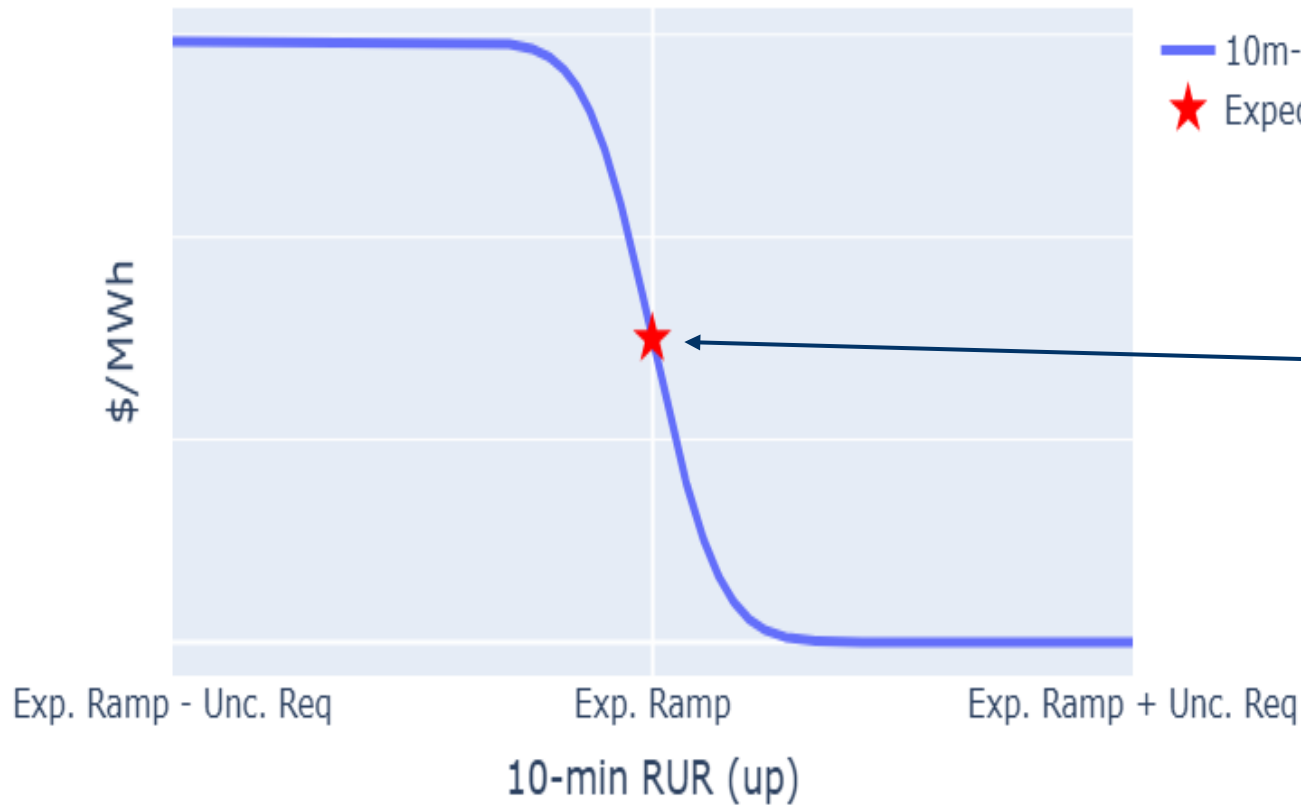
For a ramp *up* product the portion of the uncertainty distribution that reflects the probability that PJM *under-forecasted* net-load would tend to *increase* the quantity of reserves that provide value to the system as they help to mitigate this under-forecast risk.



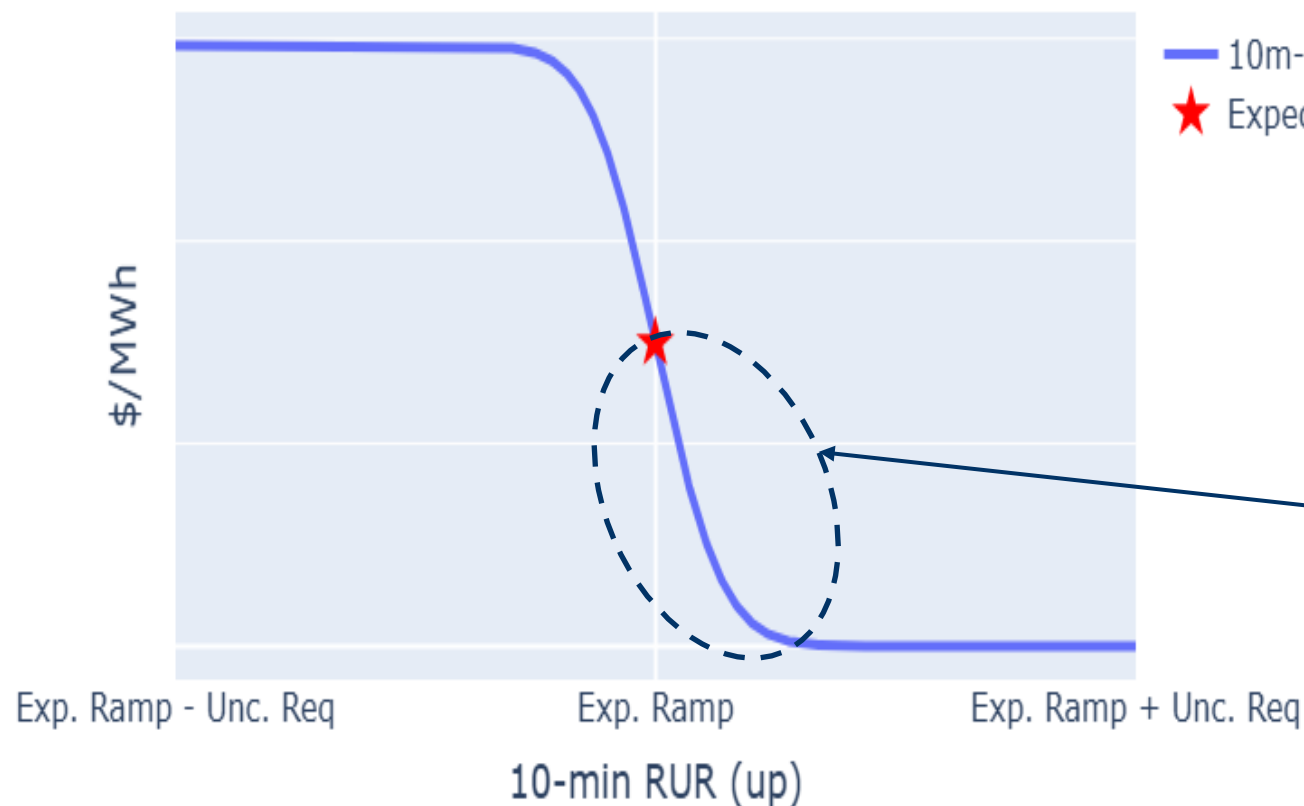
Conversely, for a ramp *up* product the portion of the uncertainty distribution that reflects the probability that PJM *over-forecasted* net-load would tend to *decrease* the market's willingness to pay for these up reserves.

- Assume that there is no wind and solar on the system and that all uncertainty and ramping reserve needs are driven by the load forecast.
- PJM forecasts that there will be 100,000 MW of load in 10 minutes
- This is an increase of 1,000 MW of load from the current operating posture at 99,000 MW
- In a world of no uncertainty, the 10-Min ramping requirement would be 1,000 MW, which would guarantee the ability to serve system load in 10 minutes

- However, there *is* uncertainty in the load that PJM will need to serve in 10 minutes driven by load forecast error.
- While the expected load in 10 minutes is 100,000 MW, there is a 5% chance that PJM has *over*-forecasted that load by 100 MW and that PJM will only need to serve 99,900 MW in 10 minutes.
- There is also a symmetrical, 5% chance that PJM has *under*-forecasted that load by 100 MW and that PJM will actually need to serve 100,100 MW in 10 minutes.
- This information can be used to define the shape of the 10-Min RUR demand curve.

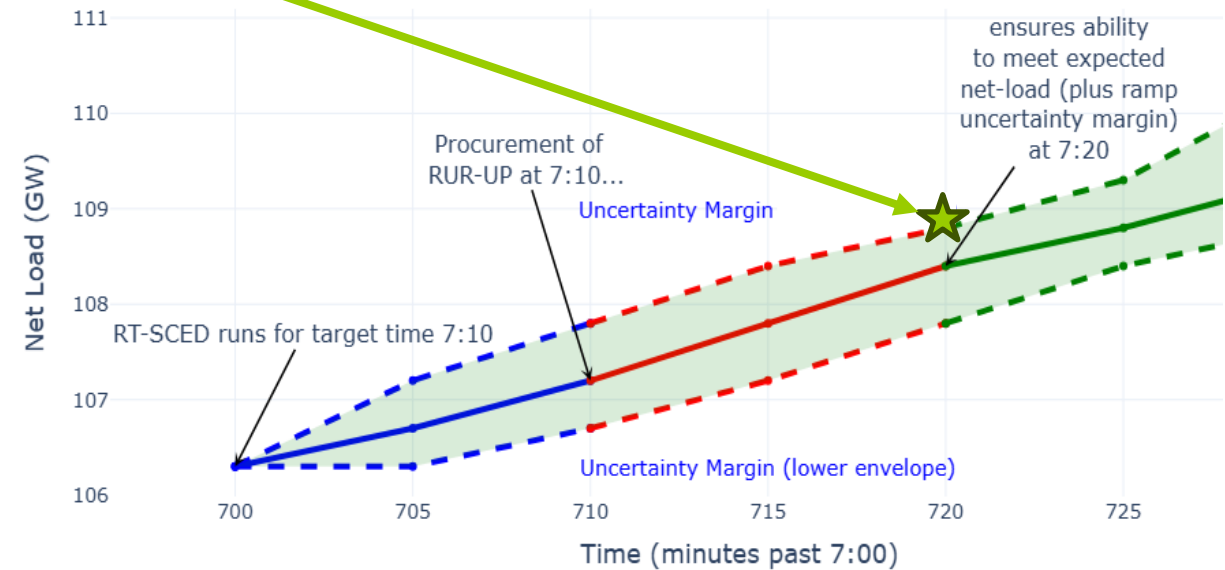
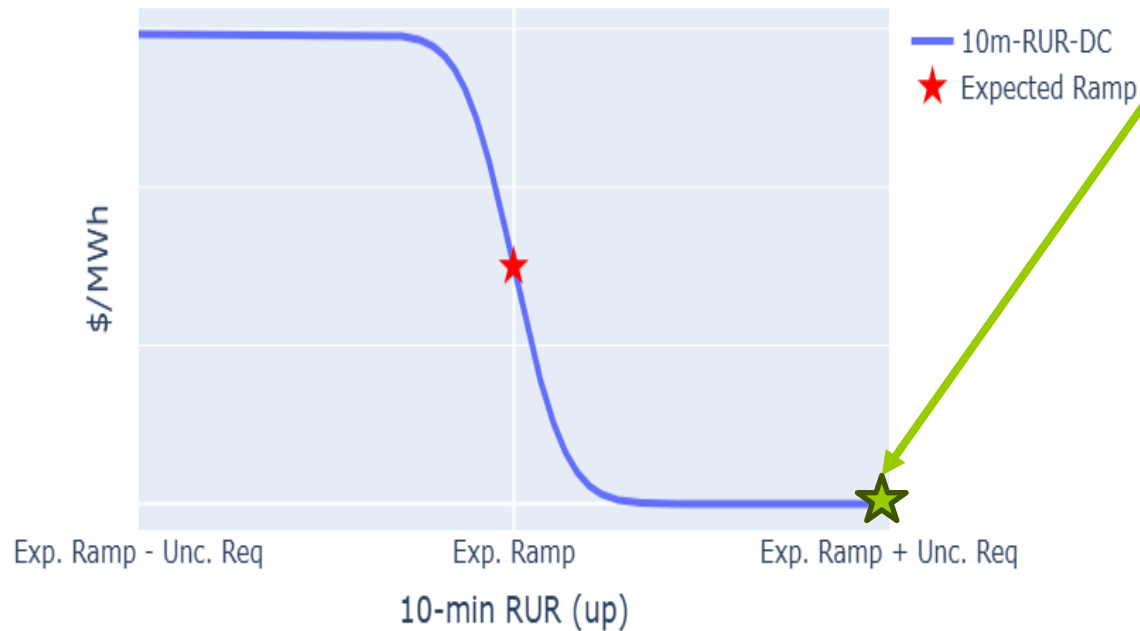


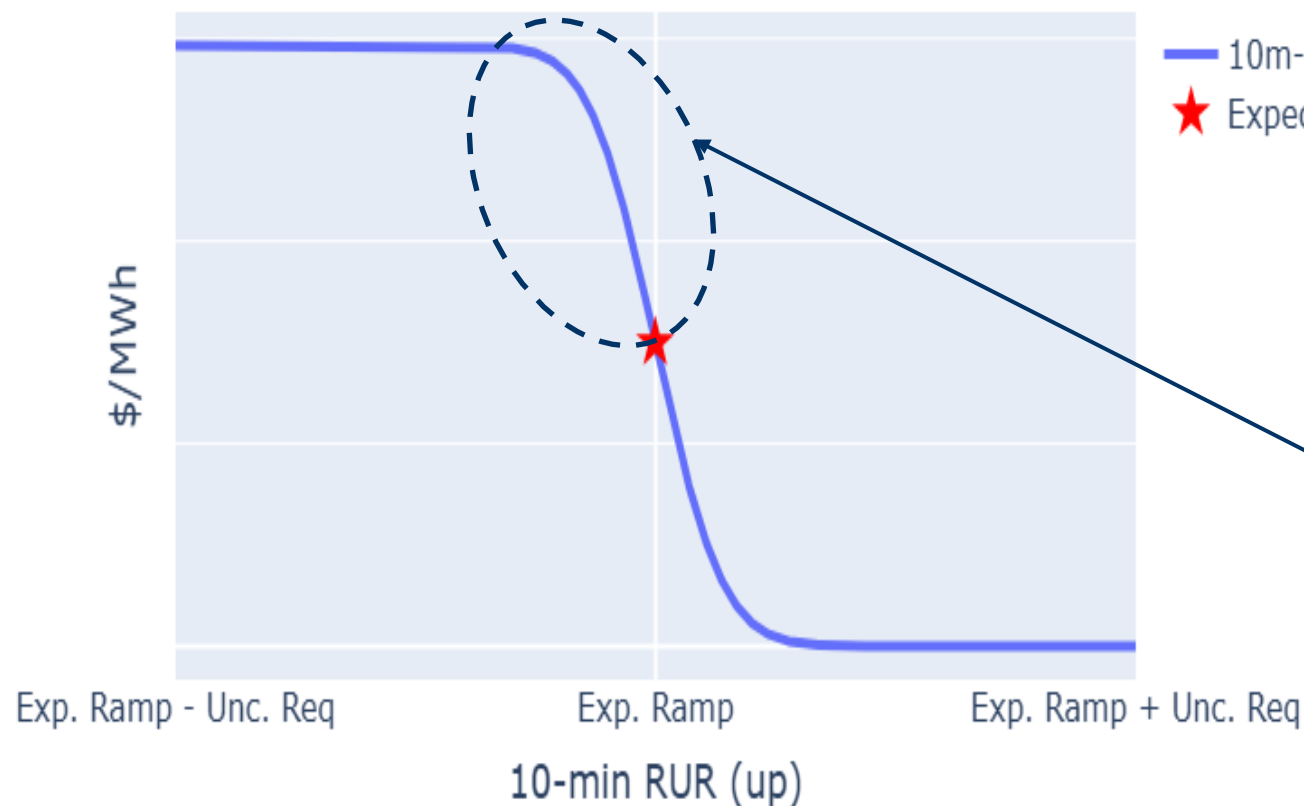
The red star represents PJM's net-load forecast for the 10 minutes following the target time. This is PJM's best understanding of the net-load PJM will need to serve in the next 10 minutes.



The downward sloping portion of the ORDC below this forecast of expected net-load ramp represents the value that reserves provide to mitigate the risk that PJM has *under-*forecasted net-load in the next 10 minutes. As the curve approaches zero, this represents the decreasing probability of the net-load uncertainty materializing. This essentially reflects that the lower the probability of occurrence the less the market is willing to pay for reserves to mitigate the reliability risk.

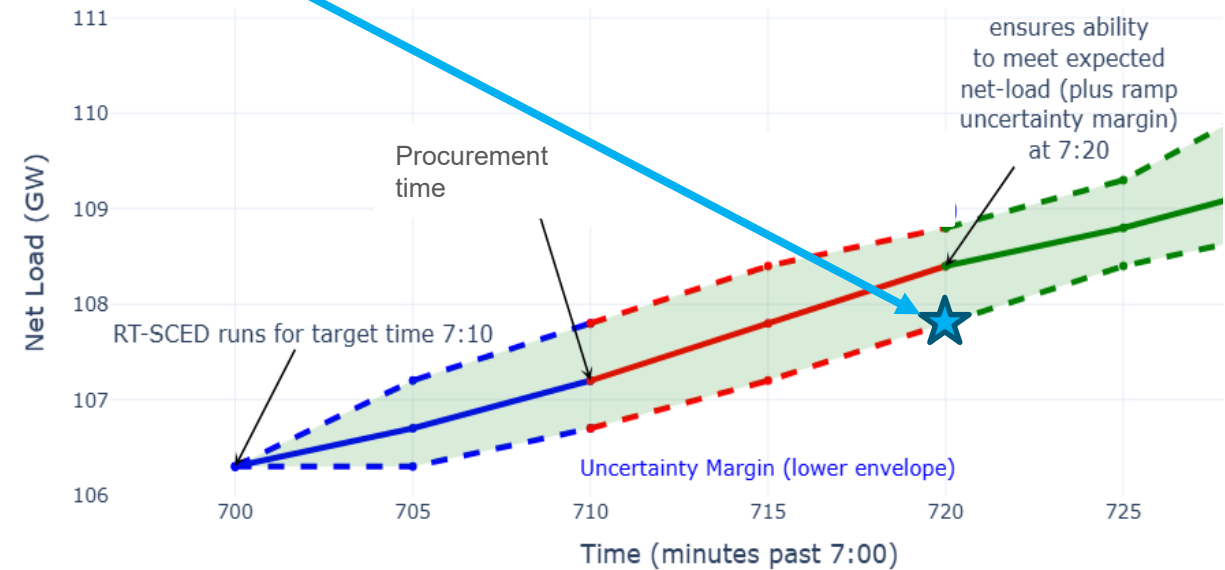
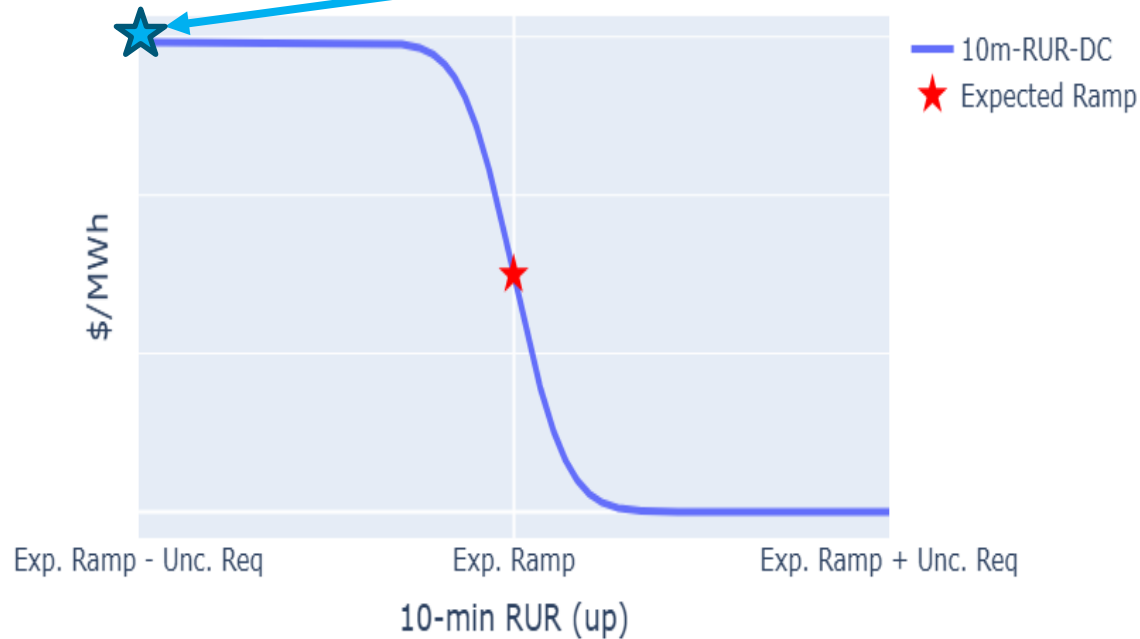
These points both correspond to what you'll hear us refer to as the “worst-case ramp-up” scenario. This is essentially the most net-load PJM would expect to need to serve given forecasted net-load ramp and uncertainty.





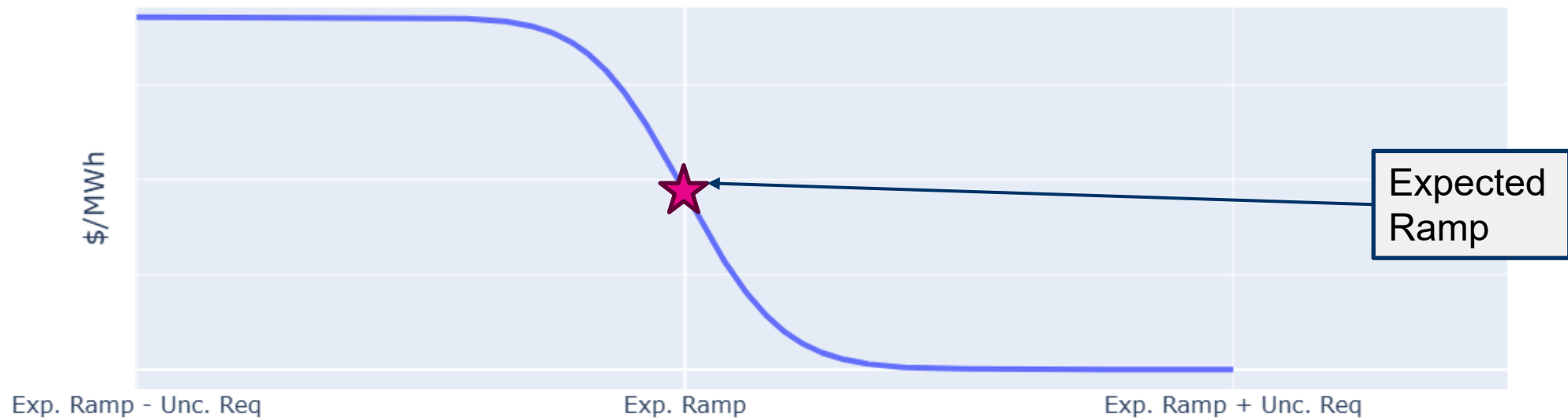
The downward sloping portion of the ORDC above this forecast of expected net-load ramp represents the market's willingness to pay for reserves given the possibility that PJM has *over-forecasted* its net-load for the next 10 minutes. The price the market is willing to pay for reserves increases as it approaches near certainty that the reserve quantity is less than the amount of net-load PJM will need to serve in the next 10 minutes.

These points both correspond to what you'll hear us refer to as the “best-case ramp-up” scenario. This is essentially the least net-load PJM would expect to need to serve given forecasted net-load ramp and uncertainty.



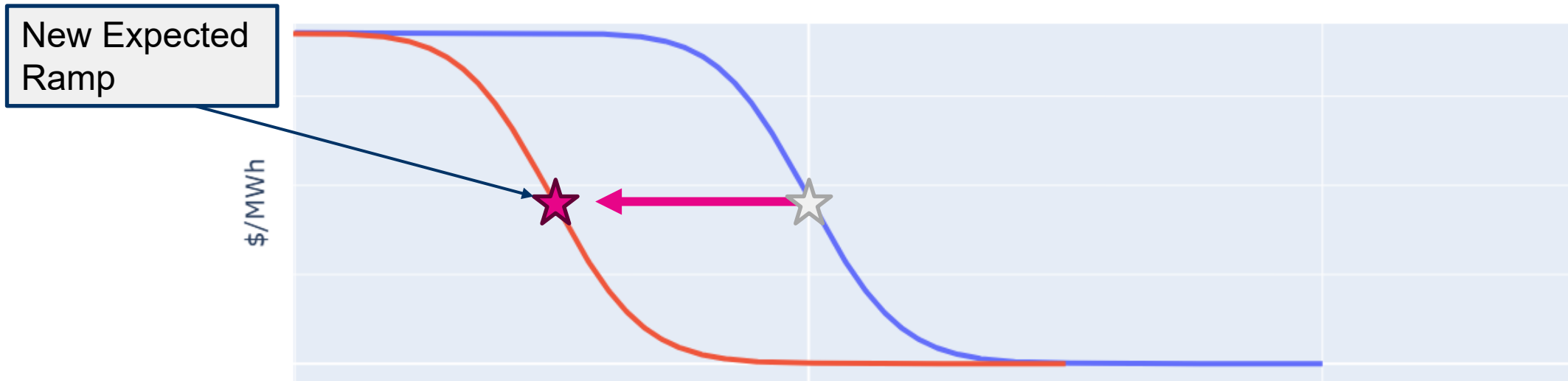
Demand Curve Shifting to Reflect Expected Ramp

- As the expected ramp changes based on operational conditions, this will tend to shift the 10-Min RUR Demand Curve.
- Assume the uncertainty distribution is symmetrical around the expected net-load ramp and that the expected net-load ramp component of the requirement is equal to the uncertainty portion of the requirement.



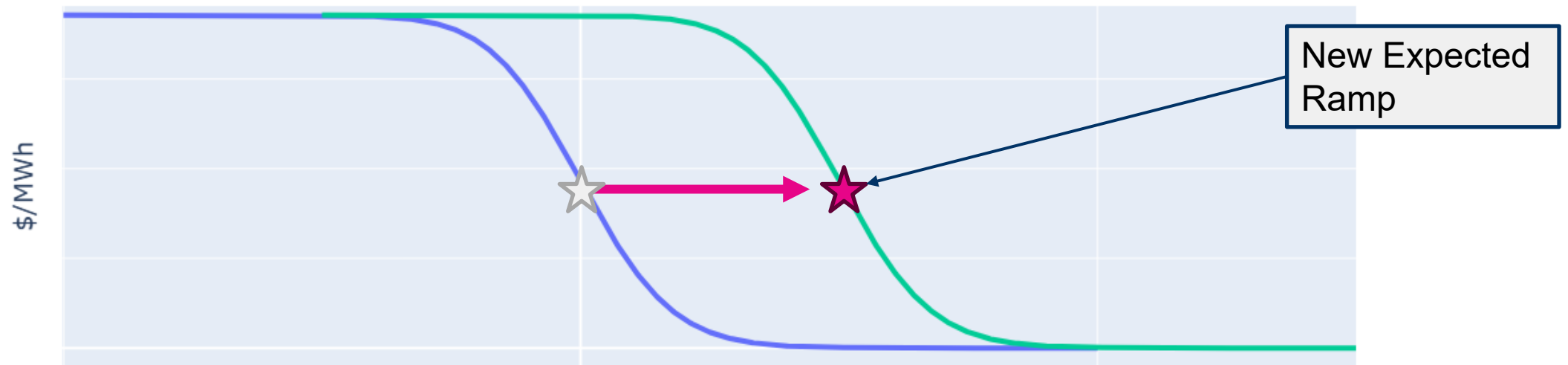
Demand Curve Shifting to Reflect Expected Ramp

- Now assume that the uncertainty remains the same, but the expected net-load ramp shifts by 50% in the negative direction. The expected ramp is still positive (i.e., PJM is still in a net-load ramp up posture), but the magnitude of that ramp was decreased by 50%.



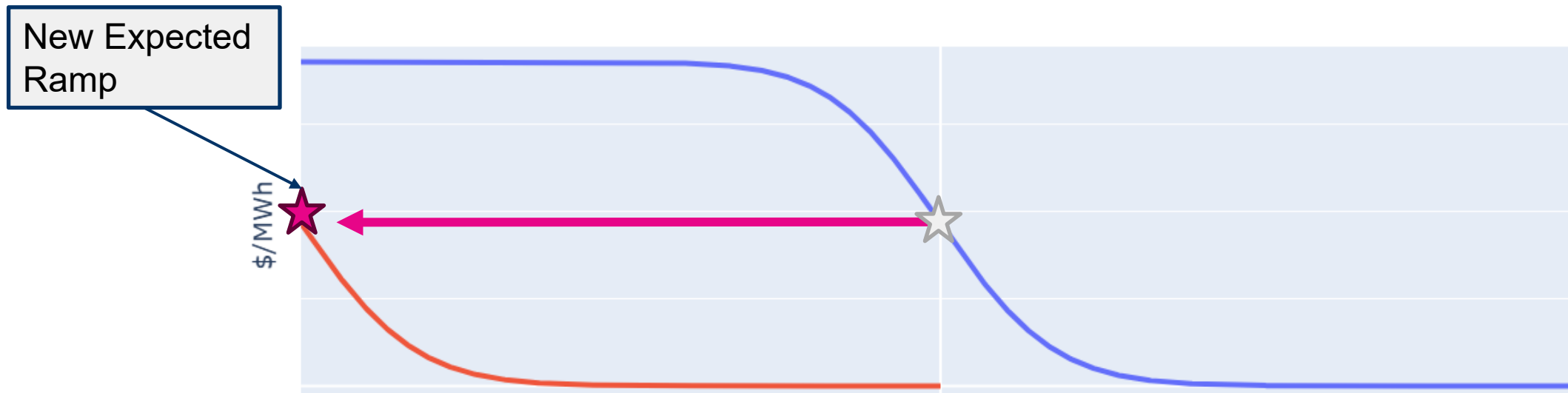
Demand Curve Shifting to Reflect Expected Ramp

- Now imagine that the opposite occurs and the expected net-load ramp now shifts by 50% in the positive direction, meaning that the magnitude of the expected up-ramp has increased by 50%.



Demand Curve Shifting to Reflect Expected Ramp

- Now imagine that the expected net-load ramp shifts by 100% in the negative direction (essentially, expected net-load ramp is 0 MW).
- In this case, the only positive portion of the ORDC is the positive uncertainty component above the expected net-load forecast.





The purpose of doing this shifting is to reflect how expected net-load ramp changes the risk that PJM will not be able to meet its net-load forecast, recognizing the uncertainty around that forecast.



At times of no expected net-load ramp, the only 10-Min RUR portion of the ORDC that would be modeled in PJM's markets would be the uncertainty portion as shown in the final graphical example.



While none of the graphical examples presented so far have depicted this, during ramping down periods, the expected net-load ramp would be negative, which would shift the curve to the left of the 0 axis. *Note that later examples in this presentation go through this scenario in more detail.*



Taken to an extreme (i.e., during a significant ramp down period) the 10-Min RUR Up Demand Curve could shift fully below the zero axis, meaning that the market would not clear any 10-Min RUR Up. PJM would set a floor in such that reserve requirements would not go below zero.

Observations on this Ramping and Uncertainty Design



The ORDCs for the 10-Min RUR product would be dynamic based on the forecasted net-load ramp for a given interval.



While the highest penalty factor (i.e., the highest y-axis \$/MWh value in the ORDC) would always be the same, the shifting of the curve could mean that in a given interval, the effective highest penalty factor modeled in the market could be lower (it would never be higher.)



This is an intentional element of the design that PJM believes appropriately captures the value of reserves based on operational conditions.

PJM's Perspective on Reflecting Expected Net-Load Ramp in ORDC Design



PJM believes that this shifting in the ORDC more accurately reflects the value of these reserves in mitigating the risk that PJM will not be able to serve its future net-load ramp.



By reflecting the positive expected ramp during ramping up periods, this design ensures that the market doesn't under-procure reserves during high-risk, tight conditions, such as during evening summer periods when load is increasing and solar is decreasing.



By recognizing the negative expected ramp during ramp down periods, this design ensures that the market doesn't over-procure reserves for 10-Min RUR up when they are not needed.

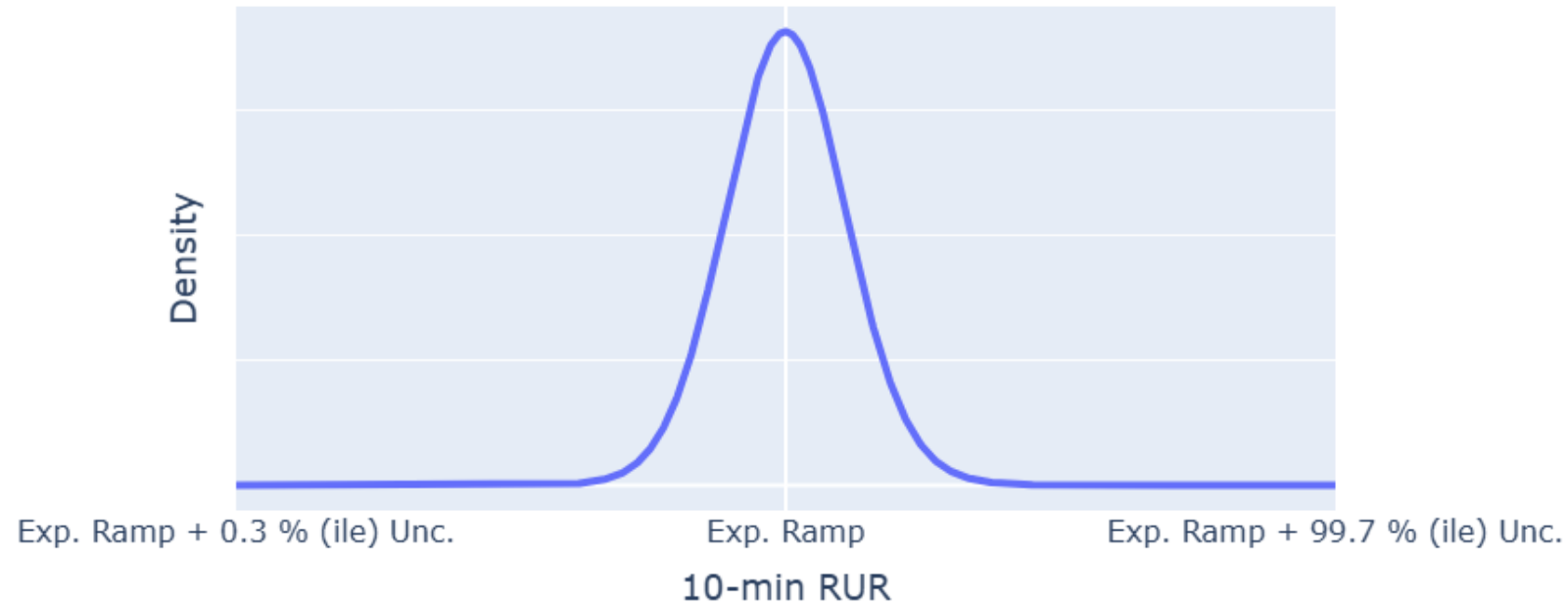
Details of the Methodology and Examples for 10-Min RUR Demand Curves

Concepts elucidated via Up RUR

- Uncertainty analysis based on bi-directional uncertainty around 10-min expected net-load ramp in historical data from Jan 2023 to Sep 2025
- Normalized by inter-quantile range of 0.3 percentile (**negative valued implying over-forecasting net-load**) to 99.7 percentile (**positive implying under-forecasting**), such that
 - Leftmost point on the X-axis represents expected ramp + 0.3 percentile of historical uncertainty
 - X-axis centered on expected ramp
 - Rightmost point on X-axis is expected ramp + 99.7 percentile of historical uncertainty
- Uncertainty distribution fit on this data, and the curve for probability of going short SR in 10 minutes as a function of 10-Min RUR is 1-CDF (cumulative distribution function) of the uncertainty distribution
 - The shape of the demand curve is a scaled version of the curve for probability of going short SR in 10 minutes at a specific RUR level

The uncertainty distribution is ~ symmetric around expected ramp

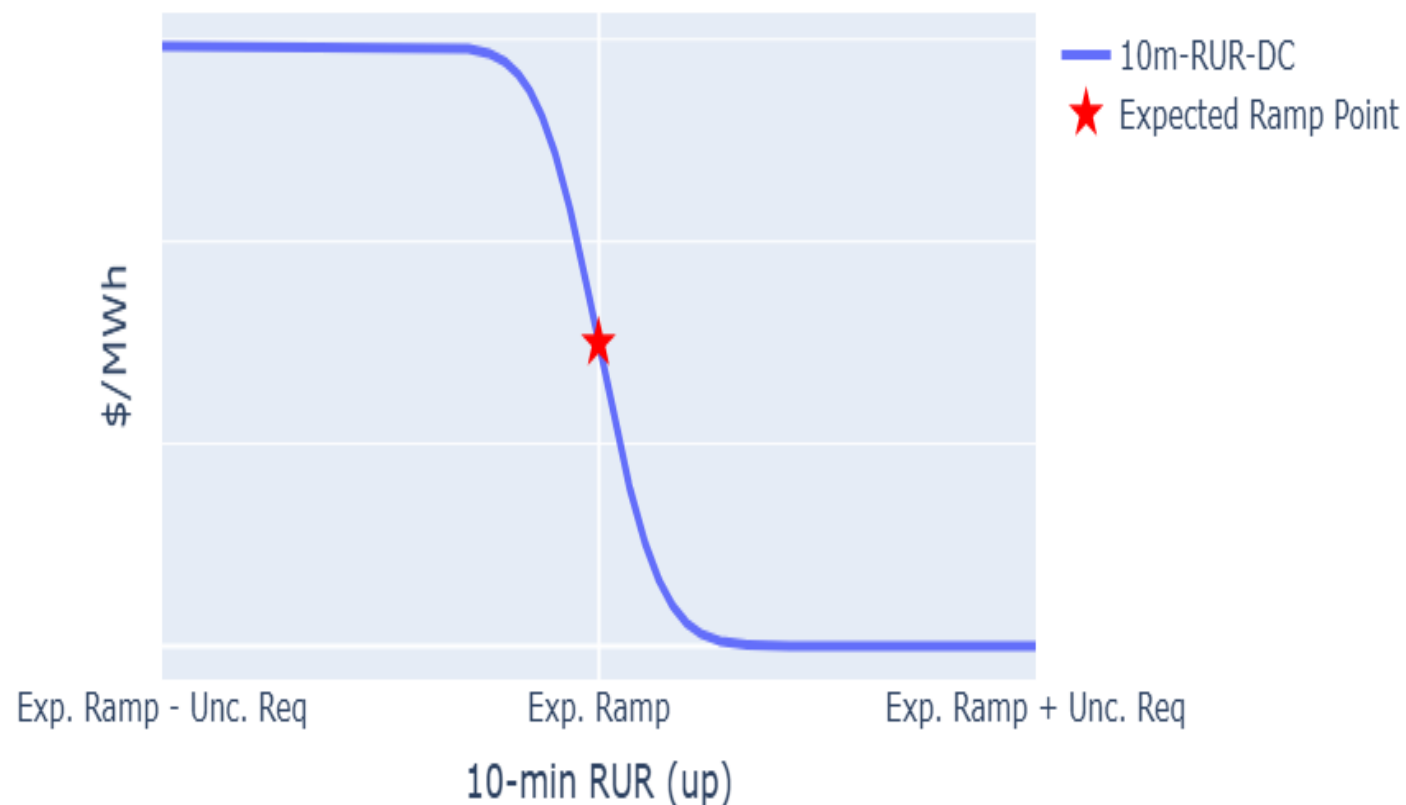
The uncertainty analysis on the historical data yields an approximately symmetric distribution around expected ramp, indicating that there is no significant bias towards over- or under-forecasting net-load



The symmetry of the above density function leads to the symmetric demand curve in the following slide, which is a scaled version of

$$1 - \text{CDF} = 1 - \text{integral of the density function}$$

- Positive values of uncertainty indicate under-forecasting of net-load ramp
 - Worst case up ramp need is Expected Ramp + Uncertainty requirement
 - Best case up ramp need is Expected Ramp – Uncertainty requirement
- This allows for a demand curve centered at expected ramp with
 - Expected Ramp – Uncertainty Req as the highest priced point
 - Expected Ramp + Uncertainty Req priced close to \$0



Example Demand Curves for 10-Min RUR (Up)

These examples are mappings from the “original” 10-Min RUR Demand Curve shown in the preceding section to “effective” demand curves with x-axis in terms of MW values of expected ramp and uncertainty

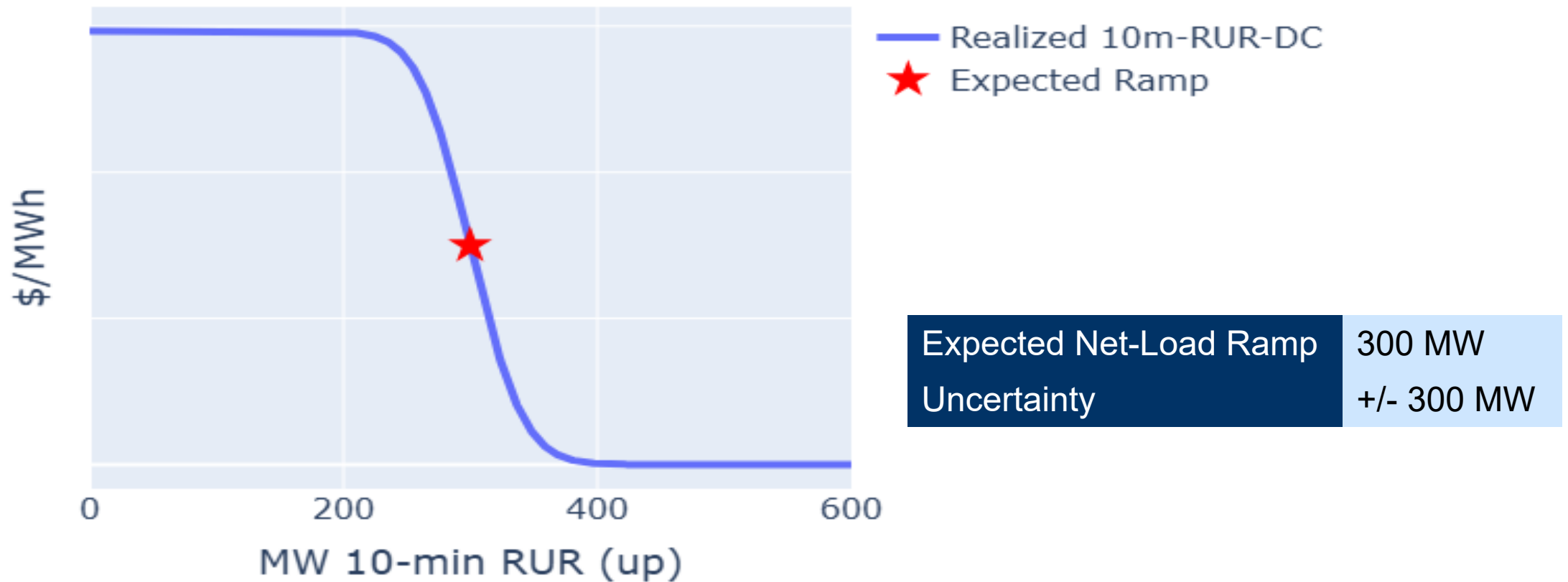
Example 0: Expected ramp and uncertainty are equal

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is 100,300 MW
- ☐ This yields an **expected net-load ramp of 300 MW**
- ☐ Uncertainty model yields **+/-300 MW of uncertainty** around the net-load forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = 0 \text{ MW}$
- “Worst-case” up-ramp need: $\text{expected ramp} + \text{uncertainty} = 600 \text{ MW}$
- The highest price of the 10-min up RUR demand curve is applied to 0 MW
- The demand curve is centered at 300 MW (expected ramp), priced at approximately half the highest price point
- The price of the demand curve at 600 MW is approximately \$0/MWh

Example 0: Expected Ramp and Uncertainty are Equal

Realized 10-Min RUR Up curve has same shape as curve from preceding section



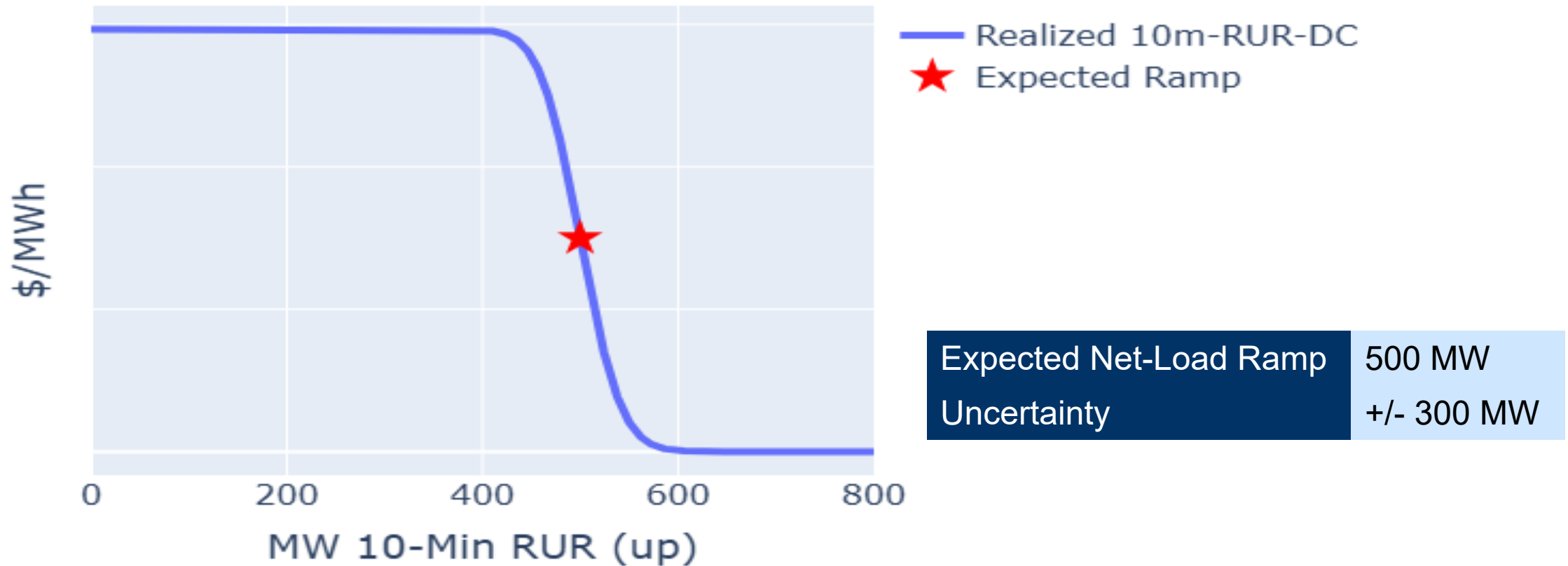
Example 1: Expected ramp is greater than uncertainty

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is 100,500 MW
- ☐ This yields an **expected ramp of 500 MW**
- ☐ Model yields **+/-300 MW uncertainty req.** about net-load ramp forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = 200 \text{ MW}$
- “Worst-case” up-ramp need: $\text{expected ramp} + \text{uncertainty} = 800 \text{ MW}$
- The highest price of the 10-Min RUR Up demand curve is applied from 0 MW to 200 MW
- The demand curve at 500 MW is priced at approximately half the highest price point (“star” pt)
- The price of the demand curve at 800 MW is approximately \$0/MWh

Example 1: Expected ramp is greater than uncertainty

Realized demand curve right-shifted compared to the curve in the preceding section

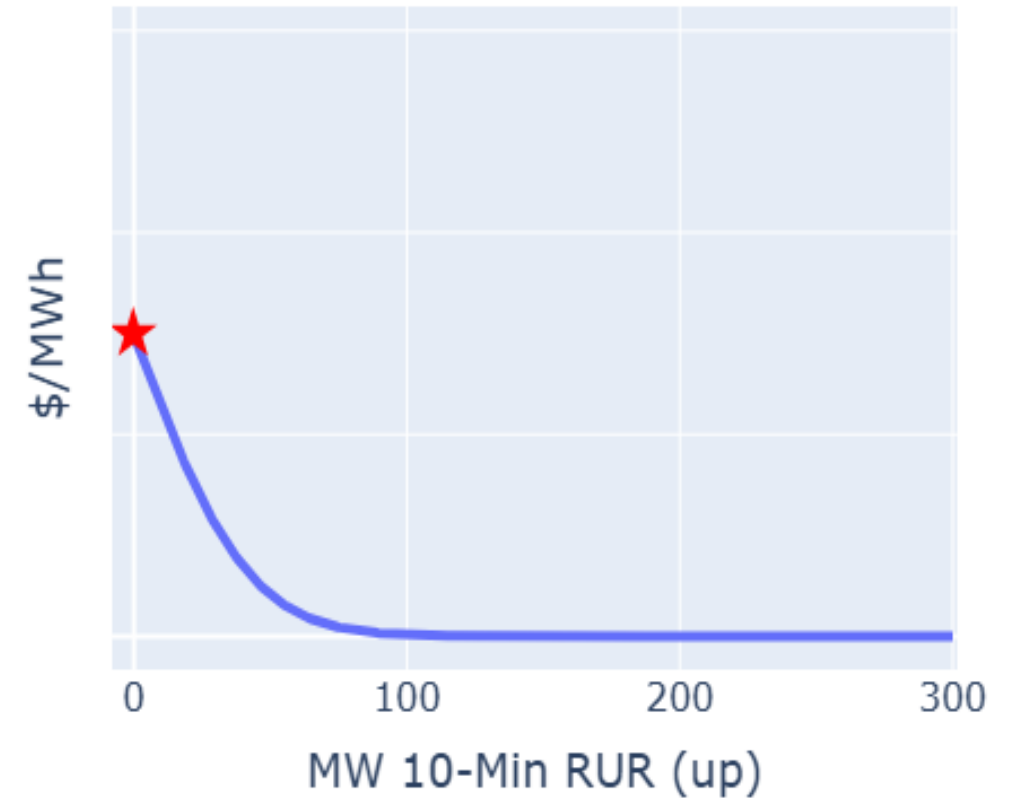
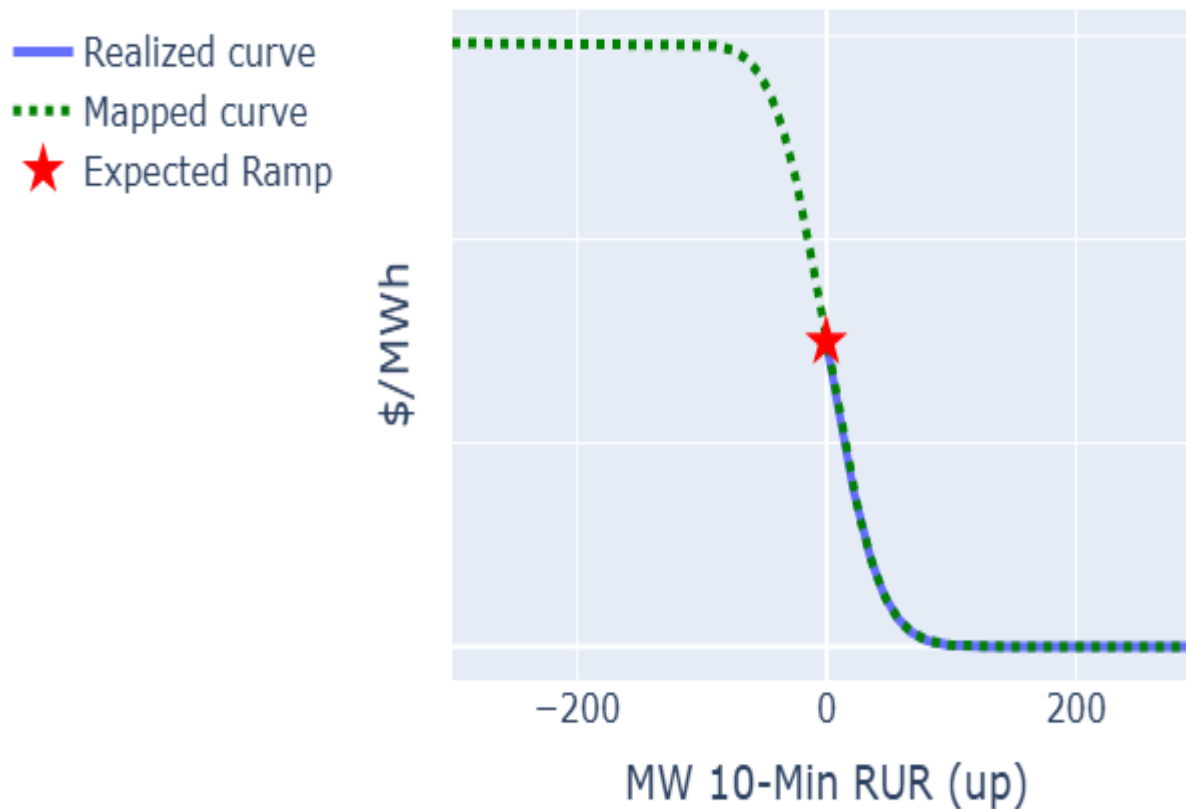


Example 2: Expected ramp is 0 MW

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is also 100,000 MW
- ☐ This yields an **expected ramp of 0 MW**
- ☐ Model yields **+/-300 MW of uncertainty** around net-load ramp forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = -300 \text{ MW}$
- “Worst-case” up-ramp need: $\text{expected ramp} + \text{uncertainty} = 300 \text{ MW}$
- 0 MW point on the demand curve priced at “star” (price point at expected ramp)
- The price of the demand curve at 300 MW is approximately \$0/MWh
- Negative MW values on the demand curve are excluded

Realized demand curve (solid blue line on both figures) only includes right half of mapped curve



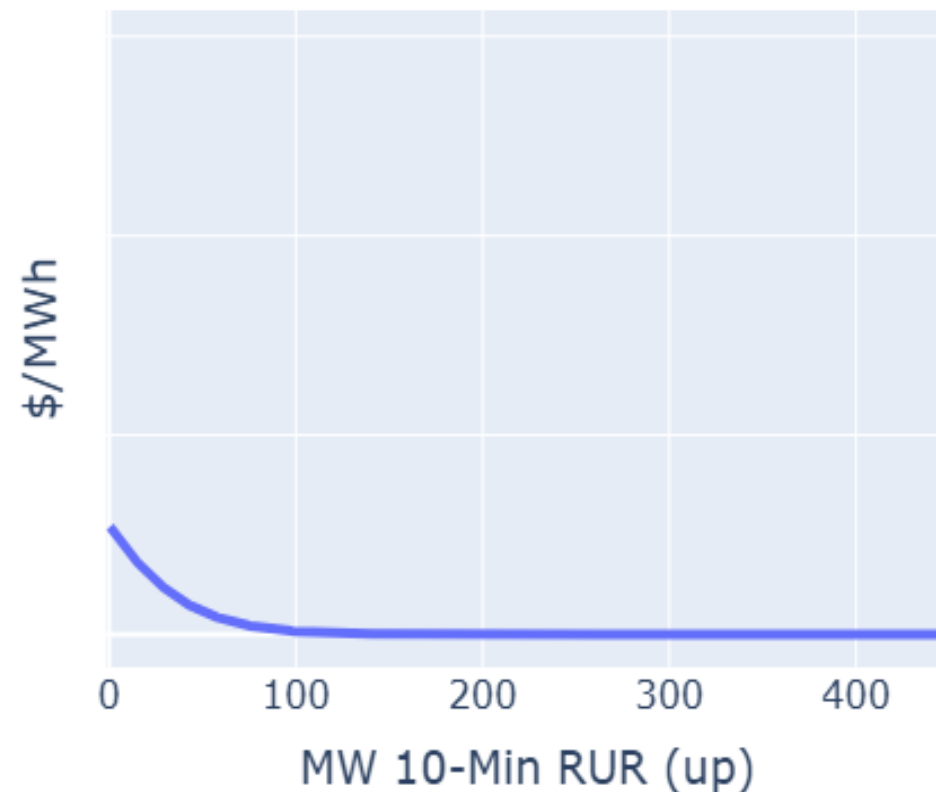
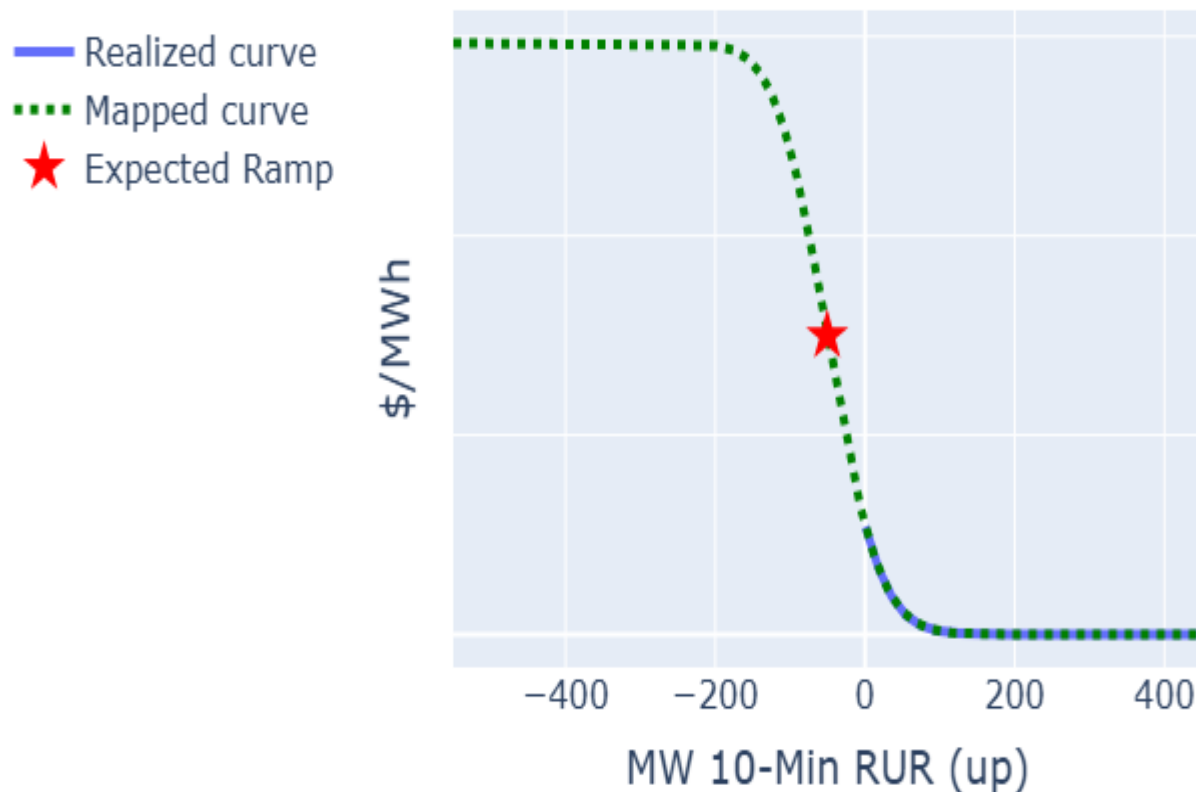
Example 3: Expected ramp is negative

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is also 99,950 MW
- ☐ This yields an **expected down ramp of 50 MW**
- ☐ Model yields **+/-500 MW of uncertainty** around net-load ramp forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = -550 \text{ MW}$
- “Worst-case” up-ramp need: $\text{expected ramp} + \text{uncertainty} = 450 \text{ MW}$
- Since negative MW values on the demand curve are excluded, the realized demand curve only includes the tail (rightmost 45%) of the mapped demand curve
- Curve sloping downward from 0 MW which is priced at $\sim 20\%$ of the highest price point in original curve
- The price at 450 MW is approximately \$0/MWh

Example 3: Expected ramp is negative

Realized demand curve (solid blue line with the plot on the right including only realized DC) has prices starting low and decaying quickly to very low values



Example 4: No 10-Min RUR Up would be cleared

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is also 99,800 MW
- ☐ This yields an expected down ramp of 200 MW
- ☐ Uncertainty model yields 100 MW of uncertainty around net-load ramp forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = -300 \text{ MW}$
- “Worst-case” up ramp need is still less than 0: $\text{expected ramp} + \text{uncertainty} = -100 \text{ MW}$

Since negative MW values on the demand curve are excluded,
there is no realized demand curve for up RUR (no up RUR will be cleared)

Facilitator:

Lisa Morelli, Lisa.Morelli@pjm.com

Secretary:

Amanda Egan, Amanda.Egan@pjm.com

SME/Presenter:

Emily Barrett, Emily.Barrett@pjm.com

10-Min RUR ORDC Shapes and Examples

A green speech bubble containing a white question mark, positioned above a blue speech bubble with three horizontal lines, indicating a question or contact point.

?

Member Hotline

(610) 666 – 8980

(866) 400 – 8980

custsvc@pjm.com

Acronym	Term & Definition
ORDC	Operating Reserve Demand Curves are an administrative mechanism used in the market to represent the market's maximum willingness-to-pay for reserves given a reserve quantity.
CDF	A Cumulative Distribution Function a function that describes the probability that a variable is less than or equal to a given value.
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).

**PROTECT THE
POWER GRID
THINK BEFORE
YOU CLICK!**



Be alert to
malicious
phishing emails.

Report suspicious email activity to PJM.
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Appendix A

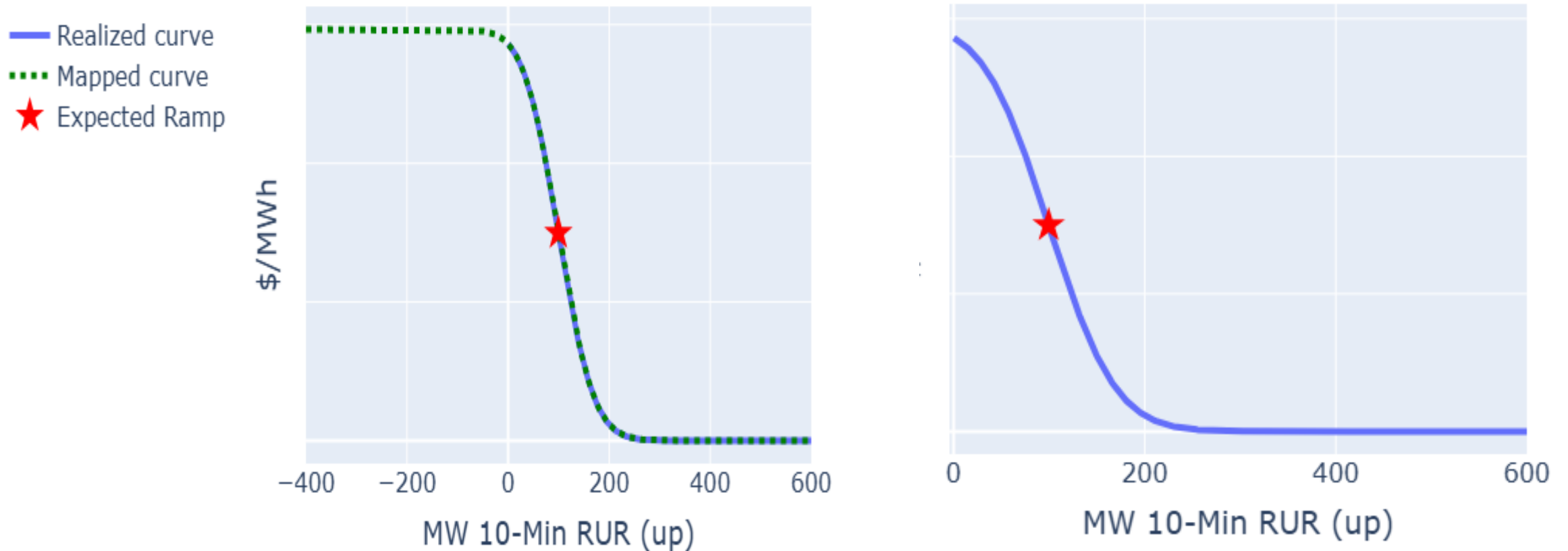
Additional Example for 10-Min RUR (Up)

Example 5: Expected ramp is less than uncertainty

- ❑ Net-load forecast at RT SCED target is 100,000 MW
- ❑ Net-load forecast 10-minute forward of target is also 100,100 MW
- ❑ This yields an **expected ramp of 100 MW**
- ❑ Model yields **+/-500 MW of uncertainty** around net-load ramp forecast

- “Best-case” up-ramp need: $\text{expected ramp} - \text{uncertainty} = -400 \text{ MW}$
- “Worst-case” up ramp need: $\text{expected ramp} + \text{uncertainty} = 600 \text{ MW}$
- Curve sloping downward from 0 MW with the price point for expected ramp reached at 100 MW
- The price at 600 MW is approximately \$0/MWh
- Negative MW values on the demand curve are excluded

Realized demand curve (solid blue line with the plot on the right including only realized curve) slopes down from 0 MW onward reaching expected price point at 100 MW

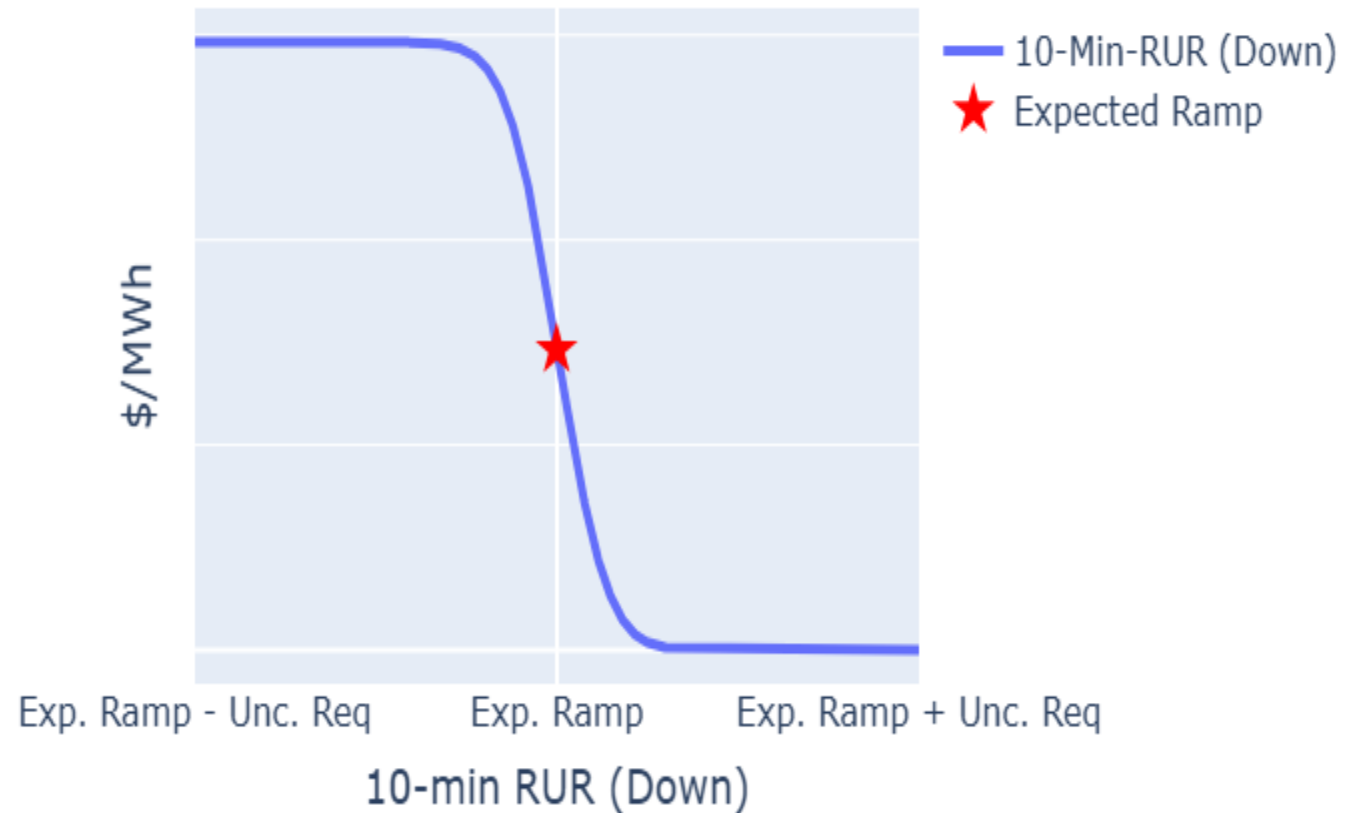


Appendix B

10-Min RUR Down

- Uncertainty analysis based on bi-directional uncertainty around 10-min expected net-load ramp in historical data from Jan 2023 to Sep 2025
- Normalized by inter-quantile range of 0.3 percentile (**negative valued implying under-forecasting net-load**) to 99.7 percentile (**positive implying over-forecasting**), such that
 - Leftmost point on the X-axis represents expected ramp + 0.3 percentile of historical uncertainty
 - X-axis centered on expected ramp
 - Rightmost point on X-axis is expected ramp + 99.7 percentile of historical uncertainty
- Uncertainty distribution fit on this data, and the curve for probability of being constrained on down ramp in 10 minutes as a function of 10-Min RUR (down) is 1-CDF (cumulative distribution function) of the uncertainty distribution
 - The shape of the demand curve is a scaled version of this probability curve at a specific 10-Min RUR (Down) level

- Positive values of uncertainty indicate over-forecasting of net-load
 - Worst case down ramp need is Expected Ramp Down + Uncertainty requirement
 - Best case down ramp need is Expected Ramp Down – Uncertainty requirement
- This allows for a demand curve centered at expected ramp with
 - Expected Ramp – Uncertainty Req as the highest priced point
 - Expected Ramp + Uncertainty Req priced close to \$0



Example 6: Expected ramp (Down) and uncertainty are equal

- ☐ Net-load forecast at RT SCED target is 100,000 MW
- ☐ Net-load forecast 10-minute forward of target is 99,700 MW
- ☐ This yields an **expected net-load ramp down of 300 MW**
- ☐ Uncertainty model yields **+/-300 MW of uncertainty** around the net-load forecast

- “Best-case” down-ramp need: $\text{expected ramp down} - \text{uncertainty} = 0 \text{ MW}$
- “Worst-case” down-ramp need: $\text{expected ramp down} + \text{uncertainty} = 600 \text{ MW}$
- The highest price of the 10-Min RUR (Down) demand curve is applied to 0 MW
- The demand curve is centered at 300 MW (expected ramp), priced at approximately half the highest price point
- The price of the demand curve at 600 MW is approximately \$0/MWh
- Note that in this example, there is no “up” RUR demand curve

Example 6: Expected Down Ramp and Uncertainty are Equal

Realized 10-Min RUR Down curve has same shape as preceding curve



Example 7: Expected ramp is 0 MW

- ❑ Net-load forecast at RT SCED target is 100,000 MW
- ❑ Net-load forecast 10-minute forward of target is also 100,000 MW
- ❑ This yields an **expected ramp of 0 MW**
- ❑ Model yields **+/-300 MW of uncertainty** around net-load ramp forecast

- “Best-case” down-ramp need: $\text{expected ramp down} - \text{uncertainty} = -300 \text{ MW}$
- “Worst-case” up ramp need: $\text{expected ramp down} + \text{uncertainty} = 300 \text{ MW}$
- Curve sloping downward from 0 MW with the price point for expected ramp
- The price at 300 MW is approximately \$0/MWh
- Negative MW values on the demand curve are excluded

Realized demand curve only includes non-negative x-axis values, that is, the right half of the mapped curve

