Reserve Markets Overview

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Overview

- Reserve Services and Products
- Offer and Capability Business Rules
- Reserve Sub-Zone Modeling
- Price Formation and Capping
- Q/A

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Reserve Services and Products

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Reserves Purpose

- Reserves are additional capacity above the expected load
  - PJM MW Requirements generally based on the online largest single contingency and 10 or 30 minute response time

- Scheduling excess capacity protects the power system against the uncertain occurrence of future operating events, including the loss of capacity or load forecasting errors

- PJM is responsible for monitoring and adjusting the reserves to ensure compliance with NERC Resource and Demand Balancing (BAL) Standards

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Reserve Markets Overview

The PJM Reserve Markets provide PJM participants with a market-based system for the purchase and sale of the Synchronized Reserve, Primary Reserve, and 30-minute Reserve Services ("Reserves")

- Every Load Serving Entity (LSE) has an hourly obligation to purchase Reserve assignments based on RT load ratio share
- In general, resources must offer their 10-min and 30-min reserve capability, unless the unit is unavailable due to an approved planned outage, maintenance outage or forced outage

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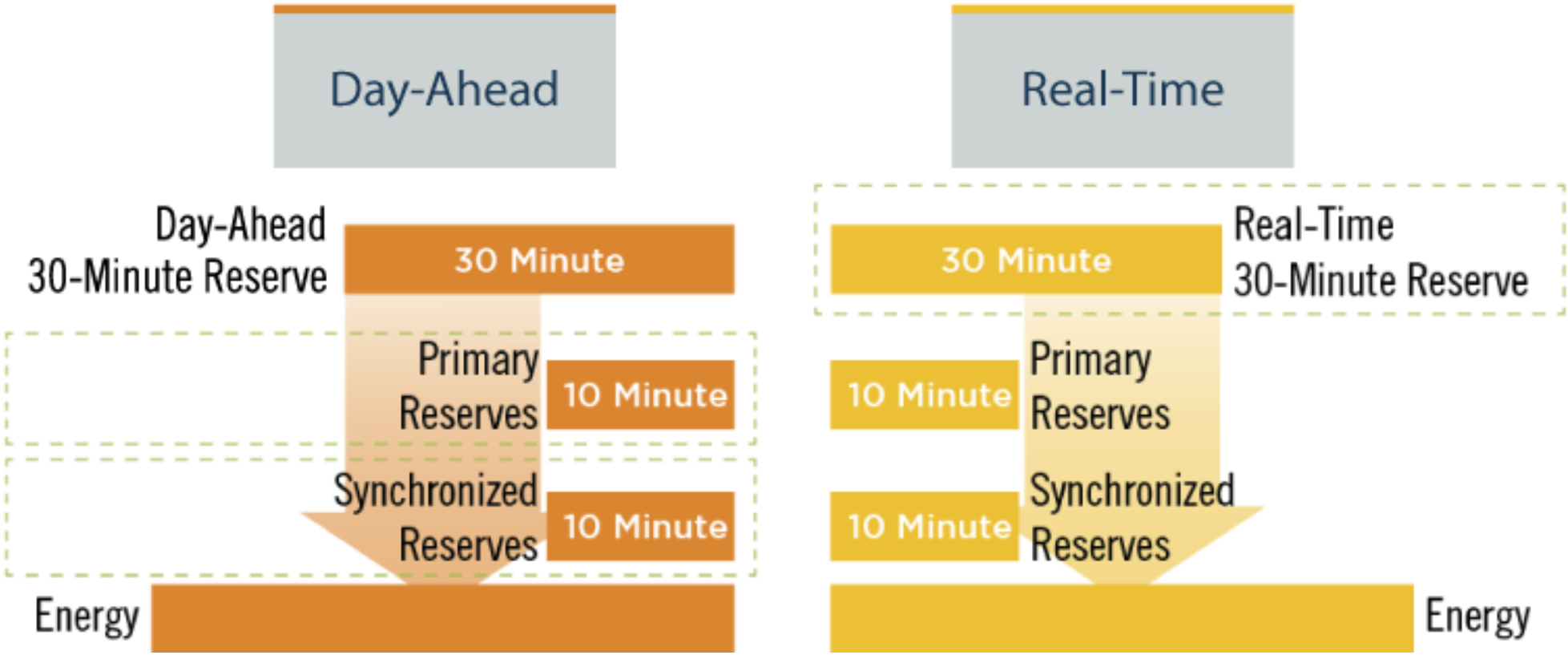
Day-Ahead and Real-Time Reserve Markets



New Reserve service(s) with the Reserve Price Formation

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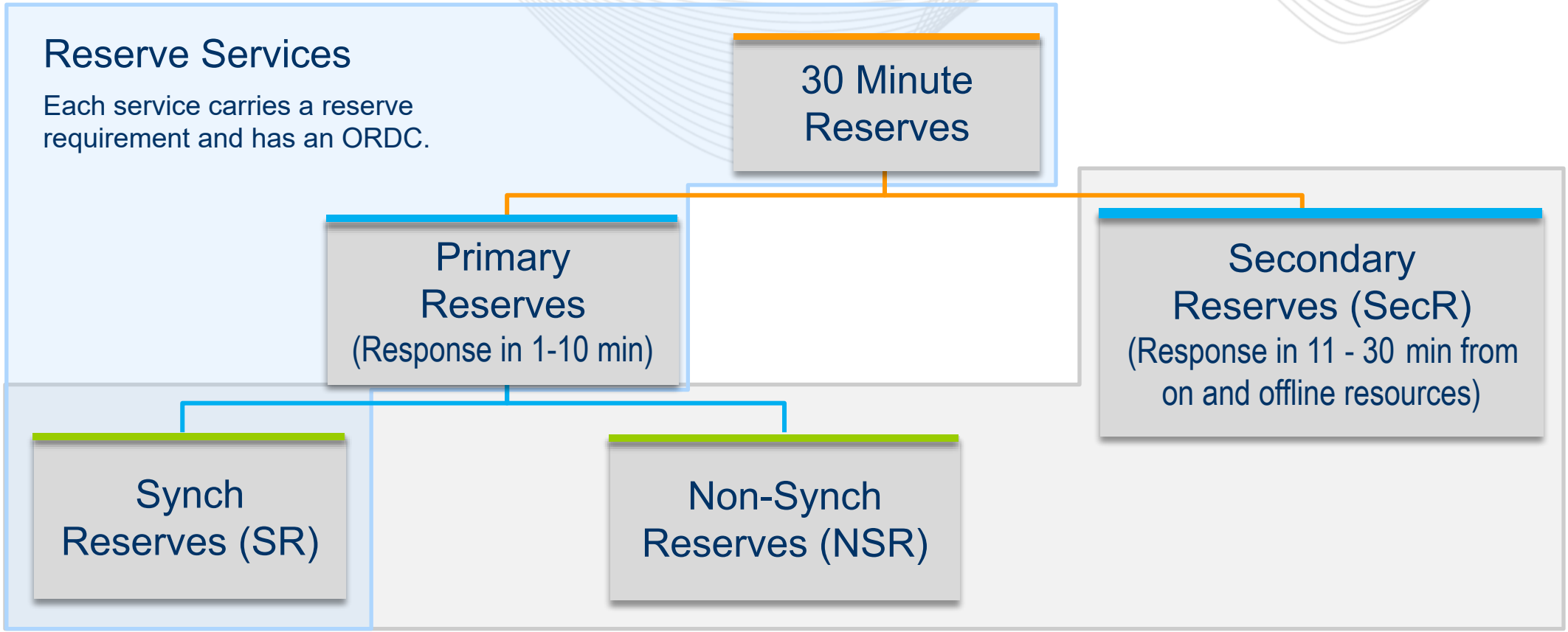
Reserve Services and Products



Clearing Price represents procurement of the Synch Reserve requirement	Clearing price represents procurement of the balance of the Primary Reserve Requirement not met by Synch Reserves	Clearing price represents procurement of the balance of the 30 Min Requirement not met by Primary Reserves

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Reserve Requirement Definition

	Reserve Service		
	Synchronized Reserve (SR)	Primary Reserve (PR)	30-Minute Reserve (30-Min)
Reliability Requirement	Largest Single Contingency	150% of Synchronized Reserve Reliability Requirement	Greater of (Primary Reserve Reliability Requirement, 3000 MW, or largest active gas contingency)
Reserve Requirement	SR Reliability Requirement + Extended Reserve Requirement	PR Reliability Requirement + Extended Reserve Requirement	30-Min Reliability Requirement + Extended Reserve Requirement

***In order to meet Reliability First (RF) Regional Criteria, PJM may schedule additional Contingency Reserves on a temporary basis in order to meet the Largest Single Contingency, as necessary to account for resource performance.

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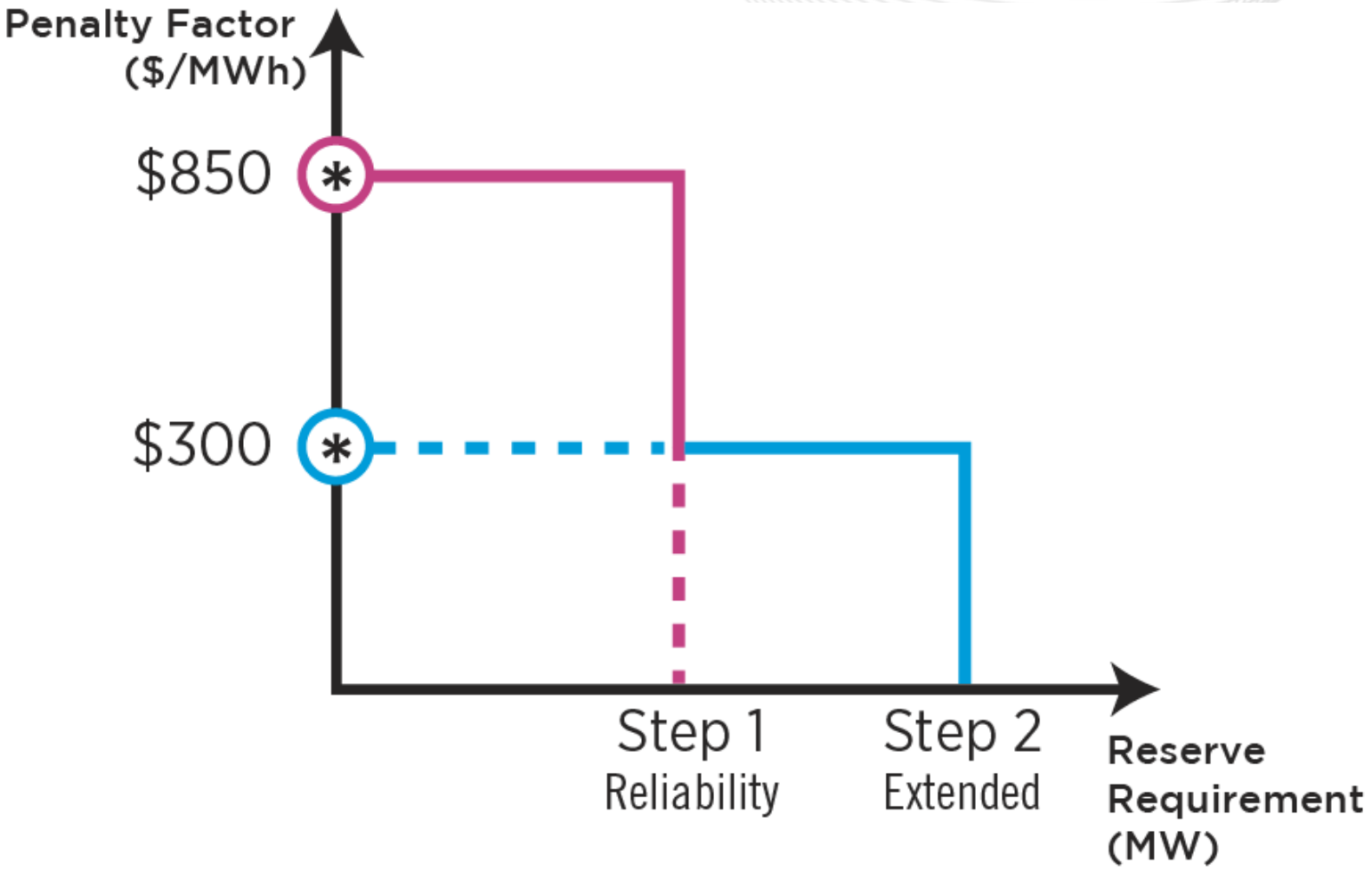
Operating Reserve Requirement and Demand Curve



Step 1 of Demand Curve

- Represents the Reliability Requirement, which is generally
  - Output of the online largest single contingency (RT)
  - EcoMax of the largest single contingency available for Energy (DA)
- Penalty factor for being short Step 1 is $850/MWh

Step 2 of Demand Curve

- Adds 190 plus Extended* MW to the Reliability Requirement
- Penalty factor for being short Step 2 is $300/MWh

*Extended MW is used to capture additional reserves to cover increased level of operational uncertainty in HWA/CWA/Emergency

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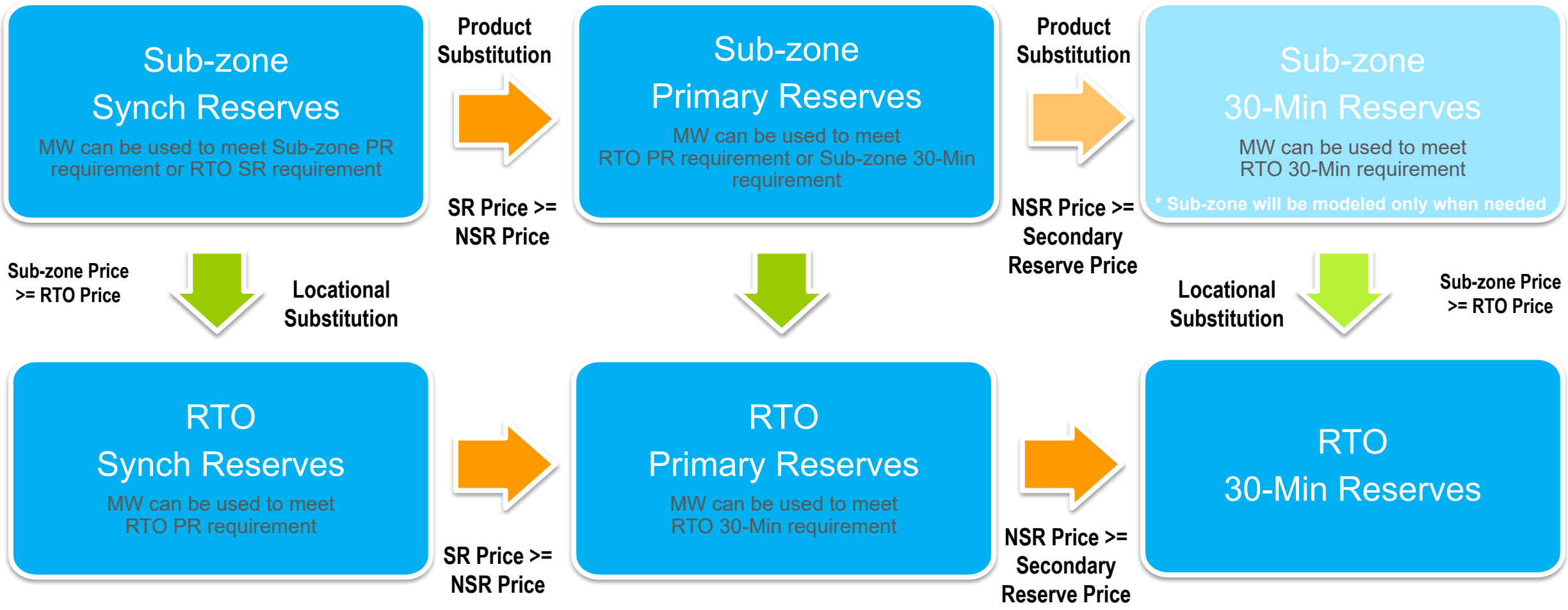
Reserve Substitution and Shadow Price Additivity



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Reserve Offer and Capability Rules

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Resource Eligibility

Generation Resources and Economic Load Response resources are eligible to provide Reserves except if:	The resource is not within the metered boundaries of PJM
	The entire output is offered as Emergency Only
	The resource type includes: Nuclear, Wind, or Solar

Nuclear, Wind and Solar resources may seek to be deemed eligible by PJM and IMM

Must submit written request to PJM and IMM containing documentation to support the resource's ability to follow dispatch
Ex/ Historical operating data showing voluntary response to reserve events and/or technical information about the physical operation of the resource
Resource will be notified within 30 business days

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Reserve Offer Requirements

All generation resources that have submitted energy offers and are eligible to provide reserves will be considered as offered into the reserve market

This excludes Hydro, Energy Storage Resources, Hybrids, and Economic Load Response resources who must submit specific reserve offers to be considered.	Generation resources with a Capacity commitment (RPM or FRR) that are capable of providing Reserves must offer their 10-minute and 30-min capability

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Reserve offers for Generation resources consist of:

Availability	Set through Energy Offer (except for ESR, Hydro, Hybrids and Economic Load Response resources who must specify separately)
MW	Calculated using Energy offer parameters (as detailed on “Calculated Capability” slide)
Price	SR offer price must be cost-based, capped at the Expected Value of Synchronized Reserve Penalty
	NSR and Secondary Reserve offer price is $0/MWh

Offer parameters can vary hourly, as today, and include: ramp rate, eco min, lesser of Synch/Secondary max and Eco max, condense to generate time (if applicable)

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A resource's choice to self-schedule or provide fixed output does not alter its capability to provide reserves. Self-scheduled units must provide reserves like all other online generating resources

PJM will calculate a self-scheduled/fixed output unit's reserve capability using the lesser of synch max or eco max, and the unit's 10 minute ramping capability, consistent with the calculations for PJM-scheduled resources	If a resource that has a reserve must offer requirement chooses to not make its reserve capability available, for example through self-scheduling or offering a fixed output, **when the resource is otherwise able to operate with a dispatchable range**, the resource is defined to be violating the reserve must offer requirement

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The maximum level of synchronized reserve offers calculation:

The Variable Operations & Maintenance component was removed from SR offers as part of the Reserve Price Formation filing.

The offer margin is the expected value of the penalty

The expected value takes into account the actual penalty, as well as the probabilities that a resource will underperform and that a synchronized reserve event will occur:

Expected Value of Synchronized Reserve Penalty =

Average Penalty Rate ($/MWh) Probability of an event * Probability of underperformance*

***At the time of implementation of this rule on October 1, 2022, the expected value of the penalty was $0.02/MWh**, and for the period from the second month after implementation through the second January 1 following the date of implementation, the expected value of the penalty has been recalculated on a monthly basis using data from the implementation date of this rule through the 15th day of the current month, and the revised value becomes effective the 1st day of the following month. Values are posted on pjm.com and capped in Markets Gateway.*

Synchronized Reserve Offer Cap Penalty

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Synchronized Reserve Offer Cap

Effective Date	Average Value of Penalty ($/MWh)
10/01/2022	0.02
12/01/2022	0.11
01/01/2023	0.09
02/01/2023	0.14
03/01/2023	0.11
04/01/2023	0.09
05/01/2023	0.07
06/01/2023	0.06
07/01/2023	0.06
08/01/2023	0.05
09/01/2023	0.05
10/01/2023	0.04

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Synch and Secondary Max Requests

If a resource cannot, due to physical characteristics, reach its Eco Max within 10 (Synch) or 30 (Secondary) minutes, it may submit documentation to be reviewed with a lower max capability

- Hourly ramp rates must be updated regularly to account for latest ambient conditions, etc.

All resource-specific documentation must be sent to the IMM and PJM for review at Reserves@pjm.com

If approved, Synch Max or Secondary Max below Eco Max may be submitted in Markets Gateway

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Calculated Capability

Reserve Market	Resource Type				
	Condensers	Other Gen	Wind/Solar/ Nuclear	ESR, Hydro, Hybrids	Economic Load Response
SR	Based on the following offer parameters submitted as part of the resource's energy offer: (A) ramp rate; (B) condense to generation time constraints; (C) Economic Minimum; and (D) the lesser of Economic Maximum and Synchronized Reserve Maximum	Based on the resource's initial energy output and the following offer parameters submitted as part of the resource's energy offer (A) ramp rate; (B) Economic Minimum; and (C) the lesser of Economic Maximum and Synchronized Reserve Maximum MW		Use SR Offer MW Constrained by Eco Limits	
NSR	Based on the following offer parameters submitted as part of the resource's energy offer: (A) startup time; (B) notification time; (C) ramp rate; (D) Economic Minimum; and (E) the lesser of Economic Maximum and Synchronized Reserve Maximum MW **Soak Time assumed to be zero**			Use NSR Offer MW for Hydro Constrained by Eco Limits	No – ELR and ESR are ineligible for NSR

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Calculated Capability – Secondary Reserves

Reserve Market	Resource Type				
	Condensers	Other Gen	Wind/Solar/ Nuclear	ESR/Hydro	Economic Load Response
SecR	Based on the following offer parameters submitted as part of the energy offer: (A) ramp rate; (B) condense to generation time constraints; (C) Economic Minimum; and (D) the lesser of Economic Maximum and Secondary Reserve Maximum MW	**Online Resources**: Based on the resource's initial energy output, the resource's available Synchronized Reserve capability; and the following offer parameters submitted as part of the energy offer: (A) ramp rate; (B) Economic Minimum; and (C) the lesser of Economic Maximum and Secondary Reserve Maximum MW **Offline Resources**: Based on the resource's available Secondary Reserve capability and the following offer parameters submitted as part of the resource's energy offer: (A) startup time; (B) notification time; (C) ramp rate; (D) Economic Minimum; and (E) the lesser of Economic Maximum and Secondary Reserve Maximum MW **Soak Time assumed to be zero**		Use SecR Offer MW Constrained by Eco Limits	

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Resource 30-Min Reserve Capability

Resources available to provide 30-Min reserve

- Online and Offline resources within RTO that are available to provide energy;
- Nuclear, Wind and Solar are not eligible, unless approved with exception;

Reserve offer MW is not allowed for conventional units. PJM calculates SR, NSR and SecR capability using ramp rate, startup/notification time, Eco limits (Synch/Secondary max), and initial MW. Examples to follow.

Hydro, Energy Storage, Hybrids, and Load Response – allow to submit reserve MW offer as their reserve capability. These resources are self-committed for energy and PJM also may not capture all the parameters (e.g. battery state of charge) necessary to accurately calculate the reserve capability.

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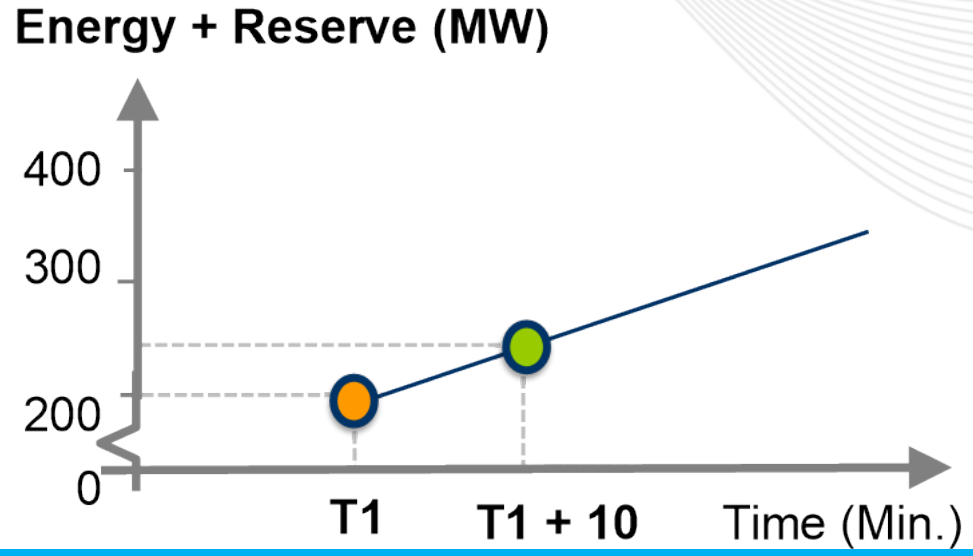
SR MW Calculation Example from an Online Gen Unit



Unit G

STATUS: **Online 200 MW**	ECOMIN: **100 MW**	ECOMAX: **600 MW**	SYNCHMAX: **500 MW**
RAMP RATE (RR): **5 MW/Min**			

SR MW Capability = max{ 0, min[min(EcoMax, SynchMax) – Initial MW, RR*10] }

= max{0, min [min(600, 500) – 200, 5*10] }

= max{0, min [500 - 200, 50] = max{0,50}

= **50 MW**

M11, Section 4.2.5.1

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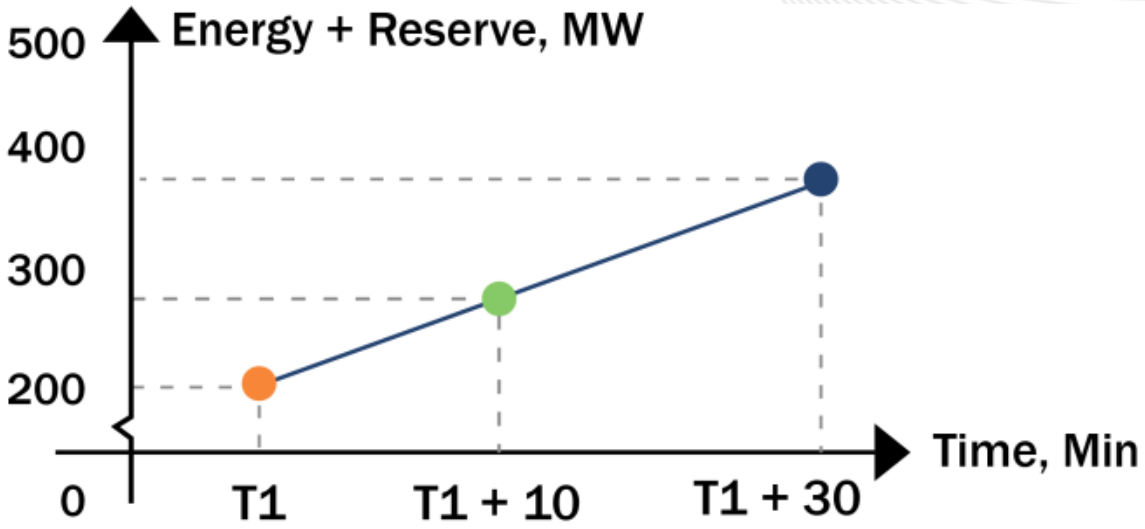
SecR MW Calculation Example from an Online Gen Unit



Unit G

STATUS: **Online 200 MW**	ECOMIN: **100 MW**	ECOMAX: **600 MW**	SYNCHMAX: **500 MW**
RAMP RATE (RR): **5 MW/Min**			

SecR MW Capability = max{ 0, min[min(EcoMax, SynchMax) – Initial MW, RR*30] – SR}

= max{0, min [min(600, 500) – 200, 5*30] – 50 }

= max{0, min [500 - 200, 150] – 50} = max{0,150-50}

= **100 MW**

M11, Section 4.2.5.1

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Segmented Ramp Rate

MW	Ramp Rate
1	1.0
150	1.5
305	15.0
474	20.0
600	1.5

1. Up to the first MW segment (1.0) is the ramp rate across from first MW segment (1.0);
2. From first MW segment (1.0) to second MW segment (150) is the ramp rate across from second MW segment (1.5);
3. From second MW segment (150.0) to third MW segment (305.0) is the ramp rate across from third MW segment (15.0);
4. From third MW segment (305.0) to fourth MW segment (474.0) is the ramp rate across from fourth MW segment (20.0)
5. From fourth MW segment (474.0) to fifth MW segment (600.0) is the ramp rate across from fifth MW segment (1.5)

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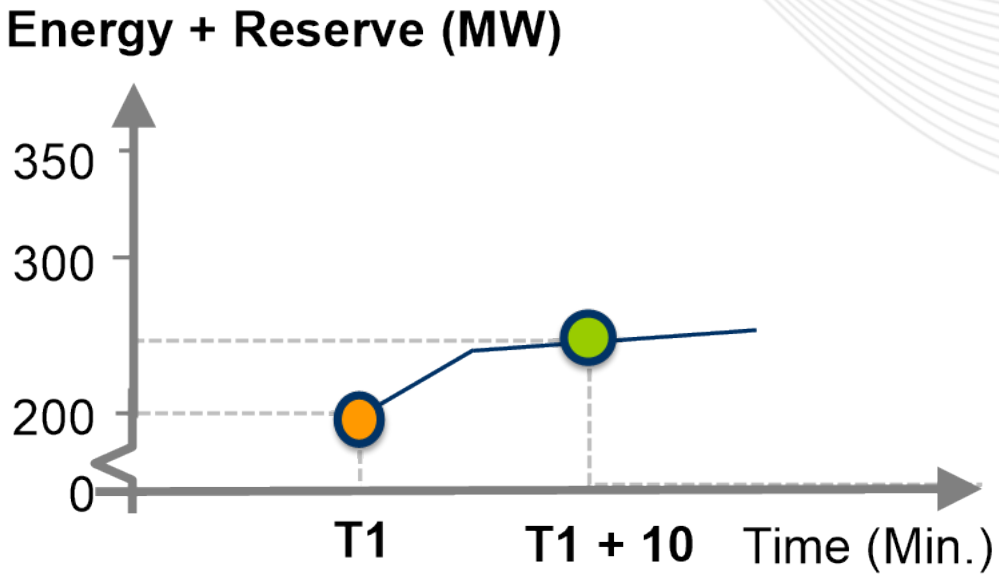
SR MW Calculation Example from an Online Gen Unit with Segmented Ramp rate



Unit S

STATUS: **Online** **200 MW**	ECOMIN: **100 MW**	ECOMAX: **600 MW**	SYNCHMAX: **500 MW**

MW	Ramp Rate (RR) MW/Min
200	1
230	5
500	0.5

SR MW Capability = max{ 0, min[min(EcoMax, SynchMax) – Initial MW, RR*10] }

= max{0, min [min(600, 500) – 200, 5 x 6 + 0.5 x 4] }

= max{0, min [500 - 200, 32]

= **32 MW**

M11, Section 4.2.5.1

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SR MW Calculation Example for Synchronous Condenser

Unit C

STATUS: **Online Condensing** **-0.2 MW**	ECOMIN: **25 MW**	ECOMAX: **60 MW**	SYNCHMAX: **60 MW**
RAMP RATE (RR): **10 MW/Min**	CONDENSE TO GEN TIME: 3 **Min**		

SR MW Capability = max{0,min [min(EcoMax, SynchMax), EcoMin + RR x (10 min – Condense to Gen Time)] }

= max{0, min [min(60, 60), 25 + 10 x (10 – 3)] }

= max{0, min [60, 25 + (10 x 7)] }

= max{0, min [60, 95] }

= **60 MW**

M11, Section 4.2.5.3

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Reserve Capability for Hydro Resources

Unit P

SCENARIO: HYDRO AND PUMP STORAGE OFFERING FULLY FOR ENERGY	ECOMIN: **250 MW**	ECOMAX: **300 MW**	Reserve Offer **50 MW**
Resource must offer reserve MW economically (Not self-scheduled)			

SR MW Capability = max{0,min [EcoMax – EcoMin, Reserve Offer MW] }

Max Energy = EcoMax – Reserve Offer MW

= max{0, min [300 – 250, 50] }

= max{0, 50}

= **50 MW**

M11, Section 4.2.5.4

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Reserve Capability for Hydro Resources

Unit P

SCENARIO: HYDRO AND PUMP STORAGE OFFERING PARTIALLY FOR ENERGY	ECOMIN: **20 MW**	ECOMAX: **30 MW**	Reserve Offer **10 MW**
Resource must offer reserve MW as self-scheduled			

SR MW Capability = max{0,min [EcoMax – EcoMin, Reserve Offer MW] }

Max Energy = **EcoMax – Reserve Offer MW**

= max{0, min [30 – 20, 10] }

= max{0, 10}

= **10 MW**

M11, Section 4.2.5.4

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Reserve MW Calculation Example from an Offline Unit

Unit N

STATUS: **Offline** **0 MW**	ECOMIN: **50 MW**	ECOMAX: **150 MW**	
RAMP RATE (RR): **10 MW/Min**		STARTUP TIME: **5 Min**	NOTIFICATION TIME: **2 Min**

NSR MW Capability = max{0,min [EcoMax, EcoMin + (10 – StartupTime – NotificationTime)*RR] }

= max{0, min [150, 50 + (10 – 5 – 2) * 10] }

= max{0, min [150, 80] }

= max{0, 80}

= **80 MW**

M11, Section 4.2.5.2

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Reserve MW Calculation Example from an Offline Unit

Unit N

STATUS: **Offline** **0 MW**	ECOMIN: **50 MW**	ECOMAX: **150 MW**	
RAMP RATE (RR): **10 MW/Min**		STARTUP TIME: **5 Min**	NOTIFICATION TIME: **2 Min**

SecR MW Capability = max{0,min [EcoMax, EcoMin + (30 – StartupTime – NotificationTime)*RR] – NSR MW}

= max{0, min [150, 50 + (30 – 5 – 2) * 10] - 80}

= max{0, min [150, 280] – 80}

= max{0, 150 – 80}

= **70 MW**

M11, Section 4.2.5.2

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What are Flexible and Inflexible Reserve Resources?

Attributes	Inflexible Reserve	Flexible Reserve
Resource Types	• Offline CT and Hydro that can operate in condense mode, • Economic Load Response	• Online/offline generating units, and • Some Economic Load Response (based on request by Participant)
Clearing Methodology	ASO, from offline/online condenser	RTSCED, from online/offline resources
Minimum Commitment Time	One hour	Not applicable
Start Up + Notification Time	About 30 Minutes	Not Applicable
Assignment Communication	30 minutes ahead of operating hour in the Award page, Markets Gateway	In real-time via ICCP and Dispatch Lambda page of Markets Gateway
Logging	Logged for one hour	Logged at every approved SCED case

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Reserves Results Posting

	What	Frequency	Location	When
Day Ahead	Synch Reserve	Hourly	Market Results in Markets Gateway	A day ahead of the operating day
	Non-synch Reserve	Hourly	Market Results in Markets Gateway	A day ahead of the operating day
	Secondary Reserve	Hourly	Market Results in Markets Gateway	A day ahead of the operating day
Real-Time	Inflexible Synch Reserve	Hourly	Market Results in Markets Gateway	30 min prior to top of hour
	Inflexible Secondary Reserve	Hourly	Market Results in Markets Gateway	30 min prior to top of hour
	Flexible Reserves	Every 5 minutes	ICCP link and Dispatch Lambda in MG	Every 5 min
	Clearing Price	Every 5 minutes	Data Miner and PJM Now	Every 5 min

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Reserve Parameters & Markets Gateway Location

Parameter	Update Available	Markets Gateway Update Location
EcoMax & EcoMin	Must be entered prior to 11 a.m. the day before the operating day Can be updated anytime to reflect real-time changes	• Generator > Unit > Detail • Demand Response > Hourly Updates • Generator > Hourly Updates
Initial Energy Output	No updates available. Based on actual resource output	N/A
Ramp Rates	Default and Daily Ramp Rates must be entered prior to 11 a.m. the day before the operating day. Ramp Rate updates can be made during the operating day 65-minutes prior to the operating hour.	• Default: Generator > Unit > Detail • Daily Ramp Rate: Generator > Unit > Ramp Rates • Updates: Generator > Unit > Ramp Rates Updates
Startup Time	Must be entered prior to 11 a.m. the day before the operating day	Generator > Unit > Detail
Notification Time	Must be entered prior to 11 a.m. the day before the operating day Notification Time updates can be made during the operating day 65-minutes prior to the operating hour.	• Demand Response > Parameters • Generator > Unit > Detail • Updates: Generator > Schedules > Detail Updates
Condense to Generation Time	Must be entered prior to 11 a.m. the day before the operating day	Generator > Unit > Detail

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Reserves Flexible Subzone Modeling

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Flexible Reserve Subzones

The Reserve Price Formation implementation introduced the ability to have Flexible Reserve Subzones to:

More dynamically adjust the reserve subzone to better reflect system conditions	Better enable reliable operations and result in market results that are more consistent with system operations

Only one subzone can be active at any given time and will be communicated in the Markets Gateway application

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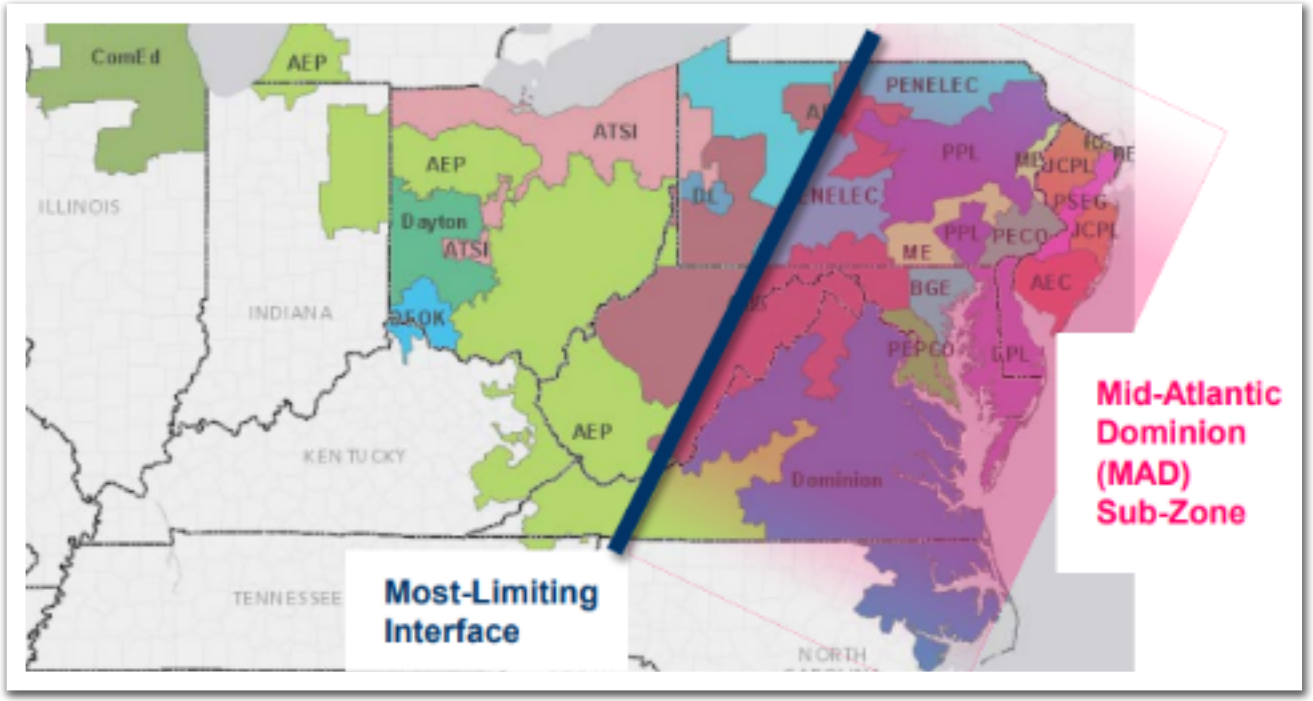
Flexible Reserve Subzone Modeling

PJM models two locations for the procurement of reserves:

RTO
Active Sub-Zone (MAD is Default)

- Each location has a Primary Reserve and Synchronous Reserve Requirement (MW)
- MAD reserve subzone is defined by the most-limiting reactive transfer interface
  - Intent is to procure reserves that will not overload critical constraints when reserves are deployed during a synchronized reserve event



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Creation of New Reserve Subzones

New reserve subzones can be defined for constraints in these three categories:

Reactive transfer interfaces (AP South, BED-BLA, etc.)	**230 KV or above actual overload constraint** (i.e. Conastone-Peach Bottom 500kV actual overload)	**Contingency overload exceeding the load dump limit on a 230kV or above facility**

New reserve subzones will be defined as far in advance as possible, and cannot be created on a same-day basis.

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Reserve Subzone Composition

Reserve subzones will be defined as all buses that have a 3% or greater (raise-help) distribution factor on the associated transmission constraint

- Definitions will be posted on Data Miner 2 via the Ancillary Services page of pjm.com
- Reserve subzone definitions will be re-evaluated and published quarterly or coincides with the network model builds

A resource may belong to multiple Reserve Subzones

- Resources assigned Reserve subzone and active subzone will reflect in Markets Gateway

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Determination of Active Subzones

As system conditions dictate, PJM may need to update the active subzone in the Reserve Markets

Active subzone for an operating day will be communicated via Active Subzone screen in Markets Gateway

By default, the 30-Minute Reserve Market will not model an active Reserve subzone	On an as needed basis, due to gas contingencies or other operational conditions, PJM may model an active Reserve subzone requirement for 30 Minute Reserves
	Activation of a Reserve subzone for 30-Minute Reserves will be done on a day ahead basis only

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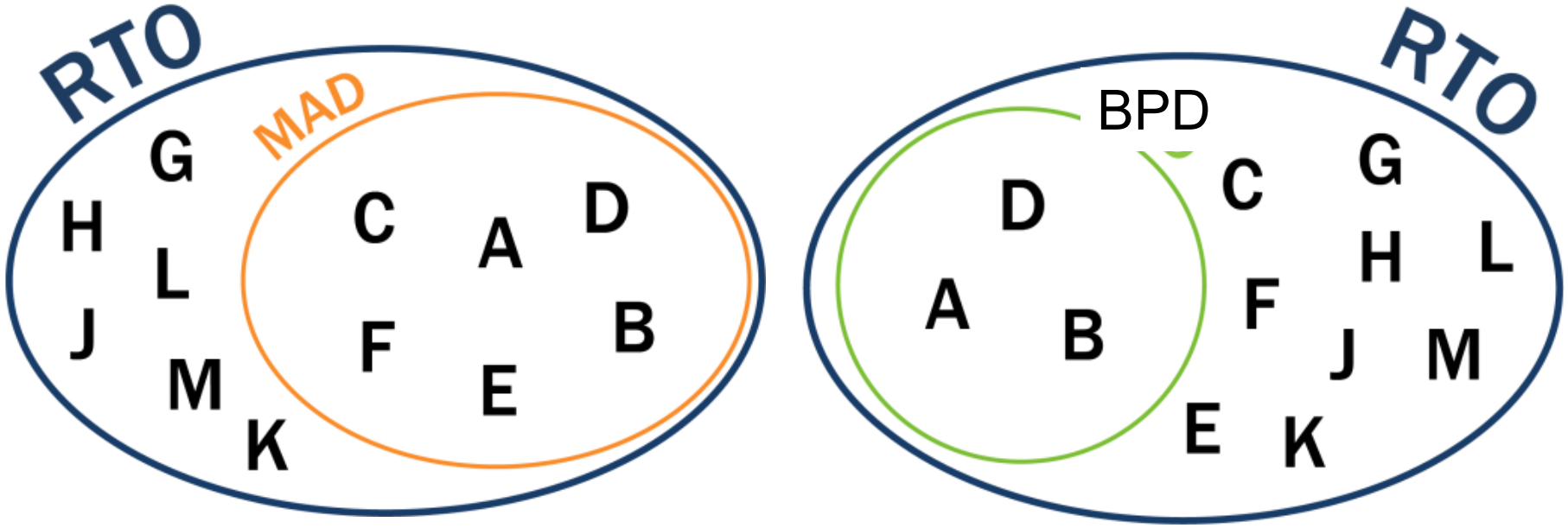
Communication of Active Subzones

Subzones will be modeled on a day-ahead basis and will apply for the entire operating day

• By default, the same subzone will be active in the Day-Ahead and Real-Time Markets	• Changes to the active reserve subzone can be made in real-time intraday on an exception basis	• Stakeholders will be notified of all intraday switches in the active reserve subzone via Markets Gateway	• Markets Gateway will reflect resource's assigned active subzone



*A-M represent resource locations

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Price Formation and Capping Rules

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Determination of Reserve Clearing Prices

Clearing Price		Calculation
30-Minute Reserve	=	Shadow Price of 30-Minute Reserve Requirement
Non-Synchronized Reserve	=	Shadow Price of Primary Reserve Requirement + Shadow Price of 30-Minute Reserve Requirement
Synchronized Reserve	=	Shadow Price of Synchronized Reserve Requirement + Shadow Price of Primary Reserve Requirement + Shadow Price of 30-Minute Reserve Requirement
Energy Price	=	Shadow Price of Power Balance Constraint (includes Reserve clearing price if marginal Energy MW comes from converting Reserve into Energy)

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Shortage Pricing

- Shortage Pricing refers to the market rules that govern how energy and reserve prices are calculated when there is not enough supply on the system to meet demand and reserve requirements.

- The goal is to provide clear, transparent pricing signals to the market indicating the current operating state of the system.

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Shortage Pricing Triggers

- Shortage Pricing will be triggered under either of the following conditions:
  - The amount of available reserves dips below the reserve requirement
    - Available Synchronized Reserve MW < Synchronized Reserve Requirement
    - Available Primary Reserve MW < Primary Reserve Requirement
    - Available 30 Minutes Reserve MW < 30 Minute Reserve Requirement
  - Voltage Reduction Action or Manual Load Dump Action is initiated
- Shortage pricing is triggered by location, by reserve zone

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Pricing Energy and Reserves

- Market Clearing Engines are simultaneously doing two things:
  - moving energy to where it is needed to meet the forecasted load, 10-mins ahead
  - calculating the available 10-min ramp capability required to meet the SR and PR requirements, and 30-min ramp capability to meet the 30-min requirement

- There can be instances when there is enough online generation capacity to meet the forecasted load, however not enough 10 minute ramp capability and/or offline resources with start up plus notification time of less than or equal to 10 minutes to move in order to meet the SR and/or PR requirements.

- Penalty factors from applicable ORDCs will only reflect in the LMP when the marginal energy MW is provided by converting a MW of assigned reserves on the marginal resource(s) to energy to serve the next MW of load.

Examples here illustrate: https://pjm.com/-/media/committees-groups/task-forces/epfstf/2022/20220316/20220316-item-03-pricing-impacts-of-reserve-shortages.ashx

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Energy Price Caps

Energy Component of LMP will be capped at the energy offer cap + 2 * Penalty Factor from first step of reserve ORDC

Max Energy Component $2,000 + 2*$850 = $3,700

Total LMPs can still rise above this level when factoring in locational congestion and loss prices.

Administrative Energy Price cap will be applied in Pricing run only.

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Reserve Price Capping

Administrative Reserve Price Capping will be implemented under Reserve Price Formation as below:

Synchronized Reserve Clearing price will be capped at 2*Penalty Factor	**$1,700**
Primary Reserve Clearing price will be capped at 1.5*Penalty Factor	**$1,275**
30 Min Reserve Clearing Price will be capped at 1*Penalty Factor	**$850**

Administrative Reserve Price Capping will be implemented in pricing run only.

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Reserve Markets Overview

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Appendix

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Submitting Reserve Availability

Reserve Market	Resource Type				
	Condensers	Other Gen*	Wind/Solar/ Nuclear	ESR/Hydro**	Economic Load Response
SR	Set Through Energy Offer			Yes, submit in Markets Gateway	
NSR				ESR is unavailable for NSR. Yes for Hydro	No - LR ineligible for NSR
SecR				Yes, submit in Markets Gateway	

*Non-Capacity Resources must be located internal to PJM
**ESR refers to resources utilizing the ESR participation model

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Self-Scheduling

Option	Reserve Market	Resource Type				
		Condensers	Other Gen	Wind/Solar/ Nuclear	ESR/Hydro	Economic Load Response
Self-Schedule Eligibility	SR	Yes				
	NSR	No				
	SecR					
Entering Self-Schedule MWs	SR	No, use PJM calculated capability			Yes, use Offer MW	
	NSR	N/A				
	SecR					

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Offer Parameters

Parameter	Reserve Market	Resource Type				
		Condensers	Other Gen	Wind/Solar/ Nuclear	ESR/Hydro	Economic Load Response
SR/SecR Max*	SR	Yes, if qualified via existing process				N/A
	NSR	N/A				
	SecR	Yes, if qualified via existing process				N/A
Offer MW	SR	No	No	No	Yes	Yes
	NSR	N/A			Yes (N/A ESR)	N/A
	SecR**	No	No	No	Yes	Yes
Offer Price	SR	Yes, cannot exceed expected value of penalty				
	NSR	N/A				
	SecR	N/A				

*SR Max and SecR Max are both able to be updated intra-hour; requests must be sent and approved by PJM and IMM

**Offer MW can be updated up to 65 mins prior to start of operating hour

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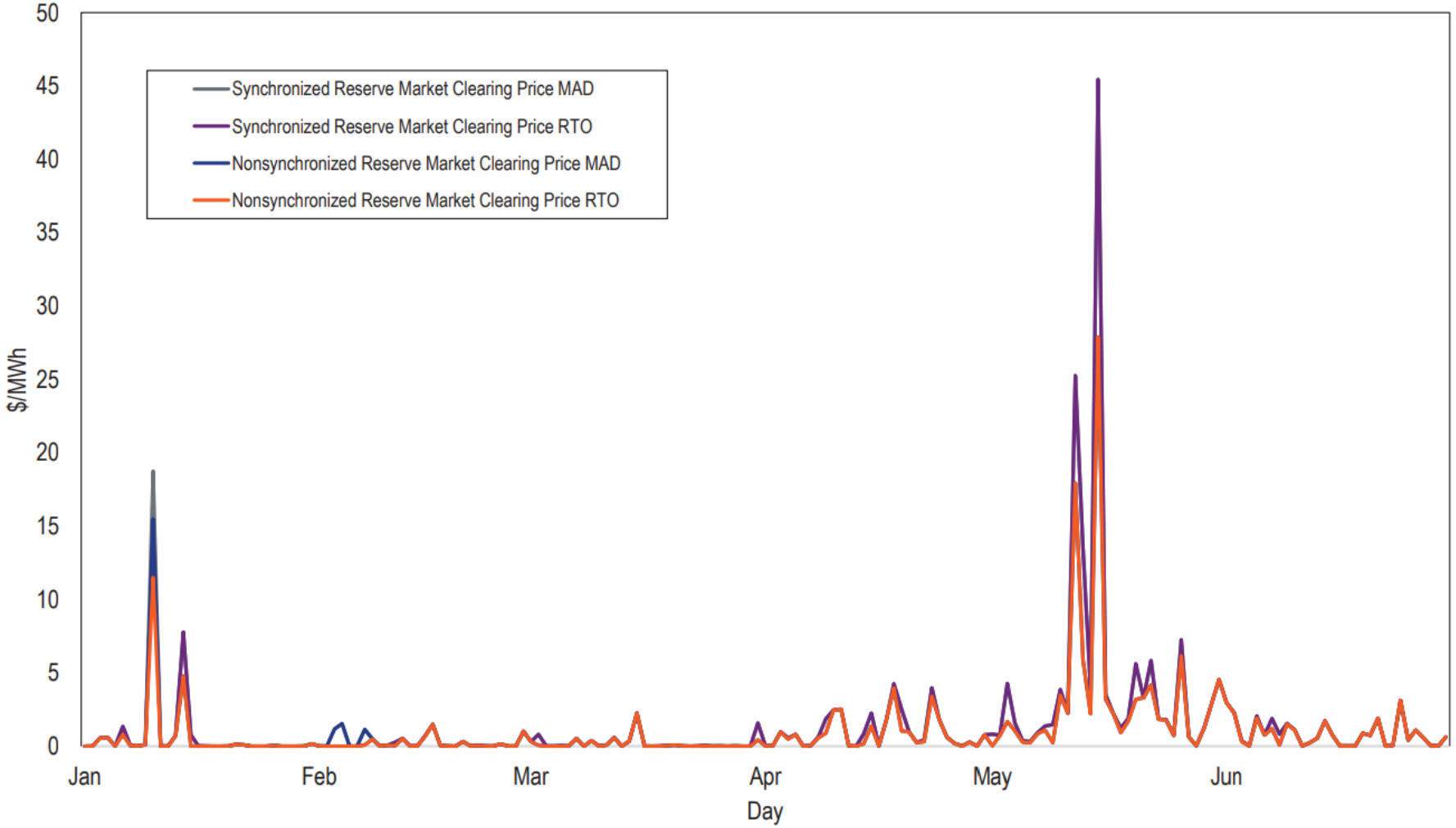
Real-Time Synch and Non-Synch Reserve Clearing Prices: January through June 2023



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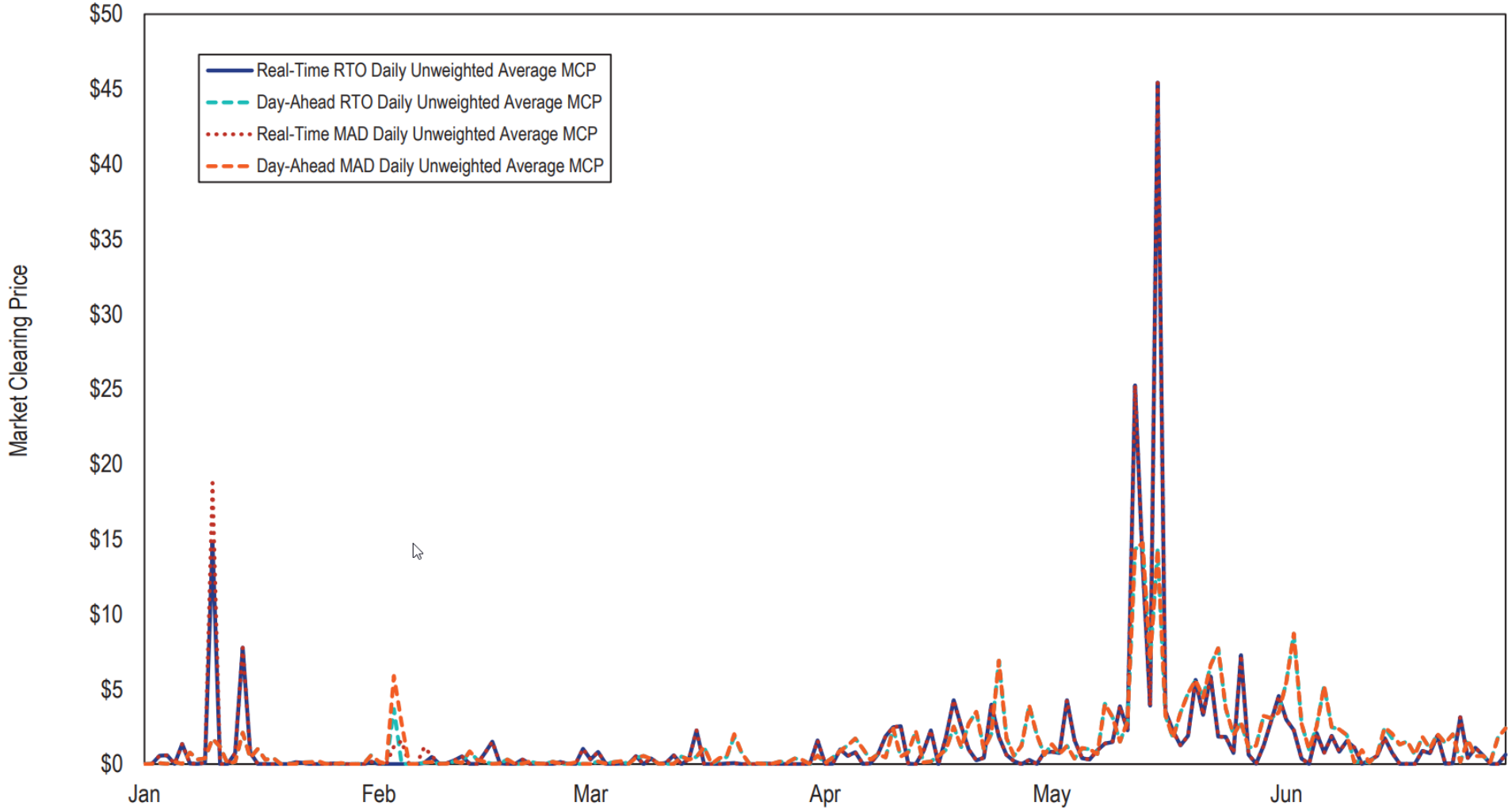
Day-Ahead and Real-Time Synchronized Reserve Market Clearing Prices – January through June 2023



Source: [Monitoring Analytics - 2023 Quarterly State of Market Report for PJM: January through June]

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