

Ancillary Service Markets

FERC defined six ancillary services in Order No. 888: scheduling, system control and dispatch; reactive supply and voltage control from generation service; regulation and frequency response service; energy imbalance service; operating reserve—synchronized reserve service; and operating reserve—supplemental reserve service.¹ PJM provides scheduling, system control and dispatch, and reactive on a cost basis. PJM provides regulation, energy imbalance, synchronized reserve, and supplemental reserve services through market mechanisms.² Although not defined by FERC as an ancillary service, black start service plays a comparable role. Black start service is provided on the basis of formula rates.

The MMU analyzed measures of market structure, conduct and performance for the PJM Synchronized Reserve Market, the PJM DADR Market, and the PJM Regulation Market in 2021.

Table 10-1 The tier 2 synchronized reserve market results were competitive

Market Element	Evaluation	Market Design
Market Structure: Regional Markets	Not Competitive	
Participant Behavior	Competitive	
Market Performance	Competitive	Mixed

- The tier 2 synchronized reserve market structure was evaluated as not competitive because of high levels of supplier concentration.
- Participant behavior was evaluated as competitive because the market rules require cost-based offers.
- Market performance was evaluated as competitive because the interaction of participant behavior with the market design results in competitive prices.
- Market design was evaluated as mixed. Market power mitigation rules result in competitive outcomes despite high levels of supplier concentration. However, tier 1 reserves are inappropriately overcompensated when the nonsynchronized reserve market clears with a nonzero price.

¹ 75 FERC ¶ 61,080 (1996).

² Energy imbalance service refers to the real-time energy market.

Table 10-2 The day-ahead scheduling reserve market results were competitive

Market Element	Evaluation	Market Design
Market Structure	Not Competitive	
Participant Behavior	Mixed	
Market Performance	Competitive	Mixed

- The DADR market structure was evaluated as not competitive because the DADR market failed the three pivotal supplier (TPS) test in 94 percent of the intervals in which the price was greater than \$0.01 per MWh.
- Participant behavior was evaluated as mixed because while most offers were equal to marginal costs, a significant proportion of offers reflected economic withholding.
- Market performance was evaluated as competitive because there were adequate offers in every hour to satisfy the requirement and the clearing prices reflected those offers, although there is concern about offers above the competitive level affecting prices. The day-ahead scheduling reserve market clearing price was above \$0 in 16.9 percent of hours in 2021. In 98.6 percent of hours when the clearing price was above \$0, the clearing price was the offer price of the marginal unit. In the remaining 1.4 percent of hours, the price included lost opportunity cost.
- Market design was evaluated as mixed because the DADR product does not include performance obligations. Offers should be based on opportunity cost only, to ensure competitive outcomes and that market power cannot be exercised.

Table 10-3 The regulation market results were not competitive

Market Element	Evaluation	Market Design
Market Structure	Not Competitive	
Participant Behavior	Competitive	
Market Performance	Not Competitive	Flawed

- The regulation market structure was evaluated as not competitive because the PJM Regulation Market failed the three pivotal supplier (TPS) test in 85.9 percent of the hours in 2021.
- Participant behavior in the PJM Regulation Market was evaluated as competitive in 2021 because market power mitigation requires competitive offers when the three pivotal supplier test is failed,

although the inclusion of a positive margin raises questions.

- Market performance was evaluated as not competitive, because all units are not paid the same price on an equivalent MW basis.
- Market design was evaluated as flawed. The market design has failed to correctly incorporate a consistent implementation of the marginal benefit factor in optimization, pricing and settlement. The market results continue to include the incorrect definition of opportunity cost. The result is significantly flawed market signals to existing and prospective suppliers of regulation.

Overview

Primary Reserve

PJM's primary reserves are made up of resources, both synchronized and nonsynchronized, that can provide energy within 10 minutes. Primary reserve is PJM's implementation of the NERC 15-minute contingency reserve requirement.³

PJM determines the primary reserve requirement based on the most severe single contingency plus 190 MW in every approved RT SCED case. Every real-time market solution calculates the available tier 1 synchronized reserve. The required synchronized reserve and nonsynchronized reserve are calculated and dispatched in every real-time market solution, and there are associated clearing prices (SRMCP and NSRMCP) assigned every five minutes. Scheduled resources are credited based on a dispatched assignment and a five minute clearing price.

Market Structure

- **Supply.** Primary reserve is satisfied by both synchronized reserve (generation or demand response currently synchronized to the grid and available within 10 minutes), and nonsynchronized reserve (generation currently off line but available to start and provide energy within 10 minutes).
- **Demand.** The PJM primary reserve requirement is 150 percent of the most severe single contingency plus 190 MW. In 2021, the average primary reserve

requirement was 2,449.6 MW in the RTO Zone and 2,436.4 in the MAD Subzone.

Tier 1 Synchronized Reserve

Synchronized reserve is provided by generators and demand response resources synchronized to the grid and capable of increasing output or decreasing load within 10 minutes in response to a PJM declared synchronized reserve event. Synchronized reserve consists of tier 1 and tier 2 synchronized reserves.

Tier 1 synchronized reserve is the capability of online resources following economic dispatch to ramp up in 10 minutes from their current output in response to a synchronized reserve event. There is no formal market for tier 1 synchronized reserve.

- **Supply.** No offers are made for tier 1 synchronized reserves. The market solution estimates tier 1 synchronized reserve as available 10 minute ramp from the energy dispatch. In 2021, there was an average hourly supply of 1,563.7 MW of tier 1 available in the RTO Zone and an average hourly supply of 788.2 MW of tier 1 synchronized reserve available within the MAD Subzone.
- **Demand.** The synchronized reserve requirement is calculated for each real-time dispatch solution as the most severe single contingency plus 190 MW within both the RTO Zone and the MAD Subzone.
- **Tier 1 Synchronized Reserve Event Response.** Tier 1 synchronized reserve is paid when a synchronized reserve event occurs and it responds. When a synchronized reserve event is called, all tier 1 response is paid for increasing its output (or reducing load for demand response) at the rate of \$50 per MWh in addition to LMP.⁴ This is the Synchronized Energy Premium Price.
- **Issues.** The competitive offer for tier 1 synchronized reserves is zero, as there is no incremental cost associated with the ability to ramp up from the current economic dispatch point and the appropriate payment for responding to an event is the synchronized energy premium price of \$50 per MWh. The tariff requires payment of the tier 2 synchronized reserve market clearing price to tier 1 resources whenever the nonsynchronized

³ See PJM, "Manual 10: Pre-Scheduling Operations," § 3.1.1 Day-ahead Scheduling (Operating Reserve, Rev. 40 (Dec. 15, 2021).

⁴ See PJM, "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.10 Settlements, Rev. 117 (Nov. 1, 2021).

reserve market clearing price rises above zero. This requirement is unnecessary and inconsistent with efficient markets. This rule has a significant impact on the cost of tier 1 synchronized reserves, resulting in a windfall payment of \$89,719,045 to tier 1 resources in 2014, \$34,397,441 in 2015, \$4,948,084 in 2016, \$2,197,514 in 2017, \$4,732,025 in 2018, \$3,217,178 in 2019, \$3,320,726 in 2020, and \$7,354,224 in 2021. The nonsynchronized reserve market clearing price was above \$0 in 2,015 intervals (1.9 percent of intervals) in 2020, none of which were during a spinning event. In 2021, the nonsynchronized reserve market clearing price was above \$0 in 2.9 percent of all intervals resulting in a net payment of \$7,364,936.

Tier 2 Synchronized Reserve Market

Tier 2 synchronized reserve is part of primary reserve and is comprised of resources that are synchronized to the grid, that may incur costs to be synchronized, and that have an obligation to respond to PJM declared synchronized reserve events. Tier 2 synchronized reserve is penalized for failure to respond to a PJM declared synchronized reserve event. In PJM the required amount of synchronized reserve is defined to be no less than the largest single contingency, and 10 minute primary reserve as no less than 150 percent of the largest single contingency, plus 190 MW. This is stricter than the NERC standard of the greater of 80 percent of the largest single contingency or 900 MW.⁵

When the synchronized reserve requirement cannot be met with tier 1 synchronized reserve, PJM uses the tier 2 synchronized reserve market to satisfy the balance of the requirement. The tier 2 synchronized reserve market includes the PJM RTO Reserve Zone and a subzone, the Mid-Atlantic Dominion Reserve Subzone (MAD).

Market Structure

- **Supply.** In 2021, the supply of daily offered and eligible tier 2 synchronized reserve was 36,355.7 MW in the RTO Zone of which 4,606.9 MW was located in the MAD Subzone.
- **Demand.** The average hourly synchronized reserve requirement was 1,697.1 MW in the RTO Reserve Zone and 1,696.5 in the Mid-Atlantic Dominion

Reserve Subzone. The hourly average cleared tier 2 synchronized reserve was 274.1 MW in the MAD Subzone and 720.5 MW in the RTO.

- **Market Concentration.** Both the Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Market and the RTO Synchronized Reserve Zone Market were characterized by structural market power in 2021.

The average HHI for tier 2 synchronized reserve in the RTO Zone was 3460 which is classified as highly concentrated.

Market Conduct

- **Offers.** There is a must offer requirement for tier 2 synchronized reserve. All nonemergency generation capacity resources are required to submit a daily offer for tier 2 synchronized reserve, unless the unit type is exempt. Tier 2 synchronized reserve offers from generating units are subject to an offer cap of marginal cost plus \$7.50 per MW, plus opportunity cost which is calculated by PJM. PJM automatically enters an offer of \$0 for tier 2 synchronized reserve when an offer is not entered by the owner. Demand resources offering into the tier 2 market are also subject to an offer cap of \$7.50 plus costs. Cost may include shutdown costs for demand response.⁶

Market Performance

- **Price.** The weighted average price for tier 2 synchronized reserve for all cleared hours in the MAD Subzone was \$7.32 per MW in 2021. The weighted average price for tier 2 synchronized reserve for all cleared intervals in the RTO Synchronized Reserve Zone was \$8.87 per MW in 2021.

Nonsynchronized Reserve Market

Nonsynchronized reserve is part of primary reserve and includes the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone (MAD). Nonsynchronized reserve is comprised of nonemergency energy resources not currently synchronized to the grid that can provide energy within 10 minutes. Nonsynchronized reserve is available to fill the primary reserve requirement above the synchronized reserve requirement. Generation owners do

⁵ NERC (June 2, 2020) <NERC Reliability Standard BAL 002-2 Glossary_of_Terms.pdf>.

⁶ Ref. PJM. "Manual 11: Energy & Ancillary Services Market Operations," Rev. 117 (Nov. 1, 2021), para. 4.2.1, p. 92

not submit supply offers for nonsynchronized reserve. PJM defines the demand curve for nonsynchronized reserve and PJM defines the supply curve based on nonemergency generation resources that are available to provide energy and can start in 10 minutes or less (based on offer parameters), and on the resource opportunity costs calculated by PJM.

Market Structure

- **Supply.** In 2021, the average supply of eligible and available nonsynchronized reserve was 1,414.6 MW in the RTO Zone.
- **Demand.** Demand for nonsynchronized reserve equals the primary reserve requirement minus the tier 1 synchronized reserve estimate and minus the scheduled tier 2 synchronized reserve.⁷
- **Market Concentration.** The MMU calculates that the three pivotal supplier test would have been failed in 99.96 percent of intervals where the price was above \$0.01 in 2021.

Market Conduct

- **Offers.** Generation owners do not submit supply offers. Nonemergency generation resources that are available to provide energy and can start in 10 minutes or less are considered available for nonsynchronized reserves by the market solution software. PJM calculates the associated offer prices based on PJM calculations of resource specific opportunity costs.

Market Performance

- **Price.** The nonsynchronized reserve price is determined by the opportunity cost of the marginal nonsynchronized reserve unit. The nonsynchronized reserve weighted average price for all intervals in the RTO Reserve Zone was \$0.31 per MW in 2021.

Secondary Reserve (DASR)

There is no NERC standard for secondary reserve. PJM defines secondary reserve in the day-ahead market as reserves (online or offline available for dispatch) that

can be converted to energy in 30 minutes. PJM defines a secondary reserve requirement but is not required to maintain this level of secondary reserve in real time.

PJM maintains a day-ahead, offer-based market for 30 minute day-ahead secondary reserve. The PJM Day-Ahead Scheduling Reserve Market (DASR) has no performance obligations except that a unit which clears the DASR market may not be on an outage in real time.⁸ If DASR units are on an outage in real time or cleared DASR MW are not available, the DASR payment is not made.

Market Structure

- **Supply.** The DASR market is a must offer market. Any resources that do not make an offer have their offer set to \$0.00 per MW. DASR is calculated by the day-ahead market solution as the lesser of the 30 minute energy ramp rate or the economic maximum MW minus the day-ahead dispatch point for all resources that can provide energy within 30 minutes of a request from PJM Dispatch.
- **Demand.** The DASR requirement is the sum of the PJM requirement and the Dominion requirement based on the VACAR reserve sharing agreement. It is calculated every year for the period November 1 through October 31. For November 1, 2020, through October 31, 2021, the DASR requirement was 4.75 percent of peak load forecast. For November 1, 2021, through October 31, 2022, the DASR requirement is 4.40 percent of peak load forecast. The average hourly DASR MW purchased in 2021 was 4,389.5 MW, a reduction from the 4,611.6 hourly MW in 2020.

Market Conduct

- **Withholding.** Economic withholding remains an issue in the DASR Market. The direct marginal cost of providing DASR is zero. PJM calculates the opportunity cost for each resource. All offers by resource owners greater than zero constitute economic withholding. In 2021, 45.3 percent of daily unit offers were above \$0.00 and 17.8 percent of daily unit offers were above \$5.

⁷ See PJM, "Manual 11: Energy & Ancillary Services Market Operations," § 4b.2.2 Non-Synchronized Reserve Zones and Levels, Rev. 117 (Nov. 1, 2021). "Because Synchronized Reserve may be utilized to meet the Primary Reserve requirement, there is no explicit requirement for non-synchronized reserves."

⁸ See PJM, "Manual 11: Energy & Ancillary Services Market Operations," § 11.2.7 Day-Ahead Scheduling Reserve Performance, Rev. 117 (Nov. 1, 2021).

- **DR.** Demand resources are eligible to participate in the DASR Market. Some demand resources have entered offers for DASR. No demand resources cleared the DASR market in 2021.

Market Performance

- **Price.** In 2021, the MW weighted average DASR price for all hours when the DASRMCP was above \$0.00 was \$1.27. The MW weighted average for all hours including hours when the price was \$0 was \$0.24.

Regulation Market

The PJM Regulation Market is a real-time market. Regulation is provided by generation resources and demand response resources that qualify to follow one of two regulation signals, RegA or RegD. PJM jointly optimizes regulation with synchronized reserve and energy to provide all three products at least cost. The PJM regulation market design includes three clearing price components: capability; performance; and opportunity cost. The RegA signal is designed for energy unlimited resources with physically constrained ramp rates. The RegD signal is designed for energy limited resources with fast ramp rates. In the regulation market RegD MW are converted to effective MW using a marginal rate of technical substitution (MRTS), called a marginal benefit factor (MBF). Correctly implemented, the MBF would be the marginal rate of technical substitution (MRTS) between RegA and RegD, holding the level of regulation service constant. The current market design is critically flawed as it has not properly implemented the MBF as an MRTS between RegA and RegD resource MW and the MBF has not been consistently applied in the optimization, clearing and settlement of the regulation market.

Market Structure

- **Supply.** In 2021, the average hourly offered supply of regulation for nonramp hours was 740.8 performance adjusted MW (744.9 effective MW). This was an increase of 19.9 performance adjusted MW (an increase of 23.7 effective MW) from 2020. In 2021, the average hourly offered supply of regulation for ramp hours was 1,066.4 performance adjusted MW (1,094.9 effective MW). This was an increase of 49.0 performance adjusted MW (an increase of 36.0 effective MW) from 2020, when the average

hourly offered supply of regulation was 1,017.4 performance adjusted MW (1,058.9 effective MW).

- **Demand.** The hourly regulation demand is 525.0 effective MW for nonramp hours and 800.0 effective MW for ramp hours.
- **Supply and Demand.** The nonramp regulation requirement of 525.0 effective MW was provided by a combination of RegA and RegD resources equal to 481.6 hourly average performance adjusted actual MW in 2021. This is an increase of 10.4 performance adjusted actual MW from 2020, when the average hourly total regulation cleared performance adjusted actual MW for nonramp hours were 492.0 performance adjusted actual MW. The ramp regulation requirement of 800.0 effective MW was provided by a combination of RegA and RegD resources equal to 707.3 hourly average performance adjusted actual MW in 2021. This is an increase of 4.9 performance adjusted actual MW from 2020, where the average hourly regulation cleared MW for ramp hours were 702.5 performance adjusted actual MW.

The ratio of the average hourly offered supply of regulation to average hourly regulation demand (performance adjusted cleared MW) for ramp hours was 1.51 in 2021 (1.45 in 2020). The ratio of the average hourly offered supply of regulation to average hourly regulation demand (performance adjusted cleared MW) for nonramp hours was 1.54 in 2021 (1.47 in 2020).

- **Market Concentration.** In 2021, the three pivotal supplier test was failed in 85.9 percent of hours. In 2021, the actual MW weighted average HHI of RegA resources was 2215 which is highly concentrated and the weighted average HHI of RegD resources was 1585 which is moderately concentrated. The weighted average HHI of all resources was 1205, which is moderately concentrated.

Market Conduct

- **Offers.** Daily regulation offer prices are submitted for each unit by the unit owner. Owners are required to submit a cost-based offer and may submit a price-based offer. Offers include both a capability offer and a performance offer. Owners must specify which signal type the unit will be following, RegA or

RegD.⁹ In 2021, there were 237 resources following the RegA signal and 53 resources following the RegD signal.

Market Performance

- **Price and Cost.** The weighted average clearing price for regulation was \$26.00 per MW of regulation in 2021, an increase of \$12.45 per MW, or 91.9 percent, from the weighted average clearing price of \$13.55 per MW in 2020. The weighted average cost of regulation in 2021 was \$31.49 per MW of regulation, an increase of 88.2 percent, from the weighted average cost of \$16.73 per MW in 2020.
- **Prices.** RegD resources continue to be incorrectly compensated relative to RegA resources due to an inconsistent application of the marginal benefit factor in the optimization, assignment and settlement processes. If the regulation market were functioning efficiently and competitively, RegD and RegA resources would be paid the same price per effective MW.
- **Marginal Benefit Factor.** The marginal benefit factor (MBF) is intended to measure the operational substitutability of RegD resources for RegA resources. The marginal benefit factor is incorrectly defined and applied in the PJM market clearing. The current incorrect and inconsistent implementation of the MBF has resulted in the PJM Regulation Market over procuring RegD relative to RegA in most hours and in an inefficient market signal about the value of RegD in every hour.

Black Start Service

Black start service is required for the reliable restoration of the grid following a blackout. Black start service is the ability of a generating unit to start without an outside electrical supply, or is the demonstrated ability of a generating unit to automatically remain operating at reduced levels when disconnected from the grid (automatic load rejection or ALR).¹⁰

In 2021, total black start charges were \$68.0 million, including \$67.6 million in revenue requirement charges and \$0.3 million in uplift charges. Black start revenue requirements consist of fixed black start service costs,

variable black start service costs, training costs, fuel storage costs, and an incentive payment. Black start uplift charges are paid to units scheduled in the day-ahead energy market or committed in real time to provide black start service under the ALR option or for black start testing. Black start zonal charges in 2021 ranged from \$43,630 in the BGE Zone to \$19,803,649 in the AEP Zone.

CRF values are a key determinant of total payments to black start units. The CRF values in PJM tariff tables should have been changed for both black start and the capacity market when the tax laws changed in December 2017. As a result, CRF values have overcompensated black start units since the changes to the tax code.

Reactive

Reactive service, reactive supply and voltage control are provided by generation and other sources of reactive power (measured in MVar). Reactive power helps maintain appropriate voltage levels on the transmission system and is essential to the flow of real power (measured in MW). The same equipment provides both MVar and MW. The current rules permit double recovery of some fixed costs.

Reactive capability charges are based on FERC approved filings that permit recovery based on an outdated cost of service approach.¹¹ All capacity costs of generators should be incorporated in the capacity market. The nonmarket cost of service approach to reactive capability payments should be eliminated. Reactive service charges are paid to units that operate in real time outside of their normal range at the direction of PJM for the purpose of providing reactive service. Total reactive charges increased 6.19 percent from \$346.4 million in 2020 to \$367.8 million in 2021. Reactive capability charges increased 6.06 percent from \$346.0 million in 2020 to \$367.0 million in 2021. Total reactive service charges in 2021 ranged from \$0 in the REC and OVEC Zones, to \$49.2 million in the AEP Zone.

Frequency Response

On February 15, 2018, the Commission issued Order No. 842, which modified the pro forma large and small generator interconnection agreements and procedures

⁹ See the 2019 State of the Market Report for PJM, Vol. II, Appendix F "Ancillary Services Markets."
¹⁰ OATT Schedule 1 § 1.3BB. There are no ALR units currently providing black start service.

¹¹ OATT Schedule 2.

to require newly interconnecting generating facilities, both synchronous and nonsynchronous, to include equipment for primary frequency response capability as a condition to receive interconnection service.¹² PJM filed revisions in compliance with Order No. 842 that incorporated the pro forma agreements into its market rules.¹³

The PJM Tariff requires that all new generator interconnection customers (Nuclear Regulatory Commission regulated facilities are exempt from this provision) have hardware and/or software that provides frequency responsive real power control with the ability to sense changes in system frequency and autonomously adjust real power output in a direction to correct for frequency deviations. This includes a governor or equivalent controls capable of operating with a maximum five percent droop and a +/- 0.036 deadband.¹⁴ In addition to resource capability, resource owners must comply by setting control systems to autonomously adjust real power output in a direction to correct for frequency deviations.

The response of generators within PJM to NERC identified frequency events remains under evaluation. A frequency event is declared when the frequency goes outside 60 Hz +/- 40 mHz for 60 continuous seconds. The NERC BAL-003-2 requirement for balancing authorities (PJM is a balancing authority) uses a threshold value (L_{10}) equal to -259.3 MW/0.1 Hz and has selected twelve frequency events between December 1, 2020, and November 30, 2021, to evaluate.

As a balancing authority, PJM requires all generators to be capable of providing primary frequency response and to operate with primary frequency response controls enabled. PJM does monitor primary frequency response during NERC identified frequency events for all resources 50 MW or greater. Exclusions to PJM monitoring include nuclear plants, offline units, units with no available headroom, units assigned to regulation, and units with a current outage ticket in eDART.

¹² See 157 FERC ¶ 61,122 (2016).

¹³ See 164 FERC ¶ 61,224 (2018).

¹⁴ OATT Attachment O § 4.7.2 (Primary Frequency Response).

Ancillary Services Costs per MWh of Load

Table 10-4 shows PJM ancillary services costs for 1999 through 2021, per MWh of load. The rates are calculated as the total charges for the specified ancillary service divided by the total PJM real-time load in MWh.¹⁵ The scheduling, system control, and dispatch category of costs is comprised of PJM scheduling, PJM system control and PJM dispatch; owner scheduling, owner system control and owner dispatch; other supporting facilities; black start services; direct assignment facilities; and ReliabilityFirst Corporation charges. The cost per MWh of load in Table 10-4 is a different metric than the cost of each ancillary service per MW of that service. The cost per MWh of load includes the effects both of price changes per MW of the ancillary service and changes in total load.

Table 10-4 History of ancillary services costs per MWh of load: 1999 through 2021^{16 17}

Year	Scheduling, Dispatch and		Synchronized		Total
	Regulation	System Control	Reactive	Reserve	
1999	\$0.15	\$0.23	\$0.26	\$0.00	\$0.64
2000	\$0.39	\$0.26	\$0.29	\$0.00	\$0.94
2001	\$0.53	\$0.71	\$0.22	\$0.00	\$1.46
2002	\$0.42	\$0.86	\$0.20	\$0.01	\$1.49
2003	\$0.50	\$1.05	\$0.24	\$0.15	\$1.94
2004	\$0.51	\$0.93	\$0.26	\$0.13	\$1.83
2005	\$0.80	\$0.72	\$0.26	\$0.11	\$1.89
2006	\$0.53	\$0.74	\$0.29	\$0.08	\$1.64
2007	\$0.63	\$0.72	\$0.29	\$0.06	\$1.70
2008	\$0.70	\$0.38	\$0.34	\$0.08	\$1.50
2009	\$0.34	\$0.29	\$0.36	\$0.05	\$1.04
2010	\$0.36	\$0.35	\$0.45	\$0.07	\$1.23
2011	\$0.32	\$0.36	\$0.41	\$0.09	\$1.18
2012	\$0.26	\$0.41	\$0.46	\$0.04	\$1.17
2013	\$0.25	\$0.41	\$0.76	\$0.04	\$1.46
2014	\$0.33	\$0.42	\$0.40	\$0.12	\$1.27
2015	\$0.23	\$0.42	\$0.37	\$0.11	\$1.13
2016	\$0.11	\$0.41	\$0.38	\$0.05	\$0.95
2017	\$0.14	\$0.47	\$0.42	\$0.06	\$1.09
2018	\$0.18	\$0.46	\$0.40	\$0.06	\$1.10
2019	\$0.12	\$0.46	\$0.43	\$0.04	\$1.05
2020	\$0.10	\$0.46	\$0.47	\$0.03	\$1.06
2021	\$0.19	\$0.49	\$0.48	\$0.08	\$1.24

¹⁵ The total prices in this table are a load-weighted, average system price per MWh by category, even if each category is not charged on that basis. These totals are presented for informational purposes and should not be used to calculate the costs of any specific market activity in PJM.

¹⁶ Note: The totals in Table 10-4 account for after the fact billing adjustments made by PJM and may not match totals presented in past reports.

¹⁷ Reactive totals include FERC approved rates for reactive capability.

Market Procurement of Real Time Ancillary Services

PJM uses market mechanisms to varying degrees in the procurement of ancillary services, including primary reserves and regulation. Ideally, all ancillary services would be procured taking full account of the interactions with the energy market. When a resource is used for an ancillary service instead of providing energy in real time, the cost of removing the resource, either fully or partially, from the energy market should be weighed against the benefit the ancillary service provides. The degree to which PJM markets account for these interactions depends on the timing of the product clearing and software limitations and the accuracy of unit parameters and offers.

The synchronized reserve market clearing is more integrated with the energy market clearing than the other ancillary services. Resources categorized as flexible tier 2 reserve, those that can provide reserves by backing down according to their ramp rate, are jointly cleared along with energy in every real-time market solution. Given the joint clearing of energy and flexible tier 2, the synchronized reserve market clearing price should always cover the opportunity cost of providing flexible tier 2. PJM should never need to pay uplift to flexible tier 2. The uplift paid to flexible tier 2 results from issues with the dispatch and pricing software timing. Inflexible tier 2 reserves, provided by resources that require longer notice to take actions to prepare for reserve deployment, are not cleared along with energy in the real-time market solution. Inflexible tier 2 reserves are cleared hourly by the Ancillary Service Optimizer (ASO). The ASO uses forward looking information about the energy market, flexible tier 2, tier 1, and regulation to estimate the costs and benefits of using a resource for inflexible tier 2 synchronized reserves.

Nonsynchronized reserves are cleared with every real-time energy market solution, but their costs are not fully known by the real-time energy market software (RT SCED) because the resources are offline. PJM uses an estimate of the cost of using a resource for nonsynchronized reserve instead of energy from a previously solved IT SCED solution. IT SCED runs every 15 minutes looking ahead at target dispatch times up to two hours in the future. The energy commitment decisions for the offline resources have already been made when the RT SCED

clears the nonsynchronized reserve market. RT SCED compares the IT SCED estimated cost of nonsynchronized reserve clearing to the RT SCED determined cost of synchronized reserve clearing in satisfying the primary reserve requirement. Nonsynchronized reserve clearing indirectly interacts with energy clearing through both products' substitutability with synchronized reserves.

Prices for the regulation and reserve markets are set by the pricing calculator (LPC), which uses the RT SCED solution as an input. The RT SCED is partially, but not fully clearing the reserve market. The software determining the prices is not clearing the regulation market. With fast start pricing implementation on September 1, 2021, the pricing calculations in LPC are not the same prices that result from the market clearing in RT SCED.

Recommendations

- The MMU recommends that all data necessary to perform the regulation market three pivotal supplier test be saved by PJM so that the test can be replicated. (Priority: Medium. First reported 2016. Status: Not adopted.)
- The MMU recommends that the total regulation (TReg) signal sent on a fleet wide basis be eliminated and replaced with individual regulation signals for each unit. (Priority: Low. First reported 2019. Status: Not adopted.)
- The MMU recommends that the ability to make dual offers (to make offers as both a RegA and a RegD resource in the same market hour) be removed from the regulation market. (Priority: High. First reported 2019. Status: Not adopted.)
- The MMU recommends that the regulation market be modified to incorporate a consistent application of the marginal benefit factor (MBF) throughout the optimization, assignment and settlement process. The MBF should be defined as the Marginal Rate of Technical Substitution (MRTS) between RegA and RegD. (Priority: High. First reported 2012. Status: Not adopted. FERC rejected.¹⁸)
- The MMU recommends that the lost opportunity cost in the ancillary services markets be calculated using the schedule on which the unit was scheduled to run

¹⁸ 162 FERC ¶ 61,295 (2018), *reh'g denied*, 170 FERC ¶ 61,259 (2020).

in the energy market. (Priority: High. First reported 2010. Status: Not adopted.¹⁹ FERC rejected.²⁰)

- The MMU recommends that the lost opportunity cost calculation used in the regulation market be based on the resource's dispatched energy offer schedule, not the lower of its price or cost offer schedule. (Priority: Medium. First reported 2010. Status: Not adopted. FERC rejected.²¹)
- The MMU recommends that, to prevent gaming, there be a penalty enforced in the regulation market as a reduction in performance score and/or a forfeiture of revenues when resource owners elect to deassign assigned regulation resources within the hour. (Priority: Medium. First reported 2016. Status: Not adopted. FERC rejected.²²)
- The MMU recommends enhanced documentation of the implementation of the regulation market design. (Priority: Medium. First reported 2010. Status: Not adopted. FERC rejected.²³)
- The MMU recommends that PJM be required to save data elements necessary for verifying the performance of the regulation market. (Priority: Medium. First reported 2010. Status: Not adopted.)
- The MMU recommends that the \$12.00 margin adder be eliminated from the definition of the cost based regulation offer because it is a markup and not a cost. (Priority: Medium. First reported Q1, 2021. Status: Not adopted.)
- The MMU recommends that PJM replace the static MidAtlantic/Dominion Reserve Subzone with a reserve zone structure consistent with the actual deliverability of reserves based on current transmission constraints. (Priority: High. First reported 2019. Status: Not adopted.)
- The MMU recommends that the \$7.50 margin be eliminated from the definition of the cost of tier 2 synchronized reserve because it is a markup and not a cost. (Priority: Medium. First reported 2018. Status: Not adopted.)

- The MMU recommends that the variable operating and maintenance cost be eliminated from the definition of the cost of tier 2 synchronized reserve and that the calculation of synchronized reserve variable operations and maintenance costs be removed from Manual 15. (Priority: Medium. First reported 2019. Status: Not adopted.)
- The MMU recommends that the components of the cost-based offers for providing regulation and synchronous condensing be defined in Schedule 2 of the Operating Agreement. (Priority: Low. First reported 2019. Status: Not adopted.)
- The MMU recommends that the rule requiring that tier 1 synchronized reserve resources be paid the tier 2 price when the nonsynchronized reserve price is above zero be eliminated immediately and that, under the current rule, tier 1 synchronized reserve resources not be paid the tier 2 price when they do not respond. (Priority: High. First reported 2013. Status: Not adopted.)
- The MMU recommends that the tier 2 synchronized reserve must offer requirement be enforced on a daily and hourly basis. The MMU recommends that PJM define a set of acceptable reasons why a unit can be made unavailable daily or hourly and require unit owners to select a reason in Markets Gateway whenever making a unit unavailable either daily or hourly or setting the offer MW to 0 MW. (Priority: Medium. First reported 2013. Status: Partially adopted.)
- The MMU recommends that, for calculating the penalty for a tier 2 resource failing to meet its scheduled obligation during a spinning event, the penalty should be based on the actual time since the last spinning event of 10 minutes or longer during which the resource performed because performance is only measured for events 10 minutes or longer. (Priority: Medium. First reported 2018. Status: Not adopted.)
- The MMU recommends that aggregation not be permitted to offset unit specific penalties for failure to respond to a synchronized reserve event. (Priority: Medium. First reported 2018. Status: Not adopted.)
- The MMU recommends that PJM eliminate the use of Degree of Generator Performance (DGP) in the synchronized reserve market solution and improve the actual tier 1 estimate. If PJM continues to use

¹⁹ This recommendation was adopted by PJM for the energy market. Lost opportunity costs in the energy market are calculated using the schedule on which the unit was scheduled to run. In the regulation market, this recommendation has not been adopted, as the LOC continues to be calculated based on the lower of price or cost in the energy market offer.

²⁰ 162 FERC ¶ 61,295 (2018), *reh'g denied*, 170 FERC ¶ 61,259 (2020).

²¹ *Id.*

²² *Id.*

²³ *Id.*

DGP, DGP should be documented in PJM's manuals. (Priority: Medium. First reported 2018. Status: Not adopted.)

- The MMU recommends that the details of VACAR Reserve Sharing Agreement (VRSA) be made public, including any responsibilities assigned to PJM and including the amount of reserves that Dominion commits to meet its obligations under the VRSA. (Priority: Medium. First reported 2020. Status: Not adopted.)
- The MMU recommends that the VRSA be terminated and, if necessary, replaced by a reserve sharing agreement between PJM and VACAR South, similar to agreements between PJM and other bordering areas. (Priority: Medium. First reported 2020. Status: Not adopted.)
- The MMU recommends that a reason code be attached to every hour in which PJM market operations adds additional DASR MW. (Priority: Medium. First reported 2015. Status: Not adopted.)
- The MMU recommends that PJM modify the DASR market to ensure that all resources cleared incur a real-time performance obligation. (Priority: Low. First reported 2013. Status: Not adopted.)
- The MMU recommends that, in order to mitigate market power, offers in the DASR market be based on opportunity cost only. (Priority: Low. First reported 2009. Modified, 2018. Status: Not adopted.)
- The MMU recommends that all resources, new and existing, have a requirement to include and maintain equipment for primary frequency response capability as a condition of interconnection service. The PJM capacity and energy markets already compensate resources for frequency response capability and any marginal costs. (Priority: Medium. First reported 2018. Status: Not adopted.)
- The MMU recommends that new CRF rates for black start units, incorporating current tax code changes, be implemented immediately. The new CRF rates should apply to all black start units. The black start units should be required to commit to providing black start service for the life of the unit. (Priority: High. First reported 2020. Status: Not adopted.)
- The MMU recommends for oil tanks shared with other resources that only a proportionate share of the minimum tank suction level (MTSL) be allocated

to black start service. The MMU further recommends that the PJM tariff be updated to clearly state how the MTSL will be calculated for black start units sharing oil tanks. (Priority: Medium. First reported 2017. Status: Adopted 2021.)

- The MMU recommends that separate cost of service payments for reactive capability be eliminated and the cost of reactive capability be recovered in the capacity market. (Priority: Medium. First reported 2016. Status: Not adopted.)
- The MMU recommends that payments for reactive capability, if continued, be based on the 0.90 power factor that PJM has determined is necessary. (Priority: Medium. First reported 2018. Status: Not adopted.)
- The MMU recommends that, if payments for reactive are continued, fleet wide cost of service rates used to compensate resources for reactive capability be eliminated and replaced with compensation based on unit specific costs. (Priority: Low. First reported 2019.²⁴ Status: Partially adopted.)
- The MMU recommends that Schedule 2 to OATT be revised to state explicitly that only generators that provide reactive capability to the transmission system that PJM operates and has responsibility for are eligible for reactive capability compensation. Specifically, such eligibility should be determined based on whether a generation facility's point of interconnection is on a transmission line that is a Monitored Transmission Facility as defined by PJM and is on a Reportable Transmission Facility as defined by PJM.²⁵ (Priority: Medium. First reported 2020. Status: Not adopted.)

Conclusion

The design of the PJM Regulation Market is significantly flawed.²⁶ The market design does not correctly incorporate the marginal rate of technical substitution (MRTS) in market clearing and settlement. The market design uses the marginal benefit factor (MBF) to incorrectly represent the MRTS and uses a mileage ratio instead of the MBF

²⁴ The MMU has discussed this recommendation in state of the market reports since 2016 but Q3, 2019 was the first time it was reported as a formal MMU recommendation.

²⁵ See PJM Transmission Facilities (note that this requires you first log into a PJM Tools account. If you do not, then the link sends you to an Access Request page, <<https://pjm.com/markets-and-operations/ops-analysis/transmission-facilities>>).

²⁶ The current PJM regulation market design that incorporates two signals using two resource types was a result of FERC Order No. 755 and subsequent orders. Order No. 755, 137 FERC ¶ 61,064 at PP 197–200 (2011).

in settlement. This failure to correctly and consistently incorporate the MRTS into the regulation market design has resulted in both underpayment and overpayment of RegD resources and in the over procurement of RegD resources in all hours. The market results continue to include the incorrect definition of opportunity cost. These issues are the basis for the MMU's conclusion that the regulation market design is flawed.

To address these flaws, the MMU and PJM developed a joint proposal which was approved by the PJM Members Committee on July 27, 2017, and filed with FERC on October 17, 2017.²⁷ The PJM/MMU joint proposal addresses issues with the inconsistent application of the marginal benefit factor throughout the optimization and settlement process in the PJM Regulation Market. FERC rejected the joint proposal on March 30, 2018, as being noncompliant with Order No. 755.²⁸ The MMU and PJM separately filed requests for rehearing, which were denied by order issued March 26, 2020.²⁹

The structure of the tier 2 synchronized reserve market has been evaluated and the MMU has concluded that these markets are not structurally competitive as they are characterized by high levels of supplier concentration and inelastic demand. As a result, these markets are operated with market clearing prices and with offers based on the marginal cost of producing the product plus a margin. As a result of these requirements, the conduct of market participants within these market structures has been consistent with competition, and the market performance results have been competitive. However, the \$7.50 margin is not a cost. The margin is effectively a rule-based form of economic withholding and is therefore not consistent with a competitive outcome. The \$7.50 margin should be eliminated. The variable operating and maintenance component of the synchronized reserve offer should also be eliminated. All variable operating and maintenance costs are incurred to provide energy and to make units available to provide energy. There are no variable operating and maintenance costs associated with providing synchronized reserve. Reserve market design changes approved by FERC and scheduled for implementation in October 2022 will

eliminate the \$7.50 per MW margin and the variable operations and maintenance costs.³⁰

Participant performance has not been adequate for tier 2 synchronized reserve. Compliance with calls to respond to actual synchronized reserve events remains significantly less than 100 percent. Actual participant performance means that the penalty structure is not an adequate incentive for performance. The October 2022 reserve market design changes do not respond to the MMU's recommendations to increase the penalties for nonperformance. All synchronized reserves should also have the same obligation to perform, but the proposed changes will mean that not all cleared reserves will be called on to perform during synchronized reserve events.³¹

The rule that requires payment of the tier 2 synchronized reserve price to tier 1 synchronized reserve resources when the nonsynchronized reserve price is greater than zero, is inefficient and results in a substantial windfall payment to the holders of tier 1 synchronized reserve resources. Tier 1 resources have no obligation to perform and pay no penalties if they do not perform, and tier 1 resources do not incur any costs when they are part of the tier 1 estimate in the market solution. Tier 1 resources are already paid for their response if they do respond to a synchronized reserve event. Tier 1 resources require no additional payment. If tier 1 resources wish to be paid as tier 2 resources, the rules provide the opportunity to make competitive offers in the tier 2 market and take on the associated obligations. Overpayment of tier 1 resources based on this rule has added more than \$100 million to the cost of primary reserve since 2014. The reserve market design changes approved by FERC and scheduled for implementation in 2022 will consolidate Tier 1 and Tier 2 reserves into a single synchronized reserve product, with a stronger must offer requirement and a single clearing price.³² This will eliminate the payment of Tier 1 based on the nonzero nonsynchronized reserve price.

The benefits of markets are realized under these approaches to ancillary service markets. Even in the presence of structurally noncompetitive markets, there

27 18 CFR § 385.211.

28 162 FERC ¶ 61,295 (2018).

29 170 FERC ¶ 61,259 (2020).

30 See FERC Docket No. EL19-58.

31 See PJM, "Intelligent Reserve Deployment - PJM Package (SRDTE)," Presentation to the Members Committee (January 26, 2022), <<https://pjm.com/-/media/committees-groups/committees/mc/2022/20220126/20220126-cac-1-synchronous-reserve-deployment-presentation.ashx>>.

32 See FERC Docket No. EL19-58.

can be transparent, market clearing prices based on competitive offers that account explicitly and accurately for opportunity cost. This is consistent with the market design goal of ensuring competitive outcomes that provide appropriate incentives without reliance on the exercise of market power and with explicit mechanisms to prevent the exercise of market power.

The MMU concludes that the regulation market results were not competitive, and the market design is significantly flawed. The MMU concludes that the synchronized reserve market results were competitive, although the \$7.50 margin should be removed. The MMU concludes that the DASR market results were competitive, although offers above the competitive level continue to affect prices.

Primary Reserve

NERC Performance Standard BAL-002-3, Disturbance Control Standard – Contingency Reserve for Recovery from a Balancing Contingency Event, requires PJM to carry sufficient contingency reserve to recover from a sudden balancing contingency (usually a loss of generation). The Contingency Event Recovery Period is the time required to return the ACE to zero if it was zero or positive before the event or to its pre-event level if it was negative at the start of the event. NERC standards set the Contingency Event Recovery Period as 15 minutes and Contingency Reserve Restoration Period as 90 minutes.³³ The NERC requirement is 100 percent compliance and status must be reported quarterly. PJM implements this contingency reserve requirement using primary reserves.³⁴ PJM maintains 10 minute reserves (primary reserve) to ensure reliability in the event of disturbances. PJM's primary reserves are made up of resources, both synchronized and nonsynchronized, that can provide energy within 10 minutes. PJM does not have a Contingency Reserve Restoration Period standard.

³³ See PJM "Manual 12: Balancing Operations," Rev. 43 (June 6, 2021) Attachment D, "the Disturbance Recovery Period is 15 minutes after the start of a Reportable Disturbance. Subsequently, PJM must fully restore the Synchronized Reserve within 90 minutes."
³⁴ See PJM "Manual 10: Pre-Scheduling Operations," § 3.1.1 Day-ahead Scheduling (Operating Reserve, Rev. 40 (Dec. 15, 2021).

Market Structure

Demand

PJM requires that 150 percent of the largest single contingency on the system be maintained as primary reserve plus 190 MW. PJM can make temporary adjustments to the primary reserve requirement when grid maintenance or outages change the largest contingency or in cases of hot weather alerts or cold weather alerts.

The primary reserve market requirement is set equal to 150 percent of the largest single contingency for each market solution, ASO, IT SCED, and RT SCED. This is usually the output of the largest generating unit to which PJM adds 190 MW. In cases where temporary switching conditions create the risk that a single fault could remove several generators, PJM will define the largest single contingency as the sum of the output of those generators.³⁵

PJM can also increase the primary and synchronized reserve requirement in cases of hot weather or cold weather alerts or escalating emergency procedures.³⁶ Such additional reserves are committed as part of the hourly (ASO) and five minute (RT SCED) processes. In 2021, the average primary reserve requirement for the RTO Zone was 2,449.6 MW. The average primary reserve requirement in the MAD Subzone was 2,436.4 MW. These averages include the hours when PJM raised the requirements.

The MMU identified instances when PJM increased the primary and synchronized reserve requirements (Table 10-5). On November 1, 2021, PJM doubled the reserve requirements for 40 hours, which resulted in significantly higher prices and reserve levels for all real-time reserve products.

³⁵ PJM Manual 11: Energy & Ancillary Services Market Operations, Rev. 117 (Nov. 1, 2021)

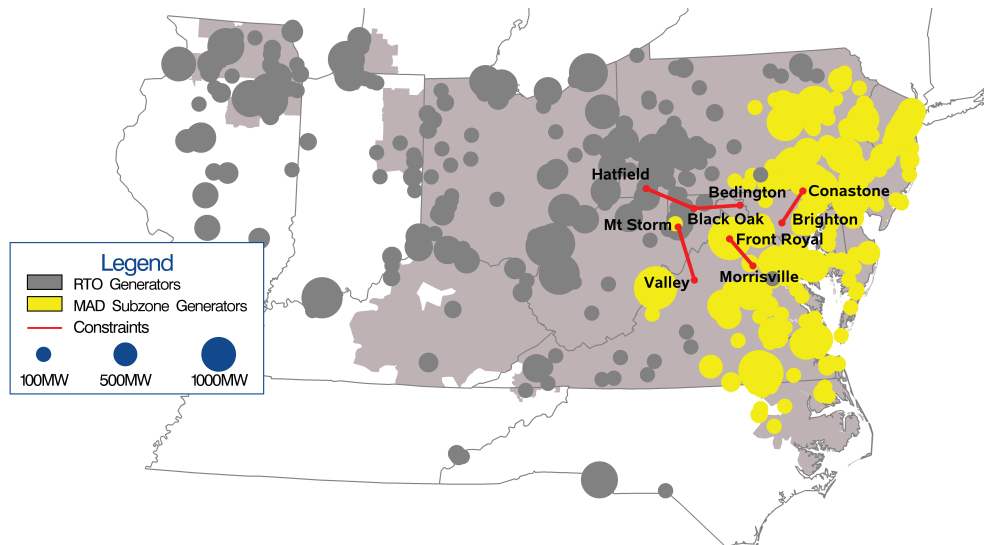
³⁶ PJM Manual 11: Energy & Ancillary Services Market Operations, Rev. 117 (Nov 1, 2021), p. 84

Table 10-5 Temporary adjustments to primary and synchronized reserve: 2021

From	To	Number of Hours	Amount of Adjustment
6-Mar-21	8-Mar-21	34	Primary Reserve (255 MW), Synchronized Reserve (170 MW)
15-Mar-21	29-Mar-21	230	Primary Reserve (230 MW), Synchronized Reserve (160 MW)
14-Jun-21	17-Jun-21	64	Primary Reserve (0 MW), Synchronized Reserve (0 MW)
28-Aug-21	30-Aug-21	50	Primary Reserve (60MW), Synchronized Reserve (125 MW)
30-Aug-21	18-Oct-21	0	Primary Reserve (0 MW), Synchronized Reserve (0 MW)
18-Oct-21	18-Oct-21	18	Primary Reserve (210 MW), Synchronized Reserve (140 MW)
22-Oct-21	30-Oct-21	174	Primary Reserve (0 MW), Synchronized Reserve (0 MW)
1-Nov-21	2-Nov-21	40	Primary Reserve (1,780 MW), Synchronized Reserve (1,180 MW)

Transmission constraints can limit the deliverability of reserves within the RTO, requiring the definition of a subzone. PJM defines a single subzone, the Mid-Atlantic Dominion (MAD) Subzone (Figure 10-1).³⁷ Figure 10-1 is a map of constraints and major generation sources. The constraints separating the RTO Zone and MAD Subzone are defined by underlying grid topology. The RTO Zone into MAD Subzone constraints reflect limits on the transmission line capacity that separate the RTO Zone and MAD Subzone. If, in the case of a spinning event, the current economic dispatch plus the current synchronized market dispatch would overload the constraint, then all additional synchronized reserve MW must be cleared from the unconstrained side of the constraints. When this occurs, the synchronized reserve prices between the RTO Zone and the MAD Subzone will diverge. PJM operators are authorized to define additional separate subzones under certain conditions.³⁸ In practice, PJM has always maintained only the MAD Subzone but for any market solution several distinct constraining paths are analyzed and the most limiting one becomes the definition for that solution.

Figure 10-1 PJM RTO Zone and MAD Subzone map of constraints and generation sources



³⁷ Additional subzones may be defined by PJM to meet system reliability needs. PJM will notify stakeholders in such an event. See "PJM Manual 11: Energy & Ancillary Services Market Operations," § 4.2.2 Synchronized Reserve Requirement Determination, Rev. 117 (Nov. 1, 2021).

³⁸ PJM Manual 11: Energy & Ancillary Services Market Operations, Rev. 117 (Nov. 1, 2021), p. 86.

The most limiting transmission constraint for power flow from the RTO Zone into the MAD Subzone since August 2017, has been the AP South Interface. The most frequent constraint in 2021 is Brighton-Conastone, then Bedington-Black Oak, and Cloverdale-Lexington.

The NERC standard requires a control area to carry primary reserve MW equal to or greater than the most severe single contingency (MSSC) plus 190 MW.³⁹ PJM requires primary reserves in the amount of 150 percent of the largest single contingency with at least 100 percent of the requirement made up of synchronized reserves.⁴⁰ In 2021, the average synchronized reserve requirement was 1,687.6 MW in the MAD Subzone and 1,696.4 MW in the RTO Zone. The synchronized reserve requirement is calculated for every real-time market dispatch solution.

Supply

The demand for primary reserve is satisfied by tier 1 synchronized reserves, tier 2 synchronized reserves and nonsynchronized reserves, subject to the requirement that synchronized reserves equal 100 percent of the largest contingency. After the synchronized reserve requirement is satisfied, the remainder of primary reserves is from the least expensive combination of synchronized and nonsynchronized reserves.

Estimated tier 1 is credited against PJM's primary reserve requirement as well as PJM's synchronized reserve requirement. In the MAD Subzone, an average of 841.9 MW of tier 1 was identified by the dispatch solutions as available in 2021 (Table 10-6).⁴¹ Tier 1 synchronized reserve fully satisfied the MAD Subzone synchronized reserve requirement or reduced the need for tier 2 synchronized reserve to self-scheduled reserves in 8.1 percent of dispatch solutions in 2021. In the RTO Zone, an average of 1,565.7 MW of tier 1 was available (Table 10-7) fully satisfying the synchronized reserve requirement in 44.4 percent of real-time dispatch solutions.

Regardless of online/offline state, all nonemergency generation capacity resources must submit a daily offer for tier 2 synchronized reserve in Markets Gateway prior to the offer submission deadline (14:15 the day prior to the operating day). Resources listed as available for tier 2 synchronized reserve without a synchronized reserve offer will have their offer price automatically set to \$0.00. Offer MW and other non-cost offer parameters can be changed during the operating day. Owners who opt in for intraday updates may change their offer price up to 65 minutes before the hour. Certain unit types including nuclear, wind, solar, and energy storage resources, are expected to have zero MW tier 2 synchronized reserve offer quantities.⁴²

After tier 1 is estimated, the remainder of the synchronized reserve requirement is met by tier 2.

In 2021, in the MAD Subzone, there was an average of 1,255.5 MW of eligible nonsynchronized reserve supply available to meet the average demand for primary reserve. (Table 10-7) In the RTO Zone, an average of 2,742.7 MW of supply was available to meet the average demand of 1,607.5 MW (Table 10-7).

Table 10-6 provides the average dispatch solution reserves, by type of reserve, used by the RT SCED market solution to satisfy the primary reserve requirement in the MAD Subzone from January 2020 through December 2021.

³⁹ NERC BAL-002-3. "Disturbance Control Standard – Contingency Reserve for Recovery from a Balancing Contingency Event," September 25, 2018. <<https://www.nerc.com/pa/Stand/Reliability%20Standards/BAL-002-3.pdf>>.

⁴⁰ "PJM Manual 13: Emergency Operations," Rev 82 (Jan. 1, 2022), p. 18.

⁴¹ ASO, Ancillary Services Optimizer. This is the hour-ahead market software that optimizes ancillary services with energy. ASO schedules hourly the Tier 2 Synchronized Reserve, Regulation, and Nonsynchronized Reserves.

⁴² See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2 PJM Synchronized Reserve Market Business Rules, Rev. 117 (Nov. 1, 2021).

Table 10-6 Average reserves used to satisfy the primary reserve requirement, MAD Subzone: January 2020 through December 2021

Year	Month	Tier 2			Total Primary Reserve MW
		Tier 1 Total MW	Synchronized Reserve MW	Nonsynchronized Reserve MW	
2020	Jan	1,276.6	325.9	1,249.0	2,851.5
2020	Feb	1,026.9	193.6	1,219.6	2,440.1
2020	Mar	980.7	259.0	1,231.8	2,471.4
2020	Apr	1,150.5	199.9	1,067.7	2,418.1
2020	May	911.1	200.5	1,177.5	2,289.0
2020	Jun	1,276.2	142.5	976.6	2,395.4
2020	Jul	995.4	210.5	1,216.0	2,421.9
2020	Aug	881.4	148.3	1,200.6	2,230.3
2020	Sep	1,016.9	88.5	1,123.2	2,228.6
2020	Oct	724.1	290.2	1,247.8	2,262.2
2020	Nov	566.4	257.2	1,188.8	2,012.5
2020	Dec	689.0	252.2	1,319.6	2,260.8
2020	Average	957.9	214.0	1,184.8	2,356.8
2021	Jan	835.6	251.1	1,330.6	2,417.3
2021	Feb	974.9	215.1	1,242.7	2,432.7
2021	Mar	881.9	213.2	1,162.6	2,257.7
2021	Apr	689.7	315.5	1,274.8	2,280.0
2021	May	651.4	247.5	1,141.4	2,040.2
2021	Jun	836.5	202.5	1,264.3	2,303.3
2021	Jul	891.3	206.0	1,262.9	2,360.2
2021	Aug	912.2	221.1	1,269.3	2,402.6
2021	Sep	909.2	234.1	1,207.5	2,350.8
2021	Oct	595.8	433.5	1,211.3	2,240.5
2021	Nov	573.7	409.7	1,326.8	2,310.2
2021	Dec	741.6	340.1	1,337.7	2,419.5
2021	Average	791.2	274.1	1,252.7	2,317.9

Table 10-7 shows the average dispatch solution reserves, by type of reserve, satisfying the primary reserve requirement in the RTO Zone in January 2020 through December 2021.

Table 10-7 Average monthly reserves used to satisfy the primary reserve requirement, RTO Zone: January 2020 through December 2021

Year	Month	Tier 2			Total Primary Reserve MW
		Tier 1 Total MW	Synchronized Reserve MW	Nonsynchronized Reserve MW	
2020	Jan	2,416.4	486.8	1,364.8	4,268.0
2020	Feb	2,284.2	283.3	1,279.6	3,847.1
2020	Mar	2,155.1	458.7	1,365.6	3,979.4
2020	Apr	2,228.6	342.1	1,174.0	3,744.7
2020	May	2,128.3	297.4	1,250.6	3,676.3
2020	Jun	2,728.9	283.7	1,082.7	4,095.3
2020	Jul	2,109.4	402.2	1,363.5	3,875.1
2020	Aug	1,972.1	398.8	1,387.0	3,757.9
2020	Sep	2,053.8	299.4	1,271.0	3,624.1
2020	Oct	1,381.3	778.2	1,612.3	3,771.7
2020	Nov	1,499.7	683.9	1,509.5	3,693.1
2020	Dec	1,512.4	697.0	1,648.3	3,857.7
2020	Average	2,039.2	450.9	1,359.1	3,849.2
2021	Jan	1,761.2	506.7	1,512.5	3,780.4
2021	Feb	1,848.8	600.3	1,515.2	3,964.3
2021	Mar	1,705.5	593.1	1,454.1	3,752.7
2021	Apr	1,313.5	748.3	1,589.6	3,651.2
2021	May	1,371.4	790.1	1,569.2	3,731.2
2021	Jun	1,701.2	614.9	1,575.7	3,891.8
2021	Jul	1,674.4	663.9	1,588.6	3,926.9
2021	Aug	1,768.0	709.8	1,598.6	4,076.4
2021	Sep	1,781.2	654.1	1,493.8	3,929.1
2021	Oct	1,111.4	816.3	1,693.7	3,871.2
2021	Nov	1,169.1	796.1	1,798.7	3,991.9
2021	Dec	1,619.2	535.1	1,563.4	3,825.8
2021	Average	1,568.7	669.1	1,579.4	3,866.1

Supply and Demand

The market solution software relevant to reserves consists of: the Ancillary Services Optimizer (ASO) solving hourly; the intermediate term security constrained economic dispatch market solution (IT SCED); and the real-time (short term) security constrained economic dispatch market solution (RT SCED).

All dispatch solutions determine the actual primary reserves required as 150 percent of the largest contingency plus 190 MW. Of this, synchronized reserves must be 100 percent of the largest contingency plus 190 MW.

If the tier 1 synchronized reserve plus ASO committed inflexible tier 2 synchronized reserve does not meet the requirement, RT SCED will commit available flexible tier 2 synchronized reserve. If there is an excess of synchronized reserve, the RT SCED may decommit previously committed flexible synchronized reserve.

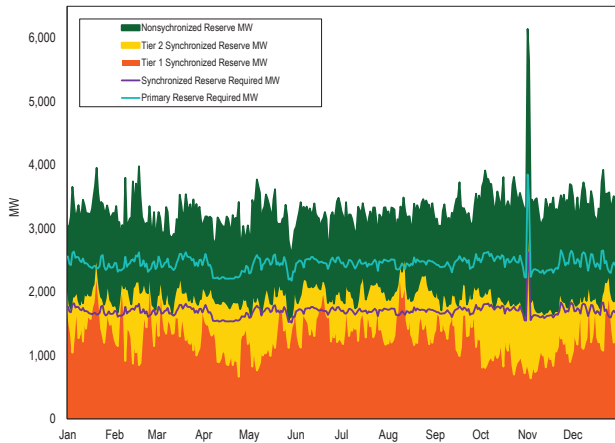
The ASO satisfied the primary reserve requirement for the RTO Zone and the MAD Subzone in all hours of

2021. RT SCED for the MAD Subzone was short, failing to satisfy the synchronized reserve requirement in 24 intervals. Three of the dispatch solutions, occurred during temporary increases in the required synchronized reserve and nonsynchronized reserve on March 17 and March 22. Three of the short intervals occurred during the 12 minute spinning event of November 12, 2021.

The market solution first estimates how much tier 1 synchronized reserve is available. If there is enough tier 1 MW available to satisfy the synchronized reserve requirement, then RT SCED economically assigns available synchronized reserve and nonsynchronized reserve to meet the remaining primary reserve requirement. If there is not enough tier 1 synchronized reserve then the remaining synchronized reserve requirement is filled with tier 2 synchronized reserve. After synchronized reserve is assigned, the primary reserve requirement is filled by economically assigning synchronized reserve and nonsynchronized reserve.

Figure 10-2 shows how the daily average market solutions satisfy the primary reserve requirement for the RTO Zone.

Figure 10-2 RTO reserve zone primary reserve MW by source (Daily Averages): January through December, 2021



In 2021, tier 1 and tier 2 were both essential to satisfying the synchronized reserve requirement. Tier 1 synchronized reserve remains the major contributor to satisfying the synchronized reserve requirement in both the RTO Zone and the MAD Subzone.

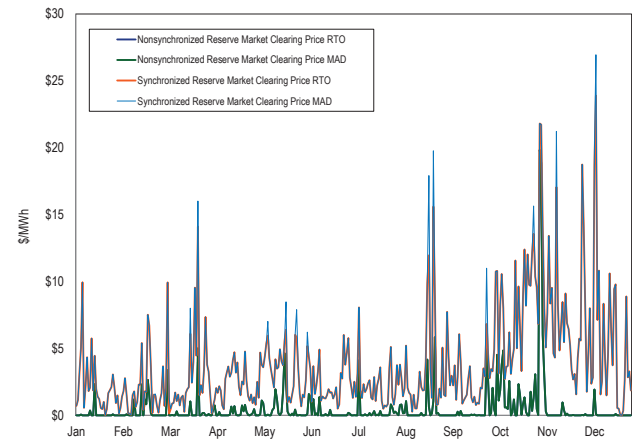
Price and Cost

The price of primary reserves results from the demand curve for primary reserves and the supply of primary reserves. The demand curve is modeled in each of the primary reserve clearing engines (ASO, IT SCED, RT SCED). The demand curve for primary reserves has two steps, with an \$850 penalty factor for primary reserve levels ranging from 0 MW to a MW amount equal to 150 percent of the MSSC and a constraint with a \$300 penalty factor for primary reserves ranging from 150 percent of MSSC to 150 percent of MSSC plus 190 MW.

The supply of primary reserves is made up of available tier 1 and tier 2 synchronized reserves and nonsynchronized reserves. Offer prices for synchronized reserve are capped at \$7.50 plus costs plus marginal cost.

Figure 10-3 shows daily weighted average synchronized and nonsynchronized market clearing prices in 2021. The MAD SRMCP and RTO SRMCP price diverged in 45 five minute intervals in 2021.

Figure 10-3 Daily average market clearing prices (\$/MWh) for synchronized reserve and nonsynchronized reserve: 2021



Tier 1 Synchronized Reserve

Tier 1 synchronized reserve is a component of primary reserve comprised of online resources following economic dispatch and able to ramp up from their current output in response to a synchronized reserve event. The tier 1 synchronized reserve for a unit is estimated as the lesser of the available 10 minute ramp or the difference between the economic dispatch point and the synchronized reserve maximum output. By default the

synchronized reserve maximum for a resource is equal to its economic maximum. Resource owners may request a lower synchronized reserve maximum if a physical limitation exists.⁴³ Tier 1 resources are identified by the market solution. Tier 1 synchronized reserve has an incremental cost of zero. Tier 1 synchronized reserve is paid under two circumstances. Tier 1 reserves are paid when they respond to a synchronized reserve event. Tier 1 reserves are paid the synchronized reserve market clearing price when the nonsynchronized reserve market clearing price is above \$0.

While PJM relies on tier 1 resources to respond to a synchronized reserve event, tier 1 resources are not obligated to respond during an event. Tier 1 resources are credited if they do respond but are not penalized if they do not.

Market Structure

Supply

All generating resources operating on the PJM system with the exception of those assigned to tier 2 synchronized reserve are available for tier 1 synchronized reserve and any response to a spinning event will be credited at the Synchronized Energy Premium Price.

Beginning in 2014, DGP (Degree of Generator Performance) was introduced as a metric to improve the accuracy of the tier 1 MW estimate used by the market solution. The available tier 1 MW estimated by the market solution for each resource is based upon its economic dispatch, and submitted synchronized reserve ramp rate, adjusted by its DGP. PJM communicates to generation operators whose tier 1 MW is part of the market solution the latest estimate of units' tier 1 MW and units' current DGP.⁴⁴ DGP should be documented in PJM's market rules.⁴⁵ DGP violates the basic PJM principle that generation owners are solely responsible for their own offers. In addition, DGP is a crude estimate of ramp rates and does not account for the actual discontinuities along unit offer curves. PJM will remove

DGP with implementation of the reserve market changes in October 2022.

The supply of tier 1 synchronized reserve available to the market solution is adjusted by eliminating tier 1 MW from unit types that cannot reliably provide synchronized reserve. These unit types are nuclear, wind, solar, landfill gas, energy storage, and hydro units.⁴⁶ These unit types are credited the synchronized energy premium price, like any other responding unit, if they respond to a spinning event. These units will not, however, be paid as tier 1 resources when the nonsynchronized reserve market clearing price goes above \$0. There is a review process for resources excluded by default from the tier 1 estimate that request to be included.⁴⁷ PJM also excludes units, regardless of type, that it deems unreliable as tier 1, though it allows those resources to provide tier 2 synchronized reserve.

Table 10-8 provides tier 1 synchronized reserve supplied by resource and fuel type in 2021, including all tier 1 credited for responding to synchronized reserve events and paid when the nonsynchronized reserve price exceeded \$0 per MW.

Table 10-8 Supply of tier 1 synchronized reserve by resource and fuel type: 2021

Unit/Fuel Type	Percent by MW	Percent by Credits
Combined Cycle	42.7%	46.8%
Steam - Coal	22.6%	22.1%
Hydro - Run of River	10.8%	8.9%
CT - Natural Gas	7.9%	8.0%
Wind	5.0%	4.3%
Solar	4.8%	4.8%
Steam - Natural Gas	2.7%	2.8%
Hydro - Pumped Storage	1.7%	0.9%
RICE - Natural Gas	0.8%	0.7%
Steam - Other	0.7%	0.7%
DSR	0.2%	0.1%
Nuclear	0.1%	0.0%
CT - Oil	0.0%	0.0%
RICE - Other	0.0%	0.0%
Steam - Oil	0.0%	0.0%
Battery	0.0%	0.0%
CT - Other	0.0%	0.0%
Fuel Cell	0.0%	0.0%
RICE - Oil	0.0%	0.0%

⁴³ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

⁴⁴ PJM. Ancillary Services, "Communication of Synchronized Reserve Quantities to Resource Owners," (May 6, 2015). <<http://www.pjm.com/-/media/markets-ops/ancillary/communication-of-synchronized-reserve-quantities-to-resource-owners.aspx>>

⁴⁵ See PJM, Generation Performance Monitor and Degree of Generator Performance Whitepaper. <<http://www.pjm.com/-/media/etools/oasis/system-information/generation-performance-monitor-and-degree-of-generator-performance-white-paper.aspx>>

⁴⁶ See PJM. "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

⁴⁷ See PJM. "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

In 2021, the SCED market solutions estimated that tier 1 MW from an average of 62 units could have an average of 1,563.7 MW of ramp available in a spinning event. For the 18 spinning events in 2021, PJM paid a total of 5,004.3 MW of tier 1 response across 46 intervals. Settlements include units like wind, solar, nuclear, and demand response which are not a part of the estimated tier 1 in the SCED market solutions.

By observing spin event response recorded in PJM's SCADA data, the MMU estimates actual response as the sum of the products contributing to total ACE increase from the time the event is initiated to 10 minutes after the event is initiated. Total increase in ACE is a summation not only of tier 1 response, but also of tier 2 response, regulation A and regulation D actual response (RegD response is sometimes a MW increase and sometimes a MW decrease), and changes to net imports/exports across PJM's boundaries (sometimes an increase and sometimes a decrease in MW).

In the RTO Reserve Zone, the average estimated tier 1 synchronized reserve was 1,563.7 MW (Table 10-7). In 36.8 percent of dispatch solutions, the estimated tier 1 synchronized reserve was greater than the synchronized reserve requirement, meaning that the synchronized reserve requirement was met entirely by tier 1 synchronized reserve plus self-scheduled tier 2.

In 2021, the average estimated tier 1 synchronized reserve within the MAD Subzone was 788.2 MW (Table 10-6). In 4.3 percent of dispatch solutions the estimated tier 1 synchronized reserve available within the MAD Subzone plus the self-scheduled tier 2 in MAD was greater than the synchronized reserve requirement and no tier 2 market needed to be cleared.

Demand

There is no required amount of tier 1 synchronized reserve. The estimated tier 1 MW are used to satisfy the total required amounts of synchronized and primary reserve.

The ancillary services market solution treats the cost of estimated tier 1 synchronized reserve as \$0, even when the nonsynchronized reserve market clearing price is above \$0. As a result, the optimization cannot and does not minimize the total cost of primary reserves. The MMU recommends that tier 1 synchronized reserve

not be paid when the nonsynchronized reserve market clearing price is above \$0.

Supply and Demand

The price of synchronized reserves results from the demand curve for synchronized reserves and the supply of synchronized reserves. The demand curve is modeled in each of the synchronized reserve clearing engines (ASO, IT SCED, RT SCED). The demand curve for synchronized reserves has two steps, with an \$850 penalty factor for synchronized reserve levels ranging from 0 MW to a MW amount equal to 100 percent of the MSSC and a constraint with a \$300 penalty factor for synchronized reserves ranging from 100 percent of MSSC to 100 percent of MSSC plus 190 MW.

When solving for the synchronized reserve requirement the market solution first estimates the amount of tier 1 available from the energy dispatch. If the requirement is not filled by tier 1, it then commits tier 2 beginning with all self scheduled synchronized reserve.

In the MAD Subzone, the market solution takes all tier 1 MW estimated to be available within the MAD Subzone as well as the synchronized reserve MW estimated to be available within the MAD Subzone from the RTO Zone (green area of Figure 10-2). If the total tier 1 synchronized reserve is less than the synchronized reserve requirement, the remainder of the synchronized reserve requirement is filled with tier 2 synchronized reserve.

Tier 1 Synchronized Reserve Payments

Tier 1 synchronized reserve is awarded credits under two distinct circumstances. In response to a spinning event, all resources (except scheduled tier 2 resources) are paid for increasing output (or reducing load for demand response) at the rate of \$50 per MWh in addition to LMP.⁴⁸ This is the Synchronized Energy Premium Price. Spinning event response is calculated as the highest output between 9 minutes and 11 minutes after the event is declared minus the lowest output between one minute before and one minute after the event is declared. Generator outputs are measured and reported to PJM every four seconds via SCADA. Total response credited to a resource is capped at 110 percent of estimated

48 See PJM, "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.10 Settlements, Rev. 117 (Nov. 1, 2021).

capability. These rules apply to all resources that are not scheduled tier 2 resources. As a result, spinning event response involves more MW response than the original estimate of tier 1. Many resources that are not included in PJM's estimate of tier 1 nevertheless respond to spinning events and in accordance with the PJM Tariff are paid the Synchronized Energy Premium Price. This can include incidental response from nuclear units or steam turbines running at maximum output. Such response is expected when the response is measured as the highest output for the two minute period around the end of an event minus lowest output from the two minute period around the start of an event. Tier 1 synchronized reserve that is part of the estimate (at market solution time) when there is no spinning event is also credited for its full estimated MW whenever the nonsynchronized reserve market clearing price is above \$0.

In the event that the nonsynchronized reserve market clearing price is above \$0 and there is a spinning event, estimated tier 1 is credited with the lesser of its actual response or its estimated capability times the SRMCP. Tier 1 synchronized reserve not part of the estimate is credited the SRMCP times its actual response.⁴⁹ In 2021, the nonsynchronized reserve market clearing price was above \$0 in 2.9 percent of intervals.

In 2021, tier 1 synchronized reserve spinning event response credits of \$375,832 were paid for 18 spinning events averaging 8.9 minutes. Table 10-9 shows the number of spinning events each month, the credits paid for tier 1 response, the number of MWh credited, and the actual response in MW.

Table 10-9 Tier 1 synchronized reserve event response credits: January 2020 through December 2021

Year	Month	Number of Spinning Events	Total Tier 1 Spinning Event Credits	Total Tier 1 Spinning Event Credited (MWh)	Total Tier 1 Spinning Response from Event Start to Event End (MW)
2020	Jan	2	\$22,200	453.2	5,438.8
2020	Feb	4	\$56,595	1,148.2	13,778.8
2020	Mar	1	\$3,514	70.3	843.5
2020	Apr	1	\$5,873	118.2	1,418.5
2020	May	1	\$11,302	226.0	2,712.6
2020	Jun	0	NA	NA	NA
2020	Jul	3	\$3,429	699.8	8,397.2
2020	Aug	0	NA	NA	NA
2020	Sep	1	\$11,390	236.2	2,843.1
2020	Oct	2	\$23,038	460.8	5,713.0
2020	Nov	1	\$7,964	159.3	2,019.3
2020	Dec	1	\$10,050	201.0	2,462.1
2020	Total	17	\$186,176	3,773.0	45,590.9
2021	Jan	1	\$6,796	135.9	1,165.0
2021	Feb	0	NA	NA	NA
2021	Mar	1	\$15,729	314.6	1,715.8
2021	Apr	2	\$40,442	808.8	4,677.8
2021	May	1	\$21,822	436.4	2,618.6
2021	Jun	2	\$16,275	325.5	3,183.2
2021	Jul	2	\$16,026	320.5	2,999.1
2021	Aug	2	\$46,487	929.7	4,666.3
2021	Sep	1	\$126,863	279.2	2,094.2
2021	Oct	2	\$27,267	545.3	3,800.4
2021	Nov	3	\$50,939	1,018.8	6,024.5
2021	Dec	1	\$7,188	143.8	1,232.3
2021	Total	18	\$375,832	5,258.6	34,177.2

Paying Tier 1 the Tier 2 Price

Tier 1 synchronized reserve has zero marginal cost and the corresponding competitive price for tier 1 synchronized reserves is also zero. However, the PJM rules artificially create a marginal cost of tier 1 when the price of nonsynchronized reserve is greater than zero and tier 1 is paid the tier 2 price. The PJM market solutions do not include that marginal cost and therefore do not solve for the efficient level of tier 1, tier 2 and nonsynchronized reserve in those cases. When called to respond to a spinning event, tier 1 is compensated at the Synchronized Energy Premium Price (Table 10-12). However, the shortage pricing tariff changes (October 1, 2012) modified the pricing of tier 1 so that tier 1 synchronized reserve is paid the tier 2 synchronized reserve market clearing price whenever the nonsynchronized reserve market clearing price rises above zero. The rationale for this change was and is unclear, but it has had a significant impact on the cost of tier 1 synchronized reserves (Table 10-10). In 2021, the nonsynchronized reserve market clearing price was above \$0.00 in 2.9 percent of all intervals. For those intervals, tier 1 synchronized reserve was paid \$7,364,936 for an average of 639.3 MW per interval of which \$7,354,224 was for intervals outside of spinning events.

⁴⁹ See PJM "Manual 28: Operating Agreement Accounting," Rev. 85 (Sep. 1, 2021) p. 59.

Table 10-10 Price of tier 1 synchronized reserve attributable to a nonsynchronized reserve price above zero: January 2020 through December 2021

Year	Month	Number of Intervals When NSRMCP > \$0	Weighted Average SRMCP When NSRMCP > \$0	Total Tier 1 MWh When NSRMCP > \$0	Total Tier 1 Credits When NSRMCP > \$0	Average Tier 1 MWh Monthly When NSRMCP > \$0
2020	Jan	0	NA	NA	NA	NA
2020	Feb	0	NA	NA	NA	NA
2020	Mar	0	NA	NA	NA	NA
2020	Apr	27	\$6.17	3,654.9	\$22,372.4	456.9
2020	May	23	\$12.22	3,005.4	\$19,219.4	333.9
2020	Jun	116	\$8.87	17,163.0	\$130,139.5	490.4
2020	Jul	166	\$13.31	22,696.6	\$253,682.3	687.8
2020	Aug	309	\$18.16	42,499.8	\$531,927.9	708.3
2020	Sep	50	\$4.50	7,277.5	\$28,657.9	519.8
2020	Oct	944	\$15.46	148,481.8	\$1,760,874.3	1,124.9
2020	Nov	255	\$20.20	33,087.6	\$448,263.5	675.3
2020	Dec	124	\$8.94	15,314.0	\$125,588.3	528.1
2020	Total	2,014	\$12.36	293,180.6	\$3,320,725.6	613.9
2021	Jan	31	\$36.20	3,625.7	\$75,336.8	604.3
2021	Feb	160	\$20.31	19,953.0	\$326,371.9	739.0
2021	Mar	60	\$95.30	7,775.0	\$724,172.5	518.3
2021	Apr	196	\$10.34	24,978.1	\$203,281.3	531.4
2021	May	644	\$12.75	74,895.9	\$797,735.9	720.2
2021	Jun	199	\$12.62	25,628.0	\$255,053.0	596.0
2021	Jul	95	\$27.79	13,751.7	\$325,970.0	528.9
2021	Aug	123	\$56.79	15,098.7	\$758,394.8	503.3
2021	Sep	123	\$26.95	18,665.3	\$454,767.7	777.7
2021	Oct	865	\$20.82	113,069.8	\$1,828,569.7	796.3
2021	Nov	490	\$33.16	54,585.5	\$1,527,555.0	941.1
2021	Dec	22	\$69.35	2,487.4	\$87,728.0	414.6
2021	Total	3,008	\$35.20	374,514.1	\$7,364,936.6	639.3

The additional payments to tier 1 synchronized reserves under the shortage pricing rule are a windfall. Table 10-11 shows the amount of windfall paid to tier 1 resources from 2014 through 2021.

Table 10-11 Windfall payments made to tier 1 resources: 2014 through 2021

Year	Windfall Payment
2014	\$89,719,045
2015	\$34,397,441
2016	\$4,948,084
2017	\$2,197,514
2018	\$4,732,025
2019	\$3,217,178
2020	\$3,320,726
2021	\$7,354,224

The additional payment does not create an incentive to provide more tier 1 synchronized reserves. The additional payment is not a payment for performance; all estimated tier 1 receives the higher payment regardless of whether they provide any response during any spinning event. Tier 1 resources are not obligated to respond to synchronized reserve events. In 2021, there were five spinning events of 10 minutes or longer. In those events, an average of 55.0 percent of the estimated tier 1 responded and 63.2 percent of tier 2 responded.

The MMU recommends that the rule requiring the payment of tier 1 synchronized reserve resources when the nonsynchronized reserve price is above zero be eliminated immediately.⁵⁰ Tier 1 should be compensated only for a response to synchronized reserve events, as it was before the shortage pricing changes. This compensation requires that when a synchronized reserve event is called, all tier 1 response is paid the synchronized energy premium price.

⁵⁰ This recommendation was presented as a proposal, "Tier 1 Compensation," to the Markets and Reliability Committee Meeting, October 22, 2015. The MMU proposal and a PJM counterproposal were both rejected.

PJM's current tier 1 compensation rules are presented in Table 10-12.

Table 10-12 Tier 1 compensation as currently implemented by PJM

Tier 1 Compensation by Type of Interval as Currently Implemented by PJM		
Interval	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWi
NSRMCP>\$0	T1 credits = T2 SRMCP * estimated tier 1 MW	T1 credits = T2 SRMCP * min(estimated tier 1 MW, actual response MWi)

The MMU's recommended compensation rules for tier 1 MW are in Table 10-13.

Table 10-13 Tier 1 compensation as recommended by MMU

Tier 1 Compensation by Type of Hour as Recommended by MMU		
Interval	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWi
NSRMCP>\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWi

Tier 2 Synchronized Reserve Market

Synchronized reserve is provided by generators or demand response resources synchronized to the grid and capable of increasing output or decreasing load within 10 minutes. Synchronized reserve consists of tier 1 and tier 2 synchronized reserves. When the synchronized reserve requirement cannot be met by tier 1 synchronized reserve, PJM clears a market to satisfy the requirement with tier 2 synchronized reserve. Tier 2 synchronized reserve is provided by online resources, either synchronized to the grid but not producing energy, or dispatched to provide synchronized reserve at an operating point below their economic dispatch point. Tier 2 synchronized reserve is also provided by demand resources that have offered to reduce load in the event of an synchronized reserve event. Tier 2 synchronized reserves are committed to be available in the event of a synchronized reserve event. Tier 2 resources have a must offer requirement. Some tier 2 resources are scheduled by the ASO 60 minutes before the operating hour and are committed to provide synchronized reserve for the entire hour. Tier 2 resources are paid the higher of the SRMCP or their offer price plus lost opportunity cost (LOC). Demand response resources are paid the clearing price (SRMCP).

Synchronized reserve resources can be flexible or inflexible. Inflexible resources are defined as those resources that require an hourly commitment due to minimum run times or staffing constraints. Examples of inflexible reserves are synchronous condensers operating in condensing mode, resources with an economic minimum (EcoMin) equal to economic maximum (EcoMax), offline CTs and hydro that can operate in the condense mode, and demand resources. Inflexible tier 2 synchronized reserve resources are committed for a full hour by the hour ahead ASO market solution. Inflexible resources require a 30 minute notification time and cannot be released for energy during the operating hour. The inflexible commitments made by the hour ahead ASO solution may satisfy only part of the tier 2 requirement. The actual requirement is determined by the RT SCED solution and the requirement

not satisfied by inflexible units is satisfied by flexible units. Flexible resources are already online for energy, require no notification time, and can be automatically dispatched.

During the operating hour, RT SCED can dispatch additional tier 2 resources. RT SCED can redispatch online tier 1 generating resources as tier 2 synchronized reserve to meet the synchronized and primary reserve requirements within the operational hour. Resources that are redispatched as tier 2 within the hour are paid the SRMCP plus any lost opportunity costs that exceed the SRMCP.

Market Structure

Supply

PJM has a must offer tier 2 synchronized reserve requirement. All nonemergency generating resources are required to submit tier 2 synchronized reserve offers. All online, nonemergency generating resources are deemed available to provide both tier 1 and tier 2 synchronized reserve although certain unit types are exempt. If PJM issues a primary reserve warning, voltage reduction warning, or manual load dump warning, all offline emergency generation capacity resources available

to provide energy must submit an offer for tier 2 synchronized reserve.⁵¹

In 2021, the Mid Atlantic Dominion (MAD) Reserve Subzone averaged 4,606.5 MW of tier 2 synchronized reserve offers, and the RTO Reserve Zone averaged 36,342.6 MW of tier 2 synchronized reserve offers (Figure 10-6).

The supply of tier 2 synchronized reserve offered in 2021 was sufficient to cover the ASO hourly requirement net of tier 1 in both the RTO Reserve Zone and the MAD Reserve Subzone.

The largest portion of cleared tier 2 synchronized reserve in 2021 was from CTs running natural gas (Table 10-14) followed by demand resources. Although demand resources are limited to providing no more than 33 percent of the total synchronized reserve requirement, the amount of tier 2 synchronized reserve required in any hour is often much less than the full synchronized reserve requirement because so much of it is met with tier 1 synchronized reserve. This means that in some hours demand resources make up considerably more than 33 percent of the cleared tier 2 MW. Demand resources often offer at a price of \$0, do not incur an LOC, and clear even when the price is \$0. As a result, their share of credits in the synchronized reserve market is much less than their share of cleared MW.

Table 10-14 Supply of Tier 2 Synchronized Reserve by Resource Type and Fuel Type: 2021

Unit / Fuel Type	Percent by MW	Percent by Credits
CT - Natural Gas	35.9%	43.2%
DSR	28.4%	11.7%
CT - Oil	12.5%	12.8%
Combined Cycle	11.9%	24.8%
Hydro - Run of River	8.0%	3.9%
Steam - Coal	2.2%	2.3%
Hydro - Pumped Storage	0.5%	0.4%
RICE - Natural Gas	0.4%	0.6%
Steam - Natural Gas	0.1%	0.2%
Battery	0.0%	0.0%
CT - Other	0.0%	0.0%
Fuel Cell	0.0%	0.0%
Nuclear	0.0%	0.0%
RICE - Other	0.0%	0.0%
Solar	0.0%	0.0%
Solar + Storage	0.0%	0.0%
Solar + Wind	0.0%	0.0%
Steam - Oil	0.0%	0.0%
Steam - Other	0.0%	0.0%
Wind	0.0%	0.0%
Wind + Storage	0.0%	0.0%

Demand

On July 12, 2017, PJM adopted a dynamic synchronized reserve requirement set equal to 100 percent of the most severe single contingency (MSSC) as the first step, and extended by a 190 MW second step.⁵² There are two circumstances in which PJM may alter the base portion of the synchronized reserve requirement from its 100 percent of the largest contingency value. Reserve requirements may be increased during a temporary switching condition when transmission outages or configuration problems cause several generation resources to be subject to a single contingency. When PJM operators anticipate periods of high load, they may bring on additional units to account for increased operational uncertainty in meeting load. When a Hot Weather Alert, Cold Weather Alert or an emergency procedure (as defined in Manual 11 § 4.2.2 Synchronized Reserve Requirement Determination) has been issued for the operating day, operators may increase the synchronized reserve requirement up to the full amount of the additional MW brought on line.⁵³

In 2021, the average synchronized reserve requirement was 1,697.1 MW in the RTO Zone and 1,696.5 in the MAD Subzone. These averages include temporary increases to the synchronized reserve requirement.

⁵¹ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

⁵² See the 2021 Quarterly State of the Market Report: January through September, Section 3: Energy Market, at "Operating Reserve Demand Curves".

⁵³ PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.2 Synchronized Reserve Requirement Determination, Rev. 117 (Nov. 1, 2021).

The RTO Reserve Zone scheduled and identified an average of 720.5 MW of tier 2 synchronized reserves in 2021. Of this, an average of 524.3 MW was scheduled hourly.

Figure 10-4 and Figure 10-5 show the average monthly synchronized reserve required and the average monthly tier 2 synchronized reserve MW scheduled (PJM scheduled plus self scheduled) from January 2020 through December 2021, for MAD Reserve Subzone and the RTO Reserve Zone. There were 33 intervals of shortage in 2019. There were 13 spinning events in 2019 but only two lasted longer than 10 minutes. There were seven intervals of shortage in 2020 and 16 spinning events with three longer than 10 minutes. In 2021, there were 19 intervals of shortage and 18 spinning events of which five were longer than 10 minutes.

Figure 10-4 MAD hourly average tier 2 synchronized reserve scheduled MW: January 2020 through December 2021

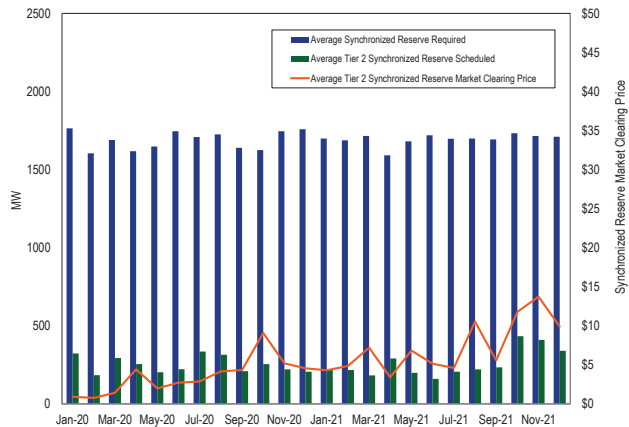
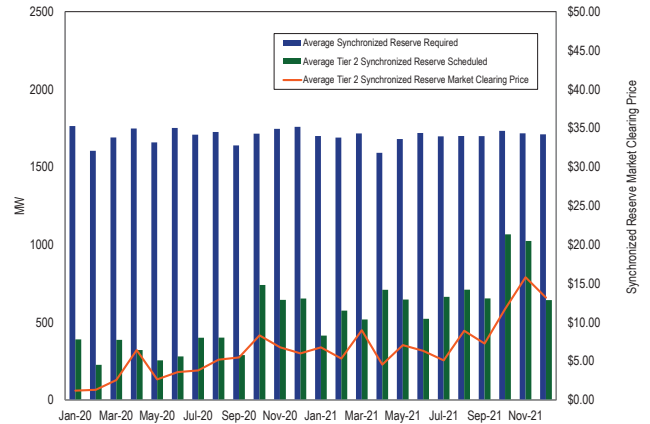


Figure 10-5 RTO hourly average tier 2 synchronized reserve scheduled MW: January 2020 through December 2021



Market Concentration

The average HHI for tier 2 synchronized reserve cleared intervals in the Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Market in 2021 was 5004, which is defined as highly concentrated. In 83.0 percent of all cleared pricing intervals the maximum market share was greater than or equal to 40 percent.

The average HHI for tier 2 synchronized reserve for cleared pricing intervals of the RTO Zone Tier 2 Synchronized Reserve Market in 2021 was 3460, which is defined as highly concentrated. In 49.3 percent of cleared intervals there was a maximum market share greater than or equal to 40 percent.

In the MAD Subzone, flexible synchronized reserve was 2.6 percent of all tier 2 synchronized reserve in 2021. In the RTO Zone, flexible synchronized reserve was 4.7 percent of all tier 2 synchronized reserve MW in 2021.

The market structure results indicate that the RTO Zone and Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Markets are not structurally competitive.

Market Behavior

Offers

Daily cost-based offers are submitted for each unit by the unit owner. For generators the offer must include, when relevant, a tier 1 synchronized reserve ramp rate, a tier 1 synchronized reserve maximum, self scheduled status, synchronized reserve availability, synchronized

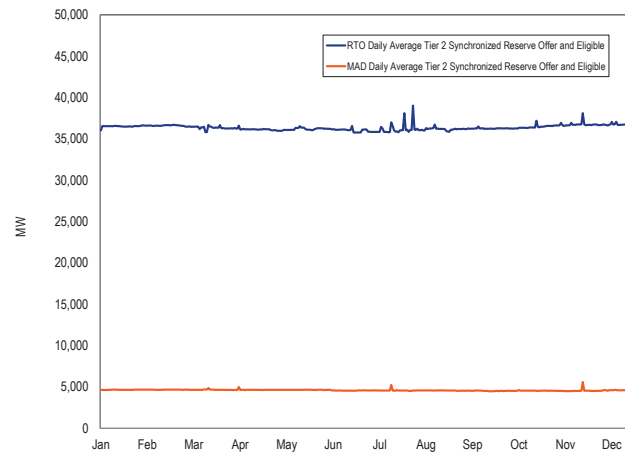
reserve offer quantity (MW), tier 2 synchronized reserve offer price, energy use for tier 2 condensing resources (MW), condense to gen cost, shutdown costs, condense startup cost, condense hourly cost, condense notification time, and spin as a condenser status. The synchronized reserve offer price made by the unit owner is subject to an offer cap of marginal cost plus a markup of \$7.50 per MW. The tier 1 synchronized reserve ramp rate must be greater than or equal to the real-time economic ramp rate. If the synchronized reserve ramp rate is greater than the economic ramp rate it must be justified by the submission of actual data from previous synchronized reserve events.⁵⁴ All suppliers are paid the higher of the market clearing price or their offer plus their unit specific opportunity cost. The offer quantity is limited to the economic maximum. PJM monitors this offer by checking to ensure that all offers are greater than or equal to 90 percent of the resource's ramp rate times 10 minutes. A resource that is unable to participate in the synchronized reserve market during a given hour may set its hourly offer to zero MW. Certain defined resource types are not required to offer tier 2 because they cannot reliably provide synchronized reserve. These include: nuclear, wind, solar, landfill gas and energy storage resources.⁵⁵

Figure 10-6 shows the daily average of hourly offered tier 2 synchronized reserve MW for both the RTO Synchronized Reserve Zone and the Mid-Atlantic Dominion Synchronized Reserve Subzone.

PJM has a tier 2 synchronized reserve must offer requirement for all generation that is online, nonemergency, and physically able to operate with an output less than dictated by economic dispatch. Tier 2 synchronized reserve offers are made on a daily basis with hourly updates permitted. Daily offers can be changed as a result of maintenance status or physical limitations only and are required regardless of online/offline state.⁵⁶ The tier 2 synchronized reserve market is not cleared based on daily offers but based on hourly updates to the daily offers. As a result of hourly updates the actual amount of eligible tier 2 MW can change significantly every hour (Figure 10-6). Changes to the

hourly offer status are only permitted when resources are physically unable to provide tier 2. Changes to hourly eligibility levels are the result of online status, minimum/maximum runtimes, minimum notification times, maintenance status and grid conditions including constraints. However, resource operators can make their units unavailable for an hour or block of hours without having to provide a reason. In 2021, synchronized reserve offers averaged 36,355.7 MW in the RTO Zone and 4,606.9 MW in the MAD Subzone.

Figure 10-6 Tier 2 synchronized reserve hourly offer and eligible volume (MW): 2021



Although tier 2 synchronized reserve has a must offer requirement, there are a large number of hours when many units make themselves unavailable for tier 2 synchronized reserve.

The MMU recommends that the tier 2 synchronized reserve must offer requirement be enforced. The MMU recommends that PJM define a set of acceptable reasons why a unit can be made unavailable daily or hourly and require unit owners to select a reason in Markets Gateway whenever making a unit unavailable either daily or hourly or setting the offer to 0 MW.⁵⁷

⁵⁴ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility Rev. 117 (September 1, 2021).

⁵⁵ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.1 Synchronized Reserve Market Eligibility Rev. 117 (Nov., 2021).

⁵⁶ See *id.* ("Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for Tier 2 Synchronized Reserve in eMKT...").

⁵⁷ PJM adopted a new business rule in the third quarter of 2017 to enforce compliance with the tier 2 must-offer requirement. PJM enters a zero dollar offer price for all units with a must offer obligation for tier 2 synchronized reserves.

Market Performance

Price

The price of tier 2 synchronized reserve is calculated in real time every five minutes by the LPC market solution for the RTO Reserve Zone and the MAD Subzone. The tier 2 synchronized reserve market price is determined not only by the offer price of each cleared MW of tier 2, but additionally by the net cost of jointly optimizing the dispatch of energy and synchronized reserve. For each MW assigned, the clearing engines determine a product substitution price, i.e. the marginal cost of replacing the reserve MW with energy from other resources. The product substitution cost is a function of the LMPs of the MW of reserve, the marginal cost of energy for the resources providing reserves, and the minimized cost of substituted MW providing energy. At the margin, the price is the sum of the offer price plus the product substitution cost of the marginal unit(s).⁵⁸ The number of marginal units by schedule type is shown in Table 10-15.

Table 10-15 Schedule used for LOC of marginal units in RTSCED Tier 2 Synchronized Reserve Market LOC calculation: 2021

Number of Marginal Units	Percent of Marginal Units with LOC Based on Cost Schedule	Percent of Marginal Units with LOC Based on Price Schedule
164,712	8.7%	91.3%

In 2021, the RTSCED cleared the RTO tier 2 synchronized reserve market in 64.1 percent of all dispatch solutions. In all other intervals there was enough tier 1 synchronized reserve to cover the synchronized reserve requirement. For intervals when the synchronized reserve requirement could not be met with tier 1, the market cleared an average of 517.5 MW of synchronized reserve (plus 166.3 MW of demand response) at a MW weighted average price of \$8.41 per hour. The tier 2 MW from both generation and load response increased beginning in October as a result of a significant decrease in estimated tier 1 MW.

The market clearing price for the MAD Subzone diverged from the RTO Zone in 45 intervals during 2021.

Supply, demand, and performance for tier 2 synchronized reserve cleared hours (price > \$0) are reflected in the price of synchronized reserve (Table 10-16).

⁵⁸ PJM Manual 11: Energy & Ancillary Services Market Operations, Rev. 117 (Nov. 1, 2021), p. 92.

Table 10-16 RTO Zone, average SRMCP and average scheduled, tier 1 estimated and demand response MW in RT SCED market solutions: January 2020 through December 2021

Year	Month	Weighted Average Synchronized Reserve Market Clearing Price	Weighted Average Dispatch Solution Reserve Market Clearing Price	Average Interval Tier 2 Generation Synchronized Reserve Purchased (MWh)	Average Interval Tier 1 Synchronized Reserve Estimated (MWh)	Average Interval Demand Response Cleared (MWh)
2020	Jan	\$1.20	\$1.18	322.4	2,410.7	67.2
2020	Feb	\$1.30	\$1.57	183.7	2,285.5	42.6
2020	Mar	\$2.56	\$2.26	293.8	2,142.0	92.8
2020	Apr	\$6.42	\$5.54	255.0	2,223.8	66.5
2020	May	\$2.65	\$2.68	202.5	2,130.4	52.6
2020	Jun	\$3.58	\$3.35	221.9	2,723.9	58.6
2020	Jul	\$3.80	\$3.72	335.4	2,102.5	65.3
2020	Aug	\$5.19	\$5.36	314.7	1,961.6	86.5
2020	Sep	\$5.47	\$4.25	209.6	2,054.2	79.2
2020	Oct	\$8.32	\$6.61	575.1	1,380.2	165.3
2020	Nov	\$6.78	\$4.77	502.6	1,500.4	141.4
2020	Dec	\$5.99	\$4.44	507.7	1,506.8	145.0
2020	Average	\$4.44		327.0	2,035.2	88.6
2021	Jan	\$6.77	\$5.30	331.8	1,761.2	88.1
2021	Feb	\$5.33	\$4.25	461.5	1,845.8	136.5
2021	Mar	\$8.98	\$6.58	431.8	1,704.9	122.6
2021	Apr	\$4.55	\$3.54	545.2	1,313.3	164.5
2021	May	\$7.06	\$5.53	594.2	1,372.3	186.4
2021	Jun	\$6.32	\$5.17	465.0	1,699.5	142.7
2021	Jul	\$5.10	\$3.88	482.5	1,676.2	177.4
2021	Aug	\$8.91	\$5.97	498.9	1,766.0	206.0
2021	Sep	\$7.26	\$4.59	431.4	1,780.0	184.6
2021	Oct	\$11.71	\$8.33	778.0	1,111.3	250.1
2021	Nov	\$15.80	\$10.74	743.6	1,166.5	228.0
2021	Dec	\$13.18	\$9.98	445.5	1,617.0	108.2
2021	Average	\$8.41	\$6.16	517.5	1,567.8	166.3

Settlement Cost

As a result of changing grid conditions, load forecasts, and unexpected generator performance, prices do not always cover the full cost to customers, including the final LOC for each resource. Because price formation occurs within the hour (on a five minute basis) but inflexible synchronized reserve commitment occurs prior to the hour, the realized, within hour price can be zero even when some tier 2 synchronized reserve is cleared. All resources cleared in the market are guaranteed to be made whole and are paid uplift credits in settlement if the SRMCP does not compensate them for their offer plus LOC.

PJM implemented fast start pricing on September 1, 2021. Between September 1, 2021 and December 31, 2021 prices were 2.1 percent higher than in the dispatch run (only intervals where the Tier 2 Synchronized Reserve price is greater than \$0 are considered). The price was above zero in the RTO Zone in 38.2 percent of intervals in 2021. (Table 10-17).

Prices were significantly higher in 2021 than they were in 2020 because of increases in the synchronized reserve requirement, higher fuel costs, and fast start pricing (Table 10-17). The MW weighted synchronized reserve market clearing price is computed for hours when the price was above \$0. The market clearing solution includes a constraint that forces all remaining synchronized reserve to be cleared from the MAD Subzone (Figure 10-1) when one of the constraints defining MAD binds. RTO/MAD prices diverged in only 45 intervals in 2021. In 2021, the MW weighted average tier 2 synchronized reserve clearing price was \$8.87 in the RTO Zone and \$7.32 in the MAD Subzone.

Table 10-17 RTO Zone tier 2 synchronized reserve MW, credits, price, and cost: 2021

Year	Month	Tier 2			Weighted Synchronized Reserve Market Clearing Price	Tier 2 Synchronized Reserve Cost	Price / Cost Ratio
		Generation and DSR Credited MWh	Tier 2 SRMCP Credits	LOC Credits			
2021	Jan	313,931	\$2,331,218	\$286,087	\$6.77	\$8.34	81.3%
2021	Feb	256,201	\$1,603,753	\$1,062,361	\$5.33	\$10.41	51.2%
2021	Mar	329,137	\$3,255,393	\$1,392,791	\$8.98	\$14.12	63.6%
2021	Apr	343,354	\$1,831,478	\$662,382	\$4.55	\$7.26	62.6%
2021	May	390,619	\$3,283,465	\$1,216,534	\$7.06	\$11.52	61.3%
2021	Jun	306,172	\$2,293,837	\$1,262,148	\$6.32	\$11.61	54.4%
2021	Jul	267,256	\$1,682,350	\$1,255,201	\$5.10	\$10.99	46.4%
2021	Aug	245,668	\$2,738,144	\$2,428,284	\$8.91	\$21.03	42.3%
2021	Sep	198,624	\$1,857,005	\$1,468,205	\$9.86	\$16.74	43.3%
2021	Oct	413,081	\$6,237,138	\$2,467,669	\$12.00	\$21.07	55.6%
2021	Nov	391,178	\$7,530,370	\$1,756,684	\$15.11	\$23.74	66.6%
2021	Dec	267,476	\$4,165,825	\$899,034	\$16.46	\$18.94	69.6%
2021		3,722,698	\$38,809,977	\$16,157,380	\$8.87	\$14.65	60.6%

Table 10-18 shows the effect of fast start pricing on the synchronized reserve market's monthly weighted average market clearing price in 2021. The weighted average market clearing price for each month is consistently higher in the pricing run than in the dispatch run.

Table 10-18 Comparison of fast start and dispatch pricing components: September 2021 through December 2021

Month	Pricing Method	Weighted Average Market Clearing Price
Sep	Fast Start	\$9.86
	Dispatch	\$9.67
Oct	Fast Start	\$12.00
	Dispatch	\$11.84
Nov	Fast Start	\$15.11
	Dispatch	\$14.76
Dec	Fast Start	\$16.46
	Dispatch	\$16.10

Performance

Tier 1 resource owners are paid for the actual amount of synchronized reserve they provide in response to a synchronized reserve event.⁵⁹ Tier 2 resource owners are paid for being available but are not paid based on the actual response to a synchronized reserve event. The MMU has identified and quantified the actual performance of scheduled tier 2 synchronized reserve resources when called on to deliver during synchronized reserve events since 2011.⁶⁰ When synchronized reserve resources self schedule or clear the Tier 2 Synchronized Reserve Market they are obligated to provide their full scheduled tier 2 MW during a synchronized reserve event. Actual synchronized reserve event response is

determined by final output minus initial output where final output is the largest output between 9 and 11 minutes after start of the event, and initial output is the lowest output between one minute before the event and one minute after the event.⁶¹ Tier 2 resources are obligated to sustain their final output for the shorter

of the length of the event or 30 minutes. Penalties are assessed for failure of a scheduled tier 2 resource to perform during any synchronized reserve event lasting 10 minutes or longer.

Tier 2 performance has not been adequate. Compliance with calls to respond to actual synchronized reserve events remains significantly less than 100 percent. For the spinning events 10 minutes or longer in 2016, the average tier 2 synchronized reserve response was 85.5 percent of all scheduled MW. In 2017, the response rate was 87.6 percent. In 2018, the response rate was 74.2 percent. In 2019, the response rate was 86.8 percent. In 2020, there were five spinning events 10 minutes or longer with an average response rate of 59.5 percent of scheduled tier 2 MW. In 2021 there were five spinning events lasting 10 minutes or longer. They had a tier 2 synchronized reserve response rate of 76.9 percent. Actual participant performance means that the penalty structure is not adequate to incent performance.

The penalty structure when a tier 2 resource fails to respond fully to a spinning event includes two components. The resource forfeits all SRMCP credits and LOC credits in the amount of the MW shortage for the day on which the event occurred. The resource also receives a penalty for all hours in the Immediate Past Interval (IPI) in the amount of MW it falls short of its scheduled MW. The penalty is applied only to the SRMCP credits, not to the LOC credits. The penalty period is calculated as the lesser of the average number

⁵⁹ See *id.* at 98.

⁶⁰ See 2011 *State of the Market Report for PJM*, Vol. II, Section 9, "Ancillary Services," at 250.

⁶¹ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4.2.10 Settlements Rev. 117 (Nov. 1, 2021).

of days between spinning events over the past two years (ISI) or the number of days since the resource last failed to respond fully. There are several problems with this penalty structure. Resource owners are permitted to aggregate the response of multiple units to offset an underresponse from one unit with an overresponse from a different unit to reduce an underresponse penalty.⁶² The IPI uses the last spinning event when the resource did comply. But for all spin events less than 10 minutes, compliance is automatically counted as 100 percent. This incorrectly truncates the IPI. The penalty applies only to the SRMCP credits not the LOC credits. But most credits awarded are for LOC.

Under the current penalty structure it is possible for a resource to not respond to any spin events and yet be paid for providing tier 2. The current penalty structure for tier 2 synchronized reserve nonperformance is not adequate to provide appropriate performance incentives.

The IPI is defined as the number of days between spinning events, regardless of duration. This definition artificially shortens the period since the last requirement to perform. The MMU continues to recommend that the IPI be defined as the number of days between spinning events 10 minutes or longer (Table 10-19). In 2021, PJM had 16 spinning events. Five of those events were 10 minutes or longer, March 9, April 30, May 26, August 23, and November 12. The previous 10 minute event was on December 16, 2020. If only events 10 minutes or longer were considered, the IPI would increase to 70 days from its current level of 25 days. Use of the currently defined average IPI is not appropriate. The penalty should be based on the actual time since the last spinning event of 10 minutes or longer during which the resource performed because performance is only measured for events 10 minutes or longer. Even using the proposed IPI the penalties may be insufficient to ensure response. A tier 2 shortfall penalty should include LOC payments as well as SRMCP and MW of shortfall.

Table 10-19 lists the total tier 2 synchronized reserve shortfall penalties for 2021 for lack of tier 2 response both by the current PJM penalty structure and the penalties if PJM adopted the proposed MMU penalty structure.

Table 10-19 Comparison of tier 2 shortfall penalties under current IPI vs. MMU recommended IPI: 2021

Penalty Type	MMU Recommended	
	Current PJM Penalty	Penalty
Day Of Event	\$55,412	\$79,900
Retroactive Charges	\$981,148	\$3,164,326
Total Penalties	\$1,036,559	\$3,244,226

Including aggregate responses from all online resources weakens the incentive to perform and creates an incentive to withhold reserves from other resources. Synchronized reserve commitment is unit specific, so the obligation to respond should also be unit specific. Any potentially offsetting response from an affiliated tier 1 resource should have been included as part of the reserves in the tier 1 estimate. Any potentially offsetting response from a tier 2 resource should have been included in that tier 2 offer.

The MMU recommends that aggregation not be permitted to offset unit specific penalties for failure to respond to a synchronized reserve event.

Spinning event response data as reported by PJM in its Operating Committee meetings is shown in Table 10-20. The tier 1 estimate is from the most recent RT SCED market solution. The tier 1 estimate includes estimated ramp only from the units that are eligible and excludes resources that have ramp available but are not part of the estimate.

Tier 1 synchronized reserve that responds to a spinning event receives a bonus payment of \$50 per MWh, based on a calculation using SCADA data, regardless of whether PJM included those reserves in the estimate.

Table 10-20 shows synchronized reserve event response compliance for tier 1 and tier 2 reserves as reported by PJM, using only response from tier 1 estimated and tier 2 cleared reserves. Actual synchronized reserve response is the total increase in MW from all resources from the moment the spinning event is called to 10 minutes after. To determine the actual tier 1 response, the calculation would subtract tier 2 response, changes in assigned regulation output (net compliance level to both RegA and RegD), and changes to net power flow across PJM's interface boundary. The overall response to spinning events is adequate or more than adequate to meet NERC requirements. PJM not only corrects the ACE disturbance that led to the event but over corrects.

⁶² See PJM "Manual 28: Operating Agreement Accounting," § 6.3 Charges for Synchronized Reserve, Rev. 85 (September 1, 2021.)

In eight of the 10 spinning events the ACE recovers not just to the NERC required level (which is the lesser of 0 or the value before the disturbance which caused the event) but overshoots.

Table 10-20 Synchronized reserve events 10 minutes or longer, tier 1 and tier 2 response compliance as reported by PJM, RTO Reserve Zone: January 2019 through December 2021

Spin Event (Day, EPT Time)	Duration (Minutes)	Tier 1 Estimate (Market Solution MW Adj by DGP)	Response from Tier 1 DGP Estimated (MW)	Tier 2 Scheduled (MW)	Tier 2 Response (MW)	Tier 2 Penalty (MW)	DGP Estimated Tier 1 Response Percent	Tier 2 Response Percent
Sep 23, 2019 12:07	11	1,485.1	1,212.1	723.2	632.1	91.1	81.6%	87.4%
Oct 1, 2019 14:56	11	265.4	143.7	1,177.4	1,016.4	161.0	54.1%	86.3%
2019 Average	11	924.7	664.1	723.2	632.1	91.1	71.8%	87.4%
Feb 18, 2020 20:15	10	2,216.1	1,434.8	40.0	1.7	38.3	64.7%	4.3%
Jul 6, 2020 21:22	10	1,464.0	526.1	479.7	415.1	64.6	35.9%	86.5%
Jul 25, 2020 16:39	11	868.4	421.6	302.3	264.8	37.5	48.5%	87.6%
Sep 10, 2020 00:29	10	1,275.4	453.6	782.6	782.6	0.0	35.6%	100.0%
Dec 16, 2020 16:49	10	268.4	196.9	527.6	413.2	114.4	73.4%	78.3%
2020 Average	10	1,218.5	606.6	426.4	375.5	51.0	49.7%	59.5%
Mar 9, 2021 07:50	10	1,354.9	635.4	884.0	540.8	343.2	46.9%	61.2%
Apr 30, 2021 16:30	12	1,487.6	610.2	508.3	407.2	101.1	41.0%	80.1%
May 26, 2021 10:17	10	1,138.4	811.0	685.2	600.2	85.0	71.2%	87.6%
Aug 23, 2021 16:44	18	879.8	597.5	896.2	667.1	229.1	67.9%	74.4%
Nov 12, 2021 17:25	12	510.0	606.7	890.7	714.6	176.1	119.0%	80.2%
2021 Average	12	1,074.1	652.2	772.9	586.0	186.9	69.2%	76.7%

Until April 2019, PJM's ASO market solution software allowed operators to bias the inflexible tier 2 synchronized reserve solution by forcing the software to assume a different tier 1 MW value than the actual estimate. PJM, in response to the MMU recommendation, no longer uses tier 1 biasing in any of its market solutions. Biasing means manually modifying (decreasing or increasing) the tier 1 synchronized reserve estimate of the market solution.

Tier 1 biasing was never referenced in PJM manuals or any public document. PJM could resume tier 1 biasing at its discretion. Although tier 1 biasing has been discontinued, PJM can and does still deselect tier 1 resources based on PJM judgment. The impact of tier 1 deselection can be very significant (Table 10-21 and Table 10-22).

Table 10-21 Units deselected for tier 1 by market solutions but awarded credits for actual response: 2021

Spinning Event	Number Units		Percent of T1 Credits		Percent of T1 MW	
	Deselected by RTSCED Awarded T1 Credits	Total T1 Credits Awarded	Awarded to Units Deselected for T1	Total T1 Credited MWh	Awarded Credits But Deselected	
1/24/2021 3:22	280	\$6,592	46.0%	1,582.2	46.0%	
3/9/2021 12:50	938	\$14,658	46.4%	1,918.9	85.0%	
4/13/2021 20:05	374	\$18,496	38.3%	4,439.0	38.3%	
4/30/2021 20:30	705	\$20,868	44.5%	2,921.5	76.3%	
5/26/2021 14:17	864	\$21,233	49.0%	5,095.8	49.0%	
6/21/2021 5:54	545	\$10,301	28.9%	2,119.0	33.7%	
6/23/2021 3:33	354	\$5,735	50.5%	1,376.5	50.5%	
7/21/2021 18:28	516	\$3,379	37.0%	811.1	37.0%	
7/25/2021 16:17	652	\$12,186	50.9%	2,924.6	50.9%	
8/23/2021 16:44	1,936	\$28,450	52.8%	6,828.0	52.8%	
8/24/2021 10:38	704	\$16,686	47.8%	4,004.7	47.8%	
9/27/2021 16:56	562	\$119,934	72.6%	3,058.7	67.8%	
10/11/2021 13:23	881	\$16,731	55.3%	4,015.5	55.3%	
10/16/2021 5:30	452	\$9,391	35.1%	2,254.0	35.1%	
11/12/2021 17:25	646	\$21,981	58.5%	5,275.5	58.5%	
11/30/2021 9:40	540	\$14,484	45.3%	3,476.1	45.3%	
11/30/2021 12:57	814	\$18,244	51.4%	4,378.5	51.3%	
12/8/2021 9:04	894	\$6,857	52.3%	1,645.6	52.3%	
2021 Averages	703	\$20,345	47.9%	3,229.2	51.8%	

Table 10-22 Comparison of market solution tier 1 estimate, tier 1 response with PJM Settlements tier 1 MW credited: January 2020 through December 2021

Start Time	Duration (Minutes)	PJM Market Solution DGP Estimated Tier 1 Estimate MW	PJM Market Solution DGP Estimated Tier 1 Response MW	PJM Settlements Tier 1 Credited Response MWh
Jan 20, 2020 14:06	7.8	1,903.6	765.9	1,306.3
Jan 23, 2020 16:17	8.7	2,084.6	1,073.0	1,860.4
Feb 7, 2020 12:06	6.4	1,233.0	730.2	2,883.9
Feb 8, 2020 03:44	8.4	1,961.4	826.1	1,517.6
Feb 10, 2020 20:15	9.6	1,333.3	824.3	1,573.8
Feb 18 2020 11:16	10.0	2,216.1	1,434.8	2,528.6
Mar 8, 2020 05:17	5.6	1,541.4	660.1	843.5
Apr 13, 2020 19:53	7.9	433.0	207.2	886.5
May 3, 2020 12:23	6.6	4,154.4	1,369.6	2,260.5
Jul 6, 2020 21:22	10.4	1,464.0	526.1	1,554.5
Jul 24, 2020 01:03	9.9	1,562.7	852.8	1,762.7
Jul 25, 2020 16:39	11.7	868.4	421.6	961.5
Sep 10, 2020 00:19	9.5	1,275.4	453.6	1,417.0
Oct 10, 2020 18:52	7.7	2,134.3	1,234.3	2,187.8
Oct 12, 2020 04:29	9.3	1,625.8	670.5	1,229.2
Nov 13, 2020 11:36	5.9	1,687.9	882.4	1,682.8
Dec 16, 2020 16:38	10.0	268.4	196.9	1,213.0
Jan 25, 2021 03:32	6.5	2,134.5	577.9	1,165.0
Mar 9, 2021 12:50	10.8	1,354.9	635.4	1,715.9
Apr 13, 2021 20:05	8.8	2,093.4	975.6	2,534.3
Apr 30, 2021 20:30	11.6	1,487.6	610.2	2,143.5
May 26, 2021 14:17	10.0	1,138.4	811.0	2,618.6
Jun 21, 2021 05:54	6.9	2,340.8	1,764.1	1,806.7
Jun 23, 2021 03:33	4.7	2,277.0	1,367.8	1,376.5
Jul 21, 2021 22:27	5.0	837.8	290.8	881.3
Jul 25, 2021 20:16	6.0	708.7	418.8	2,117.9
Aug 23, 2021 20:24	17.6	879.8	597.5	2,050.4
Aug 24, 2021 14:37	8.1	903.7	658.3	2,615.9
Sep 27, 2021 20:56	8.4	679.5	385.1	3,058.7
Oct 11, 2021 13:23	9.3	1,215.9	577.8	4,015.5
Oct 16, 2021 05:30	7.7	1,060.4	669.1	2,254.0
Nov 12, 2021 17:25	12.1	510.0	606.7	5,275.5
Nov 30, 2021 9:40	9.8	899.2	678.3	3,476.1
Nov 30, 2021 12:57	8.5	948.6	452.3	4,378.5
Dec 8, 2021 09:04	7.8	481.6	288.8	1,645.6

History of Synchronized Reserve Events

Synchronized reserve is designed to provide relief for disturbances.^{63 64} A disturbance is defined as loss of the lesser of 900 MW or 80 percent of the most severe single contingency within 60 seconds. In the absence of a disturbance, PJM operators have used synchronized reserve as a source of energy to provide relief from low ACE.

The risk of using synchronized reserves for energy or any other nondisturbance reason is that it reduces the amount of synchronized reserve available for a disturbance. Disturbances are unpredictable. Synchronized reserve has a requirement to sustain its output for only up to 30 minutes. When the need is for reserve extending past 30 minutes, secondary reserve is the appropriate source of the response. The use of synchronized reserve is an expensive solution during an hour when the hour ahead market solution and reserve dispatch indicate no shortage of primary reserve. PJM's primary reserve levels have been sufficient to recover from disturbances and should remain available in the absence of disturbances.

From January 2017 through December 2021, PJM experienced 82 synchronized reserve events (Table 10-23), approximately one and a half events per month. During this period, synchronized reserve events had an average duration of 9.0 minutes.

⁶³ 2013 State of the Market Report for PJM, Appendix F – PJM's DCS Performance, at 451–452.

⁶⁴ See PJM "Manual 12: Balancing Operations," Rev. 43 (June 6, 2021) § 4.1.2 Loading Reserves.

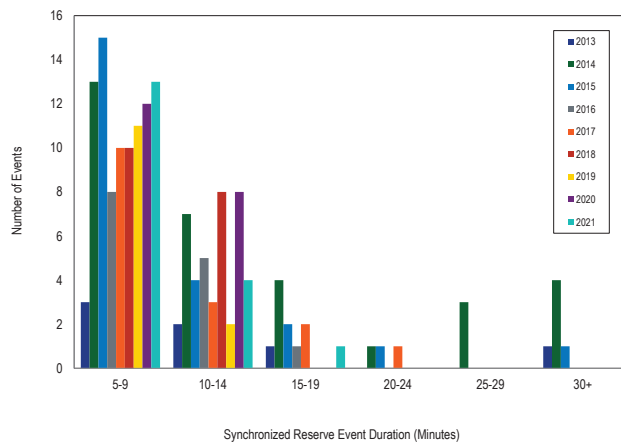
Table 10-23 Synchronized reserve events: January 2017 through December 2021⁶⁵

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
JAN-08-2017 03:21	RTO	7	JAN-01-2018 02:41	RTO	7	JAN-22-2019 22:30	RTO	8
JAN-09-2017 19:24	RTO	9	JAN-03-2018 03:00	RTO	13	JAN-31-2019 01:26	RTO	5
JAN-10-2017 13:05	MAD	9	JAN-07-2018 14:15	RTO	9	JAN-31-2019 09:26	RTO	9
JAN-15-2017 20:13	RTO	8	APR-12-2018 13:28	RTO	10	FEB-25-2019 00:25	RTO	9
JAN-23-2017 09:08	RTO	7	JUN-04-2018 10:22	RTO	6	MAR-03-2019 12:31	RTO	9
FEB-13-2017 18:30	RTO	7	JUN-29-2018 15:21	RTO	9	MAR-06-2019 22:06	RTO	9
FEB-14-2017 00:11	RTO	6	JUN-30-2018 09:46	RTO	11	JUL-27-2019 23:31	RTO	7
FEB-15-2017 06:37	RTO	6	JUL-04-2018 10:56	RTO	7	AUG-11-2019 12:14	RTO	8
MAR-23-2017 06:48	RTO	24	JUL-10-2018 15:45	RTO	13	SEP-03-2019 13:39	MAD	9
APR-08-2017 11:53	RTO	10	JUL-23-2018 09:02	RTO	8	SEP-23-2019 16:06	RTO	11
MAY-08-2017 04:18	RTO	10	JUL-23-2018 15:43	RTO	6	OCT-01-2019 18:56	RTO	11
JUN-08-2017 03:39	RTO	10	JUL-24-2018 16:17	RTO	7	DEC-11-2019 21:08	RTO	8
JUN-20-2017 05:38	RTO	9	AUG-12-2018 11:06	RTO	11	DEC-18-2019 15:07	RTO	9
SEP-04-2017 20:18	MAD	15	SEP-13-2018 09:47	RTO	7			
SEP-07-2017 09:16	RTO	9	SEP-14-2018 13:24	RTO	7			
SEP-21-2017 14:15	RTO	16	SEP-26-2018 19:08	RTO	8			
			SEP-30-2018 11:29	RTO	11			
			OCT-30-2018 10:40	RTO	11			

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
JAN-20-2020 14:06	MAD	8	JAN-24-2021 22:32	RTO	6
JAN-23-2020 16:17	RTO	9	MAR-9-2021 07:51	RTO	11
FEB-07-2020 12:06	RTO	6	APR-13-2021 20:05	RTO	9
FEB-08-2020 03:44	RTO	8	APR-30-2021 20:30	RTO	12
FEB-10-2020 20:15	RTO	9	MAY-26-2021 14:17	RTO	10
FEB-18-2020 11:16	RTO	10	JUN-21-2021 05:54	RTO	7
MAR-08-2020 05:17	MAD	5	JUN-23-2021 03:33	RTO	5
APR-13-2020 20:01	RTO	8	JUL-21-2021 18:28	RTO	5
MAY-03-2020 12:29	RTO	6	JUL-25-2021 16:17	RTO	6
JUL-06-2020 21:22	RTO	10	AUG-23-2021 16:44	RTO	18
JUL-24-2020 01:03	RTO	9	AUG-24-2021 10:38	RTO	8
JUL-25-2020 16:39	MAD	11	SEP-27-2021 16:56	RTO	8
SEP-10-2020 00:19	RTO	10	OCT-11-2021 09:23	RTO	9
OCT-10-2020 18:52	RTO	8	OCT-16-2021 01:30	RTO	8
OCT-12-2020 04:29	RTO	9	NOV-12-2021 13:25	RTO	12
NOV-13-2020 07:46	RTO	6	NOV-30-2021 05:40	RTO	9
DEC-16-2020 16:38	MAD	10	NOV-30-2021 09:57	RTO	9
			DEC-8-2021 05:04	RTO	7

Figure 10-7 shows spin event durations over the past five years.

Figure 10-7 Synchronized reserve events duration distribution curve: January 2013 through December 2021



65 For full history of spinning events, see the 2019 State of the Market Report for PJM, Appendix E - Ancillary Service Markets.

Nonsynchronized Reserve Market

Nonsynchronized reserve consists of MW available within 10 minutes but not synchronized to the grid. Startup time for nonsynchronized reserve resources is not subject to testing and is based on parameters in offers submitted by resource owners. There is no defined requirement for nonsynchronized reserves. It is available to meet the primary reserve requirement. Generation resources that have designated their entire output as emergency are not eligible to provide nonsynchronized reserves. Generation resources that are not available to provide energy are not eligible to provide nonsynchronized reserves.

The market mechanism for nonsynchronized reserve does not include any direct participation by market participants. PJM defines the demand curve for nonsynchronized reserve and PJM defines the supply curve based on nonemergency generation resources that are available to provide energy and can start in 10 minutes or less and on the associated resource opportunity costs calculated by PJM. Generation owners do not submit supply offers. Since nonsynchronized reserve is a lower quality product, its clearing price is less than or equal to the synchronized reserve market clearing price. In most hours, the nonsynchronized reserve clearing price is zero.

Market Structure

Demand

Demand for primary reserve is established by PJM as one and a half times the largest contingency. Demand for primary reserve is calculated dynamically in every synchronized and nonsynchronized reserve market solution. After filling the synchronized reserve requirement the balance of primary reserve can be made up by the most economic combination of synchronized and nonsynchronized reserve. In practice this means that the primary reserve requirement minus the scheduled synchronized reserve is the nonsynchronized requirement for the interval. PJM may increase the primary reserve requirement to cover times when a single contingency could cause an outage of several generating units or in times of high load conditions causing operational uncertainty.⁶⁶

⁶⁶ See PJM "Manual 11: Energy and Ancillary Services Market Operations," § 4.2.2 Synchronized Reserve Requirement Determination, Rev. 117 (Nov. 1, 2021).

The average scheduled hourly nonsynchronized reserve in the RTO Zone in 2021 was 1,067.3 MW. The average scheduled nonsynchronized reserve in the MAD Subzone for primary reserve was 1,059.6 MW.

Supply

Figure 10-2 shows that when tier 1 synchronized reserve does not fully meet the synchronized reserve requirement, then most of the primary reserve requirement (blue line) in excess of the synchronized reserve requirement (purple line) is satisfied by nonsynchronized reserve (green area).

There are no offers for nonsynchronized reserve. The market solution considers the available supply of nonsynchronized reserve to be all generation resources currently not synchronized to the grid but available and capable of providing energy within 10 minutes. Generators that have set themselves as unavailable or have set their output to be emergency only will not be considered. The market solution considers the offered MW to be the lesser of the economic maximum or the ramp rate times 10 minutes minus the startup and notification time. The market supply curve is constructed from the nonsynchronized units' opportunity cost of providing reserves. PJM and generation owners may agree upon exceptions to the requirements.

Nonsynchronized reserve resources are scheduled economically based on estimated LOC until the Primary Reserve requirement is filled. The nonsynchronized reserve market clearing price is determined every five minutes based on the LOC of the marginal unit. When a unit clears the nonsynchronized reserve market and is scheduled, it is committed to remain offline and available to provide 10 minute reserves.

Resources that generally qualify as nonsynchronized reserve include run of river hydro, pumped hydro, combustion turbines, combined cycles that can start in 10 minutes or less, and diesels.⁶⁷ In 2021, an average of 1,067.3 MW of nonsynchronized reserve was scheduled per five minute interval out of 1,414.6 eligible MW as part of the primary reserve requirement in the RTO Zone. If only intervals when the price was greater than \$0 are looked at, then an average of 666.9 MW of

⁶⁷ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 4b.2 Non-Synchronized Reserve Market Business Rules, Rev. 117 (Nov. 1, 2021).

nonsynchronized reserve is scheduled out of 990.3 MW available.

In 2021, CTs provided 83.9 percent of scheduled nonsynchronized reserve (Table 10-24). Natural gas was the primary fuel for nonsynchronized reserve.

Table 10-24 Supply of nonsynchronized reserve by fuel and unit type: 2021

Unit / Fuel Type	Percent by MW	Percent by Credits
CT - Natural Gas	44.1%	25.9%
CT - Oil	39.6%	61.5%
Hydro - Run of River	15.6%	11.9%
Hydro - Pumped Storage	0.4%	0.2%
CT - Other	0.2%	0.4%
RICE - Oil	0.1%	0.2%
Battery	0.0%	0.0%
Combined Cycle	0.0%	0.0%
Distributed Gen	0.0%	0.0%
Fuel Cell	0.0%	0.0%
Nuclear	0.0%	0.0%
RICE - Natural Gas	0.0%	0.0%
RICE - Other	0.0%	0.0%
Solar	0.0%	0.0%
Solar + Storage	0.0%	0.0%
Solar + Wind	0.0%	0.0%
Steam - Coal	0.0%	0.0%
Steam - Natural Gas	0.0%	0.0%
Steam - Oil	0.0%	0.0%
Steam - Other	0.0%	0.0%
Wind	0.0%	0.0%
Wind + Storage	0.0%	0.0%

Market Concentration

The supply of nonsynchronized reserves in the Mid-Atlantic Dominion Subzone and the RTO Zone was highly concentrated in 2021. Table 10-25 shows the percent of dispatch solutions with a real-time nonsynchronized reserve market clearing price greater than \$0.01 that failed the three pivotal supplier test. In 2021, on average, there were 165 dispatch cases each month with a real-time price above \$0.01, of which 99.6 percent had at least one pivotal supplier. In 2021, 99.96 percent of all tested cases, or 2,486 out of 2,487, had at least one pivotal supplier.

Table 10-25 Percent of dispatch solutions with NSRMCP greater than \$0.01 failing the three pivotal supplier test: 2021

Year	Month	Number of Dispatch Cases NSR MCP > \$0.01	Percent of Dispatch Cases NSR MCP > \$0.01 Pivotal
2021	Jan	30	100.0%
2021	Feb	149	100.0%
2021	Mar	56	100.0%
2021	Apr	192	100.0%
2021	May	615	100.0%
2021	Jun	187	100.0%
2021	Jul	92	100.0%
2021	Aug	106	100.0%
2021	Sep	108	100.0%
2021	Oct	813	100.0%
2021	Nov	477	100.0%
2021	Dec	22	95.5%
2021	Average	165	99.6%

Price

The settled price of nonsynchronized reserve is calculated in real time every five minutes for the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.

Figure 10-8 shows the daily average nonsynchronized reserve market clearing price (NSRMCP) and average credited MW for the RTO Zone. In 2021, the weighted average nonsynchronized market clearing price for all intervals was \$0.31 per MW. The average nonsynchronized reserve credited was 1,067.3 MW.

Figure 10-8 Daily average weighted RTO Zone nonsynchronized reserve market clearing price and MW purchased: 2021

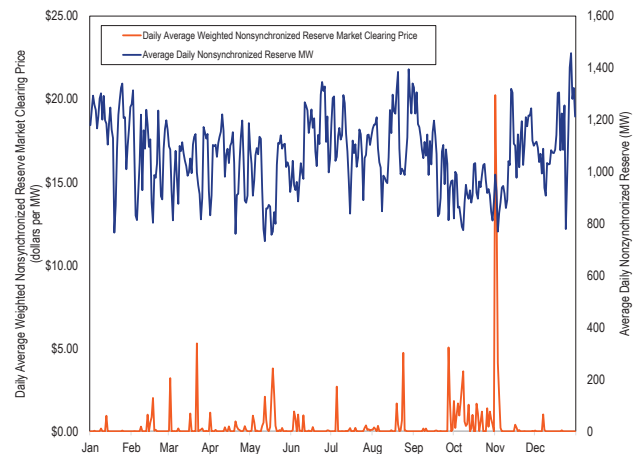


Table 10-26 shows the effect of fast start pricing on the nonsynchronized reserve market's monthly weighted average market clearing price in 2021. The weighted average market clearing price for each month is consistently higher in the pricing run than in the dispatch run.

Table 10-26 Comparison of fast start and dispatch and pricing components: 2021

Month	Pricing Method	Weighted Average Market Clearing Price
Sep	Fast Start	\$0.28
	Dispatch	\$0.24
Oct	Fast Start	\$1.26
	Dispatch	\$0.97
Nov	Fast Start	\$2.74
	Dispatch	\$2.12
Dec	Fast Start	\$0.10
	Dispatch	\$0.04

Price and Cost

As a result of changing grid conditions, load forecasts, incorrect LMP and lost opportunity cost projections, and unexpected generator performance, prices frequently do not cover the full LOC of each resource. All resources cleared in the market are guaranteed to be made whole and are paid uplift credits if the NSRMCP does not fully compensate them. When real-time LMP is greater than the generator's incremental energy offer at economic minimum, then an LOC is paid, even if LMP revenue would not have covered the unit's start and no load costs.⁶⁸

The full cost to customers of nonsynchronized reserve credits, including payments for the clearing price and uplift costs is calculated and compared to the price (Table 10-27). The closer the price to cost ratio comes to one, the more compensation is provided

In 2021, the average price of nonsynchronized reserve was \$0.48 per MW. The average credit for nonsynchronized reserve was \$1.80 per MW.

Resources that are not synchronized to the grid are generally off because it is not economic for them to produce energy. A resource scheduled for nonsynchronized reserve is obligated to remain unsynchronized even if its LMP increases above its energy offer. In that case, PJM pays the unit LOC.

⁶⁸ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 2.16 Minimum Capacity Emergency in Day-ahead Market, Rev. 117 (Nov. 1, 2021).

Table 10-27 RTO zone nonsynchronized reserve MW, charges, price, and cost: January 2020 through December 2021

Market	Year	Month	Total	Total	Weighted	Nonsynchronized Reserve Cost	Price/Cost Ratio
			Nonsynchronized Reserve MW	Nonsynchronized Reserve Charges	Nonsynchronized Reserve Market Price		
RTO Zone	2020	Jan	775,929	\$377,336	\$0.00	\$0.49	NA
RTO Zone	2020	Feb	758,614	\$138,939	\$0.00	\$0.18	NA
RTO Zone	2020	Mar	806,059	\$170,156	\$0.00	\$0.21	NA
RTO Zone	2020	Apr	665,747	\$644,306	\$0.02	\$0.97	2.1%
RTO Zone	2020	May	774,183	\$425,791	\$0.01	\$0.55	1.1%
RTO Zone	2020	Jun	619,391	\$649,601	\$0.11	\$1.05	10.4%
RTO Zone	2020	Jul	767,222	\$648,118	\$0.24	\$0.84	28.4%
RTO Zone	2020	Aug	799,233	\$1,106,678	\$0.49	\$1.38	35.4%
RTO Zone	2020	Sep	761,617	\$750,028	\$0.02	\$0.98	2.0%
RTO Zone	2020	Oct	773,420	\$1,588,183	\$0.93	\$2.05	45.2%
RTO Zone	2020	Nov	725,048	\$809,177	\$0.36	\$1.12	31.9%
RTO Zone	2020	Dec	851,859	\$921,357	\$0.07	\$1.08	6.4%
RTO Zone	2020	Total	9,078,323	\$8,229,669	\$0.19	\$0.91	18.10%
RTO Zone	2021	Jan	878,568	\$531,437	\$0.05	\$0.60	8.3%
RTO Zone	2021	Feb	706,486	\$600,304	\$0.27	\$0.85	31.8%
RTO Zone	2021	Mar	760,807	\$1,612,035	\$0.34	\$2.12	16.0%
RTO Zone	2021	Apr	752,203	\$422,508	\$0.14	\$0.56	25.8%
RTO Zone	2021	May	725,702	\$1,795,780	\$0.53	\$2.47	21.3%
RTO Zone	2021	Jun	801,295	\$942,343	\$0.19	\$1.18	16.3%
RTO Zone	2021	Jul	822,174	\$796,675	\$0.16	\$0.97	16.9%
RTO Zone	2021	Aug	818,194	\$2,612,797	\$0.39	\$3.19	12.2%
RTO Zone	2021	Sep	763,901	\$1,552,338	\$0.33	\$2.03	16.3%
RTO Zone	2021	Oct	680,051	\$1,428,601	\$1.05	\$2.10	50.1%
RTO Zone	2021	Nov	760,821	\$2,908,425	\$1.65	\$3.82	43.2%
RTO Zone	2021	Dec	832,767	\$1,571,760	\$0.05	\$1.89	2.8%
RTO Zone	2021	Total	9,302,967	\$16,775,003	\$0.43	\$1.80	23.9%

Secondary Reserve (DASR)

There is no NERC standard for secondary reserve. PJM defines secondary reserve as reserves (online or offline available for dispatch) that can be converted to energy in 30 minutes. PJM defines a secondary reserve requirement but does not currently have a defined reserve product to maintain this reserve requirement in real time.

PJM maintains a day-ahead, offer based market for 30 minute day-ahead secondary reserve. The Day-Ahead Scheduling Reserve Market (DASR) has no performance obligations except that a unit which clears the DASR market is required to be available for dispatch in real time.⁶⁹

Market Structure

Supply

Both generation and demand resources are eligible to offer DASR. DASR offers consist of price only. Available DASR MW are calculated by the market clearing engine. DASR MW are the lesser of the energy ramp rate per minute for online units times 30 minutes, or the economic maximum MW minus the day-ahead dispatch point. For offline resources capable of being online in 30 minutes, the DASR quantity is the economic maximum. In 2021, the DASR hourly average purchased was 4,919.6 MW.⁷⁰

PJM excludes resources that cannot reliably provide reserves in real time from participating in the DASR market. Such resources include nuclear, run of river hydro, self-scheduled pumped hydro, wind, solar, and energy storage resources.⁷¹ The intent is to limit cleared DASR resources to those resources actually capable of providing reserves in the real-time market. Owners of excluded resources may request an exemption from their default noneligibility.

69 See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 10.5 Aggregation for Economic and Emergency Demand Resources, Rev. 117 (Nov. 1, 2021).

70 The average hourly available DASR MW are modified from previously reported values because of a calculation error which has been fixed.

71 See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 11.2.2 Day-Ahead Scheduling Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

Of the scheduled DASR MW cleared in 2021, 80.7 percent was from CTs (Table 10-28).

Table 10-28 Scheduled DASR by fuel and unit type: 2021

Unit / Fuel Type	Percentage of DASR MW	Percentage of DASR Credits
CT - Natural Gas	62.2%	56.1%
CT - Oil	18.5%	20.5%
Hydro - Pumped Storage	11.2%	6.0%
Combined Cycle	4.9%	9.5%
Steam - Coal	2.6%	3.9%
Steam - Natural Gas	0.3%	2.6%
RICE - Oil	0.2%	0.9%
RICE - Other	0.1%	0.4%
RICE - Natural Gas	0.1%	0.1%
Steam - Other	0.0%	0.1%
Steam - Oil	0.0%	0.0%
Nuclear	0.0%	0.0%
CT - Other	0.0%	0.0%
Battery	0.0%	0.0%
Distributed Gen	0.0%	0.0%
Fuel Cell	0.0%	0.0%
Hydro - Run of River	0.0%	0.0%
Solar	0.0%	0.0%
Solar + Storage	0.0%	0.0%
Solar + Wind	0.0%	0.0%
Wind	0.0%	0.0%
Wind + Storage	0.0%	0.0%

Demand

Secondary reserve (30 minute reserve) requirements are determined by PJM for each reliability region. In the ReliabilityFirst (RFC) region, secondary reserve requirements are calculated based on historical under forecasted load rates and generator forced outage rates.⁷² The DASR requirement is calculated daily and is equal to the peak load forecast for the ReliabilityFirst region (RFC) and EKPC times the sum of the forced outage rate and the load forecast error, plus Dominion's share of the VACAR contingency reserve commitment. From November 1, 2020 through October 31, 2021, the day-ahead scheduling reserve requirement was 4.75 percent of the peak load forecast. This was based on a 2.16 percent load forecast error component and a 2.59 percent forced outage rate component. Effective November 1, 2021, through October 31, 2022, the day-ahead scheduling reserve requirement is 4.40 percent of the peak load forecast, based on a 2.03 percent LFE component and a 2.38 percent FOR component. The DASR requirement is applicable for all hours of the operating day.

72 See PJM "Manual 13: Emergency Operations," § 2.2 Reserve Requirements, Rev.82 (Jan. 1, 2022).

The DASR requirement can be increased by PJM operators under conditions of "hot weather or cold weather alert or max emergency generation alert or other escalating emergency."⁷³ The amount of additional DASR MW that may be required is the Adjusted Fixed Demand (AFD) determined by a Seasonal Conditional Demand (SCD) factor.⁷⁴ The SCD factor is calculated separately for the winter (November through March) and summer (April through October) seasons. The SCD factor is calculated every year based on the top 10 peak load days from the prior year. For November 2020 through October 2021, the SCD values were 2.12 percent for winter and 4.72 percent for summer. For November 2021 through October 2022, the SCD values are 5.84 percent for winter and 4.06 percent for summer. PJM Dispatch may also schedule additional Day-Ahead Scheduling Reserves as deemed necessary for conservative operations.⁷⁵ PJM has defined the reasons for conservative operations to include, potential fuel delivery issues, forest/brush fires, extreme weather events, environmental alerts, solar disturbances, unknown grid operating state, physical or cyber attacks.⁷⁶ The result is substantial discretion for PJM to increase the demand for DASR under a variety of circumstances. PJM invoked adjusted fixed demand in 516 hours during 2021.

The MMU recommends that PJM modify the DASR market to ensure that all resources cleared incur a real-time performance obligation. The MMU further recommends that PJM attach a reason code to all hours when adjusted fixed demand is dispatched.

Market Concentration

DASR market three pivotal supplier test results are provided in Table 10-29. Table 10-29 shows the percent of intervals with a day-ahead scheduling reserve market clearing price greater than \$0.01 that failed the three pivotal supplier test. In 2021, on average, there were 97 testable intervals each month, of which 94.0 percent had at least one pivotal supplier.

73 PJM, "Energy and Reserve Pricing & Interchange Volatility Final Proposal Report," <<http://www.pjm.com/~media/committees-groups/committees/mrc/20141030/20141030-item-04-erpv-final-proposal-report.ashx>>.

74 See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 11.2.1 Day-Ahead Scheduling Reserve Market Requirement, Rev. 117 (Nov. 1, 2021).

75 See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 11.2.1 Day-Ahead Scheduling Reserve Market Requirement, Rev. 117 (Nov. 1, 2021).

76 See PJM "Manual 13: Emergency Operations," § 3.2 Conservative Operations, Rev. 82 (Jan. 1, 2022).

Table 10-29 DADR market three pivotal supplier test results and number of hours with DADR MCP above \$0.01: January 2020 through December 2021

Year	Month	Number of Hours DADR MCP > \$0.01	Percent of Hours DADR MCP > \$0.01 Pivotal
2020	Jan	3	100.0%
2020	Feb	2	100.0%
2020	Mar	1	100.0%
2020	Apr	0	NA
2020	May	24	100.0%
2020	Jun	142	88.0%
2020	Jul	321	66.4%
2020	Aug	212	94.3%
2020	Sep	89	100.0%
2020	Oct	170	98.8%
2020	Nov	70	100.0%
2020	Dec	69	100.0%
2020	Average	92	95.2%
2021	Jan	15	100.0%
2021	Feb	26	100.0%
2021	Mar	23	100.0%
2021	Apr	93	98.9%
2021	May	79	87.3%
2021	Jun	151	78.1%
2021	Jul	148	95.9%
2021	Aug	153	84.3%
2021	Sep	131	86.3%
2021	Oct	171	98.8%
2021	Nov	140	98.6%
2021	Dec	33	100.0%
2021	Average	97	94.0%

Market Conduct

PJM rules allow any unit with reserve capability that can be converted into energy within 30 minutes to offer into the DADR market.⁷⁷ Units that do not offer have their offers set to \$0.00 per MW during the day-ahead market clearing process.

Economic withholding remains an issue in the DADR market. The marginal cost of providing DADR is zero. All offers greater than zero constitute economic withholding. In 2021, 45.3 percent of generation units offered DADR at a daily price above \$0.00 per MW. In 2021, 17.8 percent of daily offers were above \$5.00 per MW.

The MMU recommends that market solutions for the DADR market be based on opportunity cost only in order to eliminate economic withholding.

⁷⁷ See PJM "Manual 11: Energy & Ancillary Services Market Operations," § 11.2.2 Day-Ahead Scheduling Reserve Market Eligibility, Rev. 117 (Nov. 1, 2021).

Market Performance

In 2021, the DADR market cleared at a price above \$0.00 per MW in 16.4 percent of all hours. The weighted average DADR price for all cleared hours was \$0.24 per MW. The average cleared MW in all hours was 4,389.5 MW. The average cleared MW in all hours when the DADR MCP was above \$0.00 was 5,135.2 MW. The highest DADR price in 2021 was \$48.67 per MW for one hour on August 25.

The introduction of Adjusted Fixed Demand (AFD) on March 1, 2015, created a bifurcated market. Table 10-30 shows the use of AFD in previous years. In 2021, AFD hours were only used in the months of May, June, July, August, and September, as seen in Table 10-31. The resulting differences in market clearing price, MW cleared, obligation incurred, and charges to PJM load are substantial. Table 10-32 shows the differences in price and MW between AFD hours and non-AFD hours in 2021.

Table 10-30 Hours with Adjusted Fixed Demand (AFD) added to the normal DADR requirement: 2015 through 2020

Year	Number of Hours with AFD	Normal Requirement as Percentage of Forecast Load
2015	367	5.9%
2016	522	5.7%
2017	336	5.5%
2018	598	5.3%
2019	447	5.3%
2020	430	5.1%

Table 10-31 Hours with Adjusted Fixed Demand (AFD) and average increase in DADR requirement: 2021

Year	Month	Number of Hours with AFD	Average Increase in Requirement
2021	Jan	0	NA
2021	Feb	0	NA
2021	Mar	0	NA
2021	Apr	0	NA
2021	May	24	61.4%
2021	Jun	119	58.7%
2021	Jul	124	26.3%
2021	Aug	201	23.9%
2021	Sep	48	61.2%
2021	Oct	0	NA
2021	Nov	0	NA
2021	Dec	0	NA
2021	Total	516	37.7%

Table 10-32 Impact of Adjusted Fixed Demand on DASR prices and demand: 2021

Metric	Weighted Day-Ahead		
	Number of Hours	Scheduling Reserve Market Clearing Price (DASRMCP)	Average Hourly Total DASR MW
All hours	8,760	\$0.24	4,724.3
All hours when DASRMCP > \$0	1,444	\$1.27	5,314.3
All hours when AFD used	516	\$1.88	7,868.2

While the new rules allow PJM operators' substantial discretion to add to DASR demand for a variety of reasons, the rationale for each specific increase is not always clear. The MMU recommends that PJM Market Operations attach a reason code to every hour in which PJM operators add additional DASR MW above the default DASR hourly requirement. The addition of such a code would make the reason explicit, increase transparency and facilitate analysis of the use of PJM's ability to add DASR MW.

Comparing the Normal Hour column against the AFD Hour column for five metrics (Table 10-33) shows that the use of AFD for 516 hours in the 2021 significantly increased the cost of DASR. Table 10-33 shows that the cost increase was a result of a substantial increase in DASR MW cleared. The average DASR clearing price in 2021 was \$1.27 for hours when the clearing price was above \$0.00 and \$3.51 during hours when the clearing price was above \$0.00 and adjusted fixed demand was invoked by PJM Dispatch.

Table 10-33 DASR market, regular hours vs. adjusted fixed demand hours with price greater than \$0: 2021

Year	Month	Number of Hours DASRMCP > \$0		Weighted DASRMCP		Average PJM Load MW		Hourly Average Cleared DASR MW		Average Hourly DASR Credits	
		Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour
2020	Jan	3	NA	\$0.10	NA	111,016	NA	4,939	NA	\$487	NA
2020	Feb	3	NA	\$0.10	NA	109,218	NA	5,320	NA	\$508	NA
2020	Mar	1	NA	\$0.19	NA	92,458	NA	4,532	NA	\$861	NA
2020	Apr	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
2020	May	31	NA	\$0.29	NA	96,413	NA	4,711	NA	\$1,364	NA
2020	Jun	124	32	\$0.57	\$2.60	111,577	107,687	5,345	11,033	\$3,072	\$28,688
2020	Jul	122	211	\$1.43	\$3.81	121,825	124,278	5,764	9,717	\$8,243	\$37,033
2020	Aug	206	17	\$0.78	\$7.59	117,929	121,901	5,649	10,917	\$4,394	\$82,814
2020	Sep	105	NA	\$0.39	NA	102,265	NA	5,064	NA	\$1,967	NA
2020	Oct	203	NA	\$0.31	NA	80,004	NA	4,178	NA	\$1,284	NA
2020	Nov	87	NA	\$0.20	NA	89,206	NA	4,483	NA	\$917	NA
2020	Dec	90	NA	\$0.20	NA	100,921	NA	4,844	NA	\$992	NA
2020		975	260	\$0.60	\$3.92	103,134	122,080	5,043	9,957	\$3,050	\$38,999
2021	Jan	28	NA	\$0.08	NA	106,153	NA	4,847	NA	\$380	NA
2021	Feb	32	NA	\$0.16	NA	108,947	NA	4,974	NA	\$815	NA
2021	Mar	24	NA	\$0.17	NA	92,014	NA	4,327	NA	\$732	NA
2021	Apr	129	NA	\$0.21	NA	83,962	NA	3,983	NA	\$846	NA
2021	May	68	11	\$0.60	\$1.91	99,007	105,454	4,661	9,514	\$2,785	\$18,147
2021	Jun	83	77	\$0.41	\$4.55	115,654	118,494	5,170	8,973	\$2,124	\$40,839
2021	Jul	115	46	\$0.44	\$1.41	122,396	129,739	5,460	7,842	\$2,424	\$11,095
2021	Aug	110	83	\$0.35	\$3.85	121,022	133,350	5,399	7,869	\$1,877	\$30,312
2021	Sep	107	40	\$0.58	\$3.45	104,852	105,046	4,776	9,117	\$2,769	\$31,492
2021	Oct	222	NA	\$0.50	NA	87,526	NA	4,335	NA	\$2,159	NA
2021	Nov	228	NA	\$0.30	NA	89,025	NA	4,209	NA	\$1,258	NA
2021	Dec	41	NA	\$0.26	NA	100,378	NA	4,546	NA	\$1,189	NA
2021		1,187	257	\$0.39	\$3.51	99,647	122,653	4,633	8,460	\$1,791	\$29,689

Table 10-34 shows total number of hours when a DASR market cleared at a price above \$0 along with average load, cleared MW, additional MW under AFD, and total charges for the DASR market in January 2020 through December 2021.

Table 10-34 DASR market all hours of DASR market clearing price greater than \$0: January 2020 through December 2021

Year	Month	Number of Hours DASRMCP > \$0	Weighted DASR Market Clearing Price	Average Hourly RT Load MW	PJM Cleared DASR MW	PJM Cleared Additional DASR MW	Credits
2020	Jan	3	\$0.10	111,016	14,817	0	\$1,462
2020	Feb	3	\$0.10	109,218	15,961	0	\$1,524
2020	Mar	1	\$0.19	92,458	4,532	0	\$861
2020	Apr	0	NA	NA	NA	NA	NA
2020	May	31	\$0.29	96,413	146,052	0	\$42,272
2020	Jun	156	\$1.28	110,779	1,015,850	212,736	\$1,298,963
2020	Jul	333	\$3.20	123,379	2,753,429	850,906	\$8,819,472
2020	Aug	223	\$1.71	118,232	1,349,321	87,283	\$2,312,941
2020	Sep	105	\$0.39	102,265	531,772	0	\$206,569
2020	Oct	203	\$0.31	80,004	848,099	0	\$260,746
2020	Nov	87	\$0.20	89,206	390,026	0	\$79,753
2020	Dec	90	\$0.20	100,921	435,941	0	\$89,283
2020	Total	1,235	\$1.75	107,123	7,505,798	1,150,925	\$13,113,848
2021	Jan	28	\$0.08	106,153	135,710	0	\$10,640
2021	Feb	32	\$0.16	108,947	159,163	0	\$26,076
2021	Mar	24	\$0.17	92,014	103,839	0	\$17,564
2021	Apr	129	\$0.21	83,962	513,819	0	\$109,108
2021	May	79	\$0.92	99,905	421,593	53,470	\$389,001
2021	Jun	160	\$2.97	117,021	1,120,041	351,422	\$3,320,941
2021	Jul	161	\$0.80	124,494	988,574	97,972	\$789,171
2021	Aug	193	\$2.18	126,324	1,246,974	168,469	\$2,722,344
2021	Sep	147	\$1.78	104,905	875,744	150,928	\$1,555,947
2021	Oct	222	\$0.50	87,526	962,369	0	\$479,311
2021	Nov	228	\$0.30	89,025	959,656	0	\$286,903
2021	Dec	41	\$0.26	100,378	186,385	0	\$48,735
2021	Total	1,444	\$1.27	103,741	7,673,868	822,262	\$9,755,740

When the DASR requirement is increased by PJM dispatch, the reserve requirement frequently cannot be met without redispatching online resources which significantly affects the price by creating an LOC. Adjusted Fixed Demand related increases in the DASR requirement (Table 10-34) in 2020 caused prices to increase.

Regulation Market

Regulation matches generation with very short term changes in load by moving the output of selected resources up and down via an automatic control signal. Regulation is provided by generators with a short-term response capability (less than five minutes) or by demand response (DR). The PJM Regulation Market is operated as a single real-time market.

Market Design

PJM's regulation market design is a result of Order No. 755.⁷⁸ The objective of PJM's regulation market design is to minimize the cost to provide regulation using two resource types in a single market.

The regulation market includes resources following two signals: RegA and RegD. Resources responding to either

signal help control ACE (area control error). RegA is PJM's slow-oscillation regulation signal and is designed for resources with the ability to sustain energy output for long periods of time, with slower ramp rates. RegD is PJM's fast-oscillation regulation signal and is designed for resources with limited ability to sustain energy output and with faster ramp rates. Resources must qualify to follow one or both of the RegA and RegD signals, but will be assigned by the market clearing engine to follow only one signal in a given market hour.

The PJM regulation market design includes three clearing price components: capability (\$/MW, based on the MW being offered); performance (\$/mile, based on the

total MW movement requested by the control signal, known as mileage); and lost opportunity cost (\$/MW of lost revenue from the energy market as a result of providing regulation). The marginal benefit factor (MBF) and performance score translate a RegD resource's capability (actual) MW into marginal effective MW and offers into \$/effective MW.

The regulation market solution is intended to meet the regulation requirement with the least cost combination of RegA and RegD. When solving for the least cost combination of RegA and RegD MW to meet the regulation requirement, the regulation market will substitute RegD MW for RegA MW when RegD is cheaper. Performance adjusted RegA MW are used as the common unit of measure, called effective MW,

⁷⁸ Order No. 755, 137 FERC ¶ 61,064 at P 2 (2011).

of regulation service. All resource MW (RegA and RegD) are converted into effective MW. RegA MW are converted into effective MW by multiplying the RegA MW offered by their performance score. RegD MW are converted into effective MW by multiplying the RegD offered by their performance score and by the MBF. The regulation requirement is defined as the total effective MW required to provide a defined amount of area control error (ACE) control.

The regulation market converts performance adjusted RegD MW into effective MW using the MBF in the PJM design. The MBF is used to convert incremental additions of RegD MW into incremental effective MW. The total effective MW for a given amount of RegD MW equal the area under the MBF curve (the sum of the incremental effective MW contributions). RegA and RegD resources should be paid the same price per marginal effective MW.

The marginal rate of technical substitution (MRTS) is the marginal measure of substitutability of RegD resources for RegA resources in satisfying a defined regulation requirement at feasible combinations of RegA and RegD MW. While resources following RegA and RegD can both provide regulation service in PJM's Regulation Market, PJM's joint optimization is intended to determine and assign the optimal mix of RegA and RegD MW to meet the hourly regulation requirement. The optimal mix is a function of the relative effectiveness and cost of available RegA and RegD resources.

At any valid combination of RegA and RegD, regulation offers are converted to dollars per effective MW using the RegD offer and the MBF associated with that combination of RegA and RegD. The marginal contribution of a RegD MW to effective MW is equal to the MRTS associated with that RegA/RegD combination.

For example, a 1.0 MW RegD resource with a total offer price of \$2 per MW with a MBF of 0.5 and a performance score of 100 percent would be calculated as offering 0.5 effective MW (0.5 MBF times 1.00 performance score times 1 MW). The total offer price would be \$4 per effective MW (\$2 per MW offer divided by the 0.5 effective MW).

Regulation performance scores (0.0 to 1.0) measure the response of a regulating resource to its assigned

regulation signal (RegA or RegD) every 10 seconds by measuring: delay, the time delay of the regulation response to a change in the regulation signal; correlation, the correlation between the regulating resource output and the regulation signal; and precision, the difference between the regulation response and the regulation requested.⁷⁹ Performance scores are reported on an hourly basis for each resource.

Table 10-35 and Figure 10-9 show the average performance score by resource type and the signal followed in 2021. In these figures, the MW used are actual MW and the performance score is the hourly performance score of the regulation resource.⁸⁰ Each category (color bar) is based on the percentage of the full performance score distribution for each resource (or signal) type. As Figure 10-9 shows, 76.0 percent of RegD resources had average performance scores within the 0.91-1.00 range, and 25.0 percent of RegA resources had average performance scores within that range in 2021. In 2020, 82.2 percent of RegD resources had average performance scores within the 0.91-1.00 range, and 33.2 percent of RegA resources had average performance scores within that range.

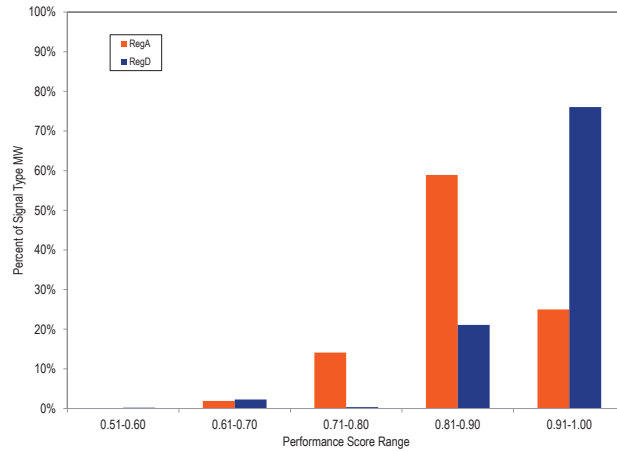
Table 10-35 Hourly average performance score by unit type: 2021

		Performance Score Range				
		51-60	61-70	71-80	81-90	91-100
RegA	Battery	-	-	-	-	-
	CC	0.0%	0.0%	0.0%	0.0%	100.0%
	CT	0.0%	0.3%	5.4%	53.7%	40.5%
	Diesel	0.0%	0.0%	0.0%	15.2%	84.8%
	DSR	0.0%	0.0%	29.3%	56.7%	14.0%
	Hydro	0.0%	0.0%	0.1%	39.9%	60.0%
	Steam	0.1%	2.7%	19.7%	66.4%	11.1%
RegD	Battery	0.2%	2.4%	0.0%	18.5%	78.8%
	CC	-	-	-	-	-
	CT	0.0%	0.0%	7.7%	77.9%	14.4%
	Diesel	0.0%	0.0%	0.8%	80.3%	18.9%
	DSR	0.1%	0.0%	6.8%	63.2%	30.0%
	Hydro	0.0%	0.4%	0.0%	34.1%	65.6%
	Steam	-	-	-	-	-

⁷⁹ PJM "Manual 12: Balancing Operations," § 4.5.6 Performance Score Calculation, Rev. 43 (June 6, 2021).

⁸⁰ Except where explicitly referred to as effective MW or effective regulation MW, MW means actual MW unadjusted for either MBF or performance factor.

Figure 10-9 Hourly average performance score by regulation signal type: 2021



Each cleared resource in a class (RegA or RegD) is allocated a portion of the class signal (RegA or RegD). This portion of the class signal is based on the cleared regulation MW of the resource relative to the cleared MW for that class. This signal is called the Total Regulation Signal (TREG) for the resource. A resource with 10 MW of capability will be provided a TREG signal asking for a positive or negative regulation movement between negative and positive 10 MW around its regulation set point.

Resources are paid Regulation Market Clearing Price (RMCP) credits and lost opportunity cost credits, which are uplift payments. If a resource's lost opportunity costs for an hour are greater than its RMCP credits, that resource receives lost opportunity cost credits equal to the difference. PJM posts clearing prices for the regulation market (RMCCP, RMPCP and RMCP) in dollars per effective MW. The regulation market clearing price (RMCP in \$/effective MW) for the hour is the simple average of the 12 five minute RMCPs within the hour. The RMCP is set in each five minute interval based on the marginal offer in each interval. The performance clearing price (RMPCP in \$/effective MW) is based on the marginal performance offer (RMPCP) for the hour. The capability clearing price (RMCCP in \$/effective MW) is equal to the difference between the RMCP for the hour and the RMPCP for the hour. This is done so the total of RMPCP plus RMCCP equals the total clearing price (RMCP) but the RMPCP is maximized.

Market solution software relevant to regulation consists of the Ancillary Services Optimizer (ASO) solving

hourly; the intermediate term security constrained economic dispatch market solution (IT SCED) solving every 15 minutes; and the real-time security constrained economic dispatch market solution (RT SCED) solving approximately every five minutes. The market clearing price is determined by pricing software (LPC) that looks at the units cleared in the most recently approved RT SCED case, approximately 10 minutes ahead of the target solution time. The marginal prices assigned by the LPC to five minute intervals are averaged over the hour for an hourly regulation market clearing price.

Market Design Issues

PJM's current regulation market design is severely flawed and is not efficient or competitive. The market results do not represent the least cost solution for the defined level of regulation service.

In a well functioning market, every resource should be paid the same clearing price per unit produced. That is not true in the PJM Regulation Market. RegA and RegD resources are not paid the same clearing price in dollars per effective MW. RegD resources are being paid more than the market clearing price. This flaw in the market design has caused operational issues, has caused over investment in RegD resources.

If all MW of regulation were treated the same in both the clearing of the market and in settlements, many of the issues in the PJM Regulation Market would be resolved. However, the current PJM rules result in the payment to RegD resources being up to 1,000 times the correct price.

RegA and RegD have different physical capabilities. In order to permit RegA and RegD to compete in the single PJM Regulation Market, RegD must be translated into the same units as RegA. One MW of RegA is one effective MW. The translation is done using the marginal benefit factor (MBF). As more RegD is added to the market, the relative value of RegD declines, based on its actual performance attributes. For example, if the MBF is 0.001, a MW of RegD is worth 0.001 MW of RegA (or 1/1,000 of a MW of RegA). This is the same thing as saying that 1.0 MW of RegD is equal to 0.001 effective MW when the MBF is 0.001.

Almost all of the issues in PJM's Regulation Market are caused by the inconsistent application of the MBF.

Because the MBF is not included in settlements, when the MBF is less than 1.0, RegD resources are paid too much. When the MBF is less than 1.0, each MW of RegD is worth less than 1.0 MW of RegA. The market design buys the correct amount of RegD, but pays RegD as if the MBF were 1.0. In an extreme case, when the MBF is 0.001, RegD MW are paid 1,000 times too much. If the market clearing price is \$1.00 per MW of RegA, RegD is paid \$1,000 per effective MW. Resolution of this problem requires that PJM pay RegD for the same effective MW it provides in regulation, 0.001 MW.

To address the identified market flaws, the MMU and PJM developed a joint proposal which was approved by the PJM Members Committee on July 27, 2017, and filed with FERC on October 17, 2017. The PJM/MMU joint proposal addresses issues with the inconsistent application of the marginal benefit factor throughout the optimization and settlement process in the PJM Regulation Market. FERC rejected the proposal finding it inconsistent with Order No. 755.

The MBF related issues with the regulation market have been raised in the PJM stakeholder process. In 2015, PJM stakeholders approved an interim, partial solution to the RegD over procurement problem which was implemented on December 14, 2015. The interim solution was designed to reduce the relative value of RegD MW in all hours and to cap purchases of RegD MW during critical performance hours. But the interim solution did not address the fundamental issues in the optimization or the lack of consistency in the application of the MBF.

Additional changes were implemented on January 9, 2017. These modifications included changing the definition of off peak and on peak hours, adjusting the currently independent RegA and RegD signals to be interdependent, and changing the 15 minute neutrality requirement of the RegD signal to a 30 minute neutrality requirement.

The January 9, 2017, design changes appear to have been intended to make RegD more valuable. That is not a reasonable design goal. The design goal should be to determine the least cost way to provide needed regulation. The RegA signal is now slower than it was previously, which may make RegA following resources less useful as ACE control. RegA is now explicitly used to support the conditional energy neutrality of RegD.

The RegD signal is now the difference between ACE and RegA. RegA is required to offset RegD when RegD moves in the opposite direction of that required by ACE control in order to permit RegD to recharge. These changes in the signal design will allow PJM to accommodate more RegD in its market solutions. The new signal design is not making the most efficient use of RegA and RegD resources. The explicit reliance on RegA to offset issues with RegD is a significant conceptual change to the design that is inconsistent with the long term design goal for regulation. PJM increased the regulation requirement as part of these changes.

The January 9, 2017, design changes replaced off peak and on peak hours with nonramp and ramp hours with definitions that vary by season. The regulation requirement for ramp hours was increased from 700 MW to 800 MW (Table 10-36). These market changes still do not address the fundamental issues in the optimization or the lack of consistency in the application of the MBF.

Table 10-36 Seasonal regulation requirement definitions⁸¹

Season	Dates	Nonramp Hours	Ramp Hours
Winter	Dec 1 - Feb 28(29)	00:00 - 03:59	04:00 - 08:59
		09:00 - 15:59	16:00 - 23:59
Spring	Mar 1 - May 31	00:00 - 04:59	05:00 - 07:59
		08:00 - 16:59	17:00 - 23:59
Summer	Jun 1 - Aug 31	00:00 - 04:59	05:00 - 13:59
		14:00 - 17:59	18:00 - 23:59
Fall	Sep 1 - Nov 30	00:00 - 04:59	05:00 - 07:59
		08:00 - 16:59	17:00 - 23:59

Performance Scores

Performance scores, by class and unit, are not an indicator of how well resources contribute to ACE control. Performance scores are an indicator only of how well the resources follow their TREG signal. High performance scores with poor signal design are not a meaningful measure of performance. For example, if ACE indicates the need for more regulation but RegD resources have provided all their available energy, the RegD regulation signal will be in the opposite direction of what is needed to control ACE. So, despite moving in the wrong direction for ACE control, RegD resources would get a good performance score for following the RegD signal and will be paid for moving in the wrong direction.

⁸¹ See PJM, "Regulation Requirement Definition," <<http://www.pjm.com/~media/markets-ops/ancillary/regulation-requirement-definition.ashx>>.

The RegD signal prior to January 9, 2017, is an example of a signal that resulted in high performance scores, but due to 15 minute energy neutrality built into the signal, ran counter to ACE control at times. Energy neutrality means that energy produced equals energy used within a defined timeframe. With 15 minute energy neutrality, if a battery were following the regulation signal to provide MWh for 7.5 minutes, it would have to consume the same amount of MWh for the next 7.5 minutes. When neutrality correction of the RegD signal is triggered, it overrides ACE control in favor of achieving zero net energy over the 15 minute period. When this occurs, the RegD signal runs counter to the control of ACE and hurts rather than helps ACE. In that situation, the control of ACE, which must also offset the negative impacts of RegD, depends entirely on RegA resources following the RegA signal. High performance scores under the signal design prior to January 9, 2017, was not an indication of good ACE control.

The January 9, 2017, design changes did not address the fundamental issues with the definition of performance or the nature of payments for performance in the regulation market design. The regulation signal should not be designed to favor a particular technology. The signal should be designed to result in the lowest cost of regulation to the market. Only with a performance score based on full substitutability among resource types should payments be based on following the signal. The MRTS must be redesigned to reflect the actual capabilities of technologies to provide regulation. The PJM regulation market design remains fundamentally flawed.

In addition, the absence of a performance penalty, imposed as a reduction in performance score and/or as a forfeiture of revenues, for deselection initiated by the resource owner within the hour, creates a possible gaming opportunity for resources which may overstate their capability to follow the regulation signal. The MMU recommends that there be a penalty enforced as a reduction in performance score and/or a forfeiture of revenues when resource owners elect to deassign assigned regulation resources within the hour, to prevent gaming.

Battery Settlement

The change from 15 to 30 minute signal neutrality, implemented in the January 9, 2017, design changes, resulted in the reduction of performance scores for short

duration batteries. In April 2017 several participants filed a complaint against PJM, asserting that these changes discriminated against their battery units.⁸² The MMU objected to the complaints. Despite the unsupported assertions in the complaint, PJM settled with the participants that was approved by FERC on April 7, 2020.⁸³ Table 10-37 shows the battery units that are part of the settlement. Starting July 1, 2020, the affected battery units began receiving compensation based on the greater of their current performance score, or their rolling average actual hourly performance score for the last 100 hours the resource operated prior to the January 9, 2017, implementation of the 30-minute conditional neutrality. The additional regulation credits received as a result of the settlement are shown in Table 10-38.

Table 10-37 Batteries in settlement

Parent Company	Unit	MW
The AES Corporation	Laurel Mountain	32.0
	Warrior Run	10.0
Energy Capital Partners, LLC	Hazel	20.0
	Trent	4.0
	McHenry	20.0
Galt Power, Inc.	Beckjord 1	2.0
	Beckjord 2	2.0
	Beech Ridge	31.5
Invenergy, LLC	Grand Ridge 6	4.5
	Grand Ridge 7	31.5
	Lee Dekalb	20.0
NextEra Energy, Inc.	Garrett	10.4
	Meyersdale	18.0
	Mantua Creek	2.0
Renewable Energy Systems Holdings, LTD	Joliet	20.0
	West Chicago	20.0
Sumitomo Corporation	Willey	6.0

Table 10-38 Excess regulation credits received by settlement batteries: January through December, 2021

Month	Excess Regulation Credit (\$)
Jan	\$40,752
Feb	\$82,768
Mar	\$76,248
Apr	\$61,786
May	\$65,797
Jun	\$60,896
Jul	\$76,253
Aug	\$136,365
Sep	\$112,929
Oct	\$156,829
Nov	\$213,585
Dec	\$118,995
Total	\$1,203,204

⁸² See FERC Docket Nos. EL17-64-000 and EL17-65-000.

⁸³ See 170 FERC ¶ 61,258 (2020).

In addition to paying uneconomic regulation credits based on inflated performance scores, the settlement also requires that the affected battery units be cleared in the regulation market regardless of whether their offer was economic. As long as the settlement batteries are offered as either self scheduled with a zero offer, or as a zero priced offer, they must be cleared despite the fact that these units would not necessarily have cleared based on economics.⁸⁴ In order to comply with this condition, PJM clears additional MW beyond what is needed for the regulation requirement in cases where the settlement battery units did not clear but met the offer rules of the settlement. This results in excess charges to customers for regulation service. Table 10-39 shows the impact of clearing additional MW beyond what is needed for the regulation requirement, as a result of the battery settlement. Other changes in market dynamics starting in the third quarter of 2021 reduced the impact of this settlement rule because most of the settlement units clear based on economics. In 2021, the battery settlement resulted in customers paying \$359,644 more than needed to compensate the additional MW from settlement batteries that would not have otherwise cleared. As a result of the battery settlement, PJM customers in 2021 over paid for regulation by \$1.6M (the sum of Table 10-38 and Table 10-39).

Table 10-39 Excess payments and MW cleared due to battery settlement: January through December, 2021

Month	Battery Settlement Impact	
	Regulation Credits	Additional Cleared Regulation MW
Jan	\$49,387	3,149.4
Feb	\$24,776	1,727.7
Mar	\$37,648	3,192.6
Apr	\$78,650	4,872.3
May	\$117,329	7,718.7
Jun	\$2,092	147.4
Jul	\$1,856	26.3
Aug	\$205	8.5
Sep	\$955	26.9
Oct	\$33,819	1,046.2
Nov	\$12,888	238.7
Dec	\$39	4.9
Total	\$359,644	22,159.4

Regulation Signal

As with any signal design for substitutable resources, the MBF function should be determined by the ability of RegA and RegD resources to follow their signals, including conditions under which neutrality cannot be

maintained by RegD resources. The ability of energy limited RegD to provide ACE control depends on the availability of excess RegA capability to support RegD under the conditional neutrality design. When RegD resources are largely energy limited resources, a correctly calculated MBF would exhibit a rapid decrease in the MBF value for every MW of RegD added. The result is that only a small amount of energy limited RegD is economic. The current and proposed signals and corresponding MBF functions do not reflect these principles or the actual substitutability of resource types.

Marginal Benefit Factor Issues

The MBF function, as implemented in the PJM Regulation Market, is not equal to the MRTS between RegA and RegD. The MBF is not consistently applied throughout the market design, from optimization to settlement, and market clearing does not confirm that the resulting combinations of RegA and RegD are realistic and can meet the defined regulation demand. The calculation of total regulation cleared using the MBF is incorrect.⁸⁵

The result has been that the PJM Regulation Market has over procured RegD relative to RegA in most hours, has provided a consistently inefficient market signal to participants regarding the value of RegD in every hour, and has overpaid for RegD. This over procurement has degraded the ability of PJM to control ACE in some hours while at the same time increasing the cost of regulation. When the price paid for RegD is above the level defined by an accurate MBF function, there is an artificial incentive for inefficient entry of RegD resources.

PJM and the MMU filed a joint proposal with FERC on October 17, 2017, to address issues with the inconsistent application of the marginal benefit factor throughout the optimization and settlement process in the PJM Regulation Market, but the proposal was rejected by FERC.⁸⁶

Marginal Benefit Factor Not Correctly Defined

The MBF used in the PJM Regulation Market prior to the December 14, 2015, changes did not accurately reflect the MRTS between RegA and RegD resources under the old market design, and it does not accurately reflect the MRTS between RegA and RegD resources under

⁸⁴ See *id.* at P 17.

⁸⁵ The MBF, as used in this report, refers to PJM's incorrectly calculated MBF and not the MBF equivalent to the MRTS.

⁸⁶ 162 FERC ¶ 61,295 (2018), *reh'g denied*, 170 FERC ¶ 61,259 (2020).

the current design. The MBF function is incorrectly defined and improperly implemented in the current PJM Regulation Market.

The MBF should be the marginal rate of technical substitution between RegA and RegD MW at different, feasible combinations of RegA and RegD that can be used to provide a defined level of regulation service. The objective of the market design is to find, given the relative costs of RegA and RegD MW, the least cost feasible combination of RegA and RegD MW. If the MBF function is incorrectly defined, or improperly implemented in the market clearing and settlement, the resulting combinations of RegA and RegD will not represent the least cost solution and may not be a feasible way to reach the target level of regulation.

The MBF is not included in PJM's settlement process. This is a design flaw that results in incorrect payments for regulation. The issue results from two FERC orders. From October 1, 2012, through October 31, 2013, PJM implemented a FERC order that required the MBF to be fixed at 1.0 for settlement calculations only. On October 2, 2013, FERC directed PJM to eliminate the use of the MBF entirely from settlement calculations of the capability and performance credits and replace it with the RegD to RegA mileage ratio in the performance credit paid to RegD resources, effective retroactively to October 1, 2012.⁸⁷ That rule continues in effect. The result of the current FERC order is that the MBF is used in market clearing to determine the relative value of an additional MW of RegD, but the MBF is not used in the settlement for RegD.

If the MBF were consistently applied, every resource would receive the same clearing price per marginal effective MW. But the MBF is not consistently applied and resources do not receive the same clearing price per marginal effective MW.

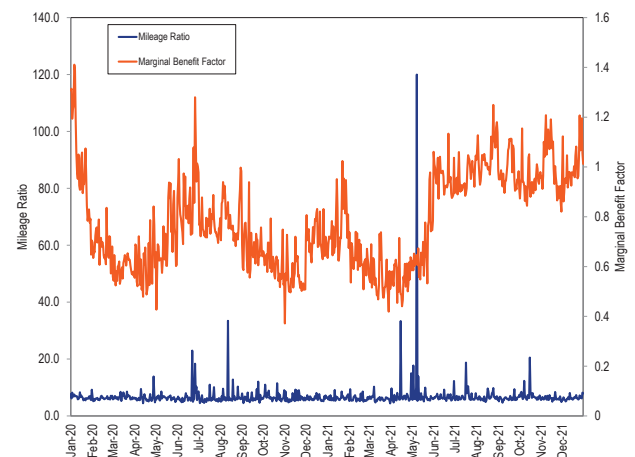
The change in design decreased RegA mileage (the change in MW output in response to regulation signal per MW of capability), increased the proportion of cleared RegD resources' capability that was called by the RegD signal (increased REG for a given MW) to better match offered capability, increased the mileage required of RegD resources and changed the energy

neutrality component of the signal from a strict 15 minute neutrality to a conditional 30 minute neutrality. The changes in signal design increased the mileage ratio (the ratio of RegD mileage to RegA mileage). In addition, to adapt to the 30 minute neutrality requirement, some RegD resources decreased their offered capability to maintain their performance.

Figure 10-10 shows the daily average MBF and the mileage ratio. The weighted average mileage ratio increased from 6.55 in 2020, to 6.95 in 2021 (an increase of 6.2 percent). The average MBF increased from 0.71 in 2020, to 0.84 in 2021 (an increase of 17.3 percent). The high mileage ratios are the result of the mechanics of the mileage ratio calculation. Extreme mileage ratios result when the RegA signal is fixed at a single value (pegged) to control ACE and the RegD signal is not. If RegA is held at a constant MW output, mileage is zero for RegA. The result of a fixed RegA signal is that RegA mileage is very small and therefore the mileage ratio is very large.

These results are an example of why it is not appropriate to use the mileage ratio, rather than the MBF, to measure the relative value of RegA and RegD resources. In these events, RegA resources are providing ACE control by providing a fixed level of MW output which means zero mileage, while RegD resources alternate between helping and hurting ACE control, both of which result in positive mileage.

Figure 10-10 Daily average MBF and mileage ratio: January 2020 through December 2021



87 145 FERC ¶ 61,011 (2013).

The increase in the average mileage ratio caused by the signal design changes introduced on January 9, 2017, caused a large increase in payments to RegD resources on a performance adjusted MW basis.

Table 10-40 shows RegD resource payments on a performance adjusted actual MW basis and RegA resource payments on a performance adjusted MW basis by month, from January 1, 2020, through December 31, 2021. The average regulation market clearing price in 2021 was \$12.45 higher than in 2020 (See Table 10-40). Coupled with the average MBFs of less than 1.0, RegD continued to be overpaid compared to RegA on a performance adjusted actual MW basis. In 2021, RegD resources earned 20.7 percent more per performance adjusted actual MW than RegA resources (23.2 percent in 2020) due to the inclusion of the mileage ratio in RegD MW settlement.

Table 10-40 Average monthly price paid per performance adjusted actual MW of RegD and RegA: January 2020 through December 2021

		Settlement Payments		
Year	Month	RegD (\$/Performance Adjusted MW)	RegA (\$/Performance Adjusted MW)	Percent RegD Overpayment (\$/Performance Adjusted MW)
2020	Jan	\$16.51	\$13.05	26.5%
	Feb	\$11.83	\$9.57	23.6%
	Mar	\$11.06	\$8.60	28.6%
	Apr	\$14.29	\$11.45	24.8%
	May	\$14.72	\$12.46	18.2%
	Jun	\$15.09	\$11.85	27.3%
	Jul	\$18.02	\$15.63	15.3%
	Aug	\$18.11	\$14.83	22.2%
	Sep	\$12.68	\$10.33	22.7%
	Oct	\$21.82	\$17.31	26.0%
	Nov	\$19.45	\$15.25	27.5%
	Dec	\$18.18	\$15.34	18.6%
Yearly		\$16.01	\$13.00	23.2%
2021	Jan	\$14.29	\$11.43	25.1%
	Feb	\$23.87	\$19.90	19.9%
	Mar	\$20.81	\$17.93	16.0%
	Apr	\$20.86	\$16.73	24.6%
	May	\$20.22	\$16.42	23.2%
	Jun	\$23.01	\$18.40	25.1%
	Jul	\$24.09	\$19.33	24.6%
	Aug	\$37.86	\$31.77	19.2%
	Sep	\$34.62	\$28.59	21.1%
	Oct	\$46.15	\$38.91	18.6%
	Nov	\$61.59	\$52.92	16.4%
	Dec	\$33.56	\$26.85	25.0%
Yearly		\$30.08	\$24.93	20.7%

The current settlement process does not result in paying RegA and RegD resources the same price per effective MW. RegA resources are paid on the basis of dollars per effective MW of RegA. RegD resources are not paid in terms of dollars per effective MW of RegA because the MBF is not used in settlements. Instead of being paid based on the MBF, (RMCCP + RMPCP)*MBF, RegD resources are paid based on the mileage ratio (RMCCP + (RMPCP*mileage ratio)). Because the RMCCP component makes up the majority of the overall clearing price, when the MBF is above one, RegD resources can be underpaid on a per effective MW basis by the current payment method, unless offset by a high mileage ratio. When the MBF is less than one, RegD resources are overpaid on a per effective MW basis, unless offset by a low mileage ratio. The average MBF was less than 1.0 in 2021 (0.84).

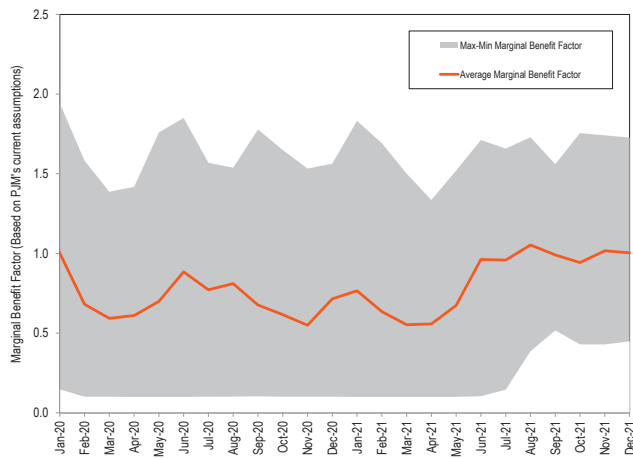
The effect of using the mileage ratio instead of the MBF for purposes of settlement is illustrated in Table 10-41. Table 10-41 shows how much RegD resources are currently being paid, adjusted to a per effective MW basis, on average, in 2020 and 2021 under the current rules, compared to how much RegD resources should have been paid if they were actually paid for effective MW. Using the MBF consistently throughout the PJM regulation market would result in RegA and RegD resources being paid exactly the same on a per effective MW basis. However, the PJM regulation market only uses the MBF in the market clearing and setting of price on a dollar per effective MW basis, it does not use the MBF to convert RegD MW into effective MW for purposes of settlement. Because the MBF is not used to convert RegD MW into effective MW for purposes settlement, RegD resources are paid the dollar per effective MW price, but this is paid for performance adjusted MW, not for effective MW. This causes the MW value of RegD resources to be inflated in settlement when the MBF is less than one. In 2021, the MBF averaged 0.84, while the average daily mileage ratio was 6.95, resulting in RegD resources being paid \$8.9 million more than they would have been paid on an effective MW basis if the MBF were correctly implemented. In 2020, the MBF averaged 0.72, and the average mileage ratio was 6.55, resulting in RegD resources being paid \$9.3 million more than they would have been paid if the MBF were correctly implemented.

Table 10-41 Average monthly price paid per effective MW of RegD and RegA under mileage and MBF based settlement: January 2020 through December 2021⁸⁸

RegD Settlement Payments						
Year	Month	Mileage Based RegD	Marginal Rate of Technical	RegA	Percent RegD	Total RegD
		(\$/Effective MW)	Substitution Based RegD		Overpayment	
		(\$/Effective MW)	(\$/Effective MW)	(\$/Effective MW)	(\$/Effective MW)	Overpayment (\$)
2020	Jan	\$19.61	\$13.05	\$13.05	50.3%	\$318,560
	Feb	\$25.79	\$9.57	\$9.57	169.5%	\$505,037
	Mar	\$29.47	\$8.60	\$8.60	242.6%	\$665,219
	Apr	\$38.85	\$11.45	\$11.45	239.4%	\$745,528
	May	\$37.37	\$12.46	\$12.46	199.9%	\$746,137
	Jun	\$25.00	\$11.85	\$11.85	111.0%	\$548,730
	Jul	\$34.99	\$15.63	\$15.63	123.9%	\$657,628
	Aug	\$31.78	\$14.83	\$14.83	114.4%	\$753,199
	Sep	\$28.51	\$10.33	\$10.33	175.9%	\$661,906
	Oct	\$69.18	\$17.31	\$17.31	299.6%	\$1,534,621
	Nov	\$63.11	\$15.25	\$15.25	313.8%	\$1,319,529
	Dec	\$43.39	\$15.34	\$15.34	182.9%	\$886,873
Yearly		\$37.30	\$13.00	\$13.00	186.9%	\$9,342,966
2021	Jan	\$30.47	\$11.43	\$11.43	166.6%	\$558,397
	Feb	\$88.91	\$19.90	\$19.90	346.7%	\$1,310,283
	Mar	\$61.03	\$17.93	\$17.93	240.4%	\$1,277,850
	Apr	\$65.99	\$16.73	\$16.73	294.3%	\$1,492,094
	May	\$39.55	\$16.42	\$16.42	140.9%	\$1,081,445
	Jun	\$26.57	\$18.40	\$18.40	44.4%	\$457,543
	Jul	\$27.36	\$19.33	\$19.33	41.5%	\$513,186
	Aug	\$38.23	\$31.77	\$31.77	20.4%	\$288,112
	Sep	\$35.63	\$28.59	\$28.59	24.6%	\$410,694
	Oct	\$51.13	\$38.91	\$38.91	31.4%	\$688,515
	Nov	\$63.20	\$52.92	\$52.92	19.4%	\$377,458
	Dec	\$33.94	\$26.85	\$26.85	26.4%	\$399,675
Yearly		\$46.48	\$24.93	\$24.93	86.4%	\$8,855,253

Figure 10-11 shows, the monthly maximum, minimum and average MBF, for January 2020 through December 2021. The average daily MBF in 2021 was 0.84. The average daily MBF in 2020 was 0.72. The bottom of the MBF range results from PJM’s administratively defined MBF minimum threshold of 0.1. The increase in the minimum and average MBF starting in the third quarter of 2021 was the result of a reduction in RegD offered MW and cleared MW (See Figure 10-16).

Figure 10-11 Maximum, minimum, and average PJM calculated MBF by month: January 2020 through December 2021



⁸⁸ There was an error in previously reported versions of this table. The total RegD overpayment column was overstated. The correct values are included here.

The MMU recommends that the regulation market be modified to incorporate a consistent and correct application of the MBF throughout the optimization, assignment and settlement process.⁸⁹

The overpayment of RegD has resulted in offers from RegD resources that are almost all at an effective cost of \$0.00 (\$0.00 offers plus self scheduled offers). RegD MW providers are ensured that such offers will clear and will be paid a price determined by the offers of RegA resources. This is evidence of the impact of the flaws in the clearing engine and the overpayment of RegD resources on the offer behavior of RegD resources.

Table 10-42 shows, by month, cleared RegD MW with an effective price of \$0.00 (units with zero offers plus self scheduled units) for January 2020 through December 2021. In 2021, an average of 98.6 percent of all RegD MW clearing the market had an effective offer of \$0.00. In the first 2020, an average of 99.7 percent of all cleared RegD MW had an effective cost of \$0.00. In 2021, an average of 71.6 percent of all RegD offers were self scheduled, compared to an average of 76.2 percent of all RegD offers in 2020.

The high percentage of self scheduled offers is a result of the incentives created by the flaws in the regulation market. Because self scheduled offers are price takers, they are cleared along with the zero cost offers in the market clearing engine. However, unlike zero cost offers, self scheduled offers do not risk having an LOC added to their offer during the market clearing process, ensuring that self scheduled offers have a zero cost during market clearing. Given the increasing saturation of the regulation market with RegD MW, specifically demand response and battery units which do not receive LOC, market participants eligible for LOC that offer at zero instead of self scheduling, run the risk of an LOC added to their offer, and thus not clearing the market.

The average monthly RegD cleared in the market decreased 10.0 MW (5.2 percent), from 193.5 MW in 2020 to 183.5 MW in 2021. The average monthly RegD cleared with an effective cost of zero decreased 11.9 MW (6.2 percent), from 193.0 MW in 2020 to 181.1 MW in 2021. Self scheduled RegD cleared MW decreased 15.5 MW (10.5 percent), from 147.4 MW in 2020 to 131.9 MW in 2021. Average cleared RegD MW with a zero cost offer increased 3.6 MW (7.9 percent), from 45.6 MW in 2020 to 49.2 MW in 2021. The decrease in the average monthly RegD cleared resulted in the increase of the average monthly MBF seen in Figure 10-11.

⁸⁹ See "Regulation Market Review," Operating Committee (May 5, 2015) <<http://www.pjm.com/~media/committees-groups/committees/oc/20150505/20150505-item-17-regulation-market-review.ashx>>.

Table 10–42 Average cleared RegD MW and average cleared RegD with an effective price of \$0.00 by month: January 2020 through December 2021

Average Performance Adjusted Cleared RegD MW								
Year	Month	\$0.00 Offer		Self Scheduled		Total Effective Cost of Zero	Effective Cost of Zero Percentage of Total	Total
		\$0.00 Offer	Percent of Total	Self Scheduled	Percentage of Total			
2020	Jan	32.1	18.8%	137.2	80.5%	169.2	99.4%	170.3
	Feb	48.8	24.6%	149.6	75.4%	198.5	100.0%	198.5
	Mar	48.0	24.4%	148.1	75.5%	196.1	100.0%	196.1
	Apr	47.1	24.0%	149.3	75.9%	196.4	99.9%	196.7
	May	43.2	22.6%	147.6	77.3%	190.8	99.9%	191.0
	Jun	47.7	24.7%	143.8	74.5%	191.4	99.2%	192.9
	Jul	47.9	24.0%	151.0	75.7%	199.0	99.8%	199.4
	Aug	48.2	24.5%	147.5	74.9%	195.6	99.3%	196.9
	Sep	40.7	21.3%	149.7	78.4%	190.4	99.7%	191.0
	Oct	46.2	23.7%	148.7	76.1%	194.9	99.8%	195.3
	Nov	50.3	25.3%	148.5	74.7%	198.8	100.0%	198.9
	Dec	47.2	24.1%	147.9	75.7%	195.1	99.8%	195.4
Yearly		45.6	23.6%	147.4	76.2%	193.0	99.7%	193.5
2021	Jan	49.6	26.1%	139.9	73.7%	189.6	99.9%	189.8
	Feb	52.4	25.6%	152.3	74.4%	204.7	100.0%	204.7
	Mar	47.2	23.3%	155.4	76.7%	202.6	100.0%	202.6
	Apr	48.6	24.0%	154.0	76.0%	202.7	100.0%	202.7
	May	47.5	24.8%	143.8	75.0%	191.3	99.9%	191.6
	Jun	45.8	25.2%	133.3	73.4%	179.2	98.6%	181.7
	Jul	48.4	26.4%	130.7	71.4%	179.1	97.8%	183.1
	Aug	49.9	28.4%	120.8	68.6%	170.8	97.0%	176.0
	Sep	50.8	30.6%	111.1	67.1%	161.8	97.7%	165.6
	Oct	50.6	30.2%	114.6	68.3%	165.3	98.5%	167.7
	Nov	50.2	30.6%	109.0	66.5%	159.2	97.1%	164.0
	Dec	49.4	28.6%	118.0	68.2%	167.5	96.8%	173.0
Yearly		49.2	26.8%	131.8	71.9%	181.0	98.7%	183.4

Incorrect MBF and total effective MW when clearing units with dual product offers

Under PJM market rules, regulation units that have the capability to provide both RegA and RegD MW are permitted to submit an offer for both signal types in the same market hour. While the objective of the PJM market design is to find the least cost combination of RegA and RegD resources to provide the required level of regulation service, the method of clearing the regulation market for an hour in which one or more units has a dual offer is incorrect and leads to solutions that are not the most economic.

In order for the clearing engine to provide the correct economic solution when the pool of available resources contains one or more units with dual offers, the calculation would have to be performed iteratively to determine which of the dual offers would provide the least cost solution. But this is not how PJM clears the regulation market when there are dual offer units. PJM rank orders the regulation supply curve by potential effective cost assuming the dual offer resources are available as both RegA and RegD resources simultaneously, and assigns every RegD resource, including dual offer resources, a unit specific benefit factor.

Each dual offer resource is assigned to run as either a RegD or RegA resource based on which of the two offers has a lower effective cost. But PJM does not redefine the supply curve using appropriately recalculated unit specific benefit factors for the remaining RegD resources prior to clearing the market.

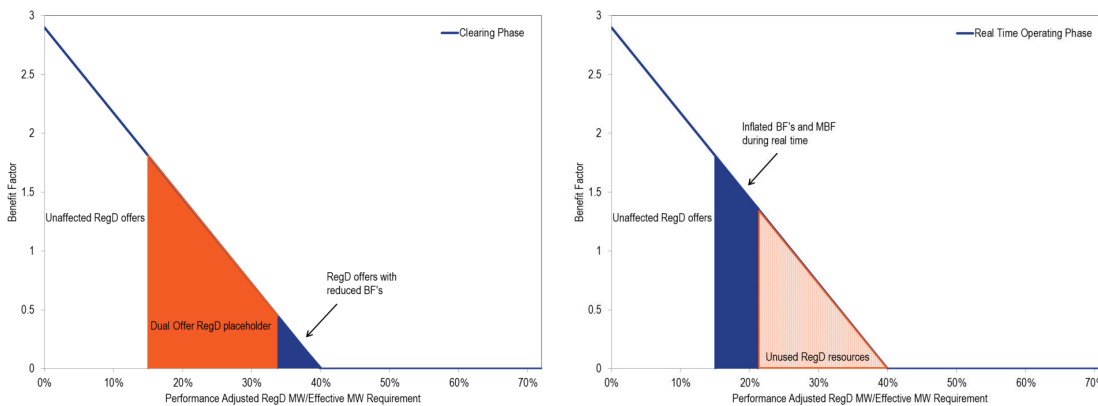
During the clearing phase, the MBF of RegD resources is a function of the RegD MW that clear. The MBF for all RegD resources declines as more RegD resources are cleared. Based on this relationship, in the case where a dual offer unit is assigned to be a RegA resource rather than a RegD resource, the MBF of remaining RegD resources in the supply curve should increase. The placeholder RegD MW from the dual offer should be removed, the cleared MW from below the placeholder should be shifted up the supply/MBF curve, and additional RegD MW offers that were pushed below an MBF of zero and initially not included, should be considered. But PJM does not recalculate the MBF values for the remaining RegD resources when determining the cleared effective MW needed to satisfy the regulation requirement

during the clearing phase. The result is that the MBF in the clearing phase is incorrectly low, and the actual amount of effective MW procured is higher.

After meeting the target effective MW to satisfy the regulation requirement for that hour through the clearing process, the unit specific benefit factors of those displaced units are recalculated in the real-time operating phase and increased based on their actual contribution. The effective MW contributions of those originally displaced units are correctly calculated in the operating phase, but because the supply for that hour has already been set based on their incorrect effective MW, the solution includes more effective MW than calculated in the clearing phase. As a result, the market solution includes more than the target level of effective MW in the actual operating hour.

The issue is illustrated in Figure 10-12. The example shows a clearing phase and a real time operating phase. In this example, a 150 MW unit offers both RegA and RegD. The 150 MW unit's position in the RegD effective cost curve and the potential effective MW are represented as the orange area under the curve in the clearing phase. The effective MW of the cleared RegD resources with higher effective costs are represented by the blue triangle in the clearing phase. Not shown are additional RegD MW with higher effective costs that were assigned an MBF of 0 and not cleared. The 150 MW dual offer unit is chosen to operate as a RegA resource in the operational hour. As a result, the cleared supply for RegA in the clearing phase is the same RegA supply realized in the real time operating phase. But that is not the case for the RegD supply. Since the supply curve and unit specific benefit factors of RegD MW are not recalculated in the clearing phase after the 150 MW RegD offer is removed, the amount of effective MW realized in the real-time operating phase is inconsistent with the clearing phase. Because the RegD portion of the 150 MW dual offer unit was not chosen to be RegD MW, the RegD resources represented by the blue triangle in the clearing phase will contribute more effective MW (the blue area in the real-time solution phase) in the real-time solution phase than was assumed in the clearing phase because the MBF in the clearing phase was too low. Since the blue area under the curve in the real-time solution phase is greater than the blue area in the clearing phase and the amount of RegA remains the same between the clearing phase and real-time operating phase, the market will have cleared too many effective MW relative to the effective MW requirement. The MBF in the operating phase is higher than if the clearing had been solved correctly.

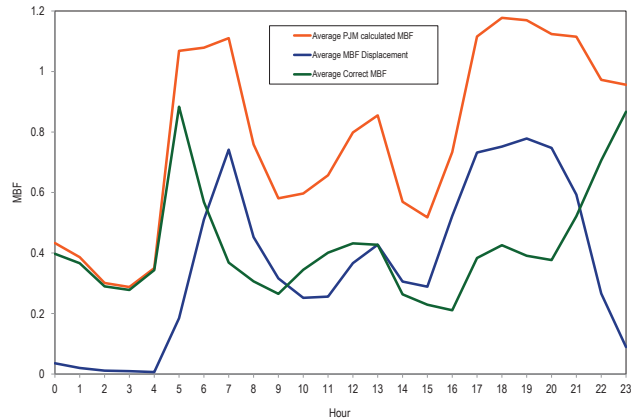
Figure 10-12 Clearing phase BF/effective MW reduction, real-time BF/effective MW inflation, and exclusion of available RegD resources



In 2021, all hours had at least one unit with a dual offer. In 2021, 37.6 percent of all hours had at least one dual offer unit that was chosen to run as RegA, resulting in an average MBF increase of 0.48 in the operating phase. If the market had been cleared correctly, the correct average MBF would have been significantly lower in real time (operating phase), because additional RegD offers with lower benefit factors that were initially excluded, would have been included after the removal of the dual offer placeholder, reducing the MBF. Figure 10-13 illustrates

the PJM calculated average MBF in real time (operating phase), the average MBF displacement due to dual offers clearing as RegA, and what the correct average MBF would have been in each hour of the day for 2021 if the clearing solution were solved correctly.

Figure 10-13 Effect of PJM's current dual offer clearing method on the average MBF in each hour of the day: 2021



Absent the ability to correctly clear dual offers, the MMU recommends that the ability of resources to submit dual offers be removed. Under this revision to the rules, resources could offer as either RegA or RegD in a given hour, but not both within the same market hour.

Price Spikes

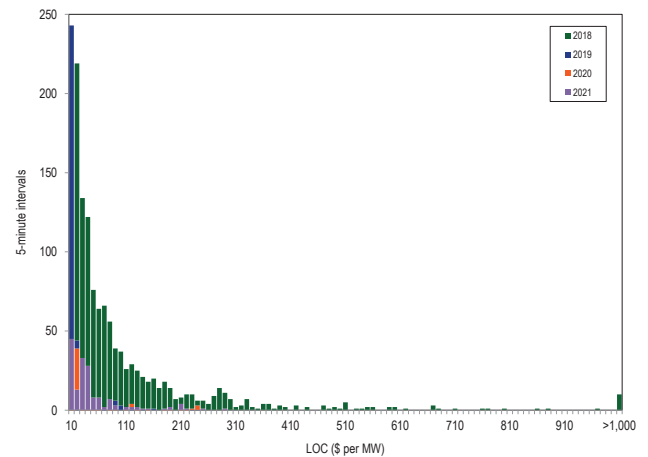
Beginning in 2018, extreme price spikes were identified in the regulation market. The price spikes were caused by a combination of the inconsistent application of the MBF in the market design and the discrepancy between the hour ahead estimated LOC and the actual realized within hour LOC.

The regulation market is cleared on an hour ahead basis, using offers that are adjusted by dividing each component of an offer (capability, performance, and lost opportunity cost) by the product of the unit specific benefit factor and unit specific performance score. To calculate the hour ahead estimate of the adjusted LOC offer component, hour ahead projections of LMPs are used. Units are then cleared based on the sum of each of their hour ahead adjusted offer components. The actual LOC is used to determine the final, actual interval specific all in offer of RegD resources.

In some cases the estimated LOC is very low or zero but the actual within hour LOC is a positive number. In instances where the MBF of the within hour marginal unit is less than one (e.g. the marginal unit is a RegD unit), this discrepancy in the estimated and realized LOC will cause a large discrepancy between the expected offer price (as low as \$0/MW) and the realized offer price of the resource in the actual market result. This will cause a significant price spike in the regulation market. In cases where the MBF of the marginal resource is very low, such as 0.001, the price spikes can be very significant for a small change between expected and actual LOC. In January 2019, FERC approved PJM's proposal to create a 0.1 floor for the MBF to reduce the occurrence of these price spikes.⁹⁰ This change reduced the amount and frequency of the price spikes, but it was not designed to eliminate them and it did not eliminate them.

Figure 10-14 shows the LOC in each five minute interval in which the marginal unit had a unit specific benefit factor less than one (e.g. a RegD unit) and the LOC was greater than zero in 2018, 2019, 2020, and 2021.

Figure 10-14 LOC distribution in each five minute interval with a RegD marginal unit and an LOC greater than zero: 2018 through December 2021



⁹⁰ See 166 FERC ¶ 61,040 (2019).

For a RegD resource to clear the regulation market with an MBF of 0.001, the resource's offer, in dollars per marginal effective MW, must be less than or equal to competing offers from RegA MW. A RegD offer of 1 MW with an MBF of 0.001 and a price of \$1 per MW, would provide 0.001 effective MW at a price of \$1,000 per effective MW. So long as RegA MW are available for less than \$1,000 per effective MW, this resource will not clear. The only way for RegD MW to clear to the point where the MBF of the last MW is 0.001, is if the offer price of the relevant resources that clear, including estimated LOC, is \$0.00. But, if the same resource(s) has a positive LOC within the hour, based on real-time changes in LMP, the zero priced offer is adjusted to reflect the positive LOC, resulting in an extremely high offer and clearing price for regulation.

While an incorrect estimate of a potential LOC can result in an extremely high price, the resulting regulation market prices are mathematically correct for the price of each effective MW. The prices in every interval reflect the marginal costs of regulation given the resources dispatched and accurately reflect the marginal offer of minimally effective resources which had unexpectedly high LOC components of their within hour offers. But, due to the current market design's failure to use the MBF in settlement, RegD is not paid on a dollar per effective MW basis. This disconnect between the process of setting price and the process of paying resources is the primary source of the market failure in PJM's Regulation Market and the cause of the observed price spikes in the regulation market. In the example, the 0.001 MW from the RegD resource should be paid \$1,000 times 0.001 MW or \$1.00. But the current rules would pay the RegD resource \$1,000 times 1.0 MW or \$1,000. If the market clearing and the settlements rules were consistent, the incentive for this behavior would be eliminated. The current rules provide a strong incentive for this behavior.

The prices spikes observed in PJM's Regulation Market are a symptom of a market failure in PJM's Regulation Market caused by an inconsistent application of the MBF between market clearing and market settlement. Due to the inconsistent application of the MBF, the current market results are not consistent with a competitive market outcome. In any market, resources should be paid the marginal clearing price for their marginal contribution. In the regulation market, all resources

should be paid the marginal clearing price per effective MW and all resources in the regulation market should be paid for each of their effective MW. PJM's Regulation Market does not do this. PJM's market applies the MBF in determining the relative and total value of RegD MW in the market solution for purposes of market clearing and price, but does not apply the same logic in determining the payment of RegD for purposes of settlement. As a result, market prices do not align with payment for contributions to regulation service in market settlements.

The inconsistent application of the MBF in PJM's regulation market design is generating perverse incentives and perverse market results. The price spikes are a symptom of the problem, not the problem itself.

Uplift Calculation Issues

Regulation uplift is calculated by comparing a resource's regulation offer price plus its regulation lost opportunity cost (including shoulder LOC if applicable) adjusted by the performance score, to the clearing price credits the unit received.⁹¹ If the sum of the resources offer plus LOC is greater than the amount of clearing price credits received, additional uplift credits are given equal to the difference.

The calculation of regulation uplift during settlements for coal and natural gas units is incorrect, and results in the overpayment of uplift.⁹² In order to determine the amount of regulation uplift, the difference between the MW output of the unit while it was providing regulation is compared to the desired MW output of the unit if it had not provided regulation. The desired amount of MW output at LMP used in the calculation of regulation uplift during settlements is determined based on a unit's energy offer and the LMP during the interval being evaluated. But this desired MW does not account for the ability of a unit to actually produce the desired output because it does not take into account the physical limitations of the unit's ability to ramp. This results in the overpayment of uplift by paying for MW that the unit could not have produced given their energy market output at the beginning of the interval and their ramp rate.

⁹¹ The clearing price for each interval is set by the marginal unit's total offer (capability and performance offers plus LOC), adjusted by the marginal unit's performance score, and does not include any shoulder LOC.

⁹² Hydro units operate on a schedule rather than an energy bid, therefore a different equation is used to calculate their regulation LOC and uplift. The issue discussed does not effect that calculation. Also, demand response and battery units do not receive uplift.

Table 10-43 shows the amount of uplift overpayment by fuel type for 2021. The overpayments are calculated using a desired MW level that can be achieved based on the units' ramp rates. In 2021, overpayments totaled \$11.0 million. Coal units received 37.6 percent of the overpayment while providing 7.1 percent of settled regulation MW.

Table 10-43 Amount of LOC overpayment: January through December, 2021

Month	Uplift overpayment		
	Coal	Natural Gas	Total
Jan	\$193,493	\$158,574	\$352,066
Feb	\$192,078	\$317,746	\$509,824
Mar	\$264,985	\$429,131	\$694,115
Apr	\$193,678	\$214,241	\$407,919
May	\$467,981	\$178,919	\$646,900
Jun	\$565,172	\$233,445	\$798,618
Jul	\$162,148	\$180,590	\$342,738
Aug	\$143,573	\$361,511	\$505,084
Sep	\$218,765	\$528,205	\$746,970
Oct	\$160,570	\$772,042	\$932,612
Nov	\$1,135,649	\$2,485,585	\$3,621,234
Dec	\$444,082	\$1,015,060	\$1,459,142
Total	\$4,142,174	\$6,875,047	\$11,017,221

Market Structure

Supply

Table 10-44 shows average hourly offered MW (actual and effective), and average hourly cleared MW (actual and effective) for all hours in 2021.⁹³ Actual MW are adjusted by the historic 100-hour moving average performance score to get performance adjusted MW, and by the resource specific benefit factor to get effective MW. A resource can choose to follow either signal. For that reason, the sum of each signal type's capability can exceed the full regulation capability. Offered MW are calculated based on the offers from units that are designated as available for the day. These are daily offers that can be modified on an hourly basis up to 65 minutes before the hour.⁹⁴ Eligible MW are calculated from the hourly offers from units with daily offers and units that are offered as unavailable for the day, but still offer MW into some hours. Units with daily offers are permitted to offer above or below their daily offer from hour to hour. As a result of these hourly MW adjustments, the average hourly Eligible MW can be higher than the Offered MW.

In 2021, the average hourly offered supply of regulation for nonramp hours was 740.8 actual MW (744.9 effective MW). This was an increase of 19.9 actual MW (an increase of 23.7 effective MW) from 2020, when the average hourly offered supply of regulation was 720.9 actual MW (721.3 effective MW). In 2021, the average hourly offered supply of regulation for ramp hours was 1,066.4 actual MW (1,094.9 effective MW). This was an increase of 49.0 actual MW (an increase of 36.0 effective MW) from 2020, when the average hourly offered supply of regulation was 1,017.4 actual MW (1,058.9 effective MW).

The ratio of the average hourly offered supply of regulation to average hourly regulation demand (actual cleared MW) for ramp hours was 1.51 in 2021 (1.45 in 2020). The ratio of the average hourly offered supply of regulation to average hourly regulation demand (actual cleared MW) for nonramp hours was 1.54 in 2021 (1.47 in 2020).

⁹³ Unless otherwise noted, analysis provided in this section uses PJM market data based on PJM's internal calculations of effective MW values, based on PJM's currently incorrect MBF curve. The MMU is working with PJM to correct the MBF curve.

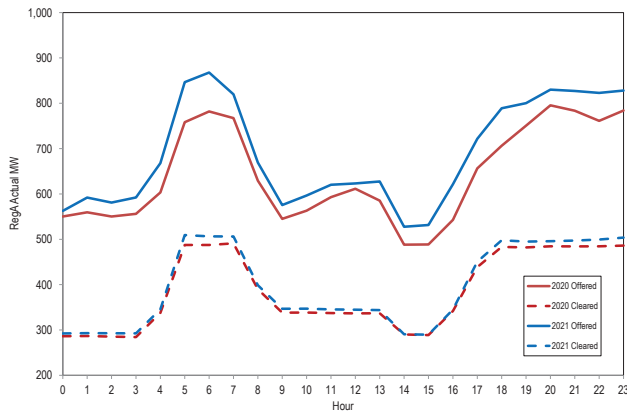
⁹⁴ See "PJM Manual 11: Energy & Ancillary Services Market Operations," § 3.2.2 Regulation Market Eligibility, Rev. 116 (September 1, 2021).

Table 10-44 Hourly average actual and effective MW offered and cleared: 2021⁹⁵

		By Resource Type			By Signal Type	
		All Regulation	Generating Resources	Demand Resources	RegA Following Resources	RegD Following Resources
Actual Offered MW	Ramp	1,066.4	1,055.4	10.9	829.6	236.8
	Nonramp	740.8	733.3	7.5	548.5	192.2
Effective Offered MW	Ramp	1,094.9	1,080.9	14.0	715.0	379.9
	Nonramp	744.9	737.6	7.3	470.6	274.4
Actual Cleared MW	Ramp	706.9	696.0	10.9	502.5	204.4
	Nonramp	481.6	474.3	7.4	291.4	190.2
Effective Cleared MW	Ramp	800.0	786.0	14.0	435.2	364.8
	Nonramp	525.2	518.0	7.2	251.7	273.5

The average hourly offered and cleared actual MW from RegA resources are shown in Figure 10-15. The average hourly offered MW from RegA resources during ramp hours for 2021 was 829.6 actual MW, an increase of 7.8 percent from 2020 (769.7 actual MW.) The average hourly offered MW from RegA resources during nonramp hours for 2021 was 548.5 actual MW, an increase of 6.6 percent from 2020 (514.5 actual MW). The average hourly cleared MW from RegA resources during ramp hours for 2021 was 502.5 actual MW, an increase of 3.2 percent from 2020 (486.9 actual MW). The average hourly cleared MW from RegA resources during nonramp hours for 2021 was 291.4 actual MW, an increase of 1.5 percent from 2020 (287.0 actual MW).

Figure 10-15 Average hourly RegA actual MW offered and cleared: January through December, 2020 through 2021⁹⁶



95 PJM operations treats some nonramp hours as ramp hours, with a regulation requirement of 800 MW rather than 525 MW. All ramp/nonramp analysis performed is based on the requirement used in each hour rather than the definitions given in Table 10-2. A ramp hour occurring during what is normally a nonramp period is treated as a ramp hour.

96 Offered MW includes MW from units that are dual offering as both RegA and RegD.

The average hourly offered MW from RegD resources during ramp hours for 2021 was 236.8 actual MW, a decrease of 4.4 percent from 2020 (247.7 actual MW). (Figure 10-16) The average hourly offered MW from RegD resources during nonramp hours for 2021 was 192.2 actual MW, a decrease of 6.9 percent from 2020 (206.4 actual MW) (Figure 10-16). The average hourly cleared MW from RegD resources during ramp hours for 2021 was 204.4 actual MW, a decrease of 5.3 percent from 2020 (216.0 actual MW). The average hourly cleared MW from RegD resources during nonramp hours for 2021 was 190.2 actual MW, a decrease of 7.2 percent from 2020 (204.9 actual MW).

Figure 10-16 Average hourly RegD actual MW offered and cleared: January through December, 2020 through 2021⁹⁷

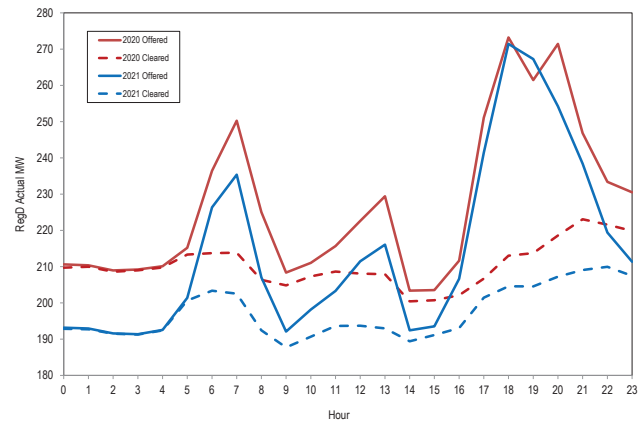


Table 10-46 provides the settled regulation MW by source unit type, the total settled regulation MW provided by all resources, the percent of settled regulation provided by unit type, and the clearing price, uplift, and total regulation credits. In Table 10-46 the MW have been adjusted by the performance score since this adjustment forms the basis of payment for units providing regulation. Total regulation performance adjusted settled MW decreased 0.2 percent from 4,625,428.8 MW in 2020 to 4,616,116.0 MW in 2021. The average proportion of regulation provided by hydro and natural gas units increased by 0.9 percent from 2020 to 2021.

97 Offered MW includes MW from units that are dual offering as both RegA and RegD.

Battery units had the largest decrease in average proportion of regulation provided, decreasing 1.3 percent, from 34.6 percent in 2020, to 33.3 percent in 2021. The total regulation credits in 2021 were \$144,298,222, an increase of 87.8 percent from \$76,837,926 in 2020. The increase in regulation credits is due, in part, to a higher LOC component of regulation prices as a result of higher energy prices in 2021 compared to 2020.

When a resource offers into the regulation market, an estimated regulation LOC is added by PJM to form a total offer (units self scheduled or not providing in the energy market have a regulation LOC of zero). After a unit clears, the actual five minute interval LMP is used to calculate each unit's regulation LOC, update their total offers, and determine a marginal unit/clearing price in each five minute interval. This within hour calculation of total offers, including LOC, uses each cleared resource's rolling 100 hour average performance score. During settlements, each unit's regulation LOC and total offers are recalculated using each unit's within hour actual performance score. This recalculated LOC and offer using the actual within hour performance score is not used to recalculate the within hour clearing price. This means that the clearing price for the hour will not equal the actual clearing price. Where the resulting market price is lower than an individual resource offer adjusted for the within hour performance score, the resource is paid uplift to make up the difference.

The top ten units that received the most uplift in 2021 are shown in Table 10-45.

Table 10-45 Top 10 recipients of regulation uplift credits: 2021

Rank	Parent Company	Unit Name	Fuel Type	Total Regulation Uplift Credit	Share of Total Regulation Uplift Credits
1	Exelon Corporation	PE MUDDY RUN 1-8 H	HYDRO	\$1,580,386	10.5%
2	American Electric Power Company Inc	AEP MITCHELL - KAMMER 2 F	COAL	\$987,142	6.6%
3	Ontario Power Generation Inc	AP LKLYN 1-4 H	HYDRO	\$545,910	3.6%
4	Atlantic Power Corporation	COM J375 MORRIS 1 CC	NATURAL GAS	\$530,645	3.5%
5	American Electric Power Company Inc	AEP AMOS 1 F	COAL	\$441,939	2.9%
6	American Electric Power Company Inc	AEP BIG SANDY 1 F	NATURAL GAS	\$391,920	2.6%
7	American Municipal Power Inc	FE FREMONT ENERGY CENTER 3 CC	NATURAL GAS	\$370,518	2.5%
8	Vistra Energy Corp	COM 935 KENDALL 3 CC	NATURAL GAS	\$367,520	2.4%
9	American Electric Power Company Inc	AEP CLINCH RIVER 2 F	NATURAL GAS	\$342,654	2.3%
10	American Electric Power Company Inc	AEP ROCKPORT 1 F	COAL	\$342,023	2.3%
Total of Top 10				\$5,900,657	39.3%
Total Regulation Uplift Credits				\$15,018,116	100.0%

The uplift credits received for each unit type are shown in Table 10-46. The total uplift credits received increased 81.2 percent from \$8,288,192 in 2020 to \$15,018,116 in 2021. This increase, like the increase in total credits, is due in part to higher LOC components of regulation prices and offers as a result of higher energy prices in 2021 compared to 2020. Natural gas units had the largest increase in uplift payments, increasing from \$2,387,575 (28.8 percent of total) in 2020, to \$7,828,163 (52.1 percent of total) in 2021. Coal units had the largest decrease in uplift payments, decreasing from \$3,675,577 (44.3 percent of total) in 2020, to \$3,936,253 (26.2 percent of total) in 2021.

Table 10-46 PJM regulation by source: 2020 and 2021⁹⁸

Year	Source	Number of Units	Performance		Clearing Price Credits	Uplift Credits	Total Regulation Credits
			Adjusted Settled Regulation (MW)	Percent of Settled Regulation			
2020	Battery	22	1,600,435	34.6%	\$25,967,275	\$0	\$25,967,275
	Coal	19	344,862	7.5%	\$5,131,262	\$3,675,577	\$8,806,839
	Hydro	27	774,796	16.8%	\$10,963,914	\$2,225,040	\$13,188,954
	Natural Gas	180	1,826,396	39.5%	\$25,137,267	\$2,387,575	\$27,524,842
	DR	21	78,939	1.7%	\$1,354,339	\$0	\$1,354,339
Total		269	4,625,428.8	100.0%	\$68,554,057	\$8,288,192	\$76,842,249
2021	Battery	23	1,538,257	33.3%	\$45,184,072	\$0	\$45,184,072
	Coal	19	329,515	7.1%	\$7,182,900	\$3,936,253	\$11,119,153
	Hydro	28	813,584	17.6%	\$22,497,027	\$3,253,700	\$25,750,727
	Natural Gas	186	1,866,425	40.4%	\$52,112,081	\$7,828,163	\$59,940,245
	DR	19	68,335	1.5%	\$2,313,038	\$0	\$2,313,038
Total		275	4,616,116.0	100.0%	\$129,289,119	\$15,018,116	\$144,307,235

⁹⁸ Biomass data have been added to the natural gas category for confidentiality purposes.

Significant flaws in the regulation market design have led to an over procurement of RegD MW primarily in the form of storage capacity. The incorrect market signals have contributed to more storage projects entering PJM's interconnection queue, despite clear evidence that the market design is flawed and despite operational evidence that the RegD market is saturated (Table 10-47).

Table 10-47 Active battery storage projects by submitted year: 2014 through 2021

Year	Number of Storage Projects	Total Capacity (MW)
2014	1	10.0
2015	5	61.0
2016	0	0.0
2017	1	2.0
2018	19	690.1
2019	60	3,933.7
2020	159	9,572.1
2021	310	24,032.6
Total	555	38,301.5

The supply of regulation can be affected by regulating units retiring from service. If all units that are requesting retirement through the 2021 retire, the supply of regulation in PJM will be reduced by less than one percent.

Demand

The demand for regulation does not change with price. The regulation requirement is set by PJM to meet NERC control standards, based on reliability objectives, which means that a significant amount of judgment is exercised by PJM in determining the actual demand. Prior to October 1, 2012, the regulation requirement was 1.0 percent of the forecast peak load for on peak hours and 1.0 percent of the forecast valley load for off peak hours. Between October 1, 2012, and December 31, 2012, PJM changed the regulation requirement several times. It had been scheduled to be reduced from 1.0 percent of peak load forecast to 0.9 percent on October 1, 2012, but instead it was changed from 1.0 percent of peak load forecast to 0.78 percent of peak load forecast. It was further reduced to 0.74 percent of peak load forecast on November 22, 2012 and reduced again to 0.70 percent of peak load forecast on December 18, 2012. On December 14, 2013, it was reduced to 700 effective MW during peak hours and 525 effective MW during off peak hours. The regulation requirement remained 700 effective MW during peak hours and 525 effective MW during off peak hours until January 9, 2017. A change to the regulation requirement was approved by the RMISTF in

2016, with an implementation date of January 9, 2017. The regulation requirement was increased from 700 effective MW to 800 effective MW during ramp hours (Table 10-36).

Table 10-48 shows the average hourly required regulation by month and the ratio of supply to demand for both actual and effective MW, for ramp and nonramp hours. The average hourly required regulation by month is an average of the ramp and nonramp hours in the month. Changes in the actual MW required to satisfy the regulation requirement are the result of the amount of RegD actual MW cleared. When more RegD MW are cleared, the MBF is lower, resulting in those actual MW being worth less effective MW, requiring more actual MW to satisfy the requirement. When MBFs are higher, the actual MW of RegD are worth more effective MW, reducing the amount of actual MW needed to satisfy the requirement.

The nonramp regulation requirement of 525.0 effective MW was provided by a combination of RegA and RegD resources equal to 481.6 hourly average performance adjusted actual MW in 2021. This is a decrease of 10.4 performance adjusted actual MW from 2020, when the average hourly total regulation cleared performance adjusted actual MW for nonramp hours were 492.0 performance adjusted actual MW. The ramp regulation requirement of 800.0 effective MW was provided by a combination of RegA and RegD resources equal to 707.3 hourly average performance adjusted actual MW in 2021. This is an increase of 4.9 performance adjusted actual MW from 2020, where the average hourly regulation cleared MW for ramp hours were 702.5 performance adjusted actual MW.

Table 10–48 Required regulation and ratio of supply to requirement: January 2020 through December 2021

Hours	Month	Average Required Regulation (MW)		Average Required Regulation (Effective MW)		Ratio of Supply MW to MW Requirement		Ratio of Supply Effective MW to Effective MW Requirement	
		2020	2021	2020	2021	2020	2021	2020	2021
Ramp	Jan	712.9	713.2	800.1	800.0	1.36	1.59	1.25	1.42
	Feb	694.3	709.7	800.0	800.0	1.31	1.53	1.22	1.37
	Mar	692.5	713.8	800.1	800.0	1.33	1.54	1.24	1.38
	Apr	707.5	702.8	800.1	800.0	1.41	1.48	1.29	1.33
	May	711.8	705.5	800.1	800.0	1.42	1.45	1.31	1.32
	Jun	705.5	698.8	800.0	799.9	1.52	1.50	1.38	1.36
	Jul	702.8	699.0	800.1	799.9	1.57	1.54	1.42	1.38
	Aug	705.1	707.4	800.0	800.0	1.47	1.58	1.34	1.43
	Sep	694.8	710.7	799.8	800.0	1.46	1.47	1.33	1.35
	Oct	696.0	712.9	800.1	799.9	1.46	1.44	1.33	1.32
	Nov	700.9	708.4	800.1	800.0	1.43	1.41	1.30	1.30
	Dec	705.5	705.7	800.1	799.9	1.56	1.51	1.40	1.38
Nonramp	Jan	479.5	495.1	525.1	525.2	1.43	1.52	1.33	1.42
	Feb	495.9	500.4	525.1	525.1	1.45	1.59	1.37	1.47
	Mar	493.1	495.9	525.1	525.2	1.36	1.59	1.29	1.47
	Apr	492.7	490.9	525.2	525.1	1.46	1.51	1.36	1.41
	May	486.6	487.1	525.3	525.5	1.45	1.54	1.36	1.43
	Jun	490.0	478.6	525.1	525.4	1.45	1.50	1.36	1.39
	Jul	498.1	475.5	525.4	525.1	1.46	1.51	1.38	1.40
	Aug	489.8	474.4	525.0	525.2	1.43	1.60	1.35	1.47
	Sep	484.8	470.9	525.2	525.1	1.46	1.58	1.36	1.44
	Oct	491.3	471.8	525.2	525.1	1.50	1.51	1.41	1.39
	Nov	501.8	468.8	525.5	525.0	1.50	1.45	1.41	1.34
	Dec	500.8	469.5	525.1	525.0	1.63	1.57	1.50	1.42

Market Concentration

In 2021, the effective MW weighted average HHI of RegA resources was 2215 which is highly concentrated and the weighted average HHI of RegD resources was 1585 which is moderately concentrated. The weighted average HHI of all resources was 1205, which is moderately concentrated. The weighted average HHI reflects the fact that different owners have large market shares in the RegA and RegD markets.

Table 10–49 includes a monthly summary of three pivotal supplier (TPS) results. In 2021, the three pivotal supplier test was failed in 85.9 percent of hours. In 2021, the actual MW weighted average HHI of RegA resources was 2215 which is highly concentrated and the weighted average HHI of RegD resources was 1585 which is moderately concentrated. The weighted average HHI of all resources was 1205, which is moderately concentrated. The MMU concludes that the PJM Regulation Market in 2021 was characterized by structural market power. The results presented here are calculated by PJM. The MMU has been unable to verify these results, as some of the underlying data necessary to replicate these calculations are not saved. PJM has submitted a request to the vendor to save all data necessary for verification.

Table 10–49 Regulation market monthly three pivotal supplier results: 2019 through 2021

Month	Percent of Hours Pivotal		
	2019	2020	2021
Jan	77.8%	99.1%	91.4%
Feb	76.0%	97.4%	88.7%
Mar	93.3%	98.3%	87.2%
Apr	93.1%	96.5%	88.5%
May	94.0%	94.9%	83.9%
Jun	91.0%	89.8%	86.4%
Jul	92.7%	89.0%	86.4%
Aug	93.1%	94.6%	76.3%
Sep	93.3%	93.3%	82.9%
Oct	96.1%	94.0%	91.9%
Nov	90.7%	91.0%	86.7%
Dec	96.1%	83.6%	80.1%
Average	90.6%	93.5%	85.9%

Market Conduct

Offers

Resources seeking to regulate must qualify to follow a regulation signal by passing a test for that signal with at least a 75 percent performance score. The regulating resource must be able to supply at least 0.1 MW of regulation and not allow the sum of its regulating ramp rate and energy ramp rate to exceed its overall ramp rate.⁹⁹ When offering into the regulation market, regulating resources must submit a cost-based offer and may submit a price-based offer (capped at \$100 per MW) by 14:15 the day before the operating day.¹⁰⁰

Offers in the PJM Regulation Market consist of a capability component for the MW of regulation capability provided and a performance component for the miles (Δ MW of regulation movement) provided. The capability component for cost-based offers is not to exceed the increased fuel costs resulting from operating the regulating unit at a lower output level than its economically optimal output level, plus a \$12.00 per MW margin. The \$12.00 margin embeds market power in the regulation offers, is not part of the cost of regulation, and should be eliminated. The performance component for cost-based offers is not to exceed the increased costs (increased short run marginal costs including increased fuel costs) resulting from moving the unit up and down to provide regulation. Batteries and flywheels have zero cost for lower efficiency from providing regulation instead of energy, as they are not net energy producers. There is an energy storage loss component for batteries and flywheels as a cost component of regulation performance offers to reflect the net energy consumed to provide regulation service.¹⁰¹

Up until one hour before the operating hour, the regulating resource must provide: status (available, unavailable, or self scheduled); capability (movement up and down in MW); regulation maximum and regulation minimum (the highest and lowest levels of energy output while regulating in MW); and the regulation signal type (RegA or RegD). Resources may offer regulation for both the RegA and RegD signals, but will be assigned to follow only one signal for a given operating hour.

⁹⁹ See "PJM Manual 11: Energy & Ancillary Services Market Operations," § 3.2.1 Regulation Market Eligibility, Rev. 116 (September 1, 2021).

¹⁰⁰ *Id.* at 3.2.2, at p 62.

¹⁰¹ See "PJM Manual 15: Cost Development Guidelines," § 7.8 Regulation Cost, Rev. 37 (Dec. 9, 2020).

Resources have the option to submit a minimum level of regulation they are willing to provide.¹⁰²

All LSEs are required to provide regulation in proportion to their load share. LSEs can purchase regulation in the regulation market, purchase regulation from other providers bilaterally, or self schedule regulation to satisfy their obligation (Table 10-51).¹⁰³ Figure 10-17 compares average hourly regulation and self scheduled regulation during ramp and nonramp hours on an effective MW basis. The average hourly regulation is the amount of regulation that actually cleared and is not the same as the regulation requirement because PJM clears the market within a two percent band around the requirement.¹⁰⁴ Self scheduled regulation comprised an average of 46.0 percent during ramp hours and 61.3 percent during nonramp hours in 2021.

Figure 10-17 Nonramp and ramp regulation levels: January 2020 through December 2021

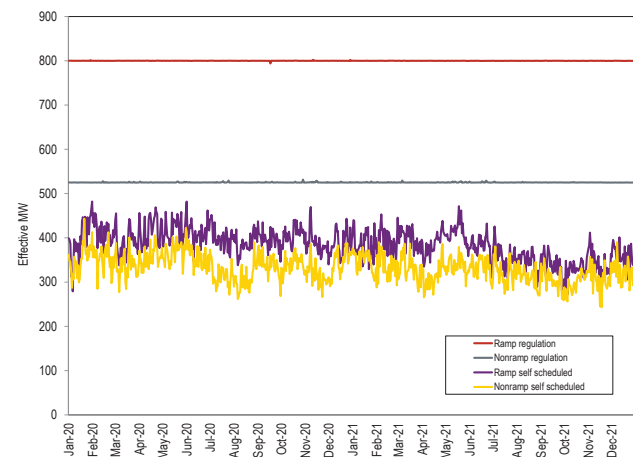


Table 10-50 shows the role of RegD resources in the regulation market. RegD resources are both a growing proportion of the market (10.9 percent of the total effective MW at the start of the performance based regulation market design in October 2012 and 46.9 percent of the total effective MW in December 2021) and a growing proportion of resources that self schedule (25.0 percent of all self scheduled effective MW in October 2012 and 70.1 percent of all self scheduled

¹⁰² See "PJM Manual 11: Energy & Ancillary Services Market Operations," § 3.2.1 Regulation Market Eligibility, Rev. 116 (September 1, 2021).

¹⁰³ See "PJM Manual 28: Operating Agreement Accounting," § 4.1 Regulation Accounting Overview, Rev. 85 (September 1, 2021).

¹⁰⁴ See "PJM Manual 11: Energy & Ancillary Services Market Operations," § 3.2.1 Regulation Market Eligibility, Rev. 116 (September 1, 2021).

effective MW in December 2021). In 2021, the average RegD percentage of total self scheduled effective MW was 71.7 percent, an increase of 0.5 percentage points from 2020, when the average was 71.2 percent.

Table 10-50 RegD self scheduled regulation by month: January 2020 through December 2021

Year	Month	RegD Self Scheduled Effective MW	RegD Effective MW	Total Self Scheduled Effective MW	Total Effective MW	RegD Percent of Total Self Scheduled Effective MW	RegD Percent of Total Effective MW
2020	Jan	253.3	311.9	376.5	674.0	67.3%	46.3%
2020	Feb	263.6	333.5	385.3	674.0	68.4%	49.5%
2020	Mar	257.9	319.9	358.9	639.9	71.9%	50.0%
2020	Apr	267.2	318.1	382.9	639.7	69.8%	49.7%
2020	May	274.6	312.2	388.5	639.8	70.7%	48.8%
2020	Jun	281.8	335.1	390.5	696.7	72.2%	48.1%
2020	Jul	252.6	343.3	369.3	697.1	68.4%	49.2%
2020	Aug	258.7	341.0	357.2	697.0	72.4%	48.9%
2020	Sep	275.4	317.2	363.3	639.6	75.8%	49.6%
2020	Oct	265.7	319.2	368.3	639.8	72.1%	49.9%
2020	Nov	255.1	321.4	346.5	640.6	73.6%	50.2%
2020	Dec	262.1	329.8	366.8	674.0	71.4%	48.9%
2020 Average		264.0	325.2	371.2	662.7	71.2%	49.1%
2021	Jan	250.5	322.4	367.7	674.0	68.1%	47.8%
2021	Feb	262.0	335.3	366.7	674.3	71.4%	49.7%
2021	Mar	263.0	321.7	359.0	639.9	73.3%	50.3%
2021	Apr	266.0	325.9	343.1	639.6	77.5%	51.0%
2021	May	256.8	320.6	368.0	639.9	69.8%	50.1%
2021	Jun	266.5	329.9	362.7	697.0	73.5%	47.3%
2021	Jul	255.4	331.6	344.6	696.9	74.1%	47.6%
2021	Aug	242.6	326.1	330.2	698.9	73.5%	46.7%
2021	Sep	219.8	302.0	319.6	639.6	68.8%	47.2%
2021	Oct	223.6	301.0	311.1	639.8	71.9%	47.1%
2021	Nov	218.5	298.9	321.2	640.3	68.0%	46.7%
2021	Dec	239.3	316.3	341.4	673.9	70.1%	46.9%
2021 Average		247.0	332.0	344.6	662.8	71.7%	48.2%

LSE's can satisfy their obligation to provide regulation by purchasing in the spot market, self scheduling, or through bilateral agreements. Increased self scheduled regulation lowers the requirement for cleared regulation, resulting in fewer MW cleared in the market and lower clearing prices. Of the LSEs' obligation to provide regulation in 2021, 52.0 percent was purchased in the PJM market, 44.1 percent was self scheduled, and 3.9 percent was purchased bilaterally (Table 10-51). Table 10-52 shows the total regulation by source including spot market regulation, self scheduled regulation, and bilateral regulation for January through December, 2012 through 2021. Table 10-51 and Table 10-52 are based on settled (purchased) MW.

Table 10-51 Regulation sources: spot market, self scheduled, bilateral purchases: January 2020 through December 2021

Year	Month	Spot Market Regulation (Unadjusted MW)	Spot Market Percent of Total	Self Scheduled Regulation (Unadjusted MW)	Self Scheduled Percent of Total	Bilateral Regulation (Unadjusted MW)	Bilateral Percent of Total	Total Regulation (Unadjusted MW)
2020	Jan	179,061.4	46.2%	190,434.8	49.1%	18,166.0	4.7%	387,662.1
2020	Feb	160,674.9	43.8%	185,702.6	50.6%	20,815.5	5.7%	367,193.0
2020	Mar	175,560.8	46.5%	181,566.1	48.1%	20,266.0	5.4%	377,392.8
2020	Apr	154,642.4	42.4%	187,819.3	51.5%	22,195.5	6.1%	364,657.2
2020	May	167,682.0	44.2%	191,949.3	50.5%	20,125.5	5.3%	379,756.8
2020	Jun	192,336.9	49.3%	178,239.7	45.7%	19,479.5	5.0%	390,056.1
2020	Jul	189,151.3	46.4%	198,595.7	48.7%	19,997.5	4.9%	407,744.5
2020	Aug	207,948.6	51.1%	181,392.4	44.6%	17,756.0	4.4%	407,097.0
2020	Sep	181,955.4	49.6%	171,428.3	46.7%	13,358.0	3.6%	366,741.7
2020	Oct	178,179.3	46.9%	186,687.3	49.1%	15,309.5	4.0%	380,176.1
2020	Nov	180,188.6	48.9%	172,941.0	46.9%	15,668.5	4.2%	368,798.1
2020	Dec	189,587.0	47.8%	188,798.6	47.6%	18,505.0	4.7%	396,890.6
	Total	2,156,968.5	47.0%	2,215,555.1	48.2%	221,642.5	4.8%	4,594,166.0
2021	Jan	186,762.8	46.6%	192,708.2	48.1%	21,466.0	5.4%	400,937.0
2021	Feb	172,967.1	47.4%	174,470.7	47.9%	17,095.5	4.7%	364,533.3
2021	Mar	182,812.8	47.3%	189,176.1	48.9%	14,910.0	3.9%	386,898.9
2021	Apr	190,444.5	51.0%	170,255.4	45.6%	12,763.0	3.4%	373,462.9
2021	May	171,841.5	44.5%	198,026.9	51.3%	16,270.0	4.2%	386,138.5
2021	Jun	211,800.7	54.2%	163,167.4	41.8%	15,526.0	4.0%	390,494.1
2021	Jul	225,587.1	55.9%	162,774.7	40.4%	15,017.5	3.7%	403,379.4
2021	Aug	234,148.0	57.9%	154,435.7	38.2%	15,577.5	3.9%	404,161.2
2021	Sep	190,656.5	53.7%	150,785.2	42.4%	13,896.0	3.9%	355,337.7
2021	Oct	212,564.6	57.0%	150,788.9	40.4%	9,873.5	2.6%	373,226.9
2021	Nov	191,647.2	53.7%	151,450.1	42.4%	13,883.0	3.9%	356,980.3
2021	Dec	211,012.8	54.1%	164,679.9	42.2%	14,258.5	3.7%	389,951.2
	Total	2,382,245.5	52.0%	2,022,719.3	44.1%	180,536.5	3.9%	4,585,501.3

Table 10-52 Regulation sources: 2012 through 2021

Year	Spot Market Regulation (Unadjusted MW)	Spot Market Percent of Total	Self Scheduled Regulation (Unadjusted MW)	Self Scheduled Percent of Total	Bilateral Regulation (Unadjusted MW)	Bilateral Percent of Total	Total Regulation (Unadjusted MW)
2012	6,149,110.0	78.6%	1,484,446.2	19.0%	193,408.0	2.5%	7,826,964.2
2013	3,088,963.1	57.7%	2,064,156.7	38.5%	204,260.5	3.8%	5,357,380.3
2014	2,327,322.4	49.3%	2,161,996.5	45.8%	231,218.0	4.9%	4,720,536.9
2015	2,546,688.3	54.4%	1,888,040.0	40.3%	250,386.1	5.3%	4,685,114.3
2016	2,260,701.6	48.6%	2,104,775.1	45.2%	287,809.5	6.2%	4,653,286.2
2017	2,504,264.1	55.2%	1,783,045.7	39.3%	250,184.5	5.5%	4,537,494.3
2018	2,755,355.7	60.5%	1,558,388.9	34.2%	243,589.5	5.3%	4,557,334.1
2019	2,367,346.1	53.1%	1,867,285.3	41.9%	221,292.5	5.0%	4,455,923.9
2020	2,156,968.5	47.0%	2,215,555.1	48.2%	221,642.5	4.8%	4,594,166.0
2021	2,382,245.5	52.0%	2,022,719.3	44.1%	180,536.5	3.9%	4,585,501.3

In 2021, DR provided an average of 10.9 MW of regulation per hour during ramp hours (12.4 MW of regulation per hour during ramp hours in 2020), and an average of 7.4 MW of regulation per hour during nonramp hours (9.2 MW of regulation per hour during nonramp hours in 2020). Generating units supplied an average of 696.0 MW of regulation per hour during ramp hours in 2021 (690.5 MW of regulation per hour during ramp hours in 2020), and an average of 474.3 MW per hour during nonramp hours in 2021 (482.8 MW of regulation per hour during nonramp hours in 2020).

Market Performance

Price

Table 10-53 shows the regulation price and regulation cost per MW for 2009 through 2021. The weighted average RMCP for 2021 was \$26.00 per MW. This is an increase of \$12.45 per MW, or 91.9 percent, from the weighted average RMCP of \$13.55 per MW in 2020. This increase in the regulation clearing price was the result of an increase in energy prices in 2021 and the related increase in the opportunity cost component of RMCP.

Table 10-53 Comparison of average price and cost for regulation: 2009 through 2021

Year	Weighted Regulation Market Price	Weighted Regulation Market Cost	Regulation Price as Percent of Cost
2009	\$23.00	\$30.68	75.0%
2010	\$18.00	\$32.86	54.8%
2011	\$16.49	\$29.72	55.5%
2012	\$19.02	\$25.32	75.1%
2013	\$30.85	\$35.79	86.2%
2014	\$44.49	\$53.82	82.7%
2015	\$31.92	\$38.36	83.2%
2016	\$19.73	\$18.13	86.7%
2017	\$16.79	\$23.03	72.9%
2018	\$25.32	\$31.94	79.3%
2019	\$16.27	\$20.32	80.1%
2020	\$13.55	\$16.73	81.0%
2021	\$26.00	\$31.49	82.6%

The introduction of fast start pricing in the PJM energy market on September 1, 2021, had an effect on the regulation market LOC included in regulation offers and in the resulting clearing price for regulation. Table 10-54 shows the effect of fast start pricing on the regulation market monthly component of price from September through December, 2021.

Table 10-54 Comparison of fast start and dispatch and pricing components: September through December, 2021

Month	Pricing Method	Weighted Average Price (\$/Perf. Adj. Actual MW)		
		Capability Clearing Price	Performance Clearing Price	Regulation Market Clearing Price
Sep	Fast Start	\$29.08	\$1.34	\$30.41
	Dispatch	\$27.22	\$1.34	\$28.55
Oct	Fast Start	\$39.92	\$1.47	\$41.40
	Dispatch	\$35.64	\$1.47	\$37.12
Nov	Fast Start	\$54.40	\$1.88	\$56.28
	Dispatch	\$50.56	\$1.88	\$52.43
Dec	Fast Start	\$27.37	\$1.42	\$28.79
	Dispatch	\$25.62	\$1.42	\$27.05

Figure 10-18 shows the capability price, performance price, and the opportunity cost component for the PJM Regulation Market on a performance adjusted MW basis. The regulation clearing price is determined based on the marginal unit's total offer (RCP + RPP + PJM calculated LOC). Then the maximum performance offer price (RPP) of any of the cleared units is used to set the marginal performance clearing price for the purposes of settlements. The difference between the marginal total clearing price and the highest performance clearing price (RMPCP) is the marginal capability clearing price (RMCCP). The capability price presented here is equal to the clearing price, minus the maximum cleared performance offer price. This data is based on actual five minute interval operational data.

Figure 10-18 illustrates the components of the regulation market clearing price. Each section represents the contribution of the lost opportunity cost (green area), capability price (blue area), and performance price (orange area), to the total price. From this figure, it is clear that the lost opportunity cost is the predominant component of the total clearing price.

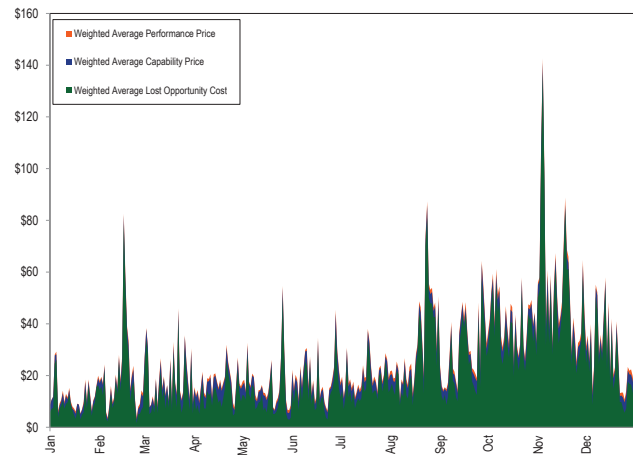
Figure 10-18 Regulation market clearing price components (Dollars per MW): 2021

Table 10-55 shows the capability and performance components of the monthly average regulation prices. These components differ from the components of the marginal unit's offers in Figure 10-18 because the performance component of the settlement price for each hour is determined from the average of the highest performance offers in each five minute interval, calculated independent of the marginal unit's offers in those intervals.

Table 10-55 Regulation market monthly component of price (Dollars per MW): 2021

Month	Weighted Average Regulation Market Capability Clearing Price (\$/Perf. Adj. Actual MW)	Weighted Average Regulation Market Performance Clearing Price (\$/Perf. Adj. Actual MW)	Weighted Average Regulation Market Clearing Price (\$/Perf. Adj. Actual MW)
Jan	\$11.50	\$0.62	\$12.12
Feb	\$19.64	\$0.96	\$20.60
Mar	\$18.48	\$0.68	\$19.20
Apr	\$16.40	\$0.95	\$17.34
May	\$15.77	\$0.86	\$16.63
Jun	\$18.26	\$0.97	\$19.22
Jul	\$18.98	\$1.05	\$20.02
Aug	\$31.77	\$1.36	\$33.13
Sep	\$29.08	\$1.34	\$30.41
Oct	\$39.92	\$1.47	\$41.40
Nov	\$54.40	\$1.88	\$56.28
Dec	\$27.37	\$1.42	\$28.79
Average	\$24.88	\$1.12	\$26.00

Monthly and total annual scheduled regulation MW and regulation charges, as well as monthly average regulation price and regulation cost are shown in Table 10-56. Total scheduled regulation is based on settled performance adjusted MW. The total of all regulation charges in 2021 was \$144.4 million, compared to \$76.9 million in 2020.

Table 10-56 Total regulation charges: 2020 through 2021

Year	Month	Scheduled Regulation (MW)	Total Regulation Charges (\$)	Weighted Average Regulation Market Price (\$/MW)	Cost of Regulation (\$/MW)	Price as Percent of Cost
2020	Jan	387,662.1	\$6,495,664	\$13.70	\$16.76	81.7%
2020	Feb	367,193.0	\$4,630,253	\$10.12	\$12.61	80.3%
2020	Mar	377,392.8	\$4,619,257	\$9.06	\$12.24	74.0%
2020	Apr	364,657.2	\$5,646,138	\$12.10	\$15.48	78.1%
2020	May	379,756.8	\$6,078,957	\$12.97	\$16.01	81.0%
2020	Jun	390,056.1	\$6,072,212	\$12.31	\$15.57	79.1%
2020	Jul	407,744.5	\$7,732,029	\$16.14	\$18.96	85.1%
2020	Aug	407,097.0	\$7,566,611	\$15.36	\$18.59	82.6%
2020	Sep	366,741.7	\$4,909,677	\$10.88	\$13.39	81.2%
2020	Oct	380,176.1	\$8,168,776	\$17.64	\$21.49	82.1%
2020	Nov	368,798.1	\$7,381,789	\$15.95	\$20.02	79.7%
2020	Dec	396,890.6	\$7,562,483	\$15.79	\$19.05	82.9%
	Yearly	4,594,166.0	\$76,860,642	\$13.55	\$16.73	81.0%
2021	Jan	400,937.0	\$6,038,564	\$12.12	\$15.06	80.5%
2021	Feb	364,533.3	\$9,401,619	\$20.60	\$25.79	79.9%
2021	Mar	386,898.9	\$8,793,373	\$19.20	\$22.73	84.5%
2021	Apr	373,462.9	\$7,951,303	\$17.34	\$21.29	81.5%
2021	May	386,138.5	\$8,051,297	\$16.62	\$20.85	79.7%
2021	Jun	390,494.1	\$9,654,112	\$19.22	\$24.72	77.8%
2021	Jul	403,379.4	\$9,696,300	\$20.02	\$24.04	83.3%
2021	Aug	404,161.2	\$15,414,276	\$33.13	\$38.14	86.9%
2021	Sep	355,337.7	\$12,923,840	\$30.41	\$36.37	83.6%
2021	Oct	373,226.9	\$18,334,407	\$41.40	\$49.12	84.3%
2021	Nov	356,980.3	\$24,453,797	\$56.28	\$68.50	82.2%
2021	Dec	389,951.2	\$13,662,814	\$28.79	\$35.04	82.2%
	Yearly	4,585,501.3	\$144,375,702	\$26.00	\$31.49	82.6%

The capability, performance, and opportunity cost components of the cost of regulation are shown in Table 10-57. Total scheduled regulation is based on settled performance adjusted MW. In 2021, the average total cost of regulation was \$31.49 per MW, 88.2 percent higher than \$16.73 in 2020. In 2021, the monthly average capability component cost of regulation was \$25.25, 92.9 percent higher than \$13.09 in 2020. In 2021, the monthly average performance component cost of regulation was \$2.94, 60.8 percent higher than \$1.83 in 2020. The increase of the average total cost in 2021 versus 2020, was primarily a result of higher LOC values due to higher prices in the energy market.

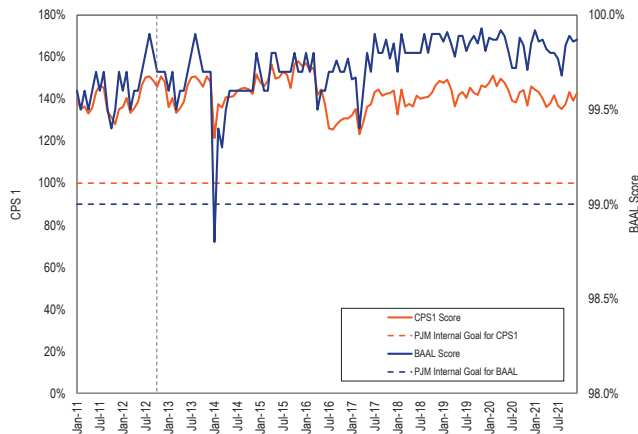
Table 10-57 Components of regulation cost: January 2020 through December 2021

Year	Month	Scheduled Regulation (MW)	Cost of Regulation Capability (\$/MW)	Cost of Regulation Performance (\$/MW)	Opportunity Cost (\$/MW)	Total Cost (\$/MW)
2020	Jan	387,662.1	\$13.32	\$1.80	\$1.64	\$16.76
	Feb	367,193.0	\$9.90	\$1.35	\$1.36	\$12.61
	Mar	377,392.8	\$8.71	\$1.46	\$2.07	\$12.24
	Apr	364,657.2	\$11.68	\$1.77	\$2.03	\$15.48
	May	379,756.8	\$12.66	\$1.39	\$1.95	\$16.01
	Jun	390,056.1	\$11.74	\$1.94	\$1.88	\$15.57
	Jul	407,744.5	\$15.74	\$1.54	\$1.68	\$18.96
	Aug	407,097.0	\$14.80	\$2.01	\$1.78	\$18.59
	Sep	366,741.7	\$10.42	\$1.49	\$1.47	\$13.39
	Oct	380,176.1	\$16.90	\$2.80	\$1.78	\$21.49
	Nov	368,798.1	\$15.21	\$2.70	\$2.11	\$20.02
	Dec	396,890.6	\$15.40	\$1.72	\$1.94	\$19.05
Yearly		4,594,166.0	\$13.09	\$1.83	\$1.81	\$16.73
2021	Jan	400,937.0	\$11.71	\$1.67	\$1.68	\$15.06
	Feb	364,533.3	\$19.90	\$2.52	\$3.37	\$25.79
	Mar	386,898.9	\$18.70	\$1.86	\$2.16	\$22.73
	Apr	373,462.9	\$16.63	\$2.66	\$2.00	\$21.29
	May	386,138.5	\$15.87	\$2.40	\$2.58	\$20.85
	Jun	390,494.1	\$18.45	\$2.54	\$3.73	\$24.72
	Jul	403,379.4	\$19.25	\$2.68	\$2.10	\$24.04
	Aug	404,161.2	\$32.19	\$3.36	\$2.58	\$38.14
	Sep	355,337.7	\$29.45	\$3.41	\$3.52	\$36.37
	Oct	373,226.9	\$40.60	\$3.97	\$4.55	\$49.12
	Nov	356,980.3	\$55.46	\$4.80	\$8.24	\$68.50
	Dec	389,951.2	\$27.87	\$3.67	\$3.50	\$35.04
Total		4,585,501.3	\$25.25	\$2.94	\$3.29	\$31.49

Performance Standards

PJM’s performance as measured by CPS1 and BAAL standards is shown in Figure 10-19 for every month from January 2011 through December 2021 with the dashed vertical line marking the date (October 1, 2012) of the implementation of the Performance Based Regulation Market design.¹⁰⁵ The horizontal dashed lines represent PJM internal goals for CPS1 and BAAL performance.

Figure 10-19 Monthly CPS1 and BAAL performance: January 2011 through December 2021



105 See 2019 State of the Market Report for PJM, Appendix F: Ancillary Services.

Black Start Service

Black start service is required for the reliable restoration of the grid following a blackout. Black start service is the ability of a generating unit to start without an outside electrical supply, or the demonstrated ability of a generating unit to automatically remain operating at reduced levels when disconnected from the grid (automatic load rejection or ALR).¹⁰⁶ Although PJM has raised the issue, there are no firm fuel requirements for black start units.

PJM does not have a market to provide black start service, but compensates black start resource owners on the basis of cost of service rates defined in the tariff.¹⁰⁷

PJM defines required black start capability zonally, while recognizing that the most effective way to provide black start service may be across zones. Under the current rules PJM has substantial flexibility in procuring black start resources and is responsible for black start resource selection.

On April 7, 2021, PJM issued an incremental RFP for additional black start service in the BGE and PEPCO Zones. The RFP is a two stage process. Level one submissions were due May 10, 2021. Level two submissions were due May 31, 2021. On November 1, 2021, PJM made awards for the April 7, 2021 incremental RFP. The planned in service date is April 1, 2023.¹⁰⁸

Total black start charges are the sum of black start revenue requirement charges and black start uplift (operating reserve) charges. Black start revenue requirements for black start units consist of fixed black start service costs, variable black start service costs, training costs, fuel storage costs, and an incentive factor applicable when CRF rates are not used. The tariff specifies how to calculate each component of the revenue requirement formula.¹⁰⁹ Black start resources can choose to recover fixed costs under a formula rate based on zonal Net CONE and unit ICAP rating, a cost recovery rate based on incremental black start NERC-CIP compliance capital costs, or a cost recovery rate based on FERC-approved rate plus capital costs for new investment. In addition,

PJM applies a cost recovery rate based on incremental black start equipment capital costs.

Black start uplift (operating reserve) charges are paid to units committed in real time to provide black start service or for black start testing.¹¹⁰ Total black start charges are allocated monthly to PJM customers proportionally to their zone and nonzone peak transmission use and point to point transmission reservations.¹¹¹ It is not clear why it is reasonable to have different charges for black start service across zones as the service is to ensure that PJM as a whole can recover from a large scale outage.

In 2021, total black start charges were \$67.96 million, an increase of \$3.09 million (4.76 percent) from 2020. Uplift charges for black start service increased from \$0.23 million 2020 to \$0.32 million (37.1 percent) in 2021. Table 10-58 shows total charges each year from 2010 through 2021.¹¹²

Table 10-58 Black start revenue requirement charges: 2010 through 2021

Year	Revenue Requirement		Total
	Charges	Uplift Charges	
2010	\$11,490,379	\$0	\$11,490,379
2011	\$13,695,331	\$0	\$13,695,331
2012	\$18,749,617	\$8,384,651	\$27,134,269
2013	\$20,874,535	\$86,701,561	\$107,576,097
2014	\$26,945,112	\$32,906,733	\$59,851,845
2015	\$56,425,648	\$5,175,644	\$61,601,292
2016	\$69,376,257	\$279,017	\$69,655,275
2017	\$69,258,169	\$257,174	\$69,515,342
2018	\$64,439,926	\$294,753	\$64,734,679
2019	\$64,327,918	\$226,014	\$64,553,932
2020	\$64,643,080	\$230,754	\$64,873,834
2021	\$67,645,753	\$316,437	\$67,962,190

Black start zonal charges in 2021 ranged from \$43,630 in the BGE Zone to \$19,803,649 in the AEP Zone. For each zone, Table 10-59 shows black start charges, the sum of monthly zonal peak loads multiplied by the number of days of the month in which the peak load occurred, and black start rates (calculated as charges per MW-day). Customers paid an average of \$1.16 per MW-day for black start service in 2021.

¹⁰⁶ OATT Schedule 1 § 1.3BB.

¹⁰⁷ See OATT Schedule 6A para. 18.

¹⁰⁸ RFPs issued can be found on the PJM website. See PJM. <<http://www.pjm.com/markets-and-operations/ancillary-services.aspx>>.

¹⁰⁹ See OATT Schedule 6A para. 18.

¹¹⁰ There are no black start units currently using the ALR option.

¹¹¹ OATT Schedule 6A (paras. 25, 26 and 27 outline how charges are to be applied).

¹¹² Starting December 1, 2012, PJM defined a separate black start uplift category. ALR units accounted for the high uplift charges in 2013 – 2015. All ALR units had been replaced by April 2015.

Table 10-59 Black start zonal charges: 2020 and 2021¹¹³

Zone	2020					2021				
	Revenue Requirement Charges	Uplift Charges	Total Charges	Peak Load (MW)	Black Start Rate (\$/MW-day)	Revenue Requirement Charges	Uplift Charges	Total Charges	Peak Load (MW)	Black Start Rate (\$/MW-day)
ACEC	\$2,572,240	\$10,709	\$2,582,949	2,737	\$2.58	\$2,256,528	\$26,011	\$2,282,539	2,635	\$2.37
AEP	\$17,243,608	\$26,537	\$17,270,145	22,498	\$2.10	\$19,741,659	\$61,990	\$19,803,649	21,615	\$2.51
APS	\$3,813,141	\$1,159	\$3,814,300	9,596	\$1.09	\$5,322,896	\$1,135	\$5,324,031	8,638	\$1.69
ATSI	\$5,574,883	\$10,481	\$5,585,364	12,567	\$1.21	\$5,581,214	\$6,593	\$5,587,807	12,465	\$1.23
BGE	\$138,490	\$628	\$139,118	6,706	\$0.06	\$43,535	\$95	\$43,630	6,700	\$0.02
COMED	\$8,176,146	\$22,638	\$8,198,784	20,949	\$1.07	\$9,353,385	\$36,616	\$9,390,000	20,220	\$1.27
DAY	\$218,116	\$14,120	\$232,236	3,259	\$0.19	\$233,178	\$13,958	\$247,136	3,309	\$0.20
DUKE	\$357,187	\$13,990	\$371,177	5,052	\$0.20	\$384,287	\$12,598	\$396,885	4,975	\$0.22
DUQ	\$43,485	\$15,810	\$59,295	2,662	\$0.06	\$271,036	\$1,338	\$272,374	2,668	\$0.28
DOM	\$4,856,415	\$23,222	\$4,879,637	19,931	\$0.67	\$5,226,310	\$56,494	\$5,282,803	20,061	\$0.72
DPL	\$2,147,289	\$17,353	\$2,164,642	4,098	\$1.44	\$1,621,172	\$15,479	\$1,636,651	4,086	\$1.10
EKPC	\$324,084	\$1,641	\$325,725	3,074	\$0.29	\$332,380	\$2,076	\$334,456	2,720	\$0.34
JCPLC	\$2,753,548	\$3,058	\$2,756,606	6,057	\$1.24	\$677,277	\$2,564	\$679,841	5,903	\$0.32
MEC	\$388,691	\$28,169	\$416,860	2,986	\$0.38	\$500,219	\$20,033	\$520,253	2,976	\$0.48
OVEC	\$0	\$0	\$0	NA	NA	\$0	\$0	\$0	NA	NA
PECO	\$1,394,979	\$1,261	\$1,396,240	8,428	\$0.45	\$1,459,560	\$2,199	\$1,461,759	8,148	\$0.49
PE	\$4,327,013	\$8,952	\$4,335,964	3,015	\$3.93	\$4,368,997	\$12,851	\$4,381,848	2,911	\$4.12
PEPCO	\$1,549,645	\$7,218	\$1,556,864	6,191	\$0.69	\$331,735	\$10,971	\$342,707	5,887	\$0.16
PPL	\$3,059,144	\$10,441	\$3,069,585	7,939	\$1.06	\$4,876,895	\$10,154	\$4,887,050	7,260	\$1.84
PSEG	\$2,513,183	\$2,350	\$2,515,534	9,753	\$0.70	\$1,749,798	\$9,300	\$1,759,098	9,557	\$0.50
REC	\$0	\$0	\$0	NA	NA	\$0	\$0	\$0	NA	NA
(Imp/Exp/Wheels)	\$3,191,793	\$11,017	\$3,202,810	8,201	\$1.07	\$3,313,690	\$13,983	\$3,327,673	7,866	\$1.16
Total	\$64,643,080	\$230,754	\$64,873,834	165,696	\$1.07	\$67,645,753	\$316,437	\$67,962,190	160,599	\$1.16

Table 10-60 provides a revenue requirement estimate by zone for the 2021/2022, 2022/2023, and 2023/2024 Delivery Years.¹¹⁴ Revenue requirement values are rounded up to the nearest \$50,000 to reflect uncertainty about future black start revenue requirement costs. These values are illustrative only. The estimates are based on the best available data including current black start unit revenue requirements, expected black start unit termination and in service dates, changes in recovery rates, and owner provided cost estimates of incoming black start units at the time of publication and may change significantly.

Table 10-60 Black start zonal revenue requirement estimate: 2021/2022 through 2023/2024 Delivery Years

Zone	2021 / 2022 Revenue Requirement	2022 / 2023 Revenue Requirement	2023 / 2024 Revenue Requirement
ACEC	\$2,150,000	\$2,150,000	\$2,150,000
AEP	\$20,800,000	\$20,550,000	\$20,600,000
APS	\$7,950,000	\$7,950,000	\$7,950,000
ATSI	\$5,900,000	\$5,900,000	\$5,900,000
BGE	\$50,000	\$50,000	\$350,000
COMED	\$10,050,000	\$9,400,000	\$9,500,000
DAY	\$300,000	\$250,000	\$250,000
DUKE	\$450,000	\$350,000	\$350,000
DUQ	\$2,150,000	\$2,100,000	\$2,100,000
DOM	\$5,550,000	\$5,350,000	\$5,400,000
DPL	\$1,350,000	\$1,250,000	\$1,300,000
EKPC	\$400,000	\$300,000	\$300,000
JCPLC	\$650,000	\$550,000	\$600,000
MEC	\$550,000	\$450,000	\$500,000
OVEC	\$0	\$0	\$0
PECO	\$1,600,000	\$1,350,000	\$1,400,000
PE	\$4,650,000	\$4,550,000	\$4,600,000
PEPCO	\$300,000	\$200,000	\$650,000
PPL	\$5,350,000	\$5,200,000	\$5,250,000
PSEG	\$1,950,000	\$1,850,000	\$1,850,000
REC	\$0	\$0	\$0
Total	\$72,150,000	\$69,750,000	\$71,000,000

¹¹³ Peak load for each zone is used to calculate the black start rate per MW day.

¹¹⁴ The System Restoration Strategy Task Force requested that the MMU provide estimated black start revenue requirements.

CRF Issues

The capital recovery factor (CRF) defines the revenue requirement of black start units when new equipment is added to provide black start capability.¹¹⁵ The CRF is a rate, which when multiplied by the investment, provides for a return on and of capital over a defined time period. CRFs are calculated using a formula (or a correctly defined standard financial model) that accounts for the weighted average cost of capital and its components, plus depreciation and taxes. The PJM CRF table was created in 2007 as part of the new RPM capacity market design and incorporated in Attachment DD to the PJM OATT (Table 10-61). The CRF table provided for the accelerated return of incremental investment in capacity resources based on concerns about the fact that some old coal units would be making substantial investments related to pollution control. The CRF values were later added to the black start rules.¹¹⁶ The CRF table in the tariff included assumptions about tax rates that were significantly too high after the changes to the tax code in 2017. The PJM tariff tables including CRF values should have been changed for both black start and the capacity market when the tax laws changed in 2017.

Table 10-61 CRF table for existing black start units

Age of Black Start Unit (Years)	Term of Black Start Unit Commitment (Years)	Levelized CRF
1 to 5	20	0.125
6 to 10	15	0.146
11 to 15	10	0.198
16+	5	0.363

The CRF table for existing black start units includes the column header, term of black start unit commitment, which is misleading and incorrect. The column is simply the cost recovery period. Accelerated recovery reduces risk to black start units and should not be the basis for a shorter commitment. Full payment of all costs of black start investment on an accelerated basis should not be a reason for a shortened commitment period. Regardless of the recovery period, payment of the full costs of the black start investment should require commitment for the life of the unit.¹¹⁷ In addition, there is no need for such short recovery periods for black start investment costs. Two periods, based on unit age, are more than adequate.

¹¹⁵ See OATT Schedule 6A para. 18.

¹¹⁶ *Id.*

¹¹⁷ PJM's recent filing to revise Schedule 6A includes a required commitment to provide black start service for the life of the unit. See FERC Docket No. ER21-1635.

The U.S. Internal Revenue Code changed significantly in December 2017. The PJM CRF table did not change to reflect these changes. As a result, CRF values have overcompensated black start units since the changes to the tax code. The new tax law allow for a more accelerated depreciation and reduced the corporate tax rate to 21 percent.

Updated CRF rates, incorporating the tax code changes and applicable to all black start units, should be implemented immediately. The updated CRF rates should apply to all black start units because the actual tax payments for all black start units were reduced by the tax law changes. Without this change, black start units are receiving and will continue to receive an unexpected and inappropriate windfall.

On April 7, 2021, PJM filed with FERC to update the CRF values for new black start service units.¹¹⁸ PJM proposed to bifurcate the CRF calculation, applying an updated CRF calculation that incorporates the new federal tax law to new black start units while leaving the outdated and incorrect CRF in place for existing black start units. Rather than fix the inaccurate CRF values used for existing black units, PJM's filing would have made the use of inaccurate values permanent. The MMU filed comments on April 28, 2021.¹¹⁹ The MMU objected to the continued use of the outdated CRF for existing units. The MMU also introduced a CRF formula for calculating the CRF for new black start units and requested that the CRF formula be included in the tariff.^{120 121} On August 10, 2021, FERC issued an order ("August 10th Order") that accepted PJM's tariff revisions that apply to new black start units (starting service after June 6, 2021) and directed PJM to include the CRF formula proposed by the MMU.¹²² The August 10th Order also established a show cause proceeding in a new docket to "determine whether the existing rates for generating units providing Black Start Service (Black Start Units), which are based on a federal corporate income tax that pre-dates the Tax Cuts and Jobs Act of 2017 (TCJA), remains just and reasonable."¹²³ The MMU requested rehearing

¹¹⁸ See Docket No. ER21-1635-000.

¹¹⁹ See Comments of the Independent Market Monitor for PJM, FERC Docket No. ER21-1635-000 (April 28, 2021), which can be accessed at <http://www.monitoringanalytics.com/filings/2021/IMM_Comments_Docket_No_ER21-1635_20210428.pdf>.

¹²⁰ Answer and Motion for Leave to Answer of the Independent Market Monitor for PJM, ER21-1635 (May 20, 2021).

¹²¹ Comments of the Independent Market Monitor for PJM, FERC Docket No. ER21-1635 (July 2, 2021).

¹²² 176 FERC ¶ 61,080 at 42 and 44 (2021).

¹²³ 176 FERC ¶ 61,080 at 2 (2021).

over the Commission’s conclusion that the MMU had requested “retroactive changes to the rates previously paid to generators.”¹²⁴ ¹²⁵ The request for rehearing was denied.¹²⁶ PJM’s compliance filing to address the August 10 Order was accepted by letter order, subject to edits proposed by the MMU, on December 16, 2021.¹²⁷

PJM’s response to the show cause directive in the August 10th Order continued to support the use of the outdated CRF despite the Commission’s statement that the CRF values “appear to be unjust, unreasonable, unduly discriminatory or preferential, or otherwise unlawful.”¹²⁸ ¹²⁹ The MMU responded with analysis showing that PJM’s proposal for maintaining the outdated CRF values would result in \$126 million of over recovery of black start capital investments.¹³⁰

The MMU also proposed an update to the CRF that reflects the return of capital already received by existing black start units and eliminates the over recovery that occurs under the PJM proposal. The updated CRF would be set at the level that covers the tax liabilities going forward, pays a return at the required rates on the remaining capital investment, pays back the full investment and results in the required return on and of capital over the CRF term. A description of the MMU’s proposal and a formula for calculating the updated CRF are included in the MMU Comments.¹³¹

NERC – CIP

No black start units have requested new or additional black start NERC – CIP Capital Costs.¹³²

Minimum Tank Suction Level (MTSL)

PJM had permitted and in some cases required black start unit owners to charge customers for 100 percent of oil tanks even when the black start use was shared

with another facility and the black start use was only a very small share of the oil tank use. The MMU had recommended since 2017 that when black start resources share oil tanks with other resources that only a proportionate share of the minimum tank suction level (MTSL) be allocated to black start service. The MMU had also recommended that the PJM tariff be updated to clearly state how the MTSL will be calculated for black start units sharing oil tanks.

This recommendation was filed by PJM and approved by FERC.¹³³

Reactive Power Service and Capability

Suppliers of reactive power are compensated separately for reactive power service and reactive capability.

Compensation for reactive power service is based on real-time lost opportunity costs.¹³⁴ Reactive service is generally provided by units reducing real power output in order to increase reactive power output. These units are paid uplift based on lost opportunity costs.¹³⁵

Compensation for reactive capability is approved separately for each resource or resource group by FERC per Schedule 2 of the OATT. Resources may obtain FERC approval to recover a reactive revenue requirement, the reactive capability rate, from PJM customers.¹³⁶

Reactive Service, Reactive Supply and Voltage Control are provided by generation and other sources of reactive power (such as static VAR compensators and capacitor banks).¹³⁷ PJM in its role as the independent RTO and transmission provider determines the reactive capability it needs from all sources in order to reliably operate the grid. PJM, as part of its Interconnection Agreement, requires that all resources over 20 MW be able to operate at a power factor of 0.90 lagging to 0.95 leading throughout their entire operating range. Reactive power helps maintain appropriate voltages on the transmission system and must be sourced locally.

¹²⁴ Id. at 50.

¹²⁵ Request for Rehearing of the Independent Market Monitor for PJM, FERC Docket No. ER21-1635 (September 9, 2021).

¹²⁶ 177 FERC ¶ 62,017 (2021).

¹²⁷ 177 FERC ¶ 61,202 (2021).

¹²⁸ *PJM Interconnection, L.L.C., Response to Commission’s Show Cause Order*, Docket No. EL21-91 (October 12, 2021).

¹²⁹ August 10th Oder at 47.

¹³⁰ Errata Filing of the Independent Market Monitor for PJM, Attachment B at 17, Docket No. EL21-91 (November 18, 2022).

¹³¹ Id. (Attachment B, Section H at 18).

¹³² OATT Schedule 6A para. 21. “The Market Monitoring Unit shall include a Black Start Service summary in its annual State of the Market report which will set forth a descriptive summary of the new or additional Black Start NERC-CIP Capital costs requested by Black Start Units, and include a list of the types of capital costs requested and the overall cost of such capital improvements on an aggregate basis such that no data is attributable to an individual Black Start Unit.”

¹³³ See 176 FERC ¶ 61,080 (2021).

¹³⁴ See OA Schedule 1 § 3.2.3B.

¹³⁵ Id.

¹³⁶ See “PJM Manual 27: Open Access Transmission Tariff Accounting,” § 3.2 Reactive Supply and Voltage Control Credits, Rev. 93 (Aug. 31, 2020).

¹³⁷ OATT Schedule 2.

Total reactive capability charges are the sum of FERC approved reactive supply revenue requirements. Zonal reactive supply revenue requirement charges are allocated monthly to PJM customers proportionally to their zone and to any nonzone (outside of PJM) peak transmission use and daily average point to point transmission reservations.^{138 139}

In 2016, FERC began to reexamine its policies on reactive compensation.¹⁴⁰ More recently, on November 18, 2021, the FERC issued a notice of inquiry concerning reactive power capability compensation.¹⁴¹

Issues with Reactive Capability Market Design

The Market Monitor appreciates that the Commission is investigating these issues related to reactive power compensation in wholesale power markets. The NOI inquires about reactive power capability compensation under the AEP Method, alternative methods of compensation, and resources interconnected at the distribution level. The fundamental question is whether market design in the organized wholesale markets requires separate, guaranteed cost of service compensation for reactive capability. The answer is no. In the PJM market design, investment in resources is fully recoverable through markets. The PJM markets are a complete set of markets that are self sustaining. Unlike some ISO/RTO designs, the PJM market relies on markets rather than cost of service regulation or bilateral contracts to pay for capacity. Generators will invest in markets when the expected revenues provide for the payment of all costs and the return and of capital. That is the way competitive markets work. It would be more equitable, more consistent with the PJM competitive market design, and more consistent with appropriate compensation for all generator costs, including reactive, to rely on PJM markets than to continue the outdated mixing of regulatory paradigms.

Even if the PJM design worked in the way asserted by supporters of cost of service payments for reactive, the best possible outcome would be the same as the

market outcome. There would be an opportunity to recover all costs. A simple application of Occam's razor implies that the market approach should be used, as it is overwhelmingly more efficient than the current rate case, cost of service approach. Supporters of the cost of service approach have never explained why a nonmarket approach is required in PJM or why it is preferable to a market approach.

The current process is an inefficient waste of time because it relies on an atavistic regulatory paradigm that is not relevant in the PJM market framework. The AEP Method was created, before the creation of the PJM markets, by a regulated utility that had regulatory and financial reasons to want to define some generation costs as transmission costs. There is no reason to include complex rules that arbitrarily segregate a portion of a resource's capital costs as related to reactive power and that require recovery of that arbitrary portion through guaranteed revenue requirement payments based on burdensome cost of service rate proceedings.

Applying cost of service rules is costly and burdensome and unnecessary. Most reactive proceedings for generators in PJM are resolved in black box settlements that fail to address the merits of the cost support provided, result from an unsupported split the difference approach, and that, not surprisingly, produce a wide, unreasonable and discriminatory disparity among the rates per paid per MW-year.

Payments based on cost of service approaches result in distortionary impacts on PJM markets. Elimination of the reactive revenue requirement and the recognition that capital costs are not distinguishable by function would increase prices in the capacity market. The VRR curve would shift to the right, the maximum VRR price would increase and offer caps in the capacity market would increase. The simplest way to address this distortion would be to recognize that all capacity costs are recoverable in the PJM markets.

The NOI presents an opportunity to address the reactive issue using a market based approach. The best approach would be to issue a rule eliminating cost of service rates for reactive capability and allowing for recovery of capacity costs through existing markets, including a removal of any offset for reactive revenue in offers and in the capacity market demand (VRR) curve. A second

¹³⁸ OATT Schedule 2.

¹³⁹ See "PJM Manual 27: Open Access Transmission Tariff Accounting," § 3.3 Reactive Supply and Voltage Control Charges, Rev. 93 (Aug. 31, 2020).

¹⁴⁰ See *Reactive Supply Compensation in Markets Operated by Regional Transmission Organizations and Independent System Operators*, Docket No. AD16-17-000 (March 17, 2016) (Notice of Workshop).

¹⁴¹ 177 FERC ¶ 61,118 (2021).

best approach would be to limit the revenue requirement that could be filed for under the OATT Schedule 2 to a level less than or equal to the reactive revenue credit included in the capacity market design, in the VRR curve net CONE value, currently \$2,199 per MW-year.

As with all things in PJM markets, it is easy to focus on extreme complexity and lose sight of the big picture. The complexity includes power factors and power factor testing and convoluted and arbitrary allocation factors. The big picture here is that in PJM, the interrelated and self-sustaining markets provide the opportunity for all power plants to recover all their costs, including a return on and of capital, including any identifiable reactive costs. There is no reason that part of those capacity costs should be paid directly in a non-market, guaranteed, riskless revenue stream rather than in the market. The existence of the current option creates strong incentives for generators to maximize the allocation of capital costs to reactive in order to maximize guaranteed, non-market revenues.

The current process does not actually compensate resources based on their costs of investment in reactive power capability. The AEP Method assigns costs between real and reactive power based on a unit's power factor. This is effectively an allocation based on a subjective judgment rather than actual investment. There are few if any identifiable costs incurred by generators in order to provide reactive power. Separately compensating resources based on a judgment-based allocation of total capital costs was never and is not now appropriate in the PJM markets. Generating units are fully integrated power plants that produce both the real and reactive power required for grid operation.

The AEP Method originated with a regulated utility assigning costs between two sources of regulated revenue requirement. The practice persists in PJM only because it provides a significant, guaranteed stream of riskless revenue. Generation owners have an incentive to maximize such guaranteed revenue streams.

There is no logical reason to have a separate fixed payment for any part of the capacity costs of generating units in PJM. If separate cost of service rates for reactive continue, they need to be correctly integrated in the PJM market design.

The best and straightforward solution is to remove cost of service rates for reactive supply capability and to remove the offset. Investment in generation can and should be compensated entirely through markets. Removing cost of service rules would avoid the significant waste of resources incurred to develop unneeded cost of service rates.

The result would be to pay generators market-based rates for both real and reactive capacity.

The PJM market design allows for the competitive investment in generation resources. The addition of separate rules allowing for the recovery of an arbitrarily defined portion of the same investment on a cost of service basis introduces a flaw into the competitive market design. The flaw is exacerbated when separate cost of service proceedings define the revenue requirement cost to supply reactive at values ranging from \$13,044 to \$964 per MW-year. (See Table 10-64)

The real issue is that the revenue requirement approach is inconsistent with both the theory and mechanics of PJM markets. The impact is to distort market outcomes.

The rules that account for recovery of reactive revenues are built into the auction parameters, specifically, the VRR Curve. The PJM market rules explicitly account for recovery of reactive revenues of \$2,199 per MW-year through inclusion in the Net CONE parameter of the capacity market demand (VRR) curve.¹⁴² The Net CONE parameter directly affects clearing prices by affecting both the maximum capacity price and the location of the downward-sloping part of the VRR curve. In addition, market sellers, when submitting offers based on net avoidable costs must account for revenues received through cost of service reactive capability rates in the calculation.¹⁴³ Unit-specific reactive capability rates up to that level are at least consistent with that parameter. Reactive capability rates either above or below that level distort capacity market outcomes. For example, a marginal resource with reactive revenue of \$5,000 per MW-year reflected in their net ACR offer would suppress the capacity market clearing price. Conversely, a marginal resource with a reactive revenue of \$1,000 per MW-year reflected in their net ACR offer would inflate the capacity market clearing price.

¹⁴² See OATT Attachment DD § 5.10(a)(v)(A).

¹⁴³ OATT Attachment DD § 6.8(d).

Interconnection Requirements

A generating facility is not eligible for reactive payments when it is not connected directly to the PJM system and therefore does not provide reactive capability to PJM under Schedule 2, and should not receive payments for a service that it does not and cannot provide. In a number of cases now pending, the Market Monitor has challenged the eligibility of resources filing under OATT Schedule 2 because they are interconnected to facilities that PJM does not monitor and does not rely on to provide reactive capability.¹⁴⁴ The issue will be decided in a hearing currently pending at the FERC.¹⁴⁵

The issue of eligibility is significant because the number of facilities interconnecting at points that are not on the PJM system is expected to increase. Such facilities do not contribute reactive capability to PJM, and based on anticipated power factor levels and the way the AEP method has been applied for calculating reactive rates under Schedule 2, such facilities would receive significantly larger payments per MW than the facilities that do provide reactive power capability useful to PJM.¹⁴⁶ These payments are for services not provided, but also would distort the PJM capacity market by paying a large share of the fixed costs of such facilities as reactive. This approach is a faulty and inefficient and noncompetitive market design.

Fleet Rates

Cost of service rates are established under Schedule 2 of the OATT and may cover rates for single units or a fleet of units.¹⁴⁷ Until the Commission took corrective action, fleet rates remained in place in PJM even when the actual units in the fleet changed as a result of unit retirements or sales of units.¹⁴⁸ New rules require unit owners to give notice of fleet changes in an informational filing or to file a new rate based on the remaining units, but do not yet require unit specific reactive rates.¹⁴⁹

Fleet rates create confusion about what revenue is properly attributable to each unit in the fleet. Reactive rates should be stated separately for each unit, even

if multiple plants or units are considered in a single proceeding. The MMU filed with the Commission to require unit specific rates when PJM proposed limited reforms that could have corrected the oversight and compliance problems posed by fleet rates.¹⁵⁰ But PJM rules require fleet owners only to submit informational filings when a reactive unit is transferred or deactivated.¹⁵¹ The current rules do not require a rate filing, which would place the burden of proof on the company and allow for cost review.¹⁵²

The MMU also raised issues related to fleet rates in a settlement establishing a fleet rate without specifying the actual portion of the fleet rate attributable to each unit in the fleet.¹⁵³ The approach could prevent or inhibit an appropriate adjustment of the fleet requirement if a unit receiving an unspecified portion of such requirement is deactivated or transferred because third parties without access to cost information would bear the burden of proof in a complaint proceeding.¹⁵⁴ The MMU also explained that the approach makes it impossible to calculate cost-based offers from such units in the PJM Capacity Market. The settlement was approved over the MMU's objection on the grounds that the tariff does not prohibit fleet rates.¹⁵⁵

The MMU recommends that fleet rates be eliminated and that compensation be based on unit specific costs and rates and that rates be appropriately reduced when units with reactive payments retire.

Reactive Costs

In 2021, total reactive charges were \$367.8 million, a 6.19 percent increase from the \$346.0 million for 2020. Reactive capability charges increased from \$346.0 million in 2020 to \$367.0 million in 2021 and reactive service charges increased from \$0.4 million in 2020 to \$0.9 million in 2021. The \$0.9 million for reactive service charges were paid to 24 units for operation in 377 unit hours.

Table 10-62 shows reactive service charges in 2020 and 2021, reactive capability charges and total charges.

¹⁴⁴ See, e.g., FERC Docket Nos. ER21-2091, ER21-936, ER21-737, ER20-1863 & ER20-1851.

¹⁴⁵ See Whitetail Solar 1, LLC, et al., Docket No. ER20-714-003, et al.

¹⁴⁶ See *American Electric Power Service Corp.*, 80 FERC ¶ 63,006 (1997), *aff'd*, 88 FERC ¶ 61,141 (1999).

¹⁴⁷ See, e.g., OATT Schedule 2; 114 FERC ¶ 61,318 (2006).

¹⁴⁸ See 149 FERC ¶ 61,132 (2014); 151 FERC ¶ 61,224 (2015); OATT Schedule 2.

¹⁴⁹ *Id.*

¹⁵⁰ 151 FERC ¶ 61,224 at P 29 (2015).

¹⁵¹ OATT Schedule 2.

¹⁵² *Id.*

¹⁵³ See Letter Opposing Settlement, Docket No ER06-554 et al. (June 14, 2017).

¹⁵⁴ *Id.*

¹⁵⁵ 162 FERC ¶ 61,029 (2018).

Reactive service charges show charges to each zone for reactive service. Reactive capability charges show charges to each zone for reactive capability.

Table 10-62 Reactive service charges and reactive capability charges by zone: 2020 and 2021

Zone	2020			2021		
	Reactive Service Charges	Reactive Capability Charges	Total Charges	Reactive Service Charges	Reactive Capability Charges	Total Charges
ACEC	\$0	\$4,287,746	\$4,287,746	\$0	\$4,289,651	\$4,289,651
AEP	\$4,797	\$46,999,522	\$47,004,319	\$42,352	\$49,221,441	\$49,263,793
APS	\$0	\$17,913,000	\$17,913,000	\$0	\$21,260,263	\$21,260,263
ATSI	\$0	\$24,930,943	\$24,930,943	\$0	\$25,305,857	\$25,305,857
BGE	\$0	\$6,785,340	\$6,785,340	\$0	\$6,635,411	\$6,635,411
COMED	\$0	\$39,326,091	\$39,326,091	\$149,929	\$40,923,979	\$41,073,909
DAY	\$0	\$2,812,775	\$2,812,775	\$0	\$2,814,025	\$2,814,025
DUKE	\$0	\$9,528,512	\$9,528,512	\$0	\$10,642,113	\$10,642,113
DOM	\$0	\$37,363,934	\$37,363,934	\$0	\$47,169,563	\$47,169,563
DPL	\$10,538	\$10,261,586	\$10,272,124	\$1,517	\$10,398,016	\$10,399,534
DUQ	\$0	\$570,034	\$570,034	\$0	\$570,288	\$570,288
EKPC	\$46,753	\$2,177,752	\$2,224,505	\$1,231	\$2,178,720	\$2,179,951
JCPLC	\$181,574	\$7,423,374	\$7,604,947	\$0	\$7,532,142	\$7,532,142
MEC	\$4,631	\$6,126,496	\$6,131,126	\$8,696	\$6,119,642	\$6,128,338
OVEC	\$0	\$0	\$0	\$0	\$0	\$0
PECO	\$0	\$20,955,918	\$20,955,918	\$0	\$20,916,523	\$20,916,523
PE	\$0	\$16,556,066	\$16,556,066	\$0	\$17,353,604	\$17,353,604
PEPCO	\$0	\$10,838,558	\$10,838,558	\$0	\$9,873,217	\$9,873,217
PPL	\$180,337	\$35,142,051	\$35,322,388	\$705,618	\$36,819,187	\$37,524,805
PSEG	\$0	\$27,839,542	\$27,839,542	\$0	\$27,828,845	\$27,828,845
REC	\$0	\$0	\$0	\$0	\$0	\$0
(Imp/Exp/Wheels)	\$0	\$18,124,076	\$18,124,076	\$0	\$19,080,024	\$19,080,024
Total	\$428,629	\$345,963,313	\$346,391,943	\$909,343	\$366,932,512	\$367,841,855

Table 10-63 shows the units which have received reactive service credits in 2021.

Table 10-63 Reactive service credits by plant (Total Dollars): 2021

2021		Reactive Service Credits
Zone	Plant	
AEP	AEP CEREDO 1 CT	\$1,565
AEP	AEP CEREDO 4 CT	\$1,340
AEP	AEP CLINCH RIVER 2 F	\$18,677
AEP	AEP GARDEN CREEK - BUCHANAN CT 1-2	\$886
AEP	AEP WOLF HILL 1 CT	\$670
AEP	AEP WOLF HILL 2 CT	\$6,837
AEP	AEP WOLF HILL 3 CT	\$5,967
AEP	AEP WOLF HILL 4 CT	\$6,087
AEP	AEP WOLF HILL 5 CT	\$321
COMED	COM 935 KENDALL 1 CC	\$30,166
COMED	COM 935 KENDALL 2 CC	\$29,199
COMED	COM 935 KENDALL 3 CC	\$31,899
COMED	COM 935 KENDALL 4 CC	\$29,273
COMED	COM 942 NELSON 2 CC	\$29,393
DPL	DPL BAYVIEW 2 D	\$513
DPL	DPL BAYVIEW 3 D	\$513
DPL	DPL BAYVIEW 5 D	\$490
EKPC	EKPC COOPER 2 F	\$1,231
METED	ME MOUNTAIN 1 CT	\$8,696
PPL	PL HARWOOD 1-2 CT	\$16,031
PPL	PL HAZELTON 1 CT	\$65,744
PPL	PL HAZELTON 2 CT	\$265,634
PPL	PL HAZELTON 3 CT	\$197,731
PPL	PL HAZELTON 4 CT	\$160,478
Total		\$909,343

The table demonstrates the wide disparity in payments for reactive capability that result from the current cost of service rate case model settlement process.

Table 10-64 shows the settled reactive capability revenue requirements by technology effective on December 31, 2021.¹⁵⁶ The table demonstrates the wide disparity in payments for reactive capability that result from the current cost of service rate case model settlement process.

Table 10-64 Total settled reactive revenue requirements by unit type and fuel type: December 31, 2021

Unit Type	Fuel Type	Total Revenue Requirement per Year	MW	Number of Resources	Requirement per MW-year
CC	Gas	\$128,050,591.74	50,346.2	158	\$2,543.40
CT	Gas	\$49,415,243.93	28,664.0	258	\$1,723.95
CT	Oil	\$4,870,245.73	3,640.5	137	\$1,337.80
Diesel	Gas	\$1,380,092.00	105.8	5	\$13,044.35
Diesel	Oil	\$1,028,792.65	168.3	36	\$6,112.85
Diesel	Other - Gas	\$940,634.85	122.5	13	\$7,678.65
FC	Gas	\$45,000.00	2.6	1	\$17,307.69
Hydro	Water	\$18,160,605.09	6,920.8	53	\$2,624.06
Nuclear	Nuclear	\$53,552,998.67	32,655.9	31	\$1,639.92
Solar	Solar	\$1,844,502.44	299.1	13	\$6,166.84
Steam	Coal	\$62,385,763.44	47,164.4	79	\$1,322.73
Steam	Gas	\$4,275,392.92	4,434.4	19	\$964.14
Steam	Oil	\$5,032,169.50	4,583.4	11	\$1,097.91
Steam	Other - Solid	\$340,000.00	34.0	2	\$10,000.00
Steam	Wood	\$207,759.31	153.0	3	\$1,357.90
Wind	Wind	\$19,590,962.81	4,681.6	36	\$4,184.67
Total		\$351,120,755.09	183,976.5	855	\$1,908.51

Frequency Response

On February 15, 2018, the Commission issued Order No. 842, which modified the pro forma large and small generator interconnection agreements and procedures to require newly interconnecting generating facilities, both synchronous and nonsynchronous, to include equipment for primary frequency response capability as a condition to receive interconnection service.¹⁵⁷ Such equipment must include a governor or equivalent controls with the capability of operating at a maximum 5 percent droop and ± 0.036 Hz deadband (or the equivalent or better).

PJM filed revisions in compliance with Order No. 842 that substantively incorporated the pro forma agreements into its market rules.¹⁵⁸

The MMU recommends that the same capability be required of both new and existing resources. The MMU agrees with Order No. 842 that RTOs not be required to provide additional compensation specifically for frequency response. The current PJM market design provides compensation for all capacity costs, including these, in the capacity market. The current market design provides compensation, through heat rate adjusted energy offers, for any costs associated with providing frequency response. Because the PJM market design already compensates resources for frequency response capability and any costs associated with providing frequency response, any separate filings submitted on behalf of resources for compensation under section 205 of the Federal Power Act should be rejected as double recovery.

¹⁵⁶ The total amount in the final row of Table 10-30 is the amount that would be paid if the total rate effective on December 31, 2021 were effective for an entire year. The total rates effective on any given day depend on requests made by resource owners in filings to FERC and FERC approval of those rates.

¹⁵⁷ 157 FERC ¶ 61,122 (2016).

¹⁵⁸ See 164 FERC ¶ 61,224 (2018).

Frequency Control Definition

There are four distinct types of frequency control, distinguished by response timeframe and operational nature: Inertial Response, Primary Frequency Response, Secondary Frequency Control, and Tertiary Frequency Control.

- **Inertial Response.** Inertial response to frequency excursion is the natural resistance of rotating mass turbine generators to change in their stored kinetic energy. This response is immediate and resists short term changes to ACE from the instant of the disturbance up to twenty seconds after the disturbance.
- **Primary Frequency Response.** Primary frequency response is a response to a disturbance based on a local detection of frequency and local operational control settings. Primary frequency response begins within a few seconds and extends up to a minute. The purpose of primary frequency response is to arrest and stabilize the system until other measures (secondary and tertiary frequency response) become active.
- **Secondary Frequency Control.** Secondary frequency control is called regulation. In PJM it begins taking effect within 10 to 15 seconds and can maintain itself for several minutes up to an hour in some cases. It is controlled by PJM which detects the grid frequency, calculates a counterbalancing signal, and transmits that signal to all regulating resources.
- **Tertiary Frequency Control.** Tertiary frequency control and imbalance control lasting 10 minutes to an hour is available in PJM as Primary Reserve. It is initiated by an all call from the PJM control center.

VACAR Reserve Sharing Agreement

The VACAR Reserve Sharing Agreement (VRSA) is a combination of agreements among the entities in the VACAR subregion including Dominion.¹⁵⁹ VACAR is a subregion of the SERC Reliability Corporation (SERC) region. The agreement remained in effect in 2020. The agreement requires that each entity maintain primary reserves to meet the VACAR contingency reserve commitment (VACAR reserves) and deploy such reserves in the case of an emergency (e.g. loss of a unit in

VACAR).¹⁶⁰ Dominion is the only party to the VRSA that is also a transmission owner and a generation owner in PJM. The VRSA is not a public agreement. PJM is not a party to the VRSA. However, as the reliability coordinator for Dominion Virginia Power, PJM is responsible for scheduling Dominion's required reserves in the SERC region as described in the PJM manuals.¹⁶¹

PJM procures synchronized reserves and primary reserves for the PJM region, including Dominion. The synchronized reserve and primary reserve requirements are equal to the largest single contingency and 150 percent of the largest contingency. The requirement is procured separately for the RTO and the MidAtlantic Dominion area (MAD) when the largest contingency is located outside of MAD. All units in PJM that meet the synchronized or primary reserve operating parameter requirements are eligible to meet the synchronized and primary requirements as long as PJM does not deselect them.

PJM procures Day-Ahead Scheduling Reserves (DASR) for the PJM region, including Dominion, as Secondary Reserves. The DASR requirement is calculated daily and is equal to the peak load forecast for the ReliabilityFirst region (RFC) and EKPC times the sum of the forced outage rate and the load forecast error, plus Dominion's share of the VACAR contingency reserve commitment. All units in PJM that meet the DASR operating parameter requirements are eligible to meet the DASR requirement.¹⁶² There is no requirement that a specific amount of DASR be located in Dominion. Equation 10-1 shows the DASR requirement calculation.¹⁶³

¹⁵⁹ VRSA entities: Dominion, Duke Energy Progress, Duke Energy Carolinas, South Carolina Electric & Gas Company, South Carolina Public Service Authority and Cube Hydro Carolinas.

¹⁶⁰ See SERC Regional Criteria, Contingency Reserve Policy, NERC Reliability Standard BAL-002 at 10-11.

¹⁶¹ See PJM, "Manual 13: Emergency Operations," Rev. 78 (Jan. 27, 2021).

¹⁶² DASR can be provided by units that do not clear the Day-Ahead Energy Market and can start within 30 minutes or by units that clear the Day-Ahead Energy Market and can ramp up within 30 minutes.

¹⁶³ During cold weather alerts and hot weather alerts, the DASR requirement is increased to procure additional reserves.

Equation 10-1: DASR Requirement Formula

$$\text{DASR Requirement} = (\text{RFC and EKPC Peak}) \times (\text{FOR} + \text{LFE}) + \text{DOM VACAR}$$

Issues

PJM is expected to implement the reserve market changes in October 2022. These changes include the consolidation of synchronized reserves tier 1 and tier 2 and the reserve must offer requirement. With these changes, it will not be possible for Dominion to hold reserves to meet its obligations under the VRSA without failing the must offer requirement in PJM. Under the reserve market changes, it will not be possible for Dominion to meet both the VRSA and the PJM reserve rules.

Recommendations

The Market Monitor recommends that the details of VACAR Reserve Sharing Agreement (VRSA) be made public, including any responsibilities assigned to PJM and including the amount of reserves that Dominion commits to meet its obligations under the VRSA.

The Market Monitor recommends that the VRSA be terminated and, if necessary, replaced by a reserve sharing agreement between PJM and VACAR South, similar to agreements between PJM and other bordering areas.