

## Ancillary Service Markets

The United States Federal Energy Regulatory Commission (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.<sup>1</sup> 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.<sup>2</sup> Although not defined by the FERC as an ancillary service, black start service plays a comparable role. Black start service is provided on the basis of formulaic rates or cost.

The Market Monitoring Unit (MMU) analyzed measures of market structure, conduct and performance for the PJM Regulation Market, the PJM Synchronized Reserve Market, and the PJM DASR Market for 2015.

**Table 10-1 The Regulation Market results were competitive**

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

- The Regulation Market structure was evaluated as not competitive for 2015 because the Regulation Market failed the three pivotal supplier (TPS) test in 97.8 percent of the hours in 2015.
- Participant behavior in the Regulation Market was evaluated as competitive for 2015 because market power mitigation requires competitive offers when the three pivotal supplier test is failed and there was no evidence of generation owners engaging in anti-competitive behavior.
- Market performance was evaluated as competitive, despite significant issues with the market design.
- Market design was evaluated as flawed. While the design of the Regulation Market was significantly improved with changes introduced October 1, 2012, a number of issues remain. The market design

<sup>1</sup> 75 FERC ¶ 61,080 (1996).

<sup>2</sup> Energy imbalance service refers to the Real-Time Energy Market.

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.

**Table 10-2 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 competitive, cost based offers, although there is concern about failure to comply with the must offer requirement.
- 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 compensated when the non-synchronized reserve market clears with a nonzero price.

**Table 10-3 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 Day-Ahead Scheduling Reserve Market structure was evaluated as not competitive because market participants failed the three pivotal supplier test in 6.4 percent of all cleared hours in 2015.
- 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.

- Market design was evaluated as mixed because while the market is functioning effectively to provide DASR, the three pivotal supplier test and appropriate market power mitigation should be added to the market to ensure that market power cannot be exercised at times of system stress.

## Overview

### Primary Reserve

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

### Market Structure

- **Supply.** Primary reserve is satisfied by both synchronized reserve (generation or demand response currently synchronized to the grid and available within ten minutes), and non-synchronized reserve (generation currently off-line but available to start and provide energy within ten minutes).
- **Demand.** The PJM primary reserve requirement is 150 percent of the largest contingency. The primary reserve requirement in the RTO Zone was raised on January 8, 2015, to 2,175 MW of which at least 1,700 MW must be available within the Mid-Atlantic Dominion (MAD) Subzone. Adjustments to the primary reserve requirement can occur when grid maintenance or outages change the largest contingency. The actual demand for primary reserve in the RTO Zone in 2015 was 2,210.3 MW. The actual demand for primary reserve in the MAD Subzone in 2015 was 1,713.3 MW.

### Tier 1 Synchronized Reserve

Synchronized reserve is energy or demand reduction synchronized to the grid and capable of increasing output or decreasing load within ten minutes. Synchronized reserve is of two distinct types, tier 1 and tier 2.

Tier 1 synchronized reserve is part of primary reserve and is the capability of on-line resources following economic dispatch to ramp up in ten 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 reserve. The market solution estimates tier 1 synchronized reserve as available 10-minute ramp from the energy dispatch. In 2015, there was an average hourly supply of 1,363.9 MW of tier 1 for the RTO Synchronized Reserve Zone, and an average hourly supply of 1,159.6 MW of tier 1 in the Mid-Atlantic Dominion Subzone.
- **Demand.** The default hourly required synchronized reserve requirement is 1,450 MW in the RTO Reserve Zone and 1,450 MW for the Mid-Atlantic Dominion Reserve Subzone. The requirement can be met with tier 1 or tier 2 synchronized reserves.
- **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 the average of five-minute LMPs during the event, rather than hourly integrated LMP, plus \$50/MW. This is the Synchronized Energy Premium Price. The synchronized reserve event response credits for tier 1 response are independent of the tier 2 synchronized reserve market clearing price and independent of the non-synchronized reserve market clearing price.

Of tier 1 synchronized reserve estimated at market clearing, 65.7 percent actually responded during the seven distinct synchronized reserve events longer than ten minutes in 2015. PJM made changes to the way it calculated tier 1 MW for settlements beginning in July 2014. These changes improved the reported response rate by reducing the initial tier 1 estimate.

- **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 five-minute LMP plus \$50 per MWh. A tariff change included in the shortage pricing tariff changes (October 1, 2012) added the requirement to pay

<sup>3</sup> See PJM, "Manual 10: Pre-Scheduling Operations," Revision. 33 (December 22, 2015), p. 24.

tier 1 synchronized reserve the tier 2 synchronized reserve market clearing price whenever the non-synchronized 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, resulting in a windfall payment of \$10,406,363 to tier 1 resources in 2014, and \$34,135,671 in 2015.

## 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 incur costs to be synchronized, that have an obligation to respond with corresponding penalties, and that must be dispatched in order to satisfy the synchronized reserve requirement.

When the synchronized reserve requirement cannot be met with tier 1 synchronized reserve, PJM conducts a market to satisfy the balance of the requirement with tier 2 synchronized reserve. 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 2015, the supply of offered and eligible synchronized reserve was 8,549 MW in the RTO Zone of which 3,114 MW (including DSR) was available to the MAD Subzone. This was sufficient to cover the requirement in both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.
- **Demand.** The default hourly required synchronized reserve requirement was 1,450 MW in the RTO Reserve Zone and 1,450 MW for the Mid-Atlantic Dominion Reserve Subzone. The requirement can be met with tier 1 or tier 2 synchronized reserves.
- **Market Concentration.** In 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone was 5436 which is classified as highly concentrated. The MMU calculates that 55.7 percent of hours would have failed a three pivotal supplier test in the Mid-Atlantic Dominion Subzone.

In 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the RTO Synchronized

Reserve Zone was 4617 which is classified as highly concentrated. The MMU calculates that 40.2 percent of hours would have failed a three pivotal supplier test in the RTO Synchronized Reserve Zone.

The MMU concludes from these results that 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 2015.

### Market Conduct

- **Offers.** There is a must offer requirement for tier 2 synchronized reserve. All non-emergency generation capacity resources are required to submit a daily offer for tier 2 synchronized reserve. 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.

### Market Performance

- **Price.** The weighted average price for tier 2 synchronized reserve for all cleared hours in the Mid-Atlantic Dominion (MAD) Subzone was \$10.12 per MW in 2015, a decrease of \$5.38, 34.7 percent from 2014.

The weighted average price for tier 2 synchronized reserve for all cleared hours in the RTO Synchronized Reserve Zone was \$11.88 per MW in 2015, a decrease of \$1.06, 8.2 percent from 2014.

### Non-Synchronized Reserve Market

Non-synchronized reserve is part of primary reserve and includes the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone (MAD). Non-synchronized reserve is comprised of non-emergency energy resources not currently synchronized to the grid that can provide energy within ten minutes. Non-synchronized reserve is available to fill the primary reserve requirement above the synchronized reserve requirement. There is no formal market for non-synchronized reserve.

## Market Structure

- **Supply.** In 2015, the supply of eligible non-synchronized reserve was 2,550.1 MW in the RTO Zone and 1,860.8 MW in MAD Subzone.<sup>4</sup>
- **Demand.** Demand for non-synchronized reserve is the remaining primary reserve requirement after tier 1 synchronized reserve is estimated and tier 2 synchronized reserve is scheduled. In the RTO Zone, the market cleared an hourly average of 345.1 MW of non-synchronized reserve in 2015. In the MAD Subzone, the market cleared an hourly average of 390.3 MW of non-synchronized reserve.
- **Market Concentration.** In 2015, the weighted average HHI for cleared non-synchronized reserve in the Mid-Atlantic Dominion Subzone was 4133 which is classified as highly concentrated. In the RTO Zone the weighted average HHI was 4533 which is also highly concentrated. The MMU calculates that 95.1 percent of hours would have failed a three pivotal supplier test in the Mid-Atlantic Dominion Subzone and 68.0 hours would have failed a three pivotal supplier test in the RTO Zone.

## Market Conduct

- **Offers.** No offers are made for non-synchronized reserve. Non-emergency generation resources that are available to provide energy and can start in 10 minutes or less are considered available for non-synchronized reserves by the market solution software.

## Market Performance

- **Price.** The non-synchronized reserve price is determined by the opportunity cost of the marginal non-synchronized reserve unit. The non-synchronized reserve weighted average price for all cleared hours in the RTO Reserve Zone was \$1.15 per MW in 2015 and in 87.9 percent of hours the market clearing price was \$0. The non-synchronized reserve weighted average price for all cleared hours in the Mid-Atlantic Dominion (MAD) Subzone was \$1.03 and in 87.6 percent of hours the market clearing price was \$0.

<sup>4</sup> See PJM. "Manual 11; Energy & Ancillary Services Markets," Revision 79 (December 17, 2015), p. 81. "Because Synchronized Reserve may be utilized to meet the Primary Reserve requirement, there is no explicit requirement for non-synchronized reserves."

## Secondary Reserve (Day-Ahead Scheduling Reserve)

PJM maintains a day-ahead, offer-based market for 30-minute secondary reserve, designed to provide price signals to encourage resources to provide 30-minute reserve.<sup>5</sup> The DASR Market has no performance obligations.

### 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 per MW. DASR is calculated by the day-ahead market solution as the lesser of the thirty minute energy ramp rate or the emergency maximum MW minus the day-ahead dispatch point for all on-line units. In 2015, the average available hourly DASR was 36,396.0 MW.
- **Demand.** The DASR requirement in 2015 was 5.93 percent of peak load forecast, down from 6.27 percent in 2014. The average DASR MW purchased was 6,245.0 MW per hour 2015.
- **Concentration.** In 2015, the DASR Market would have failed a three pivotal supplier test in 4.1 percent of hours.

### Market Conduct

- **Withholding.** Economic withholding remains an issue in the DASR Market. The direct marginal cost of providing DASR is zero. All offers greater than zero constitute economic withholding. In 2015 a daily average of 37.9 percent of units offered above \$0. In 2015 a daily average of 11.6 percent of units offered above \$5.
- **DR.** Demand resources are eligible to participate in the DASR Market. Six demand resources have entered offers for DASR.

### Market Performance

- **Price.** The weighted average DASR market clearing price for all cleared hours in 2015 was \$2.99 per MW, an increase from \$0.63 per MW in 2014.

<sup>5</sup> See PJM. "Manual 35: Definitions and Acronyms," Revision 23 (April 11, 2014), p. 22.

## 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 a regulation signal (RegA or RegD). PJM jointly optimizes regulation with synchronized reserve and energy to provide all three services at least cost. The PJM regulation market design includes three clearing price components: capability; performance; and lost opportunity cost. The marginal benefit factor and performance score translate a resource's capability in actual MW into effective MW.

## Market Structure

- **Supply.** In 2015, the average hourly eligible supply of regulation was 1,157.8 actual MW (889.9 effective MW). This is a decrease of 122.5 actual MW (27.5 effective MW) from the same period of 2014, when the average hourly eligible supply of regulation was 1,280.3 actual MW (917.4 effective MW).
- **Demand.** The average hourly regulation demand was 640.9 actual MW (663.7 effective MW) in 2015. This is a decrease of 19.8 actual MW (0 effective MW) in the average hourly regulation demand of 660.7 actual MW (663.7 effective MW) from the same period of 2014.
- **Supply and Demand.** The ratio of the average hourly eligible supply of regulation to average hourly regulation demand required was 1.81. This is a 6.70 percent decrease from the same period of 2014 when the ratio was 1.94.
- **Market Concentration.** In 2015, the weighted average (HHI) was 1358 which is classified as moderately concentrated. In 2015, the three pivotal supplier test was failed in 97.8 percent of hours.

## 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.<sup>6</sup> In 2015, there were 291 resources following

the RegA signal and 57 resources following the RegD signal.

## Market Performance

- **Price and Cost.** The weighted average clearing price for regulation was \$31.92 per effective MW of regulation in 2015, a decrease of \$12.55 per MW, or 28.2 percent, from the same period of 2014. The cost of regulation in 2015 was \$38.36 per effective MW of regulation, a decrease of \$15.46 per MW, or 28.7 percent, from the same period of 2014. The decreases in regulation price and regulation cost resulted primarily from high energy prices in 2014, particularly in January.
- **RMCP Credits.** 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, pricing, and settlement processes. If the Regulation Market were functioning efficiently, RegD and RegA resources would be paid the same price per effective MW.
- **Marginal Benefit Factor Function.** The marginal benefit factor (MBF) measures the substitutability of RegD resources for RegA resources. The marginal benefit factor function is incorrectly applied in the market clearing and incorrectly describes the operational relationship between RegA and RegD.
- **Interim changes to the MBF function.** On December 14, 2015, PJM changed the MBF curve. The modification to the marginal benefit curve did not correct the identified issues with the optimization engine.

## 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).<sup>7</sup>

In 2015, total black start charges were \$53.6 million with \$48.4 million in revenue requirement charges

<sup>6</sup> See the 2015 State of the Market Report for PJM, Volume II, Appendix F "Ancillary Services Markets."

<sup>7</sup> OATT Schedule 1 § 1.3BB.

and \$5.2 million in 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. Black start operating reserve 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 2015 ranged from \$0.04 per MW-day in the PPL Zone (total charges were \$118,541) to \$3.81 per MW-day in the BGE Zone (total charges were \$9,277,796).

## Reactive

Reactive service, reactive supply and voltage control are provided by generation and other sources of reactive power (measured in VAR). Reactive power helps maintain appropriate voltages on the transmission system and is essential to the flow of real power (measured in MW).

In 2015, total reactive service charges were \$289.0 million, a 6.1 percent decrease from \$307.7 million in 2014. Revenue requirement charges decreased from \$281.2 million to \$278.4 million and operating reserve charges fell from \$26.5 million to \$10.7 million. Total charges in 2015 ranged from \$2,488 in the RECO Zone to \$38.5 million in the AEP Zone. Reactive service revenue requirements are based on FERC approved filings. Reactive service operating reserve charges are paid for scheduling in the Day-Ahead Energy Market and committing in real time units that provide reactive service.

## Ancillary Services Costs per MWh of Load: 2004 through 2015

Table 10-4 shows PJM ancillary services costs for 2004 through 2015, 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. 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: 2004 through 2015<sup>8</sup>**

Year	Regulation	Scheduling, Dispatch, and System Control	Reactive	Synchronized Reserve	Total
2004	\$0.50	\$0.60	\$0.25	\$0.13	\$1.48
2005	\$0.79	\$0.47	\$0.26	\$0.11	\$1.63
2006	\$0.53	\$0.48	\$0.29	\$0.08	\$1.38
2007	\$0.63	\$0.47	\$0.29	\$0.06	\$1.45
2008	\$0.68	\$0.40	\$0.31	\$0.08	\$1.47
2009	\$0.34	\$0.32	\$0.37	\$0.05	\$1.08
2010	\$0.34	\$0.38	\$0.41	\$0.07	\$1.20
2011	\$0.32	\$0.34	\$0.42	\$0.10	\$1.18
2012	\$0.26	\$0.40	\$0.43	\$0.04	\$1.13
2013	\$0.24	\$0.39	\$0.80	\$0.04	\$1.47
2014	\$0.31	\$0.37	\$0.37	\$0.20	\$1.25
2015	\$0.23	\$0.41	\$0.37	\$0.12	\$1.13

## Recommendations

- The MMU recommends that the Regulation Market be modified to incorporate a consistent application of the marginal benefit factor throughout the optimization, assignment and settlement process. (Priority: High. First reported 2012. Status: Not adopted.)
- The MMU recommends a number of market design changes to improve the performance of the Regulation Market, including use of a single clearing price based on actual LMP, modifications to the LOC calculation methodology, a software change to save some data elements necessary for verifying market outcomes, and further documentation of the implementation of the market design through SPREGO. (Priority: Medium. First reported 2010. Status: Partially adopted in 2012.)
- 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 in the energy market. (Priority: High. First reported 2010. Status: Partially Adopted.)
- The MMU recommends that the single clearing price for synchronized reserves be determined based on the actual LMP and not the forecast LMP. (Priority: Low. First reported 2010. Status: Adopted, 2012.)

<sup>8</sup> Table 10-4 no longer includes the heading for "Supplemental Operating Reserve" costs. This heading included day-ahead and balancing operating reserve charges. These charges are accounted for in the Energy Uplift (Operating Reserves) section.

- The MMU recommends that the rule requiring the payment of tier 1 synchronized reserve resources when the non-synchronized reserve price is above zero be eliminated immediately. (Priority: High. First reported 2013. Status: Not adopted. Stakeholder process.)
- The MMU recommends that no payments be made to tier 1 resources if they are deselected in the PJM market solution. The MMU also recommends that documentation of the Tier 1 synchronized reserve deselection process be published. (Priority: High. First reported Q3, 2014. Status: Adopted July 2014.)
- 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 operators to select a reason in eMkt whenever making a unit unavailable. (Priority: Medium. First reported 2013. Status: Not adopted.)
- The MMU recommends that PJM be explicit about why tier 1 biasing is used in the Tier 2 Synchronized Reserve Market. The MMU recommends that PJM define explicit rules for the use of tier 1 biasing during any phase of the market solution and identify the relevant rule for each instance of biasing. (Priority: Low. First reported 2012. Status: Not adopted.)
- The MMU recommends that PJM replace the DASR Market with a real-time secondary reserve product that is available and dispatchable in real time. (Priority: Low. First reported 2013. Status: Not adopted.)
- The MMU recommends that PJM revise the current confidentiality rules in order to specifically allow a more transparent disclosure of information regarding black start resources and their associated payments in PJM. (Priority: Low. First reported 2013. Status: Partially adopted, 2014.)
- The MMU recommends that the three pivotal supplier test and market power mitigation be incorporated in the DASR Market. (Priority: Low. First reported 2009. 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 Q2, 2015. Status: not adopted.)

## Conclusion

While the design of the Regulation Market was significantly improved with changes introduced October 1, 2012, a number of issues remain. The market results continue to include the incorrect definition of opportunity cost. The market design has failed to correctly incorporate the marginal benefit factor in optimization, pricing and settlement. The market design uses the marginal benefit factor in the optimization and pricing, but a mileage ratio in settlement. This failure to correctly incorporate marginal benefit factor into the regulation market design has resulted in both underpayment and overpayment of RegD resources and in the over procurement of RegD resources in some hours. These issues have led to the MMU's conclusion that the regulation market design is flawed.

The structure of each 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 service 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, compliance with calls to respond to actual synchronized reserve events has been an issue. The must offer requirement for tier 2 synchronized reserve has not been enforced.

The rule that requires payment of the tier 2 synchronized reserve price to tier 1 synchronized reserve resources when the non-synchronized reserve price is greater than zero, is inefficient and results in a substantial windfall payment to the holders of tier 1 synchronized reserve resources. Such tier 1 resources have no obligation to perform and pay no penalties if they do not perform. Tier 1 resources are paid for their response if they do respond. Such resources are not tier 2 resources, although they have the option to offer as tier 2, to take on tier 2 obligations and to be paid as tier 2. If tier 1 resources wish to be paid as tier 2 resources, that option is available. Application of this rule added \$10.4 million

to the cost of primary reserve in 2014 and \$34.1 million to the cost of primary reserve in 2015.

The benefits of markets are realized under these approaches to ancillary service markets. Even in the presence of structurally noncompetitive markets, there 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 competitive. The MMU concludes that the synchronized reserve market results were competitive. The MMU concludes that the DASR market results were competitive, although there is concern about offers above the competitive level affecting prices.

## Primary Reserve

PJM has an obligation to maintain ten minute reserves (primary reserve) to ensure reliability in the event of disturbances. PJM's primary reserves are made up of resources, both synchronized and non-synchronized, that can provide energy within ten minutes. Primary reserve is PJM's implementation of the NERC 10-minute contingency reserve requirement.<sup>9</sup> The NERC requirement is to carry sufficient contingency reserves to meet load requirements reliably and economically and provide reasonable protection against instantaneous load variations due to load forecasting error or loss of system capability due to generation malfunction.<sup>10</sup>

## Market Structure

### Supply

In 2015, PJM's primary reserve requirement was 2,175 MW for the RTO Zone, and 1,700 MW for the MAD Subzone. It is satisfied by tier 1 synchronized reserves, tier 2 synchronized reserves and non-synchronized reserves, subject to the requirement that synchronized reserves equal 100 percent of the largest contingency. The synchronized reserve requirement is 1,450 MW in both the Mid-Atlantic Dominion Subzone, and the RTO

Zone. After the synchronized reserve requirement is satisfied, the remainder of primary reserves can come from the least expensive combination of synchronized and non-synchronized reserves.

Estimated tier 1 is credited against PJM's primary reserve requirement. In the MAD Subzone an average of 1,159.7 MW of tier 1 was identified by the ASO market solution as available hour ahead (Table 10-6). This tier 1 reduced the amount of tier 2 and non-synchronized reserve needed to fill the synchronized reserve and primary reserve requirements. Tier 1 synchronized reserve fully satisfied the MAD Subzone synchronized reserve requirement in only 1.1 percent of hours in 2015. In the RTO Zone, an average of 1,373.9 MW of tier 1 was available (Table 10-6). Tier 1 synchronized reserve fully satisfied the RTO Zone synchronized reserve requirement in 35.9 percent of all hours.

Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for Tier 2 Synchronized Reserve in eMKT prior to the offer submission deadline (1800 the day prior to the operating day). Offer MW and other non-cost offer details can be changed during the operating day. Owners are permitted to make resources unavailable for synchronized reserve daily or hourly but only if they are physically unavailable. Certain unit types including nuclear, wind, solar, and batteries, are expected to have zero MW tier 2 synchronized reserve offer quantities.<sup>11</sup>

After tier 1 is estimated, the remainder of the synchronized reserve requirement is met by tier 2. In the MAD Subzone, there was an average of 3,114.3 MW (including DSR) of eligible tier 2 synchronized reserve available (Figure 10-11) to meet the average tier 2 hourly demand of 314.8 MW (Table 10-5). In the RTO Zone, there was an average of 8,549.2 MW of eligible Tier 2 supply, available to meet the average hourly demand of 456.9 MW (Table 10-6).

In the MAD Subzone, there was an average of 1,860.8 MW of eligible non-synchronized reserve supply available to meet the average hourly demand of 390.3 MW (Table 10-6). In the RTO Zone, an hourly average of 2,550.1 MW supply was available to meet the average hourly demand of 736.3 MW (Table 10-5).

<sup>9</sup> PJM, OATT (effective 2/5/2014), p.1740; § 1.3.29 F Primary Reserve.

<sup>10</sup> NERC, IVGTF Task 2.4 Report; Operating Practices, Procedures, and Tools, March 2011, p. 20.

<sup>11</sup> See PJM, "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 67.



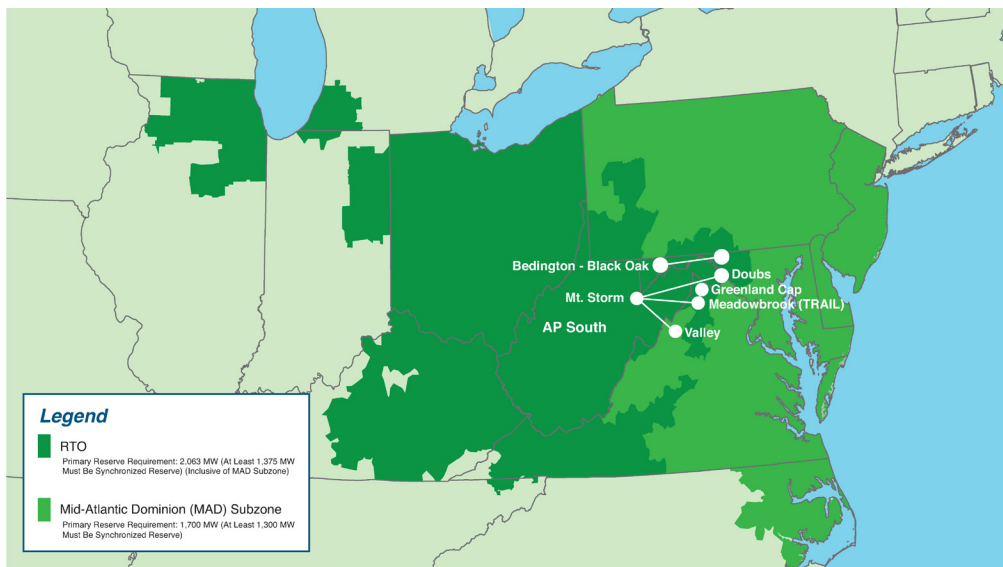
## Demand

PJM requires that 150 percent of the largest contingency on the system be maintained as primary reserve. Adjustments to this value can occur when grid maintenance or outages change the largest contingency or in cases of hot weather alerts or cold weather alerts.

On January 8, 2015, the default primary reserve requirement in the RTO Reserve Zone was raised from 2,063 MW to 2,175 MW and remained at 2,175 MW throughout 2015. In 10.2 percent of hours during 2015, PJM increased the primary reserve requirement for the RTO Zone. In 4.9 percent of hours PJM decreased the primary reserve requirement for the RTO Zone. The hourly average RTO primary reserve requirement was 2,210.3 MW in all of 2015. In 1.5 percent of hours in 2015, PJM increased the primary reserve requirement for the MAD Subzone. The actual hourly average demand for primary reserve in the MAD Subzone in all of 2015 was 1,713.3 MW.

Transmission constraints limit the deliverability of reserves within the RTO, requiring the definition of the Mid-Atlantic Dominion (MAD) Subzone.<sup>12</sup> Of the 2,175 MW RTO primary reserve requirement, 1,700 MW (Table 10-15) must be deliverable to the MAD Subzone (Figure 10-1).

**Figure 10-1 PJM RTO Zone and MAD Subzone geography: 2015**



<sup>12</sup> 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," Revision 78 (December 1, 2015), p. 69.

The Mid-Atlantic Dominion Reserve (MAD) Subzone is defined dynamically by the most limiting constraint separating MAD from the PJM RTO Reserve Zone. In 79.2 percent of hours in 2015, that constraint was the Bedington – Black Oak Interface. The AP South transfer interface constraint was the limiting constraint in 19.3 percent of hours.

PJM requires that synchronized reserves equal at least 100 percent of the largest contingency. This means that 1,450 MW of the primary reserve requirement must be synchronized reserve for both RTO Reserve Zone and the Mid Atlantic Dominion Reserve Subzone.

**Table 10-5 Average monthly tier 1 and tier 2 synchronized reserve, plus non-synchronized reserve used to satisfy the primary reserve requirement, MAD Subzone: 2015**

Year	Month	Average Tier 1 Synchronized Reserve MW	Average Tier 2 Synchronized Reserve MW	Average Non-Synchronized Reserve MW
2015	Jan	1,222.0	206.9	629.7
2015	Feb	1,176.7	305.1	437.4
2015	Mar	1,200.6	288.7	394.6
2015	Apr	1,148.8	302.8	381.3
2015	May	1,217.4	238.5	387.4
2015	Jun	1,260.3	216.6	372.1
2015	Jul	1,222.4	254.9	437.0
2015	Aug	1,176.9	293.9	421.7
2015	Sep	1,110.8	363.0	351.0
2015	Oct	1,054.4	478.5	263.6
2015	Nov	1,056.3	385.1	319.7
2015	Dec	1,069.1	443.6	288.6
2015	Average	1,159.6	314.8	390.3

**Table 10-6 Average monthly tier 1 and tier 2 synchronized reserve, and non-synchronized reserve used to satisfy the primary reserve requirement, RTO Zone: 2015**

Year	Month	Average Tier 1 Synchronized Reserve MW	Average Tier 2 Synchronized Reserve MW	Average Non-Synchronized Reserve MW
2015	Jan	1,582.7	331.7	1,074.4
2015	Feb	1,469.1	415.7	906.3
2015	Mar	1,247.2	424.8	928.5
2015	Apr	1,125.1	438.8	877.1
2015	May	1,245.1	373.1	811.5
2015	Jun	1,635.3	300.0	767.4
2015	Jul	1,620.5	320.1	752.3
2015	Aug	1,635.6	357.0	767.3
2015	Sep	1,419.2	449.9	703.1
2015	Oct	1,004.3	727.3	589.2
2015	Nov	1,217.2	616.8	347.9
2015	Dec	1,165.2	727.8	317.1
2015	Average	1,363.9	456.9	736.8

### Supply and Demand

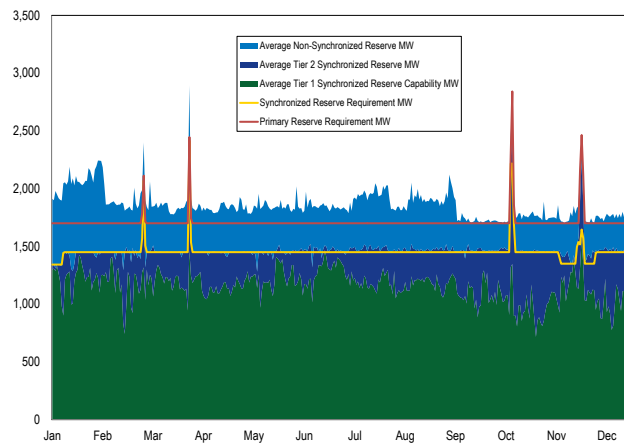
The market solution software relevant to reserves consists of: the Ancillary Services Optimizer (ASO) solving hourly; the intermediate term security constrained economic dispatch market solution (IT-SCED) solving every 15 minutes; and the real-time (short term) security constrained economic dispatch market solution (RT-SCED) solving every five minutes.

The ASO jointly optimizes energy, synchronized reserves, and non-synchronized reserves based on forecast system conditions to determine the most economic set of reserve resources to commit for the upcoming operating hour (before the hour commitments). IT-SCED runs at 15 minute intervals and jointly optimizes energy and reserves given the ASO’s inflexible unit commitments. IT-SCED estimates available tier 1 synchronized reserve and can commit additional reserves (flexibly or inflexibly) if its forecasts indicate a need. RT-SCED runs at five minute intervals and produces load forecasts up to 20 minutes ahead. The RT-SCED estimates the available tier 1 provides a real-time ancillary services solution and can commit additional tier 2 resources (flexibly or inflexibly) if it forecasts a need.

Figure 10-2 illustrates how the ASO satisfies the primary reserve requirement (orange line) for the Mid-Atlantic Dominion Subzone. For the Mid-Atlantic Dominion Reserve Zone primary reserve solution the ASO must first satisfy the synchronized reserve requirement (yellow line) which is generally 1,450 MW in the MAD Subzone.

Since the market solution considers tier 1 synchronized reserve to be zero cost, the ASO first estimates how much tier 1 synchronized reserve (green area) is available. If there is 1,450 MW of tier 1 available then ASO jointly optimizes synchronized reserve and non-synchronized reserve to assign the remaining primary reserve up to 1,700 MW. If there is not 1,450 MW of tier 1 then the remaining synchronized reserve requirement up to 1,450 MW is filled with tier 2 synchronized reserve (dark blue area). After 1,450 MW of synchronized reserve are assigned, the remaining 250 MW of the primary reserve requirement is filled by jointly optimizing synchronized reserve and non-synchronized reserve (light blue area). Since non-synchronized reserve is priced lower than or equal to synchronized reserve, almost all primary reserve between 1,450 MW and 1,700 MW is filled by non-synchronized reserve.

**Figure 10-2 Mid-Atlantic Dominion Subzone primary reserve MW by source (Daily Averages): 2015**



The solution methodology is similar for the RTO Reserve Zone (Figure 10-3) except that the required primary reserve MW is 2,175 MW.<sup>13</sup> Figure 10-3 shows how the hour ahead ASO satisfies the primary reserve requirement for the RTO Zone.

<sup>13</sup> Although tier 1 has a price of zero, changes made with shortage pricing on November 1, 2012, have given tier 1 a very high cost in some hours. This high cost raises questions about the economics of the solution methodology used by the ASO, IT-SCED, and RT-SCED market solutions which assume zero cost.

**Figure 10-3 RTO Reserve Zone primary reserve MW by source (Daily Averages): 2015**

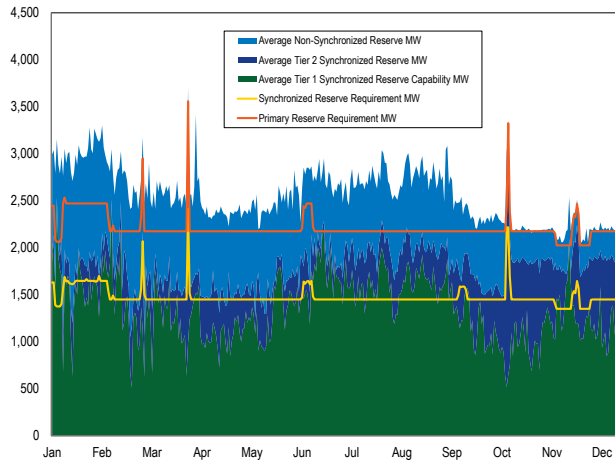


Figure 10-2 and Figure 10-3 show that tier 1 synchronized reserve remains the major contributor to satisfying the synchronized reserve requirements both in the RTO Zone and the Mid-Atlantic Dominion (MAD) Subzone.

## Price and Cost

There is a separate price and cost for each component of primary reserve. In the market solution, the cost of tier 1 synchronized reserves is zero except in defined circumstances, as there is no incremental cost associated with the ability to ramp up from the current economic dispatch point nor is there an obligation to ramp up during a synchronized reserve event. Tier 1 is credited when it responds to a synchronized reserve event. In addition, despite the absence of a performance obligation and an incremental cost to provide tier 1, PJM's current market rules require that tier 1 synchronized reserves be paid the tier 2 synchronized reserve market price in any hour that the non-synchronized reserve market clears with a price above \$0.

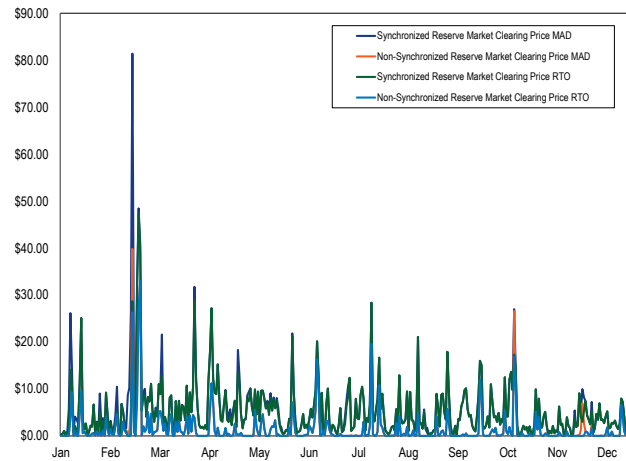
Under PJM's current market optimization approach, as available primary reserve approaches the primary reserve requirement the cost to serve the next MW of primary reserve is the non-synchronized reserve market clearing price (blue area in both Figure 10-2 and Figure 10-3).

In times of non-synchronized reserve shortage, the price of non-synchronized reserve will be capped at the currently effective penalty factor. Effective June 1, 2014, through May 31, 2015, the penalty factor for

both products is \$550 per MW. After June 1, 2015, the penalty factor is \$850 per MW. PJM will review the penalty factor annually.

Figure 10-4 shows daily average synchronized and non-synchronized market clearing prices in 2015.

**Figure 10-4 Daily weighted average market clearing prices (\$/MW) for synchronized reserve and non-synchronized reserve: 2015**



The cost of meeting PJM's primary reserve requirement (Figure 10-3) is shown in Table 10-7. Under most market conditions, most primary reserve identified by the hour ahead market solution is provided at no incremental cost by non-synchronized reserve and tier 1 synchronized reserve. The "Cost per MW" column is the total credits divided by the total MW of reserves. The "All-In Cost" column is the total credits paid divided by the load, or the total cost per MWh of energy to satisfy the primary reserve requirement.

**Table 10-7 MW credited, price, cost, and all-in price for primary reserve and its component products, RTO Reserve Zone: 2015**

Product	Share of Primary Reserve Requirement	MW Scheduled	Credits Paid	Price Per MW Reserve	Cost Per MW Reserve	All-In Cost
Tier 1 Synchronized Reserve Response	NA	7,145	\$351,212	NA	\$49.15	\$0.00
Tier 1 Synchronized Reserve	14.3%	1,715,532	\$34,135,671	\$0.00	\$19.90	\$0.04
Tier 2 Synchronized Reserve	26.9%	3,221,120	\$58,731,146	\$11.41	\$18.23	\$0.08
Non-synchronized Reserve	58.7%	7,038,700	\$13,785,091	\$1.15	\$1.96	\$0.02
Primary Reserve (total of above)	100.0%	\$11,982,497	\$107,003,120	\$0.42	\$8.93	\$0.14

## Tier 1 Synchronized Reserve

Tier 1 synchronized reserve is a component of primary reserve comprised of all on-line 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 measured as the lower of the available ten minute ramp and the difference between the economic dispatch point and the economic maximum output. Tier 1 resources are identified by the market solution and the sum of their ten minute availability equals available tier 1 synchronized reserve (green area of Figure 10-2 and Figure 10-3). Tier 1 synchronized reserve is the first element of primary reserve identified by the market software and is available at zero incremental cost unless called to respond to a synchronized reserve event or unless the non-synchronized 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 financially obligated to respond during an event.

## 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. Demand resources are not available for tier 1 synchronized reserve.

In 2015, in the RTO Reserve Zone the average hourly estimated tier 1 synchronized reserve was 1,363.9 MW (Table 10-6). In 35.9 percent of hours, the estimated tier 1 synchronized reserve was greater than the primary reserve requirement, meaning that the primary reserve requirement was met entirely by tier 1 synchronized reserve.

In 2015, in the MAD Reserve Subzone the average hour ahead estimated tier 1 synchronized reserve was 1,159.6 MW (Table 10-5). In 1.1 percent hours, the estimated tier 1 synchronized reserve was greater than the subzone requirement for synchronized reserve and no Tier 2 Synchronized Reserve Market was needed.

**Table 10-8 Monthly average market solution Tier 1 Synchronized Reserve (MW) identified hourly, 2015**

Mid-Atlantic Dominion Reserve Zone						
Year	Month	Average Hourly Tier 1 Local to MAD	Synchronized Reserve Available from RTO	Average Hourly Tier 1 Used	Minimum Hourly Tier 1 Used	Maximum Hourly Tier 1 Used
2015	Jan	622.8	599.2	1,222.0	410.4	1,450.0
2015	Feb	608.4	568.4	1,176.7	0.0	2,252.6
2015	Mar	483.1	717.5	1,200.6	163.7	2,344.6
2015	Apr	362.0	786.7	1,148.8	495.6	1,385.0
2015	May	533.9	683.5	1,217.4	599.5	2,173.0
2015	Jun	742.4	517.9	1,260.3	515.9	2,573.5
2015	Jul	712.3	510.1	1,222.4	610.2	2,298.0
2015	Aug	682.3	494.6	1,176.9	344.2	2,884.6
2015	Sep	547.1	563.6	1,110.8	398.8	2,316.8
2015	Oct	349.7	704.7	1,054.4	400.2	2,461.0
2015	Nov	518.4	537.9	1,056.3	355.0	2,163.1
2015	Dec	438.3	630.9	1,069.1	284.9	2,200.8
2015	Average	550.1	609.6	1,159.6	381.5	2,208.6

RTO Reserve Zone						
Year	Month	Average Hourly Tier 1 Local to MAD	Synchronized Reserve Available from RTO	Average Hourly Tier 1 Used	Minimum Hourly Tier 1 Used	Maximum Hourly Tier 1 Used
2015	Jan	NA	NA	1,582.7	0.0	3,240.4
2015	Feb	NA	NA	1,469.1	0.0	2,980.4
2015	Mar	NA	NA	1,247.2	0.0	2,727.6
2015	Apr	NA	NA	1,125.1	191.5	2,132.2
2015	May	NA	NA	1,245.1	0.0	3,408.5
2015	Jun	NA	NA	1,635.3	0.0	5,547.7
2015	Jul	NA	NA	1,620.5	0.0	3,443.4
2015	Aug	NA	NA	1,635.6	0.0	3,985.4
2015	Sep	NA	NA	1,419.2	0.0	3,096.5
2015	Oct	NA	NA	1,004.3	0.0	2,499.6
2015	Nov	NA	NA	1,217.2	0.0	2,909.6
2015	Dec	NA	NA	1,165.2	302.0	3,653.7
2015	Average			1,363.9	41.1	3,302.1

## Demand

There is no fixed required amount of tier 1 synchronized reserve. The Tier 1 synchronized reserve for each on-line resource is estimated from its synchronized reserve ramp rate as part of each market solution and not assigned. Given estimated tier 1, the market software (ASO) completes the primary reserve assignments under the assumption that the estimated tier 1 will be available if needed. The ancillary services market solution treats the cost of estimated tier 1 synchronized reserve as \$0, even when the non-synchronized reserve market clearing price is above \$0.

Beginning January 2015, 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. DGP is calculated for all on-line resources for each market solution. DGP measures how closely the unit has been following economic dispatch for the past thirty minutes and the available tier 1 MW for that resource is adjusted by the percentage of the DGP. In May 2015, PJM began communicating to generation operators whose tier 1 MW are part of the market solution the latest estimate of units' tier 1 MW and units' current resource specific DGP.<sup>14</sup>

For 2015, PJM estimated Tier 1 MW for an average of 147 units as part of the solution each hour. The average DGP was 84.7 percent for those 147 units.

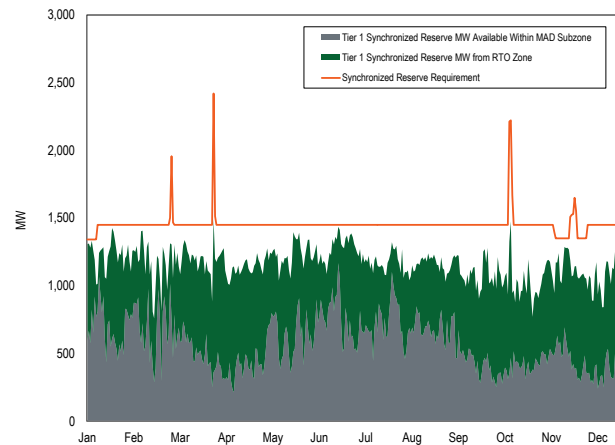
## Supply and Demand

When solving for the synchronized reserve requirement the market solution first subtracts the amount of self-scheduled synchronized reserve from the requirement and then estimates the amount of tier 1. To improve its Tier 1 estimates, PJM deselects certain resources from the tier 1 estimate. Tier 1 deselection is based on unit type, location and daily grid conditions.

In the MAD Subzone, the market solution takes all tier 1 MW estimated to be available within the MAD Subzone (gray area of Figure 10-5). It then adds the tier 1 MW estimated to be available within the MAD Subzone from the RTO Zone (green area of Figure 10-5) up to the synchronized reserve requirement. 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 (white area below the synchronized reserve required line in Figure 10-5).

**Figure 10-5 Daily average tier 1 synchronized reserve supply (MW) in the MAD Subzone: 2015**



Demand for synchronized reserve in the RTO Zone in 2015, was 2.1 percent higher than in 2014 primarily because the hourly synchronized reserve requirement was increased from 1,375 MW to 1,450 MW. There were temporary increases in the hourly synchronized reserve requirement to 2,688 MW on February 28, 2015 and to 2,615 MW on March 29, 2015 because of emergency outages. Other increases include June 10 through June 15 to 1,644 MW, September 18 through September 23 to 1,588 MW, October 19 through October 21 to 2,217 MW. Usually, the synchronized reserve requirement is increased because of planned outages in the spring and fall for periods of 10 to 14 days sometimes these outages impact the largest contingency requiring an increase in the synchronized reserve requirement. An outage from November 20 through December 12 caused a reduction in the synchronized reserve requirement to 1,350 MW.

## Tier 1 Synchronized Reserve Event Response

Tier 1 synchronized reserve is awarded credits when a synchronized reserve event occurs and it responds. These synchronized reserve event response credits for tier 1 response are independent of the tier 1 estimated, independent of the synchronized reserve market clearing

<sup>14</sup> PJM, Ancillary Services, "Communication of Synchronized Reserve Quantities to Resource Owners," <<http://www.pjm.com/~media/markets-ops/ancillary/communication-of-synchronized-reserve-quantities-to-resource-owners.ashx>> (May 6, 2015).

price, and independent of the non-synchronized reserve market clearing price. Credits are awarded to tier 1 synchronized reserve resources equal to the increase in MW output (or decrease in MW consumption for demand resources) for each five minute interval times the five minute LMP plus \$50 per MW.

In 2015, tier 1 synchronized reserve synchronized reserve event response credits of \$351,212 were paid for 7,145.0 MW of tier 1 response at an average cost per MW of \$50.99, for 22 spinning events (Table 10-9).

**Table 10-9 Tier 1 synchronized reserve event response costs: January 2014 through December 2015**

Year	Month	Synchronized Reserve Event Response Hours	Total Tier 1 Synchronized Reserve Event Response MW	Total Tier 1 Synchronized Reserve Event Response Credits	Tier 1 Synchronized Reserve Event Response Cost	Average Tier 1 MW Response
2014	Jan	12	7,827.8	\$965,846	\$123.39	521.9
2014	Feb	1	273.2	\$11,153	\$40.82	273.2
2014	Mar	5	3,029.6	\$175,902	\$58.06	605.9
2014	Apr	2	389.1	\$6,378	\$16.39	194.5
2014	May	3	717.1	\$34,906	\$48.68	239.0
2014	Jun	0	NA	NA	NA	NA
2014	Jul	2	615.6	\$35,179	\$57.15	307.8
2014	Aug	0	NA	NA	NA	NA
2014	Sep	3	1,936.2	\$143,574	\$74.15	645.4
2014	Oct	2	1,131.7	\$83,901	\$74.14	565.8
2014	Nov	4	1,349.8	\$38,895	\$28.81	337.5
2014	Dec	3	692.0	\$35,245	\$50.96	230.5
2014	Total	37	17,962.1	\$1,530,978	\$57.26	392.2
2015	Jan	1	397.3	\$8,198	\$20.64	397.3
2015	Feb	2	218.3	\$9,634	\$44.13	109.2
2015	Mar	4	2,445.8	\$105,505	\$43.14	611.4
2015	Apr	5	1,398.9	\$69,399	\$49.61	279.8
2015	May	0	NA	NA	NA	NA
2015	Jun	0	NA	NA	NA	NA
2015	Jul	1	502.2	\$25,540	\$50.86	502.2
2015	Aug	2	648.3	\$7,730	\$11.92	324.1
2015	Sep	3	678.5	\$30,077	\$44.33	226.2
2015	Oct	0	NA	NA	NA	NA
2015	Nov	2	252.9	\$15,914	\$62.92	126.5
2015	Dec	2	602.9	\$79,215	\$131.39	301.4
2015	Total	22	7,145.0	\$351,212	\$50.99	319.8

the non-synchronized 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. The non-synchronized reserve market clearing price was above \$0 in 541 hours in 2014. For those 541 hours, tier 1 synchronized reserve resources were paid a weighted average synchronized reserve market clearing price of \$30.67 per MW and earned \$10,406,363 in credits. In 2015, PJM paid \$34,135,671 in credits for tier 1 estimated during the 1,089 hours when the non-synchronized reserve market clearing price was above \$0.

## Paying Tier 1 the Tier 2 Price

The market solutions correctly treat tier 1 synchronized reserve as having zero marginal cost. The price for tier 1 synchronized reserves is zero unless tier 1 is called on to respond, as there is no incremental cost associated with providing the ability to ramp up from the current economic dispatch point. 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

**Table 10-10 Weighted price of tier 1 synchronized reserve attributable to a non-synchronized reserve price above zero: January 2014 to December 2015**

Year	Month	Total Hours When NSRMCP>\$0	Weighted Average SRMCP for Hours When NSRMCP>\$0	Total Tier 1 MW Credited for Hours When NSRMCP>\$0	Total Tier 1 Credits Paid When NSRMCP>\$0	Average Tier 1 MW Paid
2014	Jan	155	\$93.26	53,014	\$4,874,314	414.9
2014	Feb	15	\$40.18	65,332	\$337,903	560.5
2014	Mar	67	\$44.56	34,150	\$1,513,636	509.7
2014	Apr	99	\$16.07	57,047	\$916,275	576.2
2014	May	61	\$15.85	50,455	\$799,911	827.1
2014	Jun	4	\$35.46	3,335	\$118,273	833.9
2014	Jul	5	\$17.02	3,941	\$67,078	788.1
2014	Aug	0	NA	NA	NA	NA
2014	Sep	0	NA	NA	NA	NA
2014	Oct	3	\$21.59	2,146	\$46,319	715.2
2014	Nov	28	\$15.73	38,188	\$599,147	1,363.8
2014	Dec	104	\$6.93	163,552	\$1,133,507	1,739.9
2014	Total	541	\$30.67	471,159	\$10,406,363	832.9
2015	Jan	148	\$13.59	274,996	\$3,727,945	1,858.1
2015	Feb	194	\$24.83	369,111	\$9,164,267	1,902.6
2015	Mar	181	\$16.33	305,967	\$4,985,446	1,690.4
2015	Apr	66	\$25.56	102,117	\$2,587,076	1,547.2
2015	May	72	\$20.35	106,027	\$2,158,080	1,472.6
2015	Jun	95	\$17.64	185,148	\$3,183,436	1,948.9
2015	Jul	46	\$35.12	64,516	\$2,265,614	1,402.5
2015	Aug	38	\$22.40	48,479	\$1,078,199	1,275.8
2015	Sep	36	\$31.53	51,968	\$1,522,913	1,060.5
2015	Oct	113	\$17.10	126,879	\$2,169,670	1,122.8
2015	Nov	29	\$14.65	29,156	\$427,056	1,005.4
2015	Dec	51	\$16.07	53,898	\$865,969	1,005.4
2015	Total	1,069	\$21.26	1,718,263	\$34,135,671	1,441.0

The additional payments to tier 1 synchronized reserves under the shortage pricing rule can be considered a windfall. The additional payment does not create an incentive to provide more tier 1 synchronized reserves. The additional payment is not a payment for performance as all estimated tier 1 receives the payment regardless of whether they provided any response during any spinning event. Tier 1 resources are not obligated to respond to synchronized reserve events. In 2015, 89.7 percent of the market solution's estimated tier 1 resource MWh actually responded during synchronized reserve events of greater than ten minutes. Thus, 10.3 percent of tier 1 resource estimated MWh do not respond during spinning events but are paid their full estimated MW when the non-synchronized reserve price is greater than zero. Tier 2 synchronized reserve resources are paid the market clearing price for tier 2 because they stand ready to respond and incur costs to do so, have an obligation to perform and pay penalties for nonperformance.

When the next MW of non-synchronized reserve (NSR) required to satisfy the primary reserve requirement

increases in price from \$0.00 per MW to \$0.01 per MW, the cost of all tier 1 MW increases significantly.

In 2015, tier 1 MW were paid \$351,212 for responding to synchronized reserve events. Tier 1 synchronized reserve was paid \$34.1 million simply because the NSRMCP was greater than \$0 (Table 10-11).

**Table 10-11 Dollar impact of paying tier 1 synchronized reserve the SRMCP when the NSRMCP goes above \$0: January 2014 through December 2015**

Year	Month	Synchronized Reserve Events			Hours When NSRMCP > \$0		
		Total MWh	Total Credits	Average MWh Per Event	Total MW	Total Credits	Average MW Per Hour
2014	Jan	7,828	\$965,846	522	53,014	\$4,874,314	414.9
2014	Feb	273	\$11,153	273	65,332	\$337,903	560.5
2014	Mar	3,030	\$175,902	606	34,150	\$1,513,636	509.7
2014	Apr	389	\$6,378	195	57,047	\$916,275	576.2
2014	May	717	\$34,906	239	50,455	\$799,911	827.1
2014	Jun	0	\$0	0	3,335	\$118,273	833.9
2014	Jul	616	\$35,179	308	3,941	\$67,078	788.1
2014	Aug	0	\$0	0	0	\$0	0
2014	Sep	1,936	\$143,574	645	0	\$0	0
2014	Oct	1,132	\$83,901	566	2,146	\$46,319	715
2014	Nov	1,350	\$38,895	337	38,188	\$599,147	1,364
2014	Dec	258	\$12,897	129	163,552	\$1,133,507	1,740
2014	Total	17,528	1,508,631	382	471,159	10,406,363	833
2015	Jan	397	\$8,198	397	274,996	\$3,727,945	1,858
2015	Feb	218	\$9,634	109	369,111	\$9,164,267	1,903
2015	Mar	2,446	\$105,505	611	305,967	\$4,985,446	1,690
2015	Apr	1,399	\$69,399	280	102,117	\$2,587,076	1,547
2015	May	0	\$0	0	106,027	\$2,158,080	1,473
2015	Jun	0	\$0	0	182,417	\$3,183,436	1,961
2015	Jul	502	\$25,540	502	64,516	\$2,265,615	1,403
2015	Aug	648	\$7,730	324	48,479	\$1,078,199	1,276
2015	Sep	678	\$30,077	226	51,968	\$1,522,913	1,061
2015	Oct	0	\$0	0	126,879	\$2,169,670	1,123
2015	Nov	253	\$15,914	126	29,156	\$427,056	1,005
2015	Dec	603	\$79,215	301	53,898	\$865,969	1,054
2015	Total	7,145	\$351,212	320	1,715,532	\$34,135,671	1,446

The MMU recommends that the rule requiring the payment of tier 1 synchronized reserve resources when the non-synchronized reserve price is above zero be eliminated immediately. 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 average of five-minute LMPs during the event, rather than hourly integrated LMP, plus \$50/MW, termed the Synchronized Energy Premium Price.

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 Hour as Currently Implemented by PJM		
Hourly		
Parameters	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh
NSRMCP>\$0	T1 credits = T2 SRMCP * estimated tier 1 MW	T1 credits = T2 SRMCP * min(calculated tier 1 MW, actual response MWh)



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		
Hourly Parameters	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh
NSRMCP>\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh

### Tier 1 Estimate Bias

PJM dispatch can apply tier 1 estimate bias to each element of the market solution software (ASO, IT-SCED, and RT-SCED). Biasing means manually modifying (increasing or decreasing) the tier 1 synchronized reserve estimate of the market solution. This forces the market clearing engine to clear more or less tier 2 synchronized reserve and non-synchronized reserve to satisfy the synchronized reserve and primary reserve requirements than the market solution.

PJM uses tier 1 estimate biasing in the MAD Subzone of the ASO market solution (Table 10-14). Tier 1 biasing is not used in any IT-SCED solutions.

**Table 10-14 ASO tier 1 estimate biasing, January 2014 through December, 2015**

Year	Month	Number of Hours Biased Negatively	Average Negative Bias (MW)	Number of Hours Biased Positively	Average Positive Bias (MW)
2014	Jan	13	(1,419.2)	2	250.0
2014	Feb	36	(1,036.1)	1	100.0
2014	Mar	37	(1,281.1)	4	500.0
2014	Apr	32	(1,387.5)	0	0.0
2014	May	23	(909.8)	0	0.0
2014	Jun	17	(1,179.4)	3	666.7
2014	Jul	36	(1,011.1)	0	0.0
2014	Aug	31	(891.9)	1	750.0
2014	Sep	15	(1,206.7)	0	0.0
2014	Oct	67	(1,285.8)	1	500.0
2014	Nov	190	(1,134.7)	6	475.0
2014	Dec	166	(1,226.2)	1	300.0
2014	Total	663	(1,164.1)	19	295.1
2015	Jan	51	(1,731.4)	6	500.0
2015	Feb	62	(1,641.1)	0	0.0
2015	Mar	25	(794.0)	3	1,000.0
2015	Apr	31	(430.7)	0	0.0
2015	May	46	(582.6)	8	812.5
2015	Jun	25	(694.0)	1	1,000.0
2015	Jul	9	(588.9)	0	0.0
2015	Aug	1	(750.0)	1	750.0
2015	Sep	4	(475.0)	1	2,000.0
2015	Oct	24	(979.2)	0	0.0
2015	Nov	0	0.0	62	515.3
2015	Dec	1	(500.0)	59	549.2
2015	Total	279	(763.9)	141	593.9

Tier 1 biasing is not mentioned in the PJM manuals and does not appear to be defined in any public document. PJM dispatchers use tier 1 biasing to compensate for uncertainty in short-term load forecasting, generator performance, or uncertainty in the accuracy of the market solution's tier 1 estimate. Tier 1 estimate biasing directly affects the required amount of tier 2 and therefore the market results both for tier 2 synchronized reserve and for non-synchronized reserve.

The MMU recommends that PJM be more explicit about why tier 1 biasing is used in the optimized solution to the Tier 2 Synchronized Reserve Market. The MMU recommends that PJM define rules for estimating available tier 1 MW and for the use of biasing during any phase of the market solution and then identify the relevant rule for each instance of biasing.

## Tier 2 Synchronized Reserve Market

Synchronized reserve is energy or demand reduction synchronized to the grid and capable of increasing output or decreasing load within ten minutes. Synchronized reserve is of two distinct types, tier 1 and tier 2. Tier 2 synchronized reserve is primary reserve (ten minute availability) that must be dispatched in order to satisfy the synchronized reserve requirement. When the synchronized reserve requirement cannot be filled with tier 1 synchronized reserve, PJM clears a market to satisfy the requirement with tier 2 synchronized reserve.

PJM operates a Tier 2 Synchronized Reserve Market in both the RTO Synchronized Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone. Market solutions provided by the ASO, IT-SCED and RT-SCED first estimate the amount of tier 1 synchronized reserve available from the current economic dispatch and subtract that amount from the synchronized reserve requirement to determine how much tier 2 synchronized reserve is needed. Tier 2 synchronized reserve is provided by on-line 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 a synchronized reserve event. Tier 2 synchronized reserves are committed to be available in the event of a synchronized reserve event.

Tier 2 synchronized reserve resources may be inflexible for two reasons, the nature of the resource or if they are committed in the hour ahead for the full operating hour. Some resource types can only be committed by the ASO prior to the operational hour and require an hourly commitment due to physical limitations or market rules. Resources with hour ahead commitment requirements include synchronous condensers operating solely for the purpose of providing synchronized reserves and demand response that has qualified to act as synchronized reserves. Tier 2 resources are scheduled by the ASO sixty minutes before the operating hour, are committed to provide synchronized reserve for the entire hour, and are paid the higher of the SRMCP or their offer price plus lost opportunity cost (LOC). Demand response resources are paid SRMCP. Due to the hour long commitment that comes with the hour ahead ASO assignment, tier 2 synchronized reserve resources committed by the hour

ahead market solution are flagged by the system software as inflexible resources, so they cannot be released for energy for the duration of the operational hour.

During the operating hour, the IT-SCED and the RT-SCED market solutions have the ability to dispatch additional resources flexibly depending on the current forecast need for synchronized reserve. A flexible commitment is one in which the IT-SCED or RT-SCED redispatches generating resources to meet the synchronized and primary reserve requirements within the operational hour.

## Market Structure

### Supply

All non-emergency generating resources are required to submit tier 2 synchronized reserve offers. All online, non-emergency generating resources are deemed available to provide both tier 1 and tier 2 synchronized reserve. If PJM issues a primary reserve warning, voltage reduction warning, or manual load dump warning, all off line non-emergency generation capacity resources available to provide energy must submit an offer for tier 2 synchronized reserve.<sup>15</sup>

In 2015, the Mid Atlantic Dominion Reserve Subzone averaged 3,398.7 MW of synchronized reserve offers, and the RTO Reserve Zone averaged 10,565.3 MW of synchronized reserve offers (Figure 10-11).

The supply of tier 2 synchronized reserve in 2015 was sufficient to cover the requirement in both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.

The largest portion of cleared tier 2 synchronized reserve in 2015 is from CTs (Figure 10-6) 52.6 percent of all tier 2 synchronized reserve MW. Demand Resources (DR) remain a significant part of market scheduled tier 2 synchronized reserve. Although demand resources are limited to 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. The DR MW share of the total cleared Tier 2 Synchronized Reserve

<sup>15</sup> See PJM, "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 66.

Market was 17.7 percent in 2015.<sup>16</sup> This is an increase from the 15.1 percent share of the tier 2 market in 2014.

**Figure 10-6 Cleared tier 2 synchronized reserve average hourly MW per hour by unit type, RTO Zone: 2015**

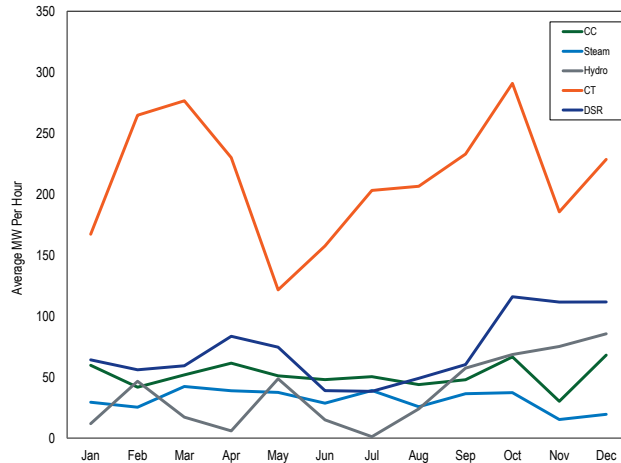
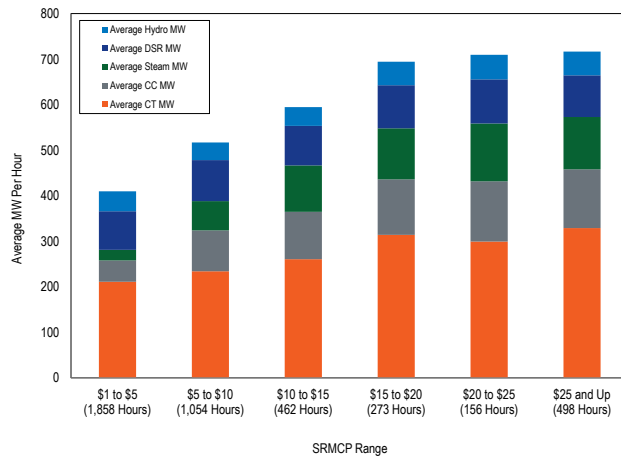


Figure 10-7 provides the average hourly cleared tier 2 MW by unit type by tier 2 clearing price range (SRMCP).

**Figure 10-7 Average hourly tier 2 MW by unit type by SRMCP Range: 2015**



Mild weather in October, November, and December caused fewer units to be operating therefore lesser tier 1 synchronized reserve availability. As a result, significantly more tier 2 synchronized reserve was cleared in those months (Table 10-18). In addition, PJM market operations utilized tier 1 biasing in an unusual way (Table 10-14) in November and December. The

<sup>16</sup> The cap on demand response participation is defined in MW terms. There is no cap on the proportion of cleared demand response consistent with the MW cap.

tier 1 estimate in the ASO market solution was biased positively in a large number of hours. In addition, there were 20 days in November and December when the primary reserve requirement was lowered, (orange line in Figure 10-3) reducing the need for non-synchronized reserve.

## Demand

Effective January 1, 2015, the synchronized reserve requirement was increased to 1,342 MW in the Mid-Atlantic Dominion Subzone, and remained at 1,375 MW in the RTO Zone. Effective January 8, 2015, the synchronized reserve requirement was increased to 1,450 MW in both the Mid-Atlantic Dominion Subzone and the RTO Zone (Table 10-15). There are two circumstances in which PJM may alter the synchronized reserve requirement from its default value. When PJM operators anticipate periods of heavy 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 escalating 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.<sup>17</sup> In January through March 2015, PJM declared 27 Cold Weather Alerts raising the synchronized reserve requirement from 1,450 MW to 1,700 for 606 hours. In June, hot weather alerts caused the synchronized reserve requirement to be raised to 1,700 MW in 114 hours.

**Table 10-15 Default Tier 2 Synchronized Reserve Markets required MW, RTO Zone and Mid-Atlantic Dominion Subzone**

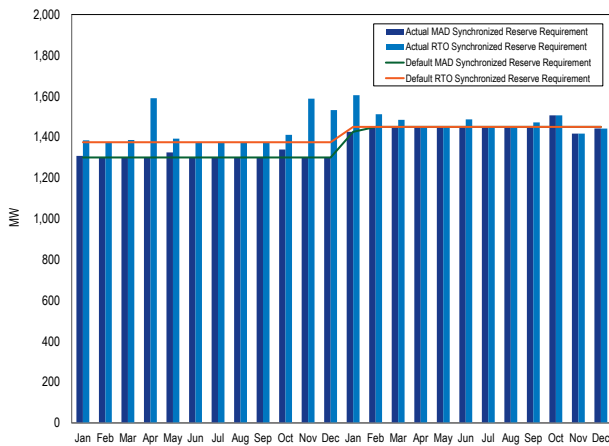
Mid-Atlantic Dominion Subzone			RTO Synchronized Reserve Zone		
From Date	To Date	Required MW	From Date	To Date	Required MW
May 10, 2008	May 8, 2010	1,150	May 10, 2008	Jan 1, 2009	1,305
May 8, 2010	Jul 13, 2010	1,200	Jan 1, 2009	Mar 15, 2010	1,320
July 13, 2010	Jan 1, 2015	1,300	Mar 15, 2010	Nov 12, 2012	1,350
Jan 1, 2015	Jan 8, 2015	1,342	Nov 12, 2012	Jan 8, 2015	1,375
Jan 8, 2015		1,450	Jan 8, 2015		1,450

PJM may also change the synchronized reserve requirement from its default value (Figure 10-1) when grid maintenance or outages change the largest contingency. In the first three months of 2015, PJM

<sup>17</sup> PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) pp. 70.

increased the synchronized reserve requirement in 38 hours in the RTO Reserve Zone (Figure 10-8) because of grid outages. The RTO synchronized reserve requirement was temporarily raised to 1,624 for 96 hours during a scheduled outage from September 20, through September 23, 2015. The RTO synchronized reserve requirement was raised for 40 hours between October 19 and October 21, 2015, for scheduled outages. The synchronized reserve requirement was reduced for 21 days between November 20, and December 12, 2015, when a scheduled outage changed the largest system contingency. The average actual synchronized reserve requirement in the MAD Subzone was 1,454.1 MW. The average actual synchronized reserve requirement in the RTO Reserve Zone was 1,477.6 MW.

**Figure 10-8 Monthly average actual vs default synchronized reserve requirements, RTO Zone and MAD Subzone: January 2014 through December 2015**



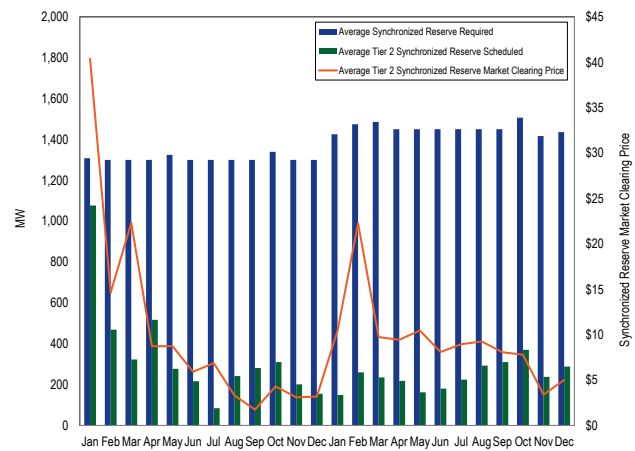
The market demand for tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone is determined by subtracting the amount of forecast tier 1 synchronized reserve available in the subzone from the subzone requirement each five-minute period. Market demand is also reduced by subtracting the amount of self-scheduled tier 2 resources.

In the RTO Reserve Zone, 60.6 percent of hours cleared a Tier 2 Synchronized Reserve Market in 2015 averaging 457.3 MW. This compares with 57.1 percent of hours averaging 831.6 MW in 2014. In the MAD Reserve Subzone, 96.9 percent of hours cleared a Tier 2 Synchronized Reserve Market in 2015 averaging 314.8

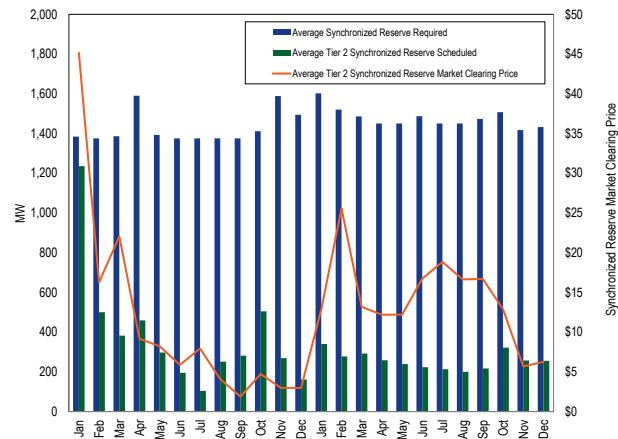
MW. This compares with 96.0 percent of hours cleared, averaging 380.1 MW in 2014.

Figure 10-9 and Figure 10-10 show the average monthly synchronized reserve required and the average monthly tier 2 synchronized reserve MW scheduled in 2014 and 2015, for the RTO Reserve Zone and MAD Reserve Subzone.

**Figure 10-9 Mid-Atlantic Dominion Reserve Subzone monthly average synchronized reserve required vs. tier 2 synchronized reserve scheduled MW: January 2014 through December 2015**



**Figure 10-10 RTO Reserve Zone monthly average synchronized reserve required vs. tier 2 synchronized reserve scheduled MW: January 2014 through December 2015**



## Market Concentration

The HHI for settled tier 2 synchronized reserve during cleared hours of the Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Market for 2015 was 5436, which is defined as highly concentrated. This is an increase from the 5163 HHI in 2014. The largest hourly market share was 100 percent and 88.1 percent of all cleared hours had a maximum market share greater than or equal to 40 percent.

The HHI for settled tier 2 synchronized reserve during cleared hours of the RTO Zone Tier 2 Synchronized Reserve Market for 2015 was 4617, which is defined as highly concentrated. This is a decrease from the 5639 HHI in 2015. The largest hourly market share was 100 percent and 67.6 percent of cleared hours had a maximum market share greater than or equal to 40 percent.

In the MAD Subzone, flexible synchronized reserve was 3.8 percent of all tier 2 synchronized reserve in 2015. In the RTO Zone, flexible synchronized reserve assigned was 3.7 percent of all tier 2 synchronized reserve in 2015.

The MMU calculates that 55.7 percent of hours failed the three pivotal supplier test in the MAD Subzone in 2015 for the inflexible Synchronized Reserve Market (excluding self-scheduled synchronized reserve) in the hour ahead market (Table 10-16) and 40.2 percent of hours failed a three pivotal supplier test in the RTO Zone in 2015.

**Table 10-16 Three pivotal supplier test results for the RTO Zone and MAD Subzone: January 2014 through December 2015**

Year	Month	Mid Atlantic Dominion	RTO Reserve Zone Pivotal
		Reserve Subzone Pivotal Supplier Hours	Supplier Hours
2014	Jan	90.7%	72.7%
2014	Feb	46.6%	22.6%
2014	Mar	37.9%	17.3%
2014	Apr	31.9%	51.6%
2014	May	22.3%	44.0%
2014	Jun	31.5%	31.3%
2014	Jul	41.6%	16.2%
2014	Aug	21.2%	17.6%
2014	Sep	25.0%	24.5%
2014	Oct	53.2%	71.8%
2014	Nov	56.4%	51.7%
2014	Dec	37.5%	48.6%
2014	Average	41.3%	39.2%
<hr/>			
2015	Jan	46.0%	34.2%
2015	Feb	87.0%	29.9%
2015	Mar	42.0%	45.2%
2015	Apr	31.1%	48.4%
2015	May	61.2%	45.3%
2015	Jun	39.2%	26.5%
2015	Jul	32.0%	25.0%
2015	Aug	32.3%	24.9%
2015	Sep	56.1%	23.5%
2015	Oct	81.5%	57.9%
2015	Nov	73.2%	49.3%
2015	Dec	87.7%	73.2%
2015	Average	55.8%	40.3%

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 offer prices are submitted for each unit by the unit owner. For generators the offer price must include 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 (a field to identify if a running CT can be dispatched for synchronized reserve). The synchronized reserve offer price made by the unit owner is subject to an offer cap of marginal cost plus \$7.50 per MW. All suppliers are paid the higher of the market clearing price or their offer plus their unit

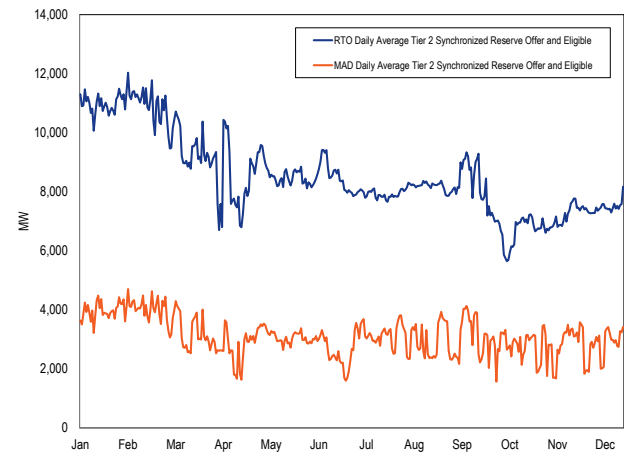
specific opportunity cost. The offer quantity is limited to the economic maximum or less if a spin maximum value is less than economic maximum is supplied (subject to prior authorization by PJM). PJM monitors this offer by checking to ensure that all offers are greater than or equal to 90 percent of the resource's ramp rate times ten minutes. A resource that is unable to participate in the synchronized reserve market during a given hour may set its hourly offer to 0 MW. A resource that cannot reliably provide synchronized reserve may offer 0 MW, e.g. nuclear, wind, solar, and batteries.

Figure 10-11 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. In 2015, the ratio of on-line and eligible tier 2 synchronized reserve to synchronized reserve required in the Mid-Atlantic Dominion Subzone was 4.14 averaged over all hours. For the RTO Synchronized Reserve Zone the ratio was 5.91.

On October 1, 2012, PJM adopted a must-offer requirement for tier 2 synchronized reserve for all generation that is online, non-emergency, 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.<sup>18</sup> Daily offer levels are stable and consistent over time. The Tier 2 Synchronized Reserve Market is not solved from 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 10-11). Changes to hourly eligibility levels are the result of on-line status, minimum/maximum runtimes, minimum notification times, maintenance status and grid conditions including constraints. But changes to the hourly offer status are only permitted when resources are physically unable to provide tier 2. Resource operators can make their units unavailable for an hour or block of hours via the eMKT unavailable option without having to provide a reason. This means that while compliance with the must offer requirement can be done daily it is not possible to verify

compliance with the tier 2 must offer requirement on an hourly basis.

**Figure 10-11 Tier 2 synchronized reserve hourly offer and eligible volume (MW), averaged daily: 2015**



Compliance with the daily must-offer requirement is unambiguously stated in Manual 11 “Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for tier 2 synchronized reserve in eMKT prior to the offer submission deadline (1800 the day prior to the operating day).”

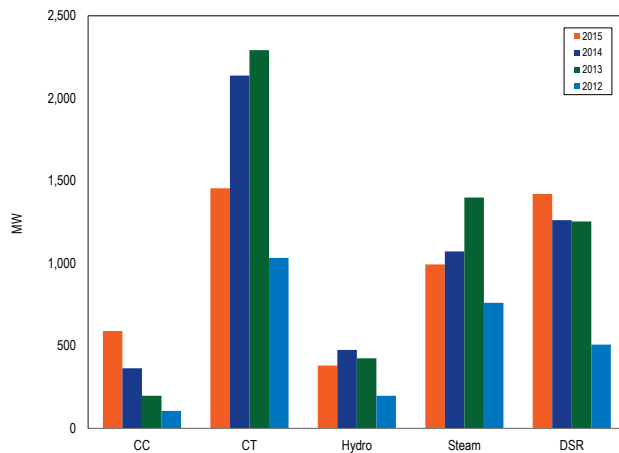
Of all non-emergency resources capable of reliably producing synchronized reserve (e.g. excluding batteries, wind, and solar), 12.9 percent have not entered a tier 2 synchronized reserve offer in violation of the must-offer rule. When tier 1 credits are awarded (either for spinning event response or because the NSRMCP is greater than \$0) these units can be awarded tier 1 credits. In December 2015, 71 distinct units without a tier 2 offer were awarded a total \$98,156 in tier 1 credits. Of this, \$85,640 were for hours when the NSRMCP greater than \$0 and the units did not have to actually produce any reserve MW.

Tier 2 synchronized reserve is subject to a must offer requirement. To help ensure compliance with this rule, the MMU recommends that PJM define a set of acceptable reasons why a unit can be made unavailable daily or hourly and require operators to select a reason in eMkt whenever making a unit unavailable.

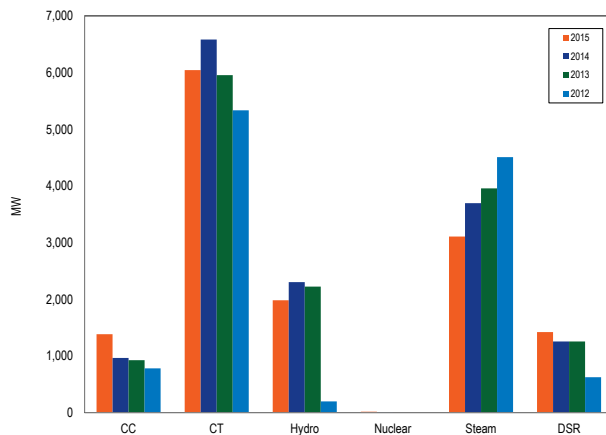
<sup>18</sup> See PJM. “Manual 11: Energy & Ancillary Services Market Operations,” Revision 79 (December 17, 2015) p. 66, “Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for Tier 2 Synchronized Reserve in eMKT...”

Figure 10-12 shows average offer MW volume by market and unit type for the MAD Subzone and Figure 10-13 shows average offer MW volume by market and unit type for the RTO Zone.

**Figure 10-12 Mid-Atlantic Dominion subzone average daily tier 2 synchronized reserve offer by unit type (MW): 2012 through 2015**



**Figure 10-13 RTO Zone average daily tier 2 synchronized reserve offer by unit type (MW): 2012 through 2015**



## Market Performance

### Price

The price of tier 2 synchronized reserve is calculated in real time every five minutes and averaged each hour for the RTO Reserve Zone and the MAD Subzone.

The MAD Subzone cleared a Tier 2 Synchronized Reserve Market averaging 314.8 MW (including self-scheduled) with a real-time price greater than \$0 in 63.6 percent of

hours in 2015, compared to 99.0 percent of hours in the first nine months of 2014.

The RTO Zone cleared a Tier 2 Synchronized Reserve Market averaging 457.3 MW (including self-scheduled) with a real-time price greater than \$0 in 58.6 percent of hours in 2015.

In 2015, the weighted average Tier 2 synchronized reserve market clearing price in the MAD Subzone for all cleared hours was \$10.12. In 2014, the weighted average synchronized reserve market clearing price in the MAD Subzone was \$15.50.

In 2015, the weighted average tier 2 synchronized reserve market clearing price in the RTO Zone for all cleared hours was \$11.88. In 2014, the weighted average synchronized reserve market clearing price in the RTO Zone was \$12.94.

Supply, performance, and demand are reflected in the price of synchronized reserve (Figure 10-9 and Figure 10-10). In February 2015, cold weather meant that on line resources which are jointly optimized with synchronized reserve were generating at or near their economic maximum. As a result, tier 2 synchronized reserve was more expensive.

**Table 10-17 Mid-Atlantic Dominion Subzone, weighted SRMCP and cleared MW (excludes self-scheduled): 2015**

Year	Month	Weighted Average Tier 2 Synchronized Reserve Market Clearing Price	Average Hourly Tier 1 Synchronized Reserve Estimated Hour Ahead (MW)	Average Hourly Demand Response Cleared (MW)	Average Tier 2 Generation Synchronized Reserve Cleared (MW)
2015	Jan	\$11.29	1,218.9	63.7	142.8
2015	Feb	\$24.12	1,179.5	46.3	224.3
2015	Mar	\$11.81	1,196.2	60.8	228.7
2015	Apr	\$10.76	1,159.4	85.0	218.1
2015	May	\$10.16	1,174.4	76.0	162.9
2015	Jun	\$10.29	1,515.5	54.5	177.7
2015	Jul	\$12.87	1,195.6	41.1	215.7
2015	Aug	\$9.25	1,152.9	49.3	247.8
2015	Sep	\$10.66	1,106.9	54.2	288.9
2015	Oct	\$7.68	1,015.6	118.2	374.4
2015	Nov	\$3.30	1,011.6	113.6	290.6
2015	Dec	\$4.71	983.4	109.0	349.4
2015	Average	\$10.13	1,159.2	72.6	243.4

**Table 10-18 RTO Zone only weighted SRMCP and cleared MW (excludes self-scheduled): 2015**

Year	Month	Weighted Average Tier 2 Synchronized Reserve Market Clearing Price	Average Hourly Tier 1 Synchronized Reserve Estimated Hour Ahead (MW)	Average Hourly Demand Response Cleared (MW)	Average Tier 2 Generation Synchronized Reserve Cleared (MW)
2015	Jan	\$13.91	1,417.5	164.8	125.2
2015	Feb	\$26.51	1,618.3	46.3	35.4
2015	Mar	\$13.44	1,285.0	60.8	140.0
2015	Apr	\$13.39	1,228.6	85.0	136.4
2015	May	\$13.77	1,239.8	76.0	134.2
2015	Jun	\$19.43	1,366.4	54.5	83.6
2015	Jul	\$21.46	1,346.1	41.1	65.2
2015	Aug	\$18.63	1,353.1	49.3	58.9
2015	Sep	\$19.12	1,156.3	54.2	64.3
2015	Oct	\$15.87	1,156.3	118.2	233.3
2015	Nov	\$6.09	1,089.5	113.6	212.6
2015	Dec	\$7.05	784.4	109.0	548.4
2015	Average	\$14.98	1,253.4	81.1	153.1

## Cost

As a result of changing grid conditions, load forecasts, and unexpected generator performance, prices do not always cover the full cost and final LOC for each resource. Because price formation occurs within the hour (on five minute basis integrated over the hour) but the 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 if the SRMCP does not compensate them for their offer plus LOC.

The full cost of tier 2 synchronized reserve including payments for the clearing price and out of market costs is calculated and compared to the price. The closer the price to cost ratio is to one hundred percent, the more the market price reflects the full cost of tier 2 synchronized reserve. A price to cost ratio close to one hundred percent is an indicator of an efficient synchronized reserve market design.

In 2015, the price to cost ratio of the RTO Zone Tier 2 Synchronized Reserve Market averaged 62.6 percent (Table 10-19); and the price to cost ratio of the MAD Subzone averaged 60.6 percent.



Table 10–19 RTO Zone, Mid–Atlantic Subzone tier 2 synchronized reserve MW, credits, price, and cost: 2015

Tier 2 Synchronized Reserve Market	Year	Month	Total MW	Total Credits	Weighted	Price/Cost	Ratio
					Synchronized Reserve Market Clearing Price		
RTO Zone	2015	Jan	225,741	\$5,089,807	\$12.24	\$22.55	54.3%
RTO Zone	2015	Feb	272,371	\$12,065,569	\$24.68	\$44.30	55.7%
RTO Zone	2015	Mar	301,564	\$7,323,630	\$12.37	\$24.29	50.9%
RTO Zone	2015	Apr	278,562	\$4,896,351	\$11.53	\$17.58	65.6%
RTO Zone	2015	May	244,947	\$4,231,841	\$11.22	\$17.28	65.0%
RTO Zone	2015	Jun	174,039	\$2,916,195	\$12.95	\$16.76	77.3%
RTO Zone	2015	Jul	194,178	\$3,435,731	\$15.28	\$17.69	86.4%
RTO Zone	2015	Aug	173,869	\$2,329,804	\$11.20	\$13.40	83.6%
RTO Zone	2015	Sep	253,762	\$4,012,473	\$12.44	\$15.81	78.7%
RTO Zone	2015	Oct	428,175	\$5,444,327	\$9.61	\$12.72	75.6%
RTO Zone	2015	Nov	298,986	\$2,821,681	\$3.92	\$9.44	41.5%
RTO Zone	2015	Dec	374,928	\$4,163,737	\$5.26	\$11.11	47.4%
RTO Zone	2015	Total	3,221,120	\$58,731,146	\$11.41	\$18.23	62.6%
MAD Subzone	2015	Jan	144,214	\$3,454,670	\$11.29	\$23.96	47.1%
MAD Subzone	2015	Feb	208,536	\$8,740,957	\$24.12	\$41.92	57.5%
MAD Subzone	2015	Mar	197,540	\$4,488,330	\$11.81	\$22.72	52.0%
MAD Subzone	2015	Apr	197,223	\$3,583,677	\$10.76	\$18.17	59.2%
MAD Subzone	2015	May	172,468	\$2,951,207	\$10.16	\$17.11	59.3%
MAD Subzone	2015	Jun	123,473	\$1,685,393	\$10.29	\$13.65	75.4%
MAD Subzone	2015	Jul	139,693	\$2,093,452	\$12.87	\$14.99	85.9%
MAD Subzone	2015	Aug	137,663	\$1,533,977	\$9.25	\$11.14	83.0%
MAD Subzone	2015	Sep	200,257	\$2,832,648	\$10.66	\$14.15	75.4%
MAD Subzone	2015	Oct	327,286	\$3,310,116	\$7.68	\$10.11	76.0%
MAD Subzone	2015	Nov	232,670	\$1,935,364	\$3.30	\$8.32	39.6%
MAD Subzone	2015	Dec	286,032	\$2,963,084	\$4.71	\$10.36	45.4%
MAD Subzone	2015	Total	2,367,055	\$39,572,874	\$10.13	\$16.72	60.6%

## Compliance

The MMU has identified and quantified the failure of scheduled tier 2 synchronized reserve resources to deliver during synchronized reserve events since 2011.<sup>19</sup> 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.<sup>20</sup> Tier 2 resources are obligated to sustain their final output for the shorter of the length of the event or 30 minutes.<sup>21</sup>

The MMU has reported the wide range of synchronized reserve event response levels and recommended that PJM take action to increase compliance rates. Penalties can be assessed for any synchronized reserve event 10 minutes or longer during which flexible or inflexible synchronized reserve was scheduled either by the resource owner or by PJM. In 2014, 20 synchronized reserve events occurred that met these criteria. In 2015, there were 21 spinning events of which seven were 10 minutes or longer.

<sup>19</sup> See the 2011 State of the Market Report for PJM, Volume II, Section 9, "Ancillary Services" at pg. 250.

<sup>20</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.10 Settlements, p. 77.

<sup>21</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.11 Verification, p. 78.

**Table 10-20 Synchronized reserve events greater than 10 minutes, Tier 2 response compliance, RTO Reserve Zone: 2015**

2015 Qualifying Synchronized Reserve Event (DD-Mon-YYYY HR)	Event Duration (Minutes)	Total Scheduled Tier 2 MW	Tier 2 Response MW	Percent T2 Compliance
03-Mar-2015 17	11	480.4	272.3	56.7%
16-Mar-2015 10	24	248.0	180.2	72.7%
17-Mar-2015 23	17	247.2	232.8	94.2%
23-Mar-2015 23	15	273.5	205.8	75.2%
07-Apr-2015 16	31	485.7	455.5	93.8%
30-Jul-2015 10	10	79.7	24.0	30.1%
28-Sep-2015 19	11	782.0	639.4	81.8%

Tier 1 resource owners are credited for the amount of synchronized reserve they provide in response to a synchronized reserve event.<sup>22</sup> Tier 2 resources owner are not credited for synchronized reserve event response. Tier 2 resources owners are penalized in the amount of their shortfall at SRMCP for the lesser of the average number of days between events, or the number of days since the previous event in which the resource did respond. For synchronized reserve events of ten minutes or longer that occurred 2015, 21.2 percent of all scheduled tier 2 synchronized reserve MW were not delivered and were penalized (Table 10-20). In addition, a tier 2 resource will be penalized for the amount of MW it falls short of its offer for the entire hour, not just for the portion of the hour covered by the synchronized reserve event.<sup>23</sup> Resource owners are permitted to aggregate the response of multiple units to offset an under response from one unit with an overresponse from a different unit for the purpose of reducing an underresponse penalty. The average number of days between events calculated by PJM Performance Compliance for 2015 is 13 days.<sup>24</sup>

<sup>22</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.12 Non Performance, p. 78.

<sup>23</sup> See PJM. "Manual 28: Operating Agreement Accounting," Revision 71 (June 1, 2015) p. 45. See also "Manual 11: Energy & Ancillary Services Market Operations," Revision 75 (April 9, 2015) § 4.2.12 Non-Performance, p. 77.

<sup>24</sup> Report to PJM Operating Committee, "Synchronized Reserve Event Performance and Penalty Days," December 3, 2014.

## History of Synchronized Reserve Events

Synchronized reserve is designed to provide relief for disturbances.<sup>25</sup> <sup>26</sup> A disturbance is defined as loss of generation and/or transmission resources. PJM also calls synchronized reserve events for non-disturbance events, which it characterizes as “low ACE.” In the absence of a disturbance, PJM dispatchers have used synchronized reserve as a source of energy to provide relief from low ACE. Such an event occurred on January 6, 2014. Five synchronized reserve events were declared during 2014 for low ACE. Five spinning events were declared for low ACE in 2015. The risk of using synchronized reserves for energy or any non-disturbance reason is that it reduces the amount of synchronized reserve available for a disturbance. Synchronized reserve has a requirement to sustain its output for up to thirty minutes. When the need is for reserve extending past thirty 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 indicated 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 disturbance.

From January 2010 through December 2015, PJM experienced 167 synchronized reserve events (Table 10-21), approximately three events per month. Synchronized reserve events had an average length of 13 minutes. Note that the number of synchronized reserve events with a duration less than ten minutes is higher in 2015 than any prior year (Figure 10-14). This corresponds with the higher rate of compliance by tier 2 synchronized reserve resources, and the higher rate of response by tier 1 resources to spinning event all calls.

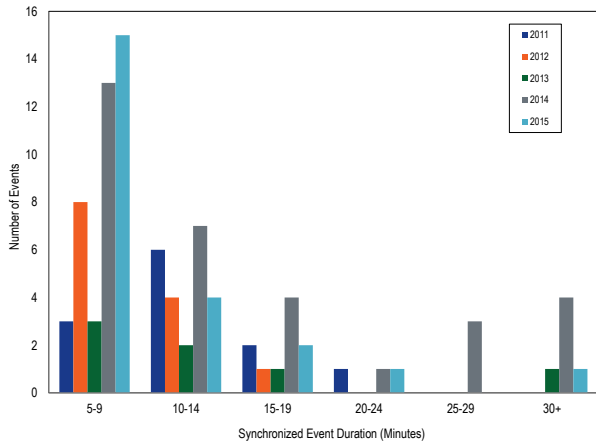
<sup>25</sup> 2013 State of the Market Report for PJM, Appendix F – PJM’s DCS Performance, pp 451–452.

<sup>26</sup> See PJM, “Manual 12: Balancing Operations,” Revision 33 (December 1, 2015) § 4.1.2 Loading Reserves pp. 36.

Table 10-21 Synchronized reserve events, January 2010 through December 2015

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
FEB-18-2010 13:27	Mid-Atlantic	19	JAN-11-2011 15:10	Mid-Atlantic	6	JAN-03-2012 16:51	RFC	9
MAR-18-2010 11:02	RFC	27	FEB-02-2011 01:21	RFC	5	JAN-06-2012 23:25	RFC	8
MAR-23-2010 20:14	RFC	13	FEB-08-2011 22:41	Mid-Atlantic	11	JAN-23-2012 15:02	Mid-Atlantic	8
APR-11-2010 13:12	RFC	9	FEB-09-2011 11:40	Mid-Atlantic	16	MAR-02-2012 19:54	RFC	9
APR-28-2010 15:09	Mid-Atlantic	8	FEB-13-2011 15:35	Mid-Atlantic	14	MAR-08-2012 17:04	RFC	6
MAY-11-2010 19:57	Mid-Atlantic	9	FEB-24-2011 11:35	Mid-Atlantic	14	MAR-19-2012 10:14	RFC	10
MAY-15-2010 03:03	RFC	6	FEB-25-2011 14:12	RFC	10	APR-16-2012 00:20	Mid-Atlantic	9
MAY-28-2010 04:06	Mid-Atlantic	5	MAR-30-2011 19:13	RFC	12	APR-16-2012 11:18	RFC	8
JUN-15-2010 00:46	RFC	34	APR-02-2011 13:13	Mid-Atlantic	11	APR-19-2012 11:54	RFC	16
JUN-19-2010 23:49	Mid-Atlantic	9	APR-11-2011 00:28	RFC	6	APR-20-2012 11:08	Mid-Atlantic	7
JUN-24-2010 00:56	RFC	15	APR-16-2011 22:51	RFC	9	JUN-20-2012 13:35	RFC	7
JUN-27-2010 19:33	Mid-Atlantic	15	APR-21-2011 20:02	Mid-Atlantic	6	JUN-26-2012 17:51	RFC	7
JUL-07-2010 15:20	RFC	8	APR-27-2011 01:22	RFC	8	JUL-23-2012 21:45	RFC	18
JUL-16-2010 20:45	Mid-Atlantic	19	MAY-02-2011 00:05	Mid-Atlantic	21	AUG-03-2012 12:44	RFC	10
AUG-11-2010 19:09	RFC	17	MAY-12-2011 19:39	RFC	9	SEP-08-2012 04:34	RFC	12
AUG-13-2010 23:19	RFC	6	MAY-26-2011 17:17	Mid-Atlantic	20	SEP-27-2012 17:19	Mid-Atlantic	7
AUG-16-2010 07:08	RFC	17	MAY-27-2011 12:51	RFC	6	OCT-17-2012 10:48	RTO	10
AUG-16-2010 19:39	Mid-Atlantic	11	MAY-29-2011 09:04	RFC	7	OCT-23-2012 22:29	RTO	19
SEP-15-2010 11:20	RFC	13	MAY-31-2011 16:36	RFC	27	OCT-30-2012 05:12	RTO	14
SEP-22-2010 15:28	Mid-Atlantic	24	JUN-03-2011 14:23	RFC	7	NOV-25-2012 16:32	RTO	12
OCT-05-2010 17:20	RFC	10	JUN-06-2011 22:02	Mid-Atlantic	9	DEC-16-2012 07:01	RTO	9
OCT-16-2010 03:22	Mid-Atlantic	10	JUN-23-2011 23:26	RFC	8	DEC-21-2012 05:51	RTO	7
OCT-16-2010 03:25	RFCNonMA	7	JUN-26-2011 22:03	Mid-Atlantic	10	DEC-21-2012 10:29	RTO	5
OCT-27-2010 10:35	RFC	7	JUL-10-2011 11:20	RFC	10			
OCT-27-2010 12:50	Mid-Atlantic	10	JUL-28-2011 18:49	RFC	12			
NOV-26-2010 14:24	RFC	13	AUG-02-2011 01:08	RFC	6			
NOV-27-2010 11:34	RFC	8	AUG-18-2011 06:45	Mid-Atlantic	6			
DEC-08-2010 01:19	RFC	11	AUG-19-2011 14:49	RFC	5			
DEC-09-2010 20:07	RFC	5	AUG-23-2011 17:52	RFC	7			
DEC-14-2010 12:02	Mid-Atlantic	24	SEP-24-2011 15:48	RFC	8			
DEC-16-2010 18:40	Mid-Atlantic	20	SEP-27-2011 14:20	RFC	7			
DEC-17-2010 22:09	Mid-Atlantic	6	SEP-27-2011 16:47	RFC	9			
DEC-29-2010 19:01	Mid-Atlantic	15	OCT-30-2011 22:39	Mid-Atlantic	10			
			DEC-15-2011 14:35	Mid-Atlantic	8			
			DEC-21-2011 14:26	RFC	18			

Figure 10-14 Synchronized reserve events duration distribution curve: 2011 through 2015



## Non-Synchronized Reserve Market

Non-synchronized reserve is reserve MW available within ten minutes but not synchronized to the grid. There is no defined requirement for non-synchronized 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 non-synchronized reserves. Generation resources that are not available to provide energy are not eligible to provide non-synchronized reserves.

Startup time for non-synchronized reserve resources is not subject to testing. There is no non-synchronized reserve offer MW or offer price. The market solution software evaluates all eligible resources and schedules them economically.

Table 10-21 Synchronized reserve events, January 2010 through December 2015 (continued)

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
JAN-22-2013 08:34	RTO	8	JAN-06-2014 22:01	RTO	68	JAN-07-2015 22:36	RTO	8
JAN-25-2013 15:01	RTO	19	JAN-07-2014 02:20	RTO	25	FEB-24-2015 02:51	RTO	5
FEB-09-2013 22:55	RTO	10	JAN-07-2014 04:18	RTO	34	FEB-26-2015 15:20	RTO	6
FEB-17-2013 23:10	RTO	13	JAN-07-2014 11:27	RTO	11	MAR-03-2015 17:02	RTO	11
APR-17-2013 01:11	RTO	11	JAN-07-2014 13:20	RTO	41	MAR-16-2015 10:25	RTO	24
APR-17-2013 20:01	RTO	9	JAN-10-2014 16:46	RTO	12	MAR-17-2015 23:34	RTO	17
MAY-07-2013 17:33	RTO	8	JAN-21-2014 18:52	RTO	6	MAR-23-2015 23:44	RTO	15
JUN-05-2013 18:54	RTO	20	JAN-22-2014 02:26	RTO	7	APR-06-2015 14:23	RTO	8
JUN-08-2013 15:19	RTO	9	JAN-22-2014 22:54	RTO	8	APR-07-2015 17:11	RTO	31
JUN-12-2013 17:35	RTO	10	JAN-25-2014 05:22	RTO	10	APR-15-2015 08:14	RTO	8
JUN-30-2013 01:22	RTO	10	JAN-26-2014 17:11	RTO	6	APR-25-2015 03:21	RTO	9
JUL-03-2013 20:40	RTO	13	JAN-31-2014 15:05	RTO	13	JUL-30-2015 14:04	RTO	10
JUL-15-2013 18:43	RTO	29	FEB-02-2014 14:03	Dominion	8	AUG-05-2015 19:47	RTO	7
JUL-28-2013 14:20	RTO	10	FEB-08-2014 06:05	Dominion	18	AUG-19-2015 16:47	RTO	9
SEP-10-2013 19:48	RTO	68	FEB-22-2014 23:05	RTO	7	SEP-05-2015 01:16	RTO	7
OCT-28-2013 10:44	RTO	33	MAR-01-2014 05:18	RTO	26	SEP-10-2015 10:12	RTO	8
DEC-01-2013 11:17	RTO	9	MAR-05-2014 21:25	RTO	8	SEP-29-2015 00:58	Mid-Atlantic	11
DEC-07-2013 19:44	RTO	7	MAR-13-2014 20:39	RTO	8	NOV-12-2015 16:42	RTO	8
			MAR-27-2014 10:37	RTO	56	NOV-21-2015 17:17	RTO	8
			APR-14-2014 01:16	RTO	10	DEC-04-2015 22:41	RTO	7
			APR-25-2014 17:33	RTO	6	DEC-24-2015 17:42	RTO	8
			MAY-01-2014 14:18	RTO	13			
			MAY-03-2014 17:11	RTO	13			
			MAY-14-2014 01:36	RTO	5			
			JUL-08-2014 03:07	RTO	9			
			JUL-25-2014 19:19	RTO	7			
			SEP-06-2014 13:32	RTO	18			
			SEP-20-2014 23:42	RTO	14			
			SEP-29-2014 10:08	RTO	15			
			OCT-20-2014 06:35	RTO	15			
			OCT-23-2014 11:03	RTO	27			
			NOV-01-2014 06:50	RTO	9			
			NOV-08-2014 02:08	RTO	8			
			NOV-22-2014 05:27	RTO	21			
			NOV-22-2014 08:19	RTO	10			
			DEC-10-2014 18:58	RTO	8			
			DEC-31-2014 21:42	RTO	12			

Prices are determined solely by the lost opportunity cost created by any deviation from economic merit order required to maintain the non-synchronized reserve commitment. Since non-synchronized reserve is a lower quality product, its clearing price is always less than or equal to the synchronized reserve market clearing price. In most hours, the non-synchronized reserve clearing price is zero.

## Market Structure

### Demand

PJM specifies that 1,700 MW of ten minute primary reserve must be available in the Mid-Atlantic Dominion Reserve Subzone of which 1,450 MW must be synchronized reserve (Figure 10-2), and that 2,175 MW of ten minute primary reserve must be available in the RTO Reserve Zone of which 1,450 MW must be synchronized reserve (Figure 10-3). The balance of primary reserve can be made up by the most economic combination of synchronized and non-synchronized reserve.

### Supply

Figure 10-2 shows that most of the primary reserve requirement (orange line) in excess of the synchronized reserve requirement (yellow line) is satisfied by non-synchronized reserve (light blue area).

There are no offers for non-synchronized reserve. Neither MW nor price is offered for non-synchronized reserve. The market solution (ASO) optimizes synchronized reserve, non-synchronized reserve, and energy to satisfy the primary reserve requirement at the lowest cost. Non-synchronized reserve resources are scheduled economically based on LOC until the Primary Reserve requirement is filled. The non-synchronized reserve market clearing price is determined at the end of the hour as the marginal unit's LOC. When a unit clears the non-synchronized reserve market and is scheduled, it is committed to remain off-line for the hour and available to provide ten minute reserves.

Equipment that generally qualifies as non-synchronized reserve include run of river hydro, pumped hydro,

## Ancillary Service Markets

The United States Federal Energy Regulatory Commission (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.<sup>1</sup> 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.<sup>2</sup> Although not defined by the FERC as an ancillary service, black start service plays a comparable role. Black start service is provided on the basis of formulaic rates or cost.

The Market Monitoring Unit (MMU) analyzed measures of market structure, conduct and performance for the PJM Regulation Market, the PJM Synchronized Reserve Market, and the PJM DASR Market for 2015.

**Table 10-1 The Regulation Market results were competitive**

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

- The Regulation Market structure was evaluated as not competitive for 2015 because the Regulation Market failed the three pivotal supplier (TPS) test in 97.8 percent of the hours in 2015.
- Participant behavior in the Regulation Market was evaluated as competitive for 2015 because market power mitigation requires competitive offers when the three pivotal supplier test is failed and there was no evidence of generation owners engaging in anti-competitive behavior.
- Market performance was evaluated as competitive, despite significant issues with the market design.
- Market design was evaluated as flawed. While the design of the Regulation Market was significantly improved with changes introduced October 1, 2012, a number of issues remain. The market design

<sup>1</sup> 75 FERC ¶ 61,080 (1996).

<sup>2</sup> Energy imbalance service refers to the Real-Time Energy Market.

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.

**Table 10-2 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 competitive, cost based offers, although there is concern about failure to comply with the must offer requirement.
- 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 compensated when the non-synchronized reserve market clears with a nonzero price.

**Table 10-3 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 Day-Ahead Scheduling Reserve Market structure was evaluated as not competitive because market participants failed the three pivotal supplier test in 6.4 percent of all cleared hours in 2015.
- 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.

- Market design was evaluated as mixed because while the market is functioning effectively to provide DASR, the three pivotal supplier test and appropriate market power mitigation should be added to the market to ensure that market power cannot be exercised at times of system stress.

## Overview

### Primary Reserve

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

### Market Structure

- **Supply.** Primary reserve is satisfied by both synchronized reserve (generation or demand response currently synchronized to the grid and available within ten minutes), and non-synchronized reserve (generation currently off-line but available to start and provide energy within ten minutes).
- **Demand.** The PJM primary reserve requirement is 150 percent of the largest contingency. The primary reserve requirement in the RTO Zone was raised on January 8, 2015, to 2,175 MW of which at least 1,700 MW must be available within the Mid-Atlantic Dominion (MAD) Subzone. Adjustments to the primary reserve requirement can occur when grid maintenance or outages change the largest contingency. The actual demand for primary reserve in the RTO Zone in 2015 was 2,210.3 MW. The actual demand for primary reserve in the MAD Subzone in 2015 was 1,713.3 MW.

### Tier 1 Synchronized Reserve

Synchronized reserve is energy or demand reduction synchronized to the grid and capable of increasing output or decreasing load within ten minutes. Synchronized reserve is of two distinct types, tier 1 and tier 2.

Tier 1 synchronized reserve is part of primary reserve and is the capability of on-line resources following economic dispatch to ramp up in ten 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 reserve. The market solution estimates tier 1 synchronized reserve as available 10-minute ramp from the energy dispatch. In 2015, there was an average hourly supply of 1,363.9 MW of tier 1 for the RTO Synchronized Reserve Zone, and an average hourly supply of 1,159.6 MW of tier 1 in the Mid-Atlantic Dominion Subzone.
- **Demand.** The default hourly required synchronized reserve requirement is 1,450 MW in the RTO Reserve Zone and 1,450 MW for the Mid-Atlantic Dominion Reserve Subzone. The requirement can be met with tier 1 or tier 2 synchronized reserves.
- **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 the average of five-minute LMPs during the event, rather than hourly integrated LMP, plus \$50/MW. This is the Synchronized Energy Premium Price. The synchronized reserve event response credits for tier 1 response are independent of the tier 2 synchronized reserve market clearing price and independent of the non-synchronized reserve market clearing price.

Of tier 1 synchronized reserve estimated at market clearing, 65.7 percent actually responded during the seven distinct synchronized reserve events longer than ten minutes in 2015. PJM made changes to the way it calculated tier 1 MW for settlements beginning in July 2014. These changes improved the reported response rate by reducing the initial tier 1 estimate.

- **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 five-minute LMP plus \$50 per MWh. A tariff change included in the shortage pricing tariff changes (October 1, 2012) added the requirement to pay

<sup>3</sup> See PJM, "Manual 10: Pre-Scheduling Operations," Revision. 33 (December 22, 2015), p. 24.

tier 1 synchronized reserve the tier 2 synchronized reserve market clearing price whenever the non-synchronized 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, resulting in a windfall payment of \$10,406,363 to tier 1 resources in 2014, and \$34,135,671 in 2015.

## 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 incur costs to be synchronized, that have an obligation to respond with corresponding penalties, and that must be dispatched in order to satisfy the synchronized reserve requirement.

When the synchronized reserve requirement cannot be met with tier 1 synchronized reserve, PJM conducts a market to satisfy the balance of the requirement with tier 2 synchronized reserve. 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 2015, the supply of offered and eligible synchronized reserve was 8,549 MW in the RTO Zone of which 3,114 MW (including DSR) was available to the MAD Subzone. This was sufficient to cover the requirement in both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.
- **Demand.** The default hourly required synchronized reserve requirement was 1,450 MW in the RTO Reserve Zone and 1,450 MW for the Mid-Atlantic Dominion Reserve Subzone. The requirement can be met with tier 1 or tier 2 synchronized reserves.
- **Market Concentration.** In 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone was 5436 which is classified as highly concentrated. The MMU calculates that 55.7 percent of hours would have failed a three pivotal supplier test in the Mid-Atlantic Dominion Subzone.

In 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the RTO Synchronized

Reserve Zone was 4617 which is classified as highly concentrated. The MMU calculates that 40.2 percent of hours would have failed a three pivotal supplier test in the RTO Synchronized Reserve Zone.

The MMU concludes from these results that 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 2015.

### Market Conduct

- **Offers.** There is a must offer requirement for tier 2 synchronized reserve. All non-emergency generation capacity resources are required to submit a daily offer for tier 2 synchronized reserve. 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.

### Market Performance

- **Price.** The weighted average price for tier 2 synchronized reserve for all cleared hours in the Mid-Atlantic Dominion (MAD) Subzone was \$10.12 per MW in 2015, a decrease of \$5.38, 34.7 percent from 2014.

The weighted average price for tier 2 synchronized reserve for all cleared hours in the RTO Synchronized Reserve Zone was \$11.88 per MW in 2015, a decrease of \$1.06, 8.2 percent from 2014.

### Non-Synchronized Reserve Market

Non-synchronized reserve is part of primary reserve and includes the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone (MAD). Non-synchronized reserve is comprised of non-emergency energy resources not currently synchronized to the grid that can provide energy within ten minutes. Non-synchronized reserve is available to fill the primary reserve requirement above the synchronized reserve requirement. There is no formal market for non-synchronized reserve.



## Market Structure

- **Supply.** In 2015, the supply of eligible non-synchronized reserve was 2,550.1 MW in the RTO Zone and 1,860.8 MW in MAD Subzone.<sup>4</sup>
- **Demand.** Demand for non-synchronized reserve is the remaining primary reserve requirement after tier 1 synchronized reserve is estimated and tier 2 synchronized reserve is scheduled. In the RTO Zone, the market cleared an hourly average of 345.1 MW of non-synchronized reserve in 2015. In the MAD Subzone, the market cleared an hourly average of 390.3 MW of non-synchronized reserve.
- **Market Concentration.** In 2015, the weighted average HHI for cleared non-synchronized reserve in the Mid-Atlantic Dominion Subzone was 4133 which is classified as highly concentrated. In the RTO Zone the weighted average HHI was 4533 which is also highly concentrated. The MMU calculates that 95.1 percent of hours would have failed a three pivotal supplier test in the Mid-Atlantic Dominion Subzone and 68.0 hours would have failed a three pivotal supplier test in the RTO Zone.

## Market Conduct

- **Offers.** No offers are made for non-synchronized reserve. Non-emergency generation resources that are available to provide energy and can start in 10 minutes or less are considered available for non-synchronized reserves by the market solution software.

## Market Performance

- **Price.** The non-synchronized reserve price is determined by the opportunity cost of the marginal non-synchronized reserve unit. The non-synchronized reserve weighted average price for all cleared hours in the RTO Reserve Zone was \$1.15 per MW in 2015 and in 87.9 percent of hours the market clearing price was \$0. The non-synchronized reserve weighted average price for all cleared hours in the Mid-Atlantic Dominion (MAD) Subzone was \$1.03 and in 87.6 percent of hours the market clearing price was \$0.

<sup>4</sup> See PJM. "Manual 11; Energy & Ancillary Services Markets," Revision 79 (December 17, 2015), p. 81. "Because Synchronized Reserve may be utilized to meet the Primary Reserve requirement, there is no explicit requirement for non-synchronized reserves."

## Secondary Reserve (Day-Ahead Scheduling Reserve)

PJM maintains a day-ahead, offer-based market for 30-minute secondary reserve, designed to provide price signals to encourage resources to provide 30-minute reserve.<sup>5</sup> The DASR Market has no performance obligations.

## 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 per MW. DASR is calculated by the day-ahead market solution as the lesser of the thirty minute energy ramp rate or the emergency maximum MW minus the day-ahead dispatch point for all on-line units. In 2015, the average available hourly DASR was 36,396.0 MW.
- **Demand.** The DASR requirement in 2015 was 5.93 percent of peak load forecast, down from 6.27 percent in 2014. The average DASR MW purchased was 6,245.0 MW per hour 2015.
- **Concentration.** In 2015, the DASR Market would have failed a three pivotal supplier test in 4.1 percent of hours.

## Market Conduct

- **Withholding.** Economic withholding remains an issue in the DASR Market. The direct marginal cost of providing DASR is zero. All offers greater than zero constitute economic withholding. In 2015 a daily average of 37.9 percent of units offered above \$0. In 2015 a daily average of 11.6 percent of units offered above \$5.
- **DR.** Demand resources are eligible to participate in the DASR Market. Six demand resources have entered offers for DASR.

## Market Performance

- **Price.** The weighted average DASR market clearing price for all cleared hours in 2015 was \$2.99 per MW, an increase from \$0.63 per MW in 2014.

<sup>5</sup> See PJM. "Manual 35: Definitions and Acronyms," Revision 23 (April 11, 2014), p. 22.

## 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 a regulation signal (RegA or RegD). PJM jointly optimizes regulation with synchronized reserve and energy to provide all three services at least cost. The PJM regulation market design includes three clearing price components: capability; performance; and lost opportunity cost. The marginal benefit factor and performance score translate a resource's capability in actual MW into effective MW.

## Market Structure

- **Supply.** In 2015, the average hourly eligible supply of regulation was 1,157.8 actual MW (889.9 effective MW). This is a decrease of 122.5 actual MW (27.5 effective MW) from the same period of 2014, when the average hourly eligible supply of regulation was 1,280.3 actual MW (917.4 effective MW).
- **Demand.** The average hourly regulation demand was 640.9 actual MW (663.7 effective MW) in 2015. This is a decrease of 19.8 actual MW (0 effective MW) in the average hourly regulation demand of 660.7 actual MW (663.7 effective MW) from the same period of 2014.
- **Supply and Demand.** The ratio of the average hourly eligible supply of regulation to average hourly regulation demand required was 1.81. This is a 6.70 percent decrease from the same period of 2014 when the ratio was 1.94.
- **Market Concentration.** In 2015, the weighted average (HHI) was 1358 which is classified as moderately concentrated. In 2015, the three pivotal supplier test was failed in 97.8 percent of hours.

## 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.<sup>6</sup> In 2015, there were 291 resources following

the RegA signal and 57 resources following the RegD signal.

## Market Performance

- **Price and Cost.** The weighted average clearing price for regulation was \$31.92 per effective MW of regulation in 2015, a decrease of \$12.55 per MW, or 28.2 percent, from the same period of 2014. The cost of regulation in 2015 was \$38.36 per effective MW of regulation, a decrease of \$15.46 per MW, or 28.7 percent, from the same period of 2014. The decreases in regulation price and regulation cost resulted primarily from high energy prices in 2014, particularly in January.
- **RMCP Credits.** 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, pricing, and settlement processes. If the Regulation Market were functioning efficiently, RegD and RegA resources would be paid the same price per effective MW.
- **Marginal Benefit Factor Function.** The marginal benefit factor (MBF) measures the substitutability of RegD resources for RegA resources. The marginal benefit factor function is incorrectly applied in the market clearing and incorrectly describes the operational relationship between RegA and RegD.
- **Interim changes to the MBF function.** On December 14, 2015, PJM changed the MBF curve. The modification to the marginal benefit curve did not correct the identified issues with the optimization engine.

## 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).<sup>7</sup>

In 2015, total black start charges were \$53.6 million with \$48.4 million in revenue requirement charges

<sup>6</sup> See the 2015 State of the Market Report for PJM, Volume II, Appendix F "Ancillary Services Markets."

<sup>7</sup> OATT Schedule 1 § 1.3BB.

and \$5.2 million in 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. Black start operating reserve 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 2015 ranged from \$0.04 per MW-day in the PPL Zone (total charges were \$118,541) to \$3.81 per MW-day in the BGE Zone (total charges were \$9,277,796).

## Reactive

Reactive service, reactive supply and voltage control are provided by generation and other sources of reactive power (measured in VAR). Reactive power helps maintain appropriate voltages on the transmission system and is essential to the flow of real power (measured in MW).

In 2015, total reactive service charges were \$289.0 million, a 6.1 percent decrease from \$307.7 million in 2014. Revenue requirement charges decreased from \$281.2 million to \$278.4 million and operating reserve charges fell from \$26.5 million to \$10.7 million. Total charges in 2015 ranged from \$2,488 in the RECO Zone to \$38.5 million in the AEP Zone. Reactive service revenue requirements are based on FERC approved filings. Reactive service operating reserve charges are paid for scheduling in the Day-Ahead Energy Market and committing in real time units that provide reactive service.

## Ancillary Services Costs per MWh of Load: 2004 through 2015

Table 10-4 shows PJM ancillary services costs for 2004 through 2015, 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. 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: 2004 through 2015<sup>8</sup>**

Year	Regulation	Scheduling, Dispatch, and System Control	Reactive	Synchronized Reserve	Total
2004	\$0.50	\$0.60	\$0.25	\$0.13	\$1.48
2005	\$0.79	\$0.47	\$0.26	\$0.11	\$1.63
2006	\$0.53	\$0.48	\$0.29	\$0.08	\$1.38
2007	\$0.63	\$0.47	\$0.29	\$0.06	\$1.45
2008	\$0.68	\$0.40	\$0.31	\$0.08	\$1.47
2009	\$0.34	\$0.32	\$0.37	\$0.05	\$1.08
2010	\$0.34	\$0.38	\$0.41	\$0.07	\$1.20
2011	\$0.32	\$0.34	\$0.42	\$0.10	\$1.18
2012	\$0.26	\$0.40	\$0.43	\$0.04	\$1.13
2013	\$0.24	\$0.39	\$0.80	\$0.04	\$1.47
2014	\$0.31	\$0.37	\$0.37	\$0.20	\$1.25
2015	\$0.23	\$0.41	\$0.37	\$0.12	\$1.13

## Recommendations

- The MMU recommends that the Regulation Market be modified to incorporate a consistent application of the marginal benefit factor throughout the optimization, assignment and settlement process. (Priority: High. First reported 2012. Status: Not adopted.)
- The MMU recommends a number of market design changes to improve the performance of the Regulation Market, including use of a single clearing price based on actual LMP, modifications to the LOC calculation methodology, a software change to save some data elements necessary for verifying market outcomes, and further documentation of the implementation of the market design through SPREGO. (Priority: Medium. First reported 2010. Status: Partially adopted in 2012.)
- 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 in the energy market. (Priority: High. First reported 2010. Status: Partially Adopted.)
- The MMU recommends that the single clearing price for synchronized reserves be determined based on the actual LMP and not the forecast LMP. (Priority: Low. First reported 2010. Status: Adopted, 2012.)

<sup>8</sup> Table 10-4 no longer includes the heading for "Supplemental Operating Reserve" costs. This heading included day-ahead and balancing operating reserve charges. These charges are accounted for in the Energy Uplift (Operating Reserves) section.

- The MMU recommends that the rule requiring the payment of tier 1 synchronized reserve resources when the non-synchronized reserve price is above zero be eliminated immediately. (Priority: High. First reported 2013. Status: Not adopted. Stakeholder process.)
- The MMU recommends that no payments be made to tier 1 resources if they are deselected in the PJM market solution. The MMU also recommends that documentation of the Tier 1 synchronized reserve deselection process be published. (Priority: High. First reported Q3, 2014. Status: Adopted July 2014.)
- 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 operators to select a reason in eMkt whenever making a unit unavailable. (Priority: Medium. First reported 2013. Status: Not adopted.)
- The MMU recommends that PJM be explicit about why tier 1 biasing is used in the Tier 2 Synchronized Reserve Market. The MMU recommends that PJM define explicit rules for the use of tier 1 biasing during any phase of the market solution and identify the relevant rule for each instance of biasing. (Priority: Low. First reported 2012. Status: Not adopted.)
- The MMU recommends that PJM replace the DASR Market with a real-time secondary reserve product that is available and dispatchable in real time. (Priority: Low. First reported 2013. Status: Not adopted.)
- The MMU recommends that PJM revise the current confidentiality rules in order to specifically allow a more transparent disclosure of information regarding black start resources and their associated payments in PJM. (Priority: Low. First reported 2013. Status: Partially adopted, 2014.)
- The MMU recommends that the three pivotal supplier test and market power mitigation be incorporated in the DASR Market. (Priority: Low. First reported 2009. 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 Q2, 2015. Status: not adopted.)

## Conclusion

While the design of the Regulation Market was significantly improved with changes introduced October 1, 2012, a number of issues remain. The market results continue to include the incorrect definition of opportunity cost. The market design has failed to correctly incorporate the marginal benefit factor in optimization, pricing and settlement. The market design uses the marginal benefit factor in the optimization and pricing, but a mileage ratio in settlement. This failure to correctly incorporate marginal benefit factor into the regulation market design has resulted in both underpayment and overpayment of RegD resources and in the over procurement of RegD resources in some hours. These issues have led to the MMU's conclusion that the regulation market design is flawed.

The structure of each 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 service 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, compliance with calls to respond to actual synchronized reserve events has been an issue. The must offer requirement for tier 2 synchronized reserve has not been enforced.

The rule that requires payment of the tier 2 synchronized reserve price to tier 1 synchronized reserve resources when the non-synchronized reserve price is greater than zero, is inefficient and results in a substantial windfall payment to the holders of tier 1 synchronized reserve resources. Such tier 1 resources have no obligation to perform and pay no penalties if they do not perform. Tier 1 resources are paid for their response if they do respond. Such resources are not tier 2 resources, although they have the option to offer as tier 2, to take on tier 2 obligations and to be paid as tier 2. If tier 1 resources wish to be paid as tier 2 resources, that option is available. Application of this rule added \$10.4 million

to the cost of primary reserve in 2014 and \$34.1 million to the cost of primary reserve in 2015.

The benefits of markets are realized under these approaches to ancillary service markets. Even in the presence of structurally noncompetitive markets, there 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 competitive. The MMU concludes that the synchronized reserve market results were competitive. The MMU concludes that the DASR market results were competitive, although there is concern about offers above the competitive level affecting prices.

## Primary Reserve

PJM has an obligation to maintain ten minute reserves (primary reserve) to ensure reliability in the event of disturbances. PJM's primary reserves are made up of resources, both synchronized and non-synchronized, that can provide energy within ten minutes. Primary reserve is PJM's implementation of the NERC 10-minute contingency reserve requirement.<sup>9</sup> The NERC requirement is to carry sufficient contingency reserves to meet load requirements reliably and economically and provide reasonable protection against instantaneous load variations due to load forecasting error or loss of system capability due to generation malfunction.<sup>10</sup>

## Market Structure

### Supply

In 2015, PJM's primary reserve requirement was 2,175 MW for the RTO Zone, and 1,700 MW for the MAD Subzone. It is satisfied by tier 1 synchronized reserves, tier 2 synchronized reserves and non-synchronized reserves, subject to the requirement that synchronized reserves equal 100 percent of the largest contingency. The synchronized reserve requirement is 1,450 MW in both the Mid-Atlantic Dominion Subzone, and the RTO

Zone. After the synchronized reserve requirement is satisfied, the remainder of primary reserves can come from the least expensive combination of synchronized and non-synchronized reserves.

Estimated tier 1 is credited against PJM's primary reserve requirement. In the MAD Subzone an average of 1,159.7 MW of tier 1 was identified by the ASO market solution as available hour ahead (Table 10-6). This tier 1 reduced the amount of tier 2 and non-synchronized reserve needed to fill the synchronized reserve and primary reserve requirements. Tier 1 synchronized reserve fully satisfied the MAD Subzone synchronized reserve requirement in only 1.1 percent of hours in 2015. In the RTO Zone, an average of 1,373.9 MW of tier 1 was available (Table 10-6). Tier 1 synchronized reserve fully satisfied the RTO Zone synchronized reserve requirement in 35.9 percent of all hours.

Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for Tier 2 Synchronized Reserve in eMKT prior to the offer submission deadline (1800 the day prior to the operating day). Offer MW and other non-cost offer details can be changed during the operating day. Owners are permitted to make resources unavailable for synchronized reserve daily or hourly but only if they are physically unavailable. Certain unit types including nuclear, wind, solar, and batteries, are expected to have zero MW tier 2 synchronized reserve offer quantities.<sup>11</sup>

After tier 1 is estimated, the remainder of the synchronized reserve requirement is met by tier 2. In the MAD Subzone, there was an average of 3,114.3 MW (including DSR) of eligible tier 2 synchronized reserve available (Figure 10-11) to meet the average tier 2 hourly demand of 314.8 MW (Table 10-5). In the RTO Zone, there was an average of 8,549.2 MW of eligible Tier 2 supply, available to meet the average hourly demand of 456.9 MW (Table 10-6).

In the MAD Subzone, there was an average of 1,860.8 MW of eligible non-synchronized reserve supply available to meet the average hourly demand of 390.3 MW (Table 10-6). In the RTO Zone, an hourly average of 2,550.1 MW supply was available to meet the average hourly demand of 736.3 MW (Table 10-5).

<sup>9</sup> PJM, OATT (effective 2/5/2014), p.1740; § 1.3.29 F Primary Reserve.

<sup>10</sup> NERC, IVGTF Task 2.4 Report; Operating Practices, Procedures, and Tools, March 2011, p. 20.

<sup>11</sup> See PJM, "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 67.

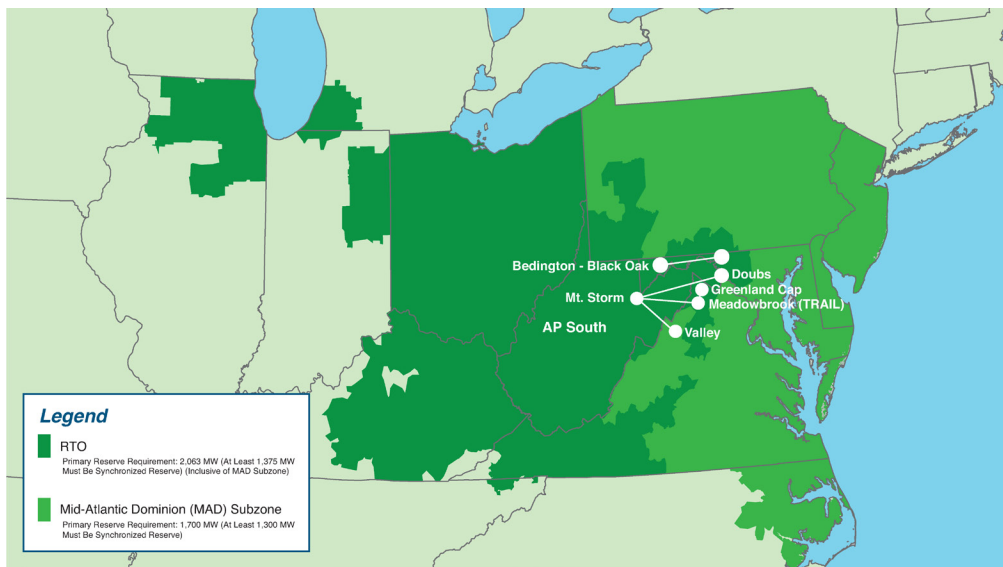
## Demand

PJM requires that 150 percent of the largest contingency on the system be maintained as primary reserve. Adjustments to this value can occur when grid maintenance or outages change the largest contingency or in cases of hot weather alerts or cold weather alerts.

On January 8, 2015, the default primary reserve requirement in the RTO Reserve Zone was raised from 2,063 MW to 2,175 MW and remained at 2,175 MW throughout 2015. In 10.2 percent of hours during 2015, PJM increased the primary reserve requirement for the RTO Zone. In 4.9 percent of hours PJM decreased the primary reserve requirement for the RTO Zone. The hourly average RTO primary reserve requirement was 2,210.3 MW in all of 2015. In 1.5 percent of hours in 2015, PJM increased the primary reserve requirement for the MAD Subzone. The actual hourly average demand for primary reserve in the MAD Subzone in all of 2015 was 1,713.3 MW.

Transmission constraints limit the deliverability of reserves within the RTO, requiring the definition of the Mid-Atlantic Dominion (MAD) Subzone.<sup>12</sup> Of the 2,175 MW RTO primary reserve requirement, 1,700 MW (Table 10-15) must be deliverable to the MAD Subzone (Figure 10-1).

**Figure 10-1 PJM RTO Zone and MAD Subzone geography: 2015**



<sup>12</sup> 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," Revision 78 (December 1, 2015), p. 69.

The Mid-Atlantic Dominion Reserve (MAD) Subzone is defined dynamically by the most limiting constraint separating MAD from the PJM RTO Reserve Zone. In 79.2 percent of hours in 2015, that constraint was the Bedington – Black Oak Interface. The AP South transfer interface constraint was the limiting constraint in 19.3 percent of hours.

PJM requires that synchronized reserves equal at least 100 percent of the largest contingency. This means that 1,450 MW of the primary reserve requirement must be synchronized reserve for both RTO Reserve Zone and the Mid Atlantic Dominion Reserve Subzone.

**Table 10-5 Average monthly tier 1 and tier 2 synchronized reserve, plus non-synchronized reserve used to satisfy the primary reserve requirement, MAD Subzone: 2015**

Year	Month	Average Tier 1 Synchronized Reserve MW	Average Tier 2 Synchronized Reserve MW	Average Non-Synchronized Reserve MW
2015	Jan	1,222.0	206.9	629.7
2015	Feb	1,176.7	305.1	437.4
2015	Mar	1,200.6	288.7	394.6
2015	Apr	1,148.8	302.8	381.3
2015	May	1,217.4	238.5	387.4
2015	Jun	1,260.3	216.6	372.1
2015	Jul	1,222.4	254.9	437.0
2015	Aug	1,176.9	293.9	421.7
2015	Sep	1,110.8	363.0	351.0
2015	Oct	1,054.4	478.5	263.6
2015	Nov	1,056.3	385.1	319.7
2015	Dec	1,069.1	443.6	288.6
2015	Average	1,159.6	314.8	390.3

**Table 10-6 Average monthly tier 1 and tier 2 synchronized reserve, and non-synchronized reserve used to satisfy the primary reserve requirement, RTO Zone: 2015**

Year	Month	Average Tier 1 Synchronized Reserve MW	Average Tier 2 Synchronized Reserve MW	Average Non-Synchronized Reserve MW
2015	Jan	1,582.7	331.7	1,074.4
2015	Feb	1,469.1	415.7	906.3
2015	Mar	1,247.2	424.8	928.5
2015	Apr	1,125.1	438.8	877.1
2015	May	1,245.1	373.1	811.5
2015	Jun	1,635.3	300.0	767.4
2015	Jul	1,620.5	320.1	752.3
2015	Aug	1,635.6	357.0	767.3
2015	Sep	1,419.2	449.9	703.1
2015	Oct	1,004.3	727.3	589.2
2015	Nov	1,217.2	616.8	347.9
2015	Dec	1,165.2	727.8	317.1
2015	Average	1,363.9	456.9	736.8

### Supply and Demand

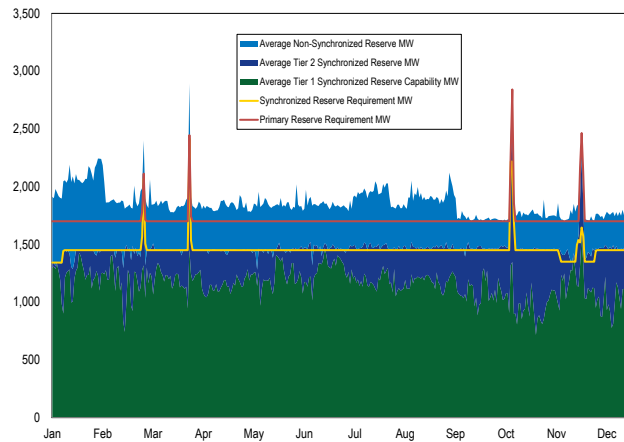
The market solution software relevant to reserves consists of: the Ancillary Services Optimizer (ASO) solving hourly; the intermediate term security constrained economic dispatch market solution (IT-SCED) solving every 15 minutes; and the real-time (short term) security constrained economic dispatch market solution (RT-SCED) solving every five minutes.

The ASO jointly optimizes energy, synchronized reserves, and non-synchronized reserves based on forecast system conditions to determine the most economic set of reserve resources to commit for the upcoming operating hour (before the hour commitments). IT-SCED runs at 15 minute intervals and jointly optimizes energy and reserves given the ASO’s inflexible unit commitments. IT-SCED estimates available tier 1 synchronized reserve and can commit additional reserves (flexibly or inflexibly) if its forecasts indicate a need. RT-SCED runs at five minute intervals and produces load forecasts up to 20 minutes ahead. The RT-SCED estimates the available tier 1 provides a real-time ancillary services solution and can commit additional tier 2 resources (flexibly or inflexibly) if it forecasts a need.

Figure 10-2 illustrates how the ASO satisfies the primary reserve requirement (orange line) for the Mid-Atlantic Dominion Subzone. For the Mid-Atlantic Dominion Reserve Zone primary reserve solution the ASO must first satisfy the synchronized reserve requirement (yellow line) which is generally 1,450 MW in the MAD Subzone.

Since the market solution considers tier 1 synchronized reserve to be zero cost, the ASO first estimates how much tier 1 synchronized reserve (green area) is available. If there is 1,450 MW of tier 1 available then ASO jointly optimizes synchronized reserve and non-synchronized reserve to assign the remaining primary reserve up to 1,700 MW. If there is not 1,450 MW of tier 1 then the remaining synchronized reserve requirement up to 1,450 MW is filled with tier 2 synchronized reserve (dark blue area). After 1,450 MW of synchronized reserve are assigned, the remaining 250 MW of the primary reserve requirement is filled by jointly optimizing synchronized reserve and non-synchronized reserve (light blue area). Since non-synchronized reserve is priced lower than or equal to synchronized reserve, almost all primary reserve between 1,450 MW and 1,700 MW is filled by non-synchronized reserve.

**Figure 10-2 Mid-Atlantic Dominion Subzone primary reserve MW by source (Daily Averages): 2015**



The solution methodology is similar for the RTO Reserve Zone (Figure 10-3) except that the required primary reserve MW is 2,175 MW.<sup>13</sup> Figure 10-3 shows how the hour ahead ASO satisfies the primary reserve requirement for the RTO Zone.

<sup>13</sup> Although tier 1 has a price of zero, changes made with shortage pricing on November 1, 2012, have given tier 1 a very high cost in some hours. This high cost raises questions about the economics of the solution methodology used by the ASO, IT-SCED, and RT-SCED market solutions which assume zero cost.

**Figure 10-3 RTO Reserve Zone primary reserve MW by source (Daily Averages): 2015**

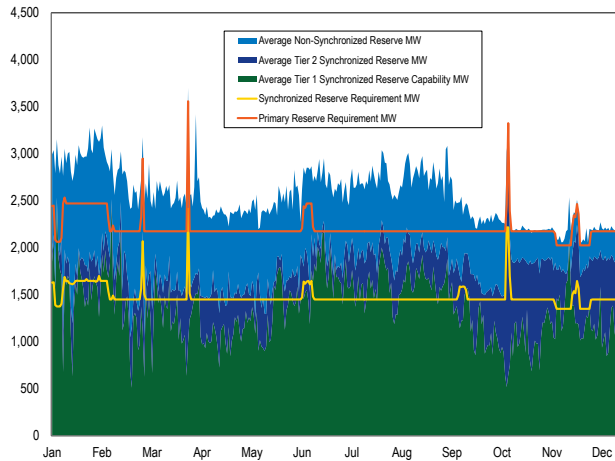


Figure 10-2 and Figure 10-3 show that tier 1 synchronized reserve remains the major contributor to satisfying the synchronized reserve requirements both in the RTO Zone and the Mid-Atlantic Dominion (MAD) Subzone.

## Price and Cost

There is a separate price and cost for each component of primary reserve. In the market solution, the cost of tier 1 synchronized reserves is zero except in defined circumstances, as there is no incremental cost associated with the ability to ramp up from the current economic dispatch point nor is there an obligation to ramp up during a synchronized reserve event. Tier 1 is credited when it responds to a synchronized reserve event. In addition, despite the absence of a performance obligation and an incremental cost to provide tier 1, PJM's current market rules require that tier 1 synchronized reserves be paid the tier 2 synchronized reserve market price in any hour that the non-synchronized reserve market clears with a price above \$0.

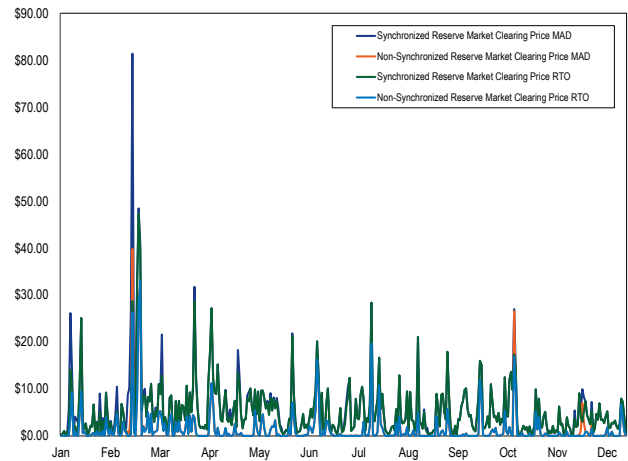
Under PJM's current market optimization approach, as available primary reserve approaches the primary reserve requirement the cost to serve the next MW of primary reserve is the non-synchronized reserve market clearing price (blue area in both Figure 10-2 and Figure 10-3).

In times of non-synchronized reserve shortage, the price of non-synchronized reserve will be capped at the currently effective penalty factor. Effective June 1, 2014, through May 31, 2015, the penalty factor for

both products is \$550 per MW. After June 1, 2015, the penalty factor is \$850 per MW. PJM will review the penalty factor annually.

Figure 10-4 shows daily average synchronized and non-synchronized market clearing prices in 2015.

**Figure 10-4 Daily weighted average market clearing prices (\$/MW) for synchronized reserve and non-synchronized reserve: 2015**



The cost of meeting PJM's primary reserve requirement (Figure 10-3) is shown in Table 10-7. Under most market conditions, most primary reserve identified by the hour ahead market solution is provided at no incremental cost by non-synchronized reserve and tier 1 synchronized reserve. The "Cost per MW" column is the total credits divided by the total MW of reserves. The "All-In Cost" column is the total credits paid divided by the load, or the total cost per MWh of energy to satisfy the primary reserve requirement.



**Table 10-7 MW credited, price, cost, and all-in price for primary reserve and its component products, RTO Reserve Zone: 2015**

Product	Share of Primary Reserve Requirement	MW Scheduled	Credits Paid	Price Per MW Reserve	Cost Per MW Reserve	All-In Cost
Tier 1 Synchronized Reserve Response	NA	7,145	\$351,212	NA	\$49.15	\$0.00
Tier 1 Synchronized Reserve	14.3%	1,715,532	\$34,135,671	\$0.00	\$19.90	\$0.04
Tier 2 Synchronized Reserve	26.9%	3,221,120	\$58,731,146	\$11.41	\$18.23	\$0.08
Non-synchronized Reserve	58.7%	7,038,700	\$13,785,091	\$1.15	\$1.96	\$0.02
Primary Reserve (total of above)	100.0%	\$11,982,497	\$107,003,120	\$0.42	\$8.93	\$0.14

## Tier 1 Synchronized Reserve

Tier 1 synchronized reserve is a component of primary reserve comprised of all on-line 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 measured as the lower of the available ten minute ramp and the difference between the economic dispatch point and the economic maximum output. Tier 1 resources are identified by the market solution and the sum of their ten minute availability equals available tier 1 synchronized reserve (green area of Figure 10-2 and Figure 10-3). Tier 1 synchronized reserve is the first element of primary reserve identified by the market software and is available at zero incremental cost unless called to respond to a synchronized reserve event or unless the non-synchronized 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 financially obligated to respond during an event.

## 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. Demand resources are not available for tier 1 synchronized reserve.

In 2015, in the RTO Reserve Zone the average hourly estimated tier 1 synchronized reserve was 1,363.9 MW (Table 10-6). In 35.9 percent of hours, the estimated tier 1 synchronized reserve was greater than the primary reserve requirement, meaning that the primary reserve requirement was met entirely by tier 1 synchronized reserve.

In 2015, in the MAD Reserve Subzone the average hour ahead estimated tier 1 synchronized reserve was 1,159.6 MW (Table 10-5). In 1.1 percent hours, the estimated tier 1 synchronized reserve was greater than the subzone requirement for synchronized reserve and no Tier 2 Synchronized Reserve Market was needed.

**Table 10-8 Monthly average market solution Tier 1 Synchronized Reserve (MW) identified hourly, 2015**

Mid-Atlantic Dominion Reserve Zone						
Year	Month	Average Hourly Tier 1 Local to MAD	Synchronized Reserve Available from RTO	Average Hourly Tier 1 Used	Minimum Hourly Tier 1 Used	Maximum Hourly Tier 1 Used
2015	Jan	622.8	599.2	1,222.0	410.4	1,450.0
2015	Feb	608.4	568.4	1,176.7	0.0	2,252.6
2015	Mar	483.1	717.5	1,200.6	163.7	2,344.6
2015	Apr	362.0	786.7	1,148.8	495.6	1,385.0
2015	May	533.9	683.5	1,217.4	599.5	2,173.0
2015	Jun	742.4	517.9	1,260.3	515.9	2,573.5
2015	Jul	712.3	510.1	1,222.4	610.2	2,298.0
2015	Aug	682.3	494.6	1,176.9	344.2	2,884.6
2015	Sep	547.1	563.6	1,110.8	398.8	2,316.8
2015	Oct	349.7	704.7	1,054.4	400.2	2,461.0
2015	Nov	518.4	537.9	1,056.3	355.0	2,163.1
2015	Dec	438.3	630.9	1,069.1	284.9	2,200.8
2015	Average	550.1	609.6	1,159.6	381.5	2,208.6

RTO Reserve Zone						
Year	Month	Average Hourly Tier 1 Local to MAD	Synchronized Reserve Available from RTO	Average Hourly Tier 1 Used	Minimum Hourly Tier 1 Used	Maximum Hourly Tier 1 Used
2015	Jan	NA	NA	1,582.7	0.0	3,240.4
2015	Feb	NA	NA	1,469.1	0.0	2,980.4
2015	Mar	NA	NA	1,247.2	0.0	2,727.6
2015	Apr	NA	NA	1,125.1	191.5	2,132.2
2015	May	NA	NA	1,245.1	0.0	3,408.5
2015	Jun	NA	NA	1,635.3	0.0	5,547.7
2015	Jul	NA	NA	1,620.5	0.0	3,443.4
2015	Aug	NA	NA	1,635.6	0.0	3,985.4
2015	Sep	NA	NA	1,419.2	0.0	3,096.5
2015	Oct	NA	NA	1,004.3	0.0	2,499.6
2015	Nov	NA	NA	1,217.2	0.0	2,909.6
2015	Dec	NA	NA	1,165.2	302.0	3,653.7
2015	Average			1,363.9	41.1	3,302.1

## Demand

There is no fixed required amount of tier 1 synchronized reserve. The Tier 1 synchronized reserve for each on-line resource is estimated from its synchronized reserve ramp rate as part of each market solution and not assigned. Given estimated tier 1, the market software (ASO) completes the primary reserve assignments under the assumption that the estimated tier 1 will be available if needed. The ancillary services market solution treats the cost of estimated tier 1 synchronized reserve as \$0, even when the non-synchronized reserve market clearing price is above \$0.

Beginning January 2015, 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. DGP is calculated for all on-line resources for each market solution. DGP measures how closely the unit has been following economic dispatch for the past thirty minutes and the available tier 1 MW for that resource is adjusted by the percentage of the DGP. In May 2015, PJM began communicating to generation operators whose tier 1 MW are part of the market solution the latest estimate of units' tier 1 MW and units' current resource specific DGP.<sup>14</sup>

For 2015, PJM estimated Tier 1 MW for an average of 147 units as part of the solution each hour. The average DGP was 84.7 percent for those 147 units.

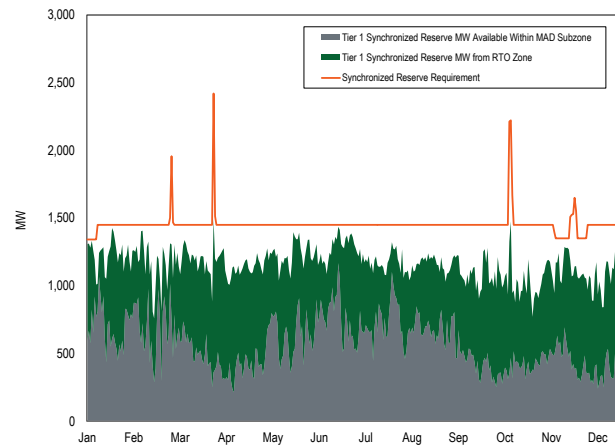
## Supply and Demand

When solving for the synchronized reserve requirement the market solution first subtracts the amount of self-scheduled synchronized reserve from the requirement and then estimates the amount of tier 1. To improve its Tier 1 estimates, PJM deselects certain resources from the tier 1 estimate. Tier 1 deselection is based on unit type, location and daily grid conditions.

In the MAD Subzone, the market solution takes all tier 1 MW estimated to be available within the MAD Subzone (gray area of Figure 10-5). It then adds the tier 1 MW estimated to be available within the MAD Subzone from the RTO Zone (green area of Figure 10-5) up to the synchronized reserve requirement. 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 (white area below the synchronized reserve required line in Figure 10-5).

**Figure 10-5 Daily average tier 1 synchronized reserve supply (MW) in the MAD Subzone: 2015**



Demand for synchronized reserve in the RTO Zone in 2015, was 2.1 percent higher than in 2014 primarily because the hourly synchronized reserve requirement was increased from 1,375 MW to 1,450 MW. There were temporary increases in the hourly synchronized reserve requirement to 2,688 MW on February 28, 2015 and to 2,615 MW on March 29, 2015 because of emergency outages. Other increases include June 10 through June 15 to 1,644 MW, September 18 through September 23 to 1,588 MW, October 19 through October 21 to 2,217 MW. Usually, the synchronized reserve requirement is increased because of planned outages in the spring and fall for periods of 10 to 14 days sometimes these outages impact the largest contingency requiring an increase in the synchronized reserve requirement. An outage from November 20 through December 12 caused a reduction in the synchronized reserve requirement to 1,350 MW.

## Tier 1 Synchronized Reserve Event Response

Tier 1 synchronized reserve is awarded credits when a synchronized reserve event occurs and it responds. These synchronized reserve event response credits for tier 1 response are independent of the tier 1 estimated, independent of the synchronized reserve market clearing

<sup>14</sup> PJM, Ancillary Services, "Communication of Synchronized Reserve Quantities to Resource Owners," <<http://www.pjm.com/~media/markets-ops/ancillary/communication-of-synchronized-reserve-quantities-to-resource-owners.ashx>> (May 6, 2015).

price, and independent of the non-synchronized reserve market clearing price. Credits are awarded to tier 1 synchronized reserve resources equal to the increase in MW output (or decrease in MW consumption for demand resources) for each five minute interval times the five minute LMP plus \$50 per MW.

In 2015, tier 1 synchronized reserve synchronized reserve event response credits of \$351,212 were paid for 7,145.0 MW of tier 1 response at an average cost per MW of \$50.99, for 22 spinning events (Table 10-9).

**Table 10-9 Tier 1 synchronized reserve event response costs: January 2014 through December 2015**

Year	Month	Synchronized Reserve Event Response Hours	Total Tier 1 Synchronized Reserve Event Response MW	Total Tier 1 Synchronized Reserve Event Response Credits	Tier 1 Synchronized Reserve Event Response Cost	Average Tier 1 MW Response
2014	Jan	12	7,827.8	\$965,846	\$123.39	521.9
2014	Feb	1	273.2	\$11,153	\$40.82	273.2
2014	Mar	5	3,029.6	\$175,902	\$58.06	605.9
2014	Apr	2	389.1	\$6,378	\$16.39	194.5
2014	May	3	717.1	\$34,906	\$48.68	239.0
2014	Jun	0	NA	NA	NA	NA
2014	Jul	2	615.6	\$35,179	\$57.15	307.8
2014	Aug	0	NA	NA	NA	NA
2014	Sep	3	1,936.2	\$143,574	\$74.15	645.4
2014	Oct	2	1,131.7	\$83,901	\$74.14	565.8
2014	Nov	4	1,349.8	\$38,895	\$28.81	337.5
2014	Dec	3	692.0	\$35,245	\$50.96	230.5
2014	Total	37	17,962.1	\$1,530,978	\$57.26	392.2
2015	Jan	1	397.3	\$8,198	\$20.64	397.3
2015	Feb	2	218.3	\$9,634	\$44.13	109.2
2015	Mar	4	2,445.8	\$105,505	\$43.14	611.4
2015	Apr	5	1,398.9	\$69,399	\$49.61	279.8
2015	May	0	NA	NA	NA	NA
2015	Jun	0	NA	NA	NA	NA
2015	Jul	1	502.2	\$25,540	\$50.86	502.2
2015	Aug	2	648.3	\$7,730	\$11.92	324.1
2015	Sep	3	678.5	\$30,077	\$44.33	226.2
2015	Oct	0	NA	NA	NA	NA
2015	Nov	2	252.9	\$15,914	\$62.92	126.5
2015	Dec	2	602.9	\$79,215	\$131.39	301.4
2015	Total	22	7,145.0	\$351,212	\$50.99	319.8

the non-synchronized 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. The non-synchronized reserve market clearing price was above \$0 in 541 hours in 2014. For those 541 hours, tier 1 synchronized reserve resources were paid a weighted average synchronized reserve market clearing price of \$30.67 per MW and earned \$10,406,363 in credits. In 2015, PJM paid \$34,135,671 in credits for tier 1 estimated during the 1,089 hours when the non-synchronized reserve market clearing price was above \$0.

## Paying Tier 1 the Tier 2 Price

The market solutions correctly treat tier 1 synchronized reserve as having zero marginal cost. The price for tier 1 synchronized reserves is zero unless tier 1 is called on to respond, as there is no incremental cost associated with providing the ability to ramp up from the current economic dispatch point. 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

**Table 10-10 Weighted price of tier 1 synchronized reserve attributable to a non-synchronized reserve price above zero: January 2014 to December 2015**

Year	Month	Total Hours When NSRMCP>\$0	Weighted Average SRMCP for Hours When NSRMCP>\$0	Total Tier 1 MW Credited for Hours When NSRMCP>\$0	Total Tier 1 Credits Paid When NSRMCP>\$0	Average Tier 1 MW Paid
2014	Jan	155	\$93.26	53,014	\$4,874,314	414.9
2014	Feb	15	\$40.18	65,332	\$337,903	560.5
2014	Mar	67	\$44.56	34,150	\$1,513,636	509.7
2014	Apr	99	\$16.07	57,047	\$916,275	576.2
2014	May	61	\$15.85	50,455	\$799,911	827.1
2014	Jun	4	\$35.46	3,335	\$118,273	833.9
2014	Jul	5	\$17.02	3,941	\$67,078	788.1
2014	Aug	0	NA	NA	NA	NA
2014	Sep	0	NA	NA	NA	NA
2014	Oct	3	\$21.59	2,146	\$46,319	715.2
2014	Nov	28	\$15.73	38,188	\$599,147	1,363.8
2014	Dec	104	\$6.93	163,552	\$1,133,507	1,739.9
2014	Total	541	\$30.67	471,159	\$10,406,363	832.9
2015	Jan	148	\$13.59	274,996	\$3,727,945	1,858.1
2015	Feb	194	\$24.83	369,111	\$9,164,267	1,902.6
2015	Mar	181	\$16.33	305,967	\$4,985,446	1,690.4
2015	Apr	66	\$25.56	102,117	\$2,587,076	1,547.2
2015	May	72	\$20.35	106,027	\$2,158,080	1,472.6
2015	Jun	95	\$17.64	185,148	\$3,183,436	1,948.9
2015	Jul	46	\$35.12	64,516	\$2,265,614	1,402.5
2015	Aug	38	\$22.40	48,479	\$1,078,199	1,275.8
2015	Sep	36	\$31.53	51,968	\$1,522,913	1,060.5
2015	Oct	113	\$17.10	126,879	\$2,169,670	1,122.8
2015	Nov	29	\$14.65	29,156	\$427,056	1,005.4
2015	Dec	51	\$16.07	53,898	\$865,969	1,005.4
2015	Total	1,069	\$21.26	1,718,263	\$34,135,671	1,441.0

The additional payments to tier 1 synchronized reserves under the shortage pricing rule can be considered a windfall. The additional payment does not create an incentive to provide more tier 1 synchronized reserves. The additional payment is not a payment for performance as all estimated tier 1 receives the payment regardless of whether they provided any response during any spinning event. Tier 1 resources are not obligated to respond to synchronized reserve events. In 2015, 89.7 percent of the market solution's estimated tier 1 resource MWh actually responded during synchronized reserve events of greater than ten minutes. Thus, 10.3 percent of tier 1 resource estimated MWh do not respond during spinning events but are paid their full estimated MW when the non-synchronized reserve price is greater than zero. Tier 2 synchronized reserve resources are paid the market clearing price for tier 2 because they stand ready to respond and incur costs to do so, have an obligation to perform and pay penalties for nonperformance.

When the next MW of non-synchronized reserve (NSR) required to satisfy the primary reserve requirement

increases in price from \$0.00 per MW to \$0.01 per MW, the cost of all tier 1 MW increases significantly.

In 2015, tier 1 MW were paid \$351,212 for responding to synchronized reserve events. Tier 1 synchronized reserve was paid \$34.1 million simply because the NSRMCP was greater than \$0 (Table 10-11).

**Table 10-11 Dollar impact of paying tier 1 synchronized reserve the SRMCP when the NSRMCP goes above \$0: January 2014 through December 2015**

Year	Month	Synchronized Reserve Events			Hours When NSRMCP > \$0		
		Total MWh	Total Credits	Average MWh Per Event	Total MW	Total Credits	Average MW Per Hour
2014	Jan	7,828	\$965,846	522	53,014	\$4,874,314	414.9
2014	Feb	273	\$11,153	273	65,332	\$337,903	560.5
2014	Mar	3,030	\$175,902	606	34,150	\$1,513,636	509.7
2014	Apr	389	\$6,378	195	57,047	\$916,275	576.2
2014	May	717	\$34,906	239	50,455	\$799,911	827.1
2014	Jun	0	\$0	0	3,335	\$118,273	833.9
2014	Jul	616	\$35,179	308	3,941	\$67,078	788.1
2014	Aug	0	\$0	0	0	\$0	0
2014	Sep	1,936	\$143,574	645	0	\$0	0
2014	Oct	1,132	\$83,901	566	2,146	\$46,319	715
2014	Nov	1,350	\$38,895	337	38,188	\$599,147	1,364
2014	Dec	258	\$12,897	129	163,552	\$1,133,507	1,740
2014	Total	17,528	1,508,631	382	471,159	10,406,363	833
2015	Jan	397	\$8,198	397	274,996	\$3,727,945	1,858
2015	Feb	218	\$9,634	109	369,111	\$9,164,267	1,903
2015	Mar	2,446	\$105,505	611	305,967	\$4,985,446	1,690
2015	Apr	1,399	\$69,399	280	102,117	\$2,587,076	1,547
2015	May	0	\$0	0	106,027	\$2,158,080	1,473
2015	Jun	0	\$0	0	182,417	\$3,183,436	1,961
2015	Jul	502	\$25,540	502	64,516	\$2,265,615	1,403
2015	Aug	648	\$7,730	324	48,479	\$1,078,199	1,276
2015	Sep	678	\$30,077	226	51,968	\$1,522,913	1,061
2015	Oct	0	\$0	0	126,879	\$2,169,670	1,123
2015	Nov	253	\$15,914	126	29,156	\$427,056	1,005
2015	Dec	603	\$79,215	301	53,898	\$865,969	1,054
2015	Total	7,145	\$351,212	320	1,715,532	\$34,135,671	1,446

The MMU recommends that the rule requiring the payment of tier 1 synchronized reserve resources when the non-synchronized reserve price is above zero be eliminated immediately. 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 average of five-minute LMPs during the event, rather than hourly integrated LMP, plus \$50/MW, termed the Synchronized Energy Premium Price.

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 Hour as Currently Implemented by PJM		
Hourly		
Parameters	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh
NSRMCP>\$0	T1 credits = T2 SRMCP * estimated tier 1 MW	T1 credits = T2 SRMCP * min(calculated tier 1 MW, actual response MWh)

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		
Hourly Parameters	No Synchronized Reserve Event	Synchronized Reserve Event
NSRMCP=\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh
NSRMCP>\$0	T1 credits = \$0	T1 credits = Synchronized Energy Premium Price * actual response MWh

### Tier 1 Estimate Bias

PJM dispatch can apply tier 1 estimate bias to each element of the market solution software (ASO, IT-SCED, and RT-SCED). Biasing means manually modifying (increasing or decreasing) the tier 1 synchronized reserve estimate of the market solution. This forces the market clearing engine to clear more or less tier 2 synchronized reserve and non-synchronized reserve to satisfy the synchronized reserve and primary reserve requirements than the market solution.

PJM uses tier 1 estimate biasing in the MAD Subzone of the ASO market solution (Table 10-14). Tier 1 biasing is not used in any IT-SCED solutions.

**Table 10-14 ASO tier 1 estimate biasing, January 2014 through December, 2015**

Year	Month	Number of Hours Biased Negatively	Average Negative Bias (MW)	Number of Hours Biased Positively	Average Positive Bias (MW)
2014	Jan	13	(1,419.2)	2	250.0
2014	Feb	36	(1,036.1)	1	100.0
2014	Mar	37	(1,281.1)	4	500.0
2014	Apr	32	(1,387.5)	0	0.0
2014	May	23	(909.8)	0	0.0
2014	Jun	17	(1,179.4)	3	666.7
2014	Jul	36	(1,011.1)	0	0.0
2014	Aug	31	(891.9)	1	750.0
2014	Sep	15	(1,206.7)	0	0.0
2014	Oct	67	(1,285.8)	1	500.0
2014	Nov	190	(1,134.7)	6	475.0
2014	Dec	166	(1,226.2)	1	300.0
2014	Total	663	(1,164.1)	19	295.1
2015	Jan	51	(1,731.4)	6	500.0
2015	Feb	62	(1,641.1)	0	0.0
2015	Mar	25	(794.0)	3	1,000.0
2015	Apr	31	(430.7)	0	0.0
2015	May	46	(582.6)	8	812.5
2015	Jun	25	(694.0)	1	1,000.0
2015	Jul	9	(588.9)	0	0.0
2015	Aug	1	(750.0)	1	750.0
2015	Sep	4	(475.0)	1	2,000.0
2015	Oct	24	(979.2)	0	0.0
2015	Nov	0	0.0	62	515.3
2015	Dec	1	(500.0)	59	549.2
2015	Total	279	(763.9)	141	593.9

Tier 1 biasing is not mentioned in the PJM manuals and does not appear to be defined in any public document. PJM dispatchers use tier 1 biasing to compensate for uncertainty in short-term load forecasting, generator performance, or uncertainty in the accuracy of the market solution's tier 1 estimate. Tier 1 estimate biasing directly affects the required amount of tier 2 and therefore the market results both for tier 2 synchronized reserve and for non-synchronized reserve.

The MMU recommends that PJM be more explicit about why tier 1 biasing is used in the optimized solution to the Tier 2 Synchronized Reserve Market. The MMU recommends that PJM define rules for estimating available tier 1 MW and for the use of biasing during any phase of the market solution and then identify the relevant rule for each instance of biasing.

## Tier 2 Synchronized Reserve Market

Synchronized reserve is energy or demand reduction synchronized to the grid and capable of increasing output or decreasing load within ten minutes. Synchronized reserve is of two distinct types, tier 1 and tier 2. Tier 2 synchronized reserve is primary reserve (ten minute availability) that must be dispatched in order to satisfy the synchronized reserve requirement. When the synchronized reserve requirement cannot be filled with tier 1 synchronized reserve, PJM clears a market to satisfy the requirement with tier 2 synchronized reserve.

PJM operates a Tier 2 Synchronized Reserve Market in both the RTO Synchronized Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone. Market solutions provided by the ASO, IT-SCED and RT-SCED first estimate the amount of tier 1 synchronized reserve available from the current economic dispatch and subtract that amount from the synchronized reserve requirement to determine how much tier 2 synchronized reserve is needed. Tier 2 synchronized reserve is provided by on-line 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 a synchronized reserve event. Tier 2 synchronized reserves are committed to be available in the event of a synchronized reserve event.

Tier 2 synchronized reserve resources may be inflexible for two reasons, the nature of the resource or if they are committed in the hour ahead for the full operating hour. Some resource types can only be committed by the ASO prior to the operational hour and require an hourly commitment due to physical limitations or market rules. Resources with hour ahead commitment requirements include synchronous condensers operating solely for the purpose of providing synchronized reserves and demand response that has qualified to act as synchronized reserves. Tier 2 resources are scheduled by the ASO sixty minutes before the operating hour, are committed to provide synchronized reserve for the entire hour, and are paid the higher of the SRMCP or their offer price plus lost opportunity cost (LOC). Demand response resources are paid SRMCP. Due to the hour long commitment that comes with the hour ahead ASO assignment, tier 2 synchronized reserve resources committed by the hour

ahead market solution are flagged by the system software as inflexible resources, so they cannot be released for energy for the duration of the operational hour.

During the operating hour, the IT-SCED and the RT-SCED market solutions have the ability to dispatch additional resources flexibly depending on the current forecast need for synchronized reserve. A flexible commitment is one in which the IT-SCED or RT-SCED redispatches generating resources to meet the synchronized and primary reserve requirements within the operational hour.

## Market Structure

### Supply

All non-emergency generating resources are required to submit tier 2 synchronized reserve offers. All online, non-emergency generating resources are deemed available to provide both tier 1 and tier 2 synchronized reserve. If PJM issues a primary reserve warning, voltage reduction warning, or manual load dump warning, all off line non-emergency generation capacity resources available to provide energy must submit an offer for tier 2 synchronized reserve.<sup>15</sup>

In 2015, the Mid Atlantic Dominion Reserve Subzone averaged 3,398.7 MW of synchronized reserve offers, and the RTO Reserve Zone averaged 10,565.3 MW of synchronized reserve offers (Figure 10-11).

The supply of tier 2 synchronized reserve in 2015 was sufficient to cover the requirement in both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.

The largest portion of cleared tier 2 synchronized reserve in 2015 is from CTs (Figure 10-6) 52.6 percent of all tier 2 synchronized reserve MW. Demand Resources (DR) remain a significant part of market scheduled tier 2 synchronized reserve. Although demand resources are limited to 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. The DR MW share of the total cleared Tier 2 Synchronized Reserve

<sup>15</sup> See PJM, "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 66.

Market was 17.7 percent in 2015.<sup>16</sup> This is an increase from the 15.1 percent share of the tier 2 market in 2014.

**Figure 10-6 Cleared tier 2 synchronized reserve average hourly MW per hour by unit type, RTO Zone: 2015**

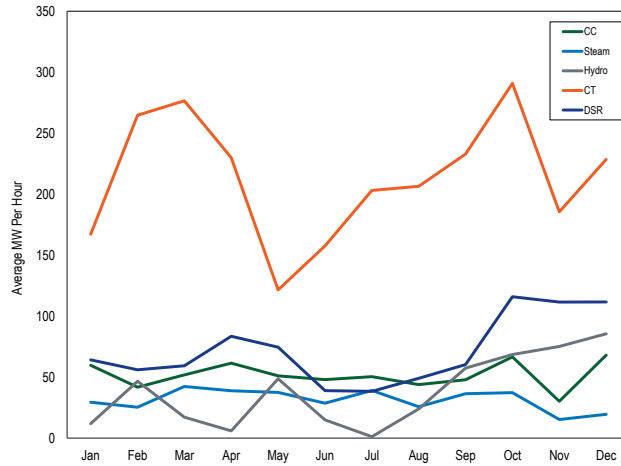
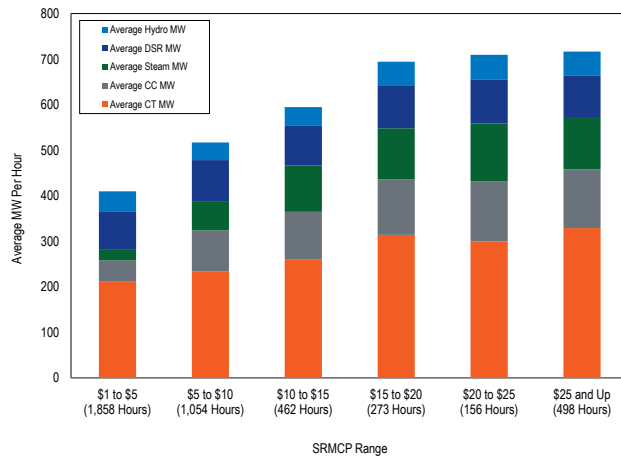


Figure 10-7 provides the average hourly cleared tier 2 MW by unit type by tier 2 clearing price range (SRMCP).

**Figure 10-7 Average hourly tier 2 MW by unit type by SRMCP Range: 2015**



Mild weather in October, November, and December caused fewer units to be operating therefore lesser tier 1 synchronized reserve availability. As a result, significantly more tier 2 synchronized reserve was cleared in those months (Table 10-18). In addition, PJM market operations utilized tier 1 biasing in an unusual way (Table 10-14) in November and December. The

<sup>16</sup> The cap on demand response participation is defined in MW terms. There is no cap on the proportion of cleared demand response consistent with the MW cap.

tier 1 estimate in the ASO market solution was biased positively in a large number of hours. In addition, there were 20 days in November and December when the primary reserve requirement was lowered, (orange line in Figure 10-3) reducing the need for non-synchronized reserve.

## Demand

Effective January 1, 2015, the synchronized reserve requirement was increased to 1,342 MW in the Mid-Atlantic Dominion Subzone, and remained at 1,375 MW in the RTO Zone. Effective January 8, 2015, the synchronized reserve requirement was increased to 1,450 MW in both the Mid-Atlantic Dominion Subzone and the RTO Zone (Table 10-15). There are two circumstances in which PJM may alter the synchronized reserve requirement from its default value. When PJM operators anticipate periods of heavy 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 escalating 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.<sup>17</sup> In January through March 2015, PJM declared 27 Cold Weather Alerts raising the synchronized reserve requirement from 1,450 MW to 1,700 for 606 hours. In June, hot weather alerts caused the synchronized reserve requirement to be raised to 1,700 MW in 114 hours.

**Table 10-15 Default Tier 2 Synchronized Reserve Markets required MW, RTO Zone and Mid-Atlantic Dominion Subzone**

Mid-Atlantic Dominion Subzone			RTO Synchronized Reserve Zone		
From Date	To Date	Required MW	From Date	To Date	Required MW
May 10, 2008	May 8, 2010	1,150	May 10, 2008	Jan 1, 2009	1,305
May 8, 2010	Jul 13, 2010	1,200	Jan 1, 2009	Mar 15, 2010	1,320
July 13, 2010	Jan 1, 2015	1,300	Mar 15, 2010	Nov 12, 2012	1,350
Jan 1, 2015	Jan 8, 2015	1,342	Nov 12, 2012	Jan 8, 2015	1,375
Jan 8, 2015		1,450	Jan 8, 2015		1,450

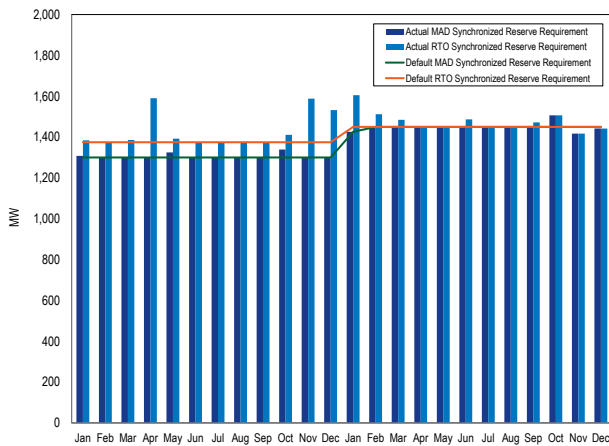
PJM may also change the synchronized reserve requirement from its default value (Figure 10-1) when grid maintenance or outages change the largest contingency. In the first three months of 2015, PJM

<sup>17</sup> PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) pp. 70.



increased the synchronized reserve requirement in 38 hours in the RTO Reserve Zone (Figure 10-8) because of grid outages. The RTO synchronized reserve requirement was temporarily raised to 1,624 for 96 hours during a scheduled outage from September 20, through September 23, 2015. The RTO synchronized reserve requirement was raised for 40 hours between October 19 and October 21, 2015, for scheduled outages. The synchronized reserve requirement was reduced for 21 days between November 20, and December 12, 2015, when a scheduled outage changed the largest system contingency. The average actual synchronized reserve requirement in the MAD Subzone was 1,454.1 MW. The average actual synchronized reserve requirement in the RTO Reserve Zone was 1,477.6 MW.

**Figure 10-8 Monthly average actual vs default synchronized reserve requirements, RTO Zone and MAD Subzone: January 2014 through December 2015**



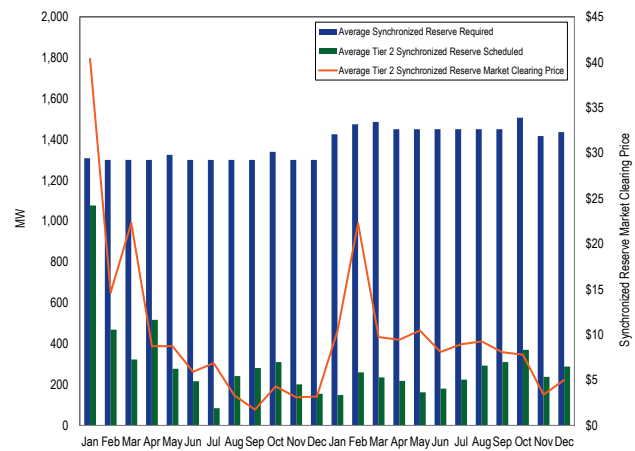
The market demand for tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone is determined by subtracting the amount of forecast tier 1 synchronized reserve available in the subzone from the subzone requirement each five-minute period. Market demand is also reduced by subtracting the amount of self-scheduled tier 2 resources.

In the RTO Reserve Zone, 60.6 percent of hours cleared a Tier 2 Synchronized Reserve Market in 2015 averaging 457.3 MW. This compares with 57.1 percent of hours averaging 831.6 MW in 2014. In the MAD Reserve Subzone, 96.9 percent of hours cleared a Tier 2 Synchronized Reserve Market in 2015 averaging 314.8

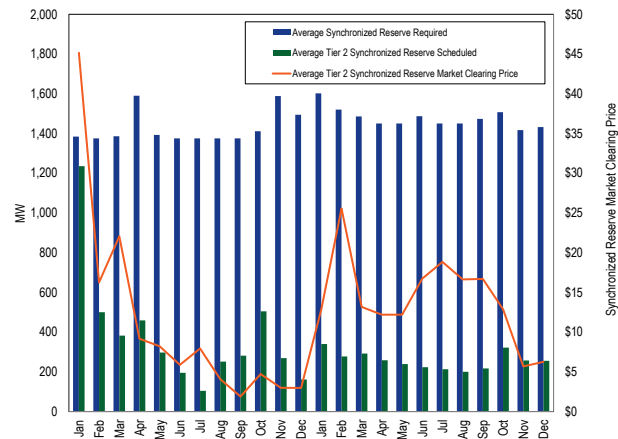
MW. This compares with 96.0 percent of hours cleared, averaging 380.1 MW in 2014.

Figure 10-9 and Figure 10-10 show the average monthly synchronized reserve required and the average monthly tier 2 synchronized reserve MW scheduled in 2014 and 2015, for the RTO Reserve Zone and MAD Reserve Subzone.

**Figure 10-9 Mid-Atlantic Dominion Reserve Subzone monthly average synchronized reserve required vs. tier 2 synchronized reserve scheduled MW: January 2014 through December 2015**



**Figure 10-10 RTO Reserve Zone monthly average synchronized reserve required vs. tier 2 synchronized reserve scheduled MW: January 2014 through December 2015**



## Market Concentration

The HHI for settled tier 2 synchronized reserve during cleared hours of the Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Market for 2015 was 5436, which is defined as highly concentrated. This is an increase from the 5163 HHI in 2014. The largest hourly market share was 100 percent and 88.1 percent of all cleared hours had a maximum market share greater than or equal to 40 percent.

The HHI for settled tier 2 synchronized reserve during cleared hours of the RTO Zone Tier 2 Synchronized Reserve Market for 2015 was 4617, which is defined as highly concentrated. This is a decrease from the 5639 HHI in 2015. The largest hourly market share was 100 percent and 67.6 percent of cleared hours had a maximum market share greater than or equal to 40 percent.

In the MAD Subzone, flexible synchronized reserve was 3.8 percent of all tier 2 synchronized reserve in 2015. In the RTO Zone, flexible synchronized reserve assigned was 3.7 percent of all tier 2 synchronized reserve in 2015.

The MMU calculates that 55.7 percent of hours failed the three pivotal supplier test in the MAD Subzone in 2015 for the inflexible Synchronized Reserve Market (excluding self-scheduled synchronized reserve) in the hour ahead market (Table 10-16) and 40.2 percent of hours failed a three pivotal supplier test in the RTO Zone in 2015.

**Table 10-16 Three pivotal supplier test results for the RTO Zone and MAD Subzone: January 2014 through December 2015**

Year	Month	Mid Atlantic Dominion	RTO Reserve Zone Pivotal
		Reserve Subzone Pivotal Supplier Hours	Supplier Hours
2014	Jan	90.7%	72.7%
2014	Feb	46.6%	22.6%
2014	Mar	37.9%	17.3%
2014	Apr	31.9%	51.6%
2014	May	22.3%	44.0%
2014	Jun	31.5%	31.3%
2014	Jul	41.6%	16.2%
2014	Aug	21.2%	17.6%
2014	Sep	25.0%	24.5%
2014	Oct	53.2%	71.8%
2014	Nov	56.4%	51.7%
2014	Dec	37.5%	48.6%
2014	Average	41.3%	39.2%
<hr/>			
2015	Jan	46.0%	34.2%
2015	Feb	87.0%	29.9%
2015	Mar	42.0%	45.2%
2015	Apr	31.1%	48.4%
2015	May	61.2%	45.3%
2015	Jun	39.2%	26.5%
2015	Jul	32.0%	25.0%
2015	Aug	32.3%	24.9%
2015	Sep	56.1%	23.5%
2015	Oct	81.5%	57.9%
2015	Nov	73.2%	49.3%
2015	Dec	87.7%	73.2%
2015	Average	55.8%	40.3%

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 offer prices are submitted for each unit by the unit owner. For generators the offer price must include 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 (a field to identify if a running CT can be dispatched for synchronized reserve). The synchronized reserve offer price made by the unit owner is subject to an offer cap of marginal cost plus \$7.50 per MW. All suppliers are paid the higher of the market clearing price or their offer plus their unit

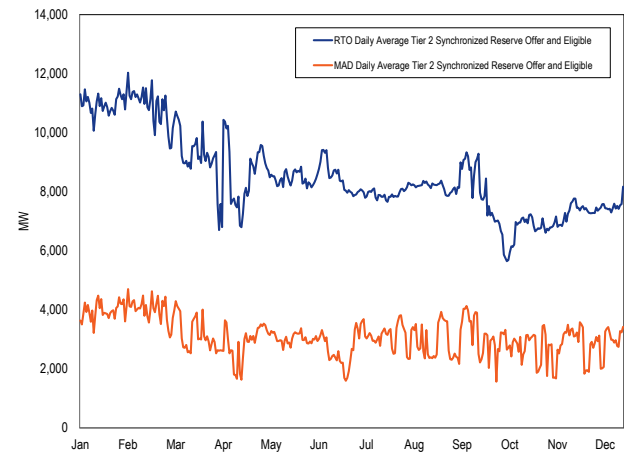
specific opportunity cost. The offer quantity is limited to the economic maximum or less if a spin maximum value is less than economic maximum is supplied (subject to prior authorization by PJM). PJM monitors this offer by checking to ensure that all offers are greater than or equal to 90 percent of the resource's ramp rate times ten minutes. A resource that is unable to participate in the synchronized reserve market during a given hour may set its hourly offer to 0 MW. A resource that cannot reliably provide synchronized reserve may offer 0 MW, e.g. nuclear, wind, solar, and batteries.

Figure 10-11 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. In 2015, the ratio of on-line and eligible tier 2 synchronized reserve to synchronized reserve required in the Mid-Atlantic Dominion Subzone was 4.14 averaged over all hours. For the RTO Synchronized Reserve Zone the ratio was 5.91.

On October 1, 2012, PJM adopted a must-offer requirement for tier 2 synchronized reserve for all generation that is online, non-emergency, 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.<sup>18</sup> Daily offer levels are stable and consistent over time. The Tier 2 Synchronized Reserve Market is not solved from 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 10-11). Changes to hourly eligibility levels are the result of on-line status, minimum/maximum runtimes, minimum notification times, maintenance status and grid conditions including constraints. But changes to the hourly offer status are only permitted when resources are physically unable to provide tier 2. Resource operators can make their units unavailable for an hour or block of hours via the eMKT unavailable option without having to provide a reason. This means that while compliance with the must offer requirement can be done daily it is not possible to verify

compliance with the tier 2 must offer requirement on an hourly basis.

**Figure 10-11 Tier 2 synchronized reserve hourly offer and eligible volume (MW), averaged daily: 2015**



Compliance with the daily must-offer requirement is unambiguously stated in Manual 11 “Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for tier 2 synchronized reserve in eMKT prior to the offer submission deadline (1800 the day prior to the operating day).”

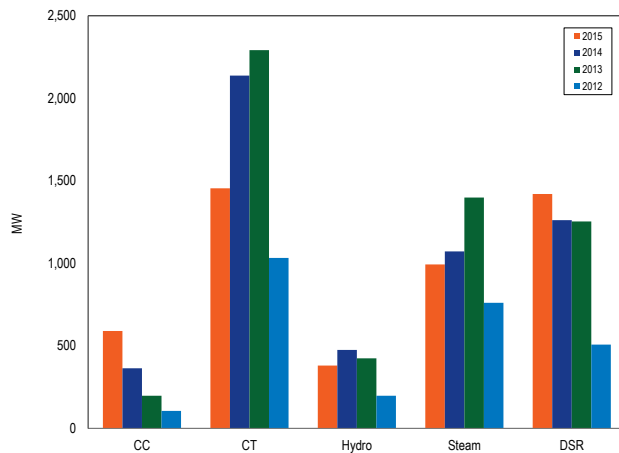
Of all non-emergency resources capable of reliably producing synchronized reserve (e.g. excluding batteries, wind, and solar), 12.9 percent have not entered a tier 2 synchronized reserve offer in violation of the must-offer rule. When tier 1 credits are awarded (either for spinning event response or because the NSRMCP is greater than \$0) these units can be awarded tier 1 credits. In December 2015, 71 distinct units without a tier 2 offer were awarded a total \$98,156 in tier 1 credits. Of this, \$85,640 were for hours when the NSRMCP greater than \$0 and the units did not have to actually produce any reserve MW.

Tier 2 synchronized reserve is subject to a must offer requirement. To help ensure compliance with this rule, the MMU recommends that PJM define a set of acceptable reasons why a unit can be made unavailable daily or hourly and require operators to select a reason in eMkt whenever making a unit unavailable.

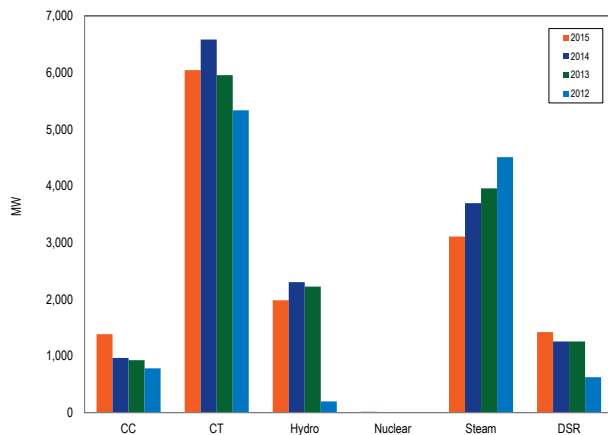
<sup>18</sup> See PJM. “Manual 11: Energy & Ancillary Services Market Operations,” Revision 79 (December 17, 2015) p. 66, “Regardless of online/offline state, all non-emergency generation capacity resources must submit a daily offer for Tier 2 Synchronized Reserve in eMKT...”

Figure 10-12 shows average offer MW volume by market and unit type for the MAD Subzone and Figure 10-13 shows average offer MW volume by market and unit type for the RTO Zone.

**Figure 10-12 Mid-Atlantic Dominion subzone average daily tier 2 synchronized reserve offer by unit type (MW): 2012 through 2015**



**Figure 10-13 RTO Zone average daily tier 2 synchronized reserve offer by unit type (MW): 2012 through 2015**



## Market Performance

### Price

The price of tier 2 synchronized reserve is calculated in real time every five minutes and averaged each hour for the RTO Reserve Zone and the MAD Subzone.

The MAD Subzone cleared a Tier 2 Synchronized Reserve Market averaging 314.8 MW (including self-scheduled) with a real-time price greater than \$0 in 63.6 percent of

hours in 2015, compared to 99.0 percent of hours in the first nine months of 2014.

The RTO Zone cleared a Tier 2 Synchronized Reserve Market averaging 457.3 MW (including self-scheduled) with a real-time price greater than \$0 in 58.6 percent of hours in 2015.

In 2015, the weighted average Tier 2 synchronized reserve market clearing price in the MAD Subzone for all cleared hours was \$10.12. In 2014, the weighted average synchronized reserve market clearing price in the MAD Subzone was \$15.50.

In 2015, the weighted average tier 2 synchronized reserve market clearing price in the RTO Zone for all cleared hours was \$11.88. In 2014, the weighted average synchronized reserve market clearing price in the RTO Zone was \$12.94.

Supply, performance, and demand are reflected in the price of synchronized reserve (Figure 10-9 and Figure 10-10). In February 2015, cold weather meant that on line resources which are jointly optimized with synchronized reserve were generating at or near their economic maximum. As a result, tier 2 synchronized reserve was more expensive.

Table 10-17 Mid-Atlantic Dominion Subzone, weighted SRMCP and cleared MW (excludes self-scheduled): 2015

Year	Month	Weighted Average Tier 2 Synchronized Reserve Market Clearing Price	Average Hourly Tier 1 Synchronized Reserve Estimated Hour Ahead (MW)	Average Hourly Demand Response Cleared (MW)	Average Tier 2 Generation Synchronized Reserve Cleared (MW)
2015	Jan	\$11.29	1,218.9	63.7	142.8
2015	Feb	\$24.12	1,179.5	46.3	224.3
2015	Mar	\$11.81	1,196.2	60.8	228.7
2015	Apr	\$10.76	1,159.4	85.0	218.1
2015	May	\$10.16	1,174.4	76.0	162.9
2015	Jun	\$10.29	1,515.5	54.5	177.7
2015	Jul	\$12.87	1,195.6	41.1	215.7
2015	Aug	\$9.25	1,152.9	49.3	247.8
2015	Sep	\$10.66	1,106.9	54.2	288.9
2015	Oct	\$7.68	1,015.6	118.2	374.4
2015	Nov	\$3.30	1,011.6	113.6	290.6
2015	Dec	\$4.71	983.4	109.0	349.4
2015	Average	\$10.13	1,159.2	72.6	243.4

Table 10-18 RTO Zone only weighted SRMCP and cleared MW (excludes self-scheduled): 2015

Year	Month	Weighted Average Tier 2 Synchronized Reserve Market Clearing Price	Average Hourly Tier 1 Synchronized Reserve Estimated Hour Ahead (MW)	Average Hourly Demand Response Cleared (MW)	Average Tier 2 Generation Synchronized Reserve Cleared (MW)
2015	Jan	\$13.91	1,417.5	164.8	125.2
2015	Feb	\$26.51	1,618.3	46.3	35.4
2015	Mar	\$13.44	1,285.0	60.8	140.0
2015	Apr	\$13.39	1,228.6	85.0	136.4
2015	May	\$13.77	1,239.8	76.0	134.2
2015	Jun	\$19.43	1,366.4	54.5	83.6
2015	Jul	\$21.46	1,346.1	41.1	65.2
2015	Aug	\$18.63	1,353.1	49.3	58.9
2015	Sep	\$19.12	1,156.3	54.2	64.3
2015	Oct	\$15.87	1,156.3	118.2	233.3
2015	Nov	\$6.09	1,089.5	113.6	212.6
2015	Dec	\$7.05	784.4	109.0	548.4
2015	Average	\$14.98	1,253.4	81.1	153.1

## Cost

As a result of changing grid conditions, load forecasts, and unexpected generator performance, prices do not always cover the full cost and final LOC for each resource. Because price formation occurs within the hour (on five minute basis integrated over the hour) but the 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 if the SRMCP does not compensate them for their offer plus LOC.

The full cost of tier 2 synchronized reserve including payments for the clearing price and out of market costs is calculated and compared to the price. The closer the price to cost ratio is to one hundred percent, the more the market price reflects the full cost of tier 2 synchronized reserve. A price to cost ratio close to one hundred percent is an indicator of an efficient synchronized reserve market design.

In 2015, the price to cost ratio of the RTO Zone Tier 2 Synchronized Reserve Market averaged 62.6 percent (Table 10-19); and the price to cost ratio of the MAD Subzone averaged 60.6 percent.

Table 10–19 RTO Zone, Mid–Atlantic Subzone tier 2 synchronized reserve MW, credits, price, and cost: 2015

Tier 2 Synchronized Reserve Market	Year	Month	Total MW	Total Credits	Weighted	Cost	Price/Cost Ratio
					Synchronized Reserve Market Clearing Price		
RTO Zone	2015	Jan	225,741	\$5,089,807	\$12.24	\$22.55	54.3%
RTO Zone	2015	Feb	272,371	\$12,065,569	\$24.68	\$44.30	55.7%
RTO Zone	2015	Mar	301,564	\$7,323,630	\$12.37	\$24.29	50.9%
RTO Zone	2015	Apr	278,562	\$4,896,351	\$11.53	\$17.58	65.6%
RTO Zone	2015	May	244,947	\$4,231,841	\$11.22	\$17.28	65.0%
RTO Zone	2015	Jun	174,039	\$2,916,195	\$12.95	\$16.76	77.3%
RTO Zone	2015	Jul	194,178	\$3,435,731	\$15.28	\$17.69	86.4%
RTO Zone	2015	Aug	173,869	\$2,329,804	\$11.20	\$13.40	83.6%
RTO Zone	2015	Sep	253,762	\$4,012,473	\$12.44	\$15.81	78.7%
RTO Zone	2015	Oct	428,175	\$5,444,327	\$9.61	\$12.72	75.6%
RTO Zone	2015	Nov	298,986	\$2,821,681	\$3.92	\$9.44	41.5%
RTO Zone	2015	Dec	374,928	\$4,163,737	\$5.26	\$11.11	47.4%
RTO Zone	2015	Total	3,221,120	\$58,731,146	\$11.41	\$18.23	62.6%
MAD Subzone	2015	Jan	144,214	\$3,454,670	\$11.29	\$23.96	47.1%
MAD Subzone	2015	Feb	208,536	\$8,740,957	\$24.12	\$41.92	57.5%
MAD Subzone	2015	Mar	197,540	\$4,488,330	\$11.81	\$22.72	52.0%
MAD Subzone	2015	Apr	197,223	\$3,583,677	\$10.76	\$18.17	59.2%
MAD Subzone	2015	May	172,468	\$2,951,207	\$10.16	\$17.11	59.3%
MAD Subzone	2015	Jun	123,473	\$1,685,393	\$10.29	\$13.65	75.4%
MAD Subzone	2015	Jul	139,693	\$2,093,452	\$12.87	\$14.99	85.9%
MAD Subzone	2015	Aug	137,663	\$1,533,977	\$9.25	\$11.14	83.0%
MAD Subzone	2015	Sep	200,257	\$2,832,648	\$10.66	\$14.15	75.4%
MAD Subzone	2015	Oct	327,286	\$3,310,116	\$7.68	\$10.11	76.0%
MAD Subzone	2015	Nov	232,670	\$1,935,364	\$3.30	\$8.32	39.6%
MAD Subzone	2015	Dec	286,032	\$2,963,084	\$4.71	\$10.36	45.4%
MAD Subzone	2015	Total	2,367,055	\$39,572,874	\$10.13	\$16.72	60.6%

## Compliance

The MMU has identified and quantified the failure of scheduled tier 2 synchronized reserve resources to deliver during synchronized reserve events since 2011.<sup>19</sup> 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.<sup>20</sup> Tier 2 resources are obligated to sustain their final output for the shorter of the length of the event or 30 minutes.<sup>21</sup>

The MMU has reported the wide range of synchronized reserve event response levels and recommended that PJM take action to increase compliance rates. Penalties can be assessed for any synchronized reserve event 10 minutes or longer during which flexible or inflexible synchronized reserve was scheduled either by the resource owner or by PJM. In 2014, 20 synchronized reserve events occurred that met these criteria. In 2015, there were 21 spinning events of which seven were 10 minutes or longer.

<sup>19</sup> See the 2011 State of the Market Report for PJM, Volume II, Section 9, "Ancillary Services" at pg. 250.

<sup>20</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.10 Settlements, p. 77.

<sup>21</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.11 Verification, p. 78.

**Table 10-20 Synchronized reserve events greater than 10 minutes, Tier 2 response compliance, RTO Reserve Zone: 2015**

2015 Qualifying Synchronized Reserve Event (DD-Mon-YYYY HR)	Event Duration (Minutes)	Total Scheduled Tier 2 MW	Tier 2 Response MW	Percent T2 Compliance
03-Mar-2015 17	11	480.4	272.3	56.7%
16-Mar-2015 10	24	248.0	180.2	72.7%
17-Mar-2015 23	17	247.2	232.8	94.2%
23-Mar-2015 23	15	273.5	205.8	75.2%
07-Apr-2015 16	31	485.7	455.5	93.8%
30-Jul-2015 10	10	79.7	24.0	30.1%
28-Sep-2015 19	11	782.0	639.4	81.8%

Tier 1 resource owners are credited for the amount of synchronized reserve they provide in response to a synchronized reserve event.<sup>22</sup> Tier 2 resources owner are not credited for synchronized reserve event response. Tier 2 resources owners are penalized in the amount of their shortfall at SRMCP for the lesser of the average number of days between events, or the number of days since the previous event in which the resource did respond. For synchronized reserve events of ten minutes or longer that occurred 2015, 21.2 percent of all scheduled tier 2 synchronized reserve MW were not delivered and were penalized (Table 10-20). In addition, a tier 2 resource will be penalized for the amount of MW it falls short of its offer for the entire hour, not just for the portion of the hour covered by the synchronized reserve event.<sup>23</sup> Resource owners are permitted to aggregate the response of multiple units to offset an under response from one unit with an overresponse from a different unit for the purpose of reducing an underresponse penalty. The average number of days between events calculated by PJM Performance Compliance for 2015 is 13 days.<sup>24</sup>

<sup>22</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015) § 4.2.12 Non Performance, p. 78.

<sup>23</sup> See PJM. "Manual 28: Operating Agreement Accounting," Revision 71 (June 1, 2015) p. 45. See also "Manual 11: Energy & Ancillary Services Market Operations," Revision 75 (April 9, 2015) § 4.2.12 Non-Performance, p. 77.

<sup>24</sup> Report to PJM Operating Committee, "Synchronized Reserve Event Performance and Penalty Days," December 3, 2014.

## History of Synchronized Reserve Events

Synchronized reserve is designed to provide relief for disturbances.<sup>25</sup> <sup>26</sup> A disturbance is defined as loss of generation and/or transmission resources. PJM also calls synchronized reserve events for non-disturbance events, which it characterizes as “low ACE.” In the absence of a disturbance, PJM dispatchers have used synchronized reserve as a source of energy to provide relief from low ACE. Such an event occurred on January 6, 2014. Five synchronized reserve events were declared during 2014 for low ACE. Five spinning events were declared for low ACE in 2015. The risk of using synchronized reserves for energy or any non-disturbance reason is that it reduces the amount of synchronized reserve available for a disturbance. Synchronized reserve has a requirement to sustain its output for up to thirty minutes. When the need is for reserve extending past thirty 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 indicated 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 disturbance.

From January 2010 through December 2015, PJM experienced 167 synchronized reserve events (Table 10-21), approximately three events per month. Synchronized reserve events had an average length of 13 minutes. Note that the number of synchronized reserve events with a duration less than ten minutes is higher in 2015 than any prior year (Figure 10-14). This corresponds with the higher rate of compliance by tier 2 synchronized reserve resources, and the higher rate of response by tier 1 resources to spinning event all calls.

<sup>25</sup> 2013 State of the Market Report for PJM, Appendix F – PJM’s DCS Performance, pp 451–452.

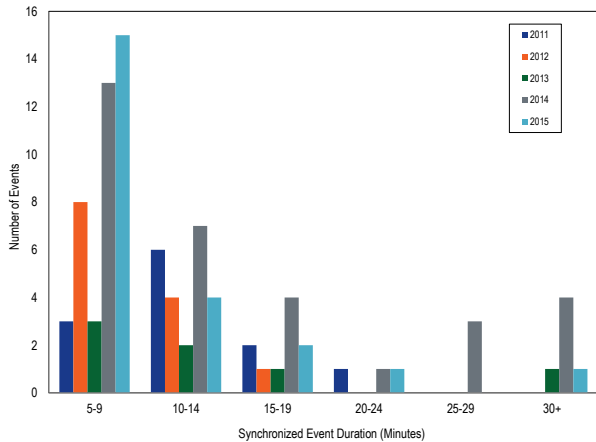
<sup>26</sup> See PJM, “Manual 12: Balancing Operations,” Revision 33 (December 1, 2015) § 4.1.2 Loading Reserves pp. 36.



Table 10-21 Synchronized reserve events, January 2010 through December 2015

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
FEB-18-2010 13:27	Mid-Atlantic	19	JAN-11-2011 15:10	Mid-Atlantic	6	JAN-03-2012 16:51	RFC	9
MAR-18-2010 11:02	RFC	27	FEB-02-2011 01:21	RFC	5	JAN-06-2012 23:25	RFC	8
MAR-23-2010 20:14	RFC	13	FEB-08-2011 22:41	Mid-Atlantic	11	JAN-23-2012 15:02	Mid-Atlantic	8
APR-11-2010 13:12	RFC	9	FEB-09-2011 11:40	Mid-Atlantic	16	MAR-02-2012 19:54	RFC	9
APR-28-2010 15:09	Mid-Atlantic	8	FEB-13-2011 15:35	Mid-Atlantic	14	MAR-08-2012 17:04	RFC	6
MAY-11-2010 19:57	Mid-Atlantic	9	FEB-24-2011 11:35	Mid-Atlantic	14	MAR-19-2012 10:14	RFC	10
MAY-15-2010 03:03	RFC	6	FEB-25-2011 14:12	RFC	10	APR-16-2012 00:20	Mid-Atlantic	9
MAY-28-2010 04:06	Mid-Atlantic	5	MAR-30-2011 19:13	RFC	12	APR-16-2012 11:18	RFC	8
JUN-15-2010 00:46	RFC	34	APR-02-2011 13:13	Mid-Atlantic	11	APR-19-2012 11:54	RFC	16
JUN-19-2010 23:49	Mid-Atlantic	9	APR-11-2011 00:28	RFC	6	APR-20-2012 11:08	Mid-Atlantic	7
JUN-24-2010 00:56	RFC	15	APR-16-2011 22:51	RFC	9	JUN-20-2012 13:35	RFC	7
JUN-27-2010 19:33	Mid-Atlantic	15	APR-21-2011 20:02	Mid-Atlantic	6	JUN-26-2012 17:51	RFC	7
JUL-07-2010 15:20	RFC	8	APR-27-2011 01:22	RFC	8	JUL-23-2012 21:45	RFC	18
JUL-16-2010 20:45	Mid-Atlantic	19	MAY-02-2011 00:05	Mid-Atlantic	21	AUG-03-2012 12:44	RFC	10
AUG-11-2010 19:09	RFC	17	MAY-12-2011 19:39	RFC	9	SEP-08-2012 04:34	RFC	12
AUG-13-2010 23:19	RFC	6	MAY-26-2011 17:17	Mid-Atlantic	20	SEP-27-2012 17:19	Mid-Atlantic	7
AUG-16-2010 07:08	RFC	17	MAY-27-2011 12:51	RFC	6	OCT-17-2012 10:48	RTO	10
AUG-16-2010 19:39	Mid-Atlantic	11	MAY-29-2011 09:04	RFC	7	OCT-23-2012 22:29	RTO	19
SEP-15-2010 11:20	RFC	13	MAY-31-2011 16:36	RFC	27	OCT-30-2012 05:12	RTO	14
SEP-22-2010 15:28	Mid-Atlantic	24	JUN-03-2011 14:23	RFC	7	NOV-25-2012 16:32	RTO	12
OCT-05-2010 17:20	RFC	10	JUN-06-2011 22:02	Mid-Atlantic	9	DEC-16-2012 07:01	RTO	9
OCT-16-2010 03:22	Mid-Atlantic	10	JUN-23-2011 23:26	RFC	8	DEC-21-2012 05:51	RTO	7
OCT-16-2010 03:25	RFCNonMA	7	JUN-26-2011 22:03	Mid-Atlantic	10	DEC-21-2012 10:29	RTO	5
OCT-27-2010 10:35	RFC	7	JUL-10-2011 11:20	RFC	10			
OCT-27-2010 12:50	Mid-Atlantic	10	JUL-28-2011 18:49	RFC	12			
NOV-26-2010 14:24	RFC	13	AUG-02-2011 01:08	RFC	6			
NOV-27-2010 11:34	RFC	8	AUG-18-2011 06:45	Mid-Atlantic	6			
DEC-08-2010 01:19	RFC	11	AUG-19-2011 14:49	RFC	5			
DEC-09-2010 20:07	RFC	5	AUG-23-2011 17:52	RFC	7			
DEC-14-2010 12:02	Mid-Atlantic	24	SEP-24-2011 15:48	RFC	8			
DEC-16-2010 18:40	Mid-Atlantic	20	SEP-27-2011 14:20	RFC	7			
DEC-17-2010 22:09	Mid-Atlantic	6	SEP-27-2011 16:47	RFC	9			
DEC-29-2010 19:01	Mid-Atlantic	15	OCT-30-2011 22:39	Mid-Atlantic	10			
			DEC-15-2011 14:35	Mid-Atlantic	8			
			DEC-21-2011 14:26	RFC	18			

Figure 10-14 Synchronized reserve events duration distribution curve: 2011 through 2015



## Non-Synchronized Reserve Market

Non-synchronized reserve is reserve MW available within ten minutes but not synchronized to the grid. There is no defined requirement for non-synchronized 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 non-synchronized reserves. Generation resources that are not available to provide energy are not eligible to provide non-synchronized reserves.

Startup time for non-synchronized reserve resources is not subject to testing. There is no non-synchronized reserve offer MW or offer price. The market solution software evaluates all eligible resources and schedules them economically.

Table 10-21 Synchronized reserve events, January 2010 through December 2015 (continued)

Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)	Effective Time	Region	Duration (Minutes)
JAN-22-2013 08:34	RTO	8	JAN-06-2014 22:01	RTO	68	JAN-07-2015 22:36	RTO	8
JAN-25-2013 15:01	RTO	19	JAN-07-2014 02:20	RTO	25	FEB-24-2015 02:51	RTO	5
FEB-09-2013 22:55	RTO	10	JAN-07-2014 04:18	RTO	34	FEB-26-2015 15:20	RTO	6
FEB-17-2013 23:10	RTO	13	JAN-07-2014 11:27	RTO	11	MAR-03-2015 17:02	RTO	11
APR-17-2013 01:11	RTO	11	JAN-07-2014 13:20	RTO	41	MAR-16-2015 10:25	RTO	24
APR-17-2013 20:01	RTO	9	JAN-10-2014 16:46	RTO	12	MAR-17-2015 23:34	RTO	17
MAY-07-2013 17:33	RTO	8	JAN-21-2014 18:52	RTO	6	MAR-23-2015 23:44	RTO	15
JUN-05-2013 18:54	RTO	20	JAN-22-2014 02:26	RTO	7	APR-06-2015 14:23	RTO	8
JUN-08-2013 15:19	RTO	9	JAN-22-2014 22:54	RTO	8	APR-07-2015 17:11	RTO	31
JUN-12-2013 17:35	RTO	10	JAN-25-2014 05:22	RTO	10	APR-15-2015 08:14	RTO	8
JUN-30-2013 01:22	RTO	10	JAN-26-2014 17:11	RTO	6	APR-25-2015 03:21	RTO	9
JUL-03-2013 20:40	RTO	13	JAN-31-2014 15:05	RTO	13	JUL-30-2015 14:04	RTO	10
JUL-15-2013 18:43	RTO	29	FEB-02-2014 14:03	Dominion	8	AUG-05-2015 19:47	RTO	7
JUL-28-2013 14:20	RTO	10	FEB-08-2014 06:05	Dominion	18	AUG-19-2015 16:47	RTO	9
SEP-10-2013 19:48	RTO	68	FEB-22-2014 23:05	RTO	7	SEP-05-2015 01:16	RTO	7
OCT-28-2013 10:44	RTO	33	MAR-01-2014 05:18	RTO	26	SEP-10-2015 10:12	RTO	8
DEC-01-2013 11:17	RTO	9	MAR-05-2014 21:25	RTO	8	SEP-29-2015 00:58	Mid-Atlantic	11
DEC-07-2013 19:44	RTO	7	MAR-13-2014 20:39	RTO	8	NOV-12-2015 16:42	RTO	8
			MAR-27-2014 10:37	RTO	56	NOV-21-2015 17:17	RTO	8
			APR-14-2014 01:16	RTO	10	DEC-04-2015 22:41	RTO	7
			APR-25-2014 17:33	RTO	6	DEC-24-2015 17:42	RTO	8
			MAY-01-2014 14:18	RTO	13			
			MAY-03-2014 17:11	RTO	13			
			MAY-14-2014 01:36	RTO	5			
			JUL-08-2014 03:07	RTO	9			
			JUL-25-2014 19:19	RTO	7			
			SEP-06-2014 13:32	RTO	18			
			SEP-20-2014 23:42	RTO	14			
			SEP-29-2014 10:08	RTO	15			
			OCT-20-2014 06:35	RTO	15			
			OCT-23-2014 11:03	RTO	27			
			NOV-01-2014 06:50	RTO	9			
			NOV-08-2014 02:08	RTO	8			
			NOV-22-2014 05:27	RTO	21			
			NOV-22-2014 08:19	RTO	10			
			DEC-10-2014 18:58	RTO	8			
			DEC-31-2014 21:42	RTO	12			

Prices are determined solely by the lost opportunity cost created by any deviation from economic merit order required to maintain the non-synchronized reserve commitment. Since non-synchronized reserve is a lower quality product, its clearing price is always less than or equal to the synchronized reserve market clearing price. In most hours, the non-synchronized reserve clearing price is zero.

## Market Structure

### Demand

PJM specifies that 1,700 MW of ten minute primary reserve must be available in the Mid-Atlantic Dominion Reserve Subzone of which 1,450 MW must be synchronized reserve (Figure 10-2), and that 2,175 MW of ten minute primary reserve must be available in the RTO Reserve Zone of which 1,450 MW must be synchronized reserve (Figure 10-3). The balance of primary reserve can be made up by the most economic combination of synchronized and non-synchronized reserve.

### Supply

Figure 10-2 shows that most of the primary reserve requirement (orange line) in excess of the synchronized reserve requirement (yellow line) is satisfied by non-synchronized reserve (light blue area).

There are no offers for non-synchronized reserve. Neither MW nor price is offered for non-synchronized reserve. The market solution (ASO) optimizes synchronized reserve, non-synchronized reserve, and energy to satisfy the primary reserve requirement at the lowest cost. Non-synchronized reserve resources are scheduled economically based on LOC until the Primary Reserve requirement is filled. The non-synchronized reserve market clearing price is determined at the end of the hour as the marginal unit's LOC. When a unit clears the non-synchronized reserve market and is scheduled, it is committed to remain off-line for the hour and available to provide ten minute reserves.

Equipment that generally qualifies as non-synchronized reserve include run of river hydro, pumped hydro,

combustion turbines, combined cycles and diesels.<sup>27</sup> In 2015, an average of 390.3 MW of non-synchronized reserve was scheduled hourly out of 1,860.8 eligible MW as part of the primary reserve requirement in the Mid-Atlantic Dominion Subzone.<sup>28</sup> In 2015, an average of 345.1 MW of non-synchronized reserve was scheduled hourly out of 2,550.1 MW eligible MW in the RTO Zone.

CTs provided 58.4 percent and hydro 38.8 percent of cleared non-synchronized reserve MW in 2015. The remaining 2.8 percent of cleared non-synchronized reserve was provided by diesel resources.

## Market Concentration

The supply of non-synchronized reserves in the Mid-Atlantic Dominion Subzone was highly concentrated except in December. The supply of non-synchronized reserves in the RTO Zone was also highly concentrated except in November and December. Moderate weather made more non-synchronized resources available in November and December. PJM market operations reduced the required amount of primary reserve from 2175 to 2025 in 20 days in November and December. PJM market operations used positive tier 1 estimate biasing in 121 hours of November and December, reducing the need for non-synchronized reserve to satisfy the primary reserve requirement.

**Table 10-22 Non-synchronized reserve market HHIs: 2015**

Year	Month	Mid Atlantic Dominion HHI	RTO HHI
2015	Jan	3455	2232
2015	Feb	3749	2201
2015	Mar	3382	3754
2015	Apr	4044	3676
2015	May	3809	5292
2015	Jun	3937	6022
2015	Jul	4115	6261
2015	Aug	4237	5555
2015	Sep	3973	5285
2015	Oct	3845	6817
2015	Nov	5375	5155
2015	Dec	5675	2149
2015	Average	4133	4533

<sup>27</sup> See PJM, "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 80.

<sup>28</sup> The 2015 State of the Market Report for PJM: January through June incorrectly stated this figure as 746.4 MW. It should have been 434.3 MW.

**Table 10-23 Non-synchronized reserve market pivotal supply test: 2015**

Year	Month	Mid Atlantic Dominion Three Pivotal Supplier Hours	Full RTO Three Pivotal Supplier Hours
2015	Jan	100.0%	81.6%
2015	Feb	95.0%	78.9%
2015	Mar	100.0%	90.7%
2015	Apr	100.0%	89.9%
2015	May	98.9%	80.0%
2015	Jun	97.2%	71.1%
2015	Jul	96.5%	83.7%
2015	Aug	97.4%	85.2%
2015	Sep	97.1%	86.4%
2015	Oct	100.0%	60.3%
2015	Nov	99.6%	8.1%
2015	Dec	58.9%	0.3%
2015	Average	95.1%	68.0%

## Price

The price of non-synchronized reserve is calculated in real time every five minutes and averaged each hour for the RTO Reserve Zone and the Mid Atlantic Dominion Reserve Subzone. Resources eligible for non-synchronized reserve make no price offer or MW offer.

Figure 10-15 shows the daily average hour ahead non-synchronized reserve market clearing price and average scheduled MW for the MAD Subzone. The MAD Subzone Non-Synchronized Reserve Market had a clearing price greater than zero in 1,089 (12.4 percent) hours in 2015, at a weighted average price of \$11.87 per MW. The weighted non-synchronized reserve market clearing price for all hours in the MAD Subzone, including cleared hours when the price was zero, was \$1.03 per MW. The maximum hourly clearing price was \$291.48 per MW on July 20, 2015. Figure 10-16 shows the daily average hour ahead non-synchronized reserve market clearing price and average scheduled MW for the RTO Zone. The RTO Zone Non-Synchronized Reserve Market had a clearing price greater than zero in 1,055 (12.0 percent) hours in 2015, at a weighted average price of \$10.49. The weighted non-synchronized reserve market clearing price for all hours in the RTO Zone including cleared hours when the price was zero, was \$1.15.

combustion turbines, combined cycles and diesels.<sup>27</sup> In 2015, an average of 390.3 MW of non-synchronized reserve was scheduled hourly out of 1,860.8 eligible MW as part of the primary reserve requirement in the Mid-Atlantic Dominion Subzone.<sup>28</sup> In 2015, an average of 345.1 MW of non-synchronized reserve was scheduled hourly out of 2,550.1 MW eligible MW in the RTO Zone.

CTs provided 58.4 percent and hydro 38.8 percent of cleared non-synchronized reserve MW in 2015. The remaining 2.8 percent of cleared non-synchronized reserve was provided by diesel resources.

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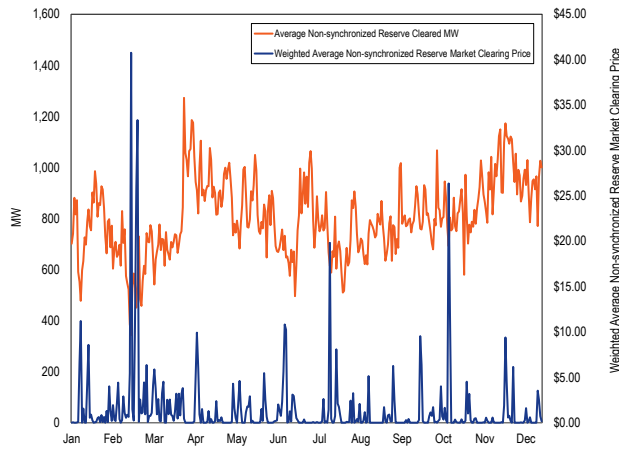
Year	Month	Mid Atlantic Dominion Three Pivotal Supplier Hours	Full RTO Three Pivotal Supplier Hours
2015	Jan	100.0%	81.6%
2015	Feb	95.0%	78.9%
2015	Mar	100.0%	90.7%
2015	Apr	100.0%	89.9%
2015	May	98.9%	80.0%
2015	Jun	97.2%	71.1%
2015	Jul	96.5%	83.7%
2015	Aug	97.4%	85.2%
2015	Sep	97.1%	86.4%
2015	Oct	100.0%	60.3%
2015	Nov	99.6%	8.1%
2015	Dec	58.9%	0.3%
2015	Average	95.1%	68.0%

## Price

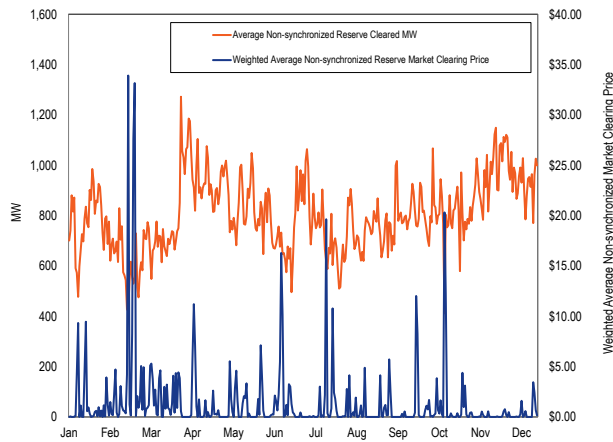
The price of non-synchronized reserve is calculated in real time every five minutes and averaged each hour for the RTO Reserve Zone and the Mid Atlantic Dominion Reserve Subzone. Resources eligible for non-synchronized reserve make no price offer or MW offer.

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**Figure 10-15 Daily average MAD subzone non-synchronized reserve market clearing price and MW purchased: 2015**



**Figure 10-16 Daily average RTO Zone non-synchronized reserve market clearing price and MW purchased: 2015**



## Price and Cost

As a result of changing grid conditions, load forecasts, and unexpected generator performance, prices sometimes 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.

The full cost of non-synchronized reserve including payments for the clearing price and uplift costs is calculated and compared to the price (Table 10-24). The closer the price to cost ratio comes to one, the more the market price reflects the full cost of non-synchronized reserve.

In 2015, the price to cost ratio of the RTO Zone Non-Synchronized Reserve Market averaged 58.7 percent; and the price to cost ratio of the MAD Subzone averaged 59.4 percent.

**Table 10-24 RTO Zone, MAD Subzone non-synchronized reserve MW, credits, price, and cost: 2015**

Market	Year	Month	Total Non-synchronized Reserve MW	Total Non-synchronized Reserve Charges	Weighted Non-synchronized Reserve Market Clearing Price	Non-synchronized Reserve Cost	Price/Cost Ratio
RTO Zone	2015	Jan	576,785	\$1,228,205	\$1.16	\$2.13	54.5%
RTO Zone	2015	Feb	412,564	\$2,810,932	\$4.09	\$6.81	60.1%
RTO Zone	2015	Mar	551,828	\$1,387,010	\$1.51	\$2.51	60.0%
RTO Zone	2015	Apr	688,059	\$734,711	\$0.90	\$1.07	84.1%
RTO Zone	2015	May	633,935	\$1,060,846	\$0.94	\$1.67	55.9%
RTO Zone	2015	Jun	526,821	\$1,015,756	\$1.35	\$1.93	70.0%
RTO Zone	2015	Jul	561,665	\$1,060,091	\$1.03	\$1.89	54.8%
RTO Zone	2015	Aug	547,883	\$551,968	\$0.54	\$1.01	53.8%
RTO Zone	2015	Sep	563,351	\$926,350	\$0.88	\$1.64	53.3%
RTO Zone	2015	Oct	608,554	\$1,129,090	\$1.47	\$1.86	79.2%
RTO Zone	2015	Nov	638,440	\$826,524	\$0.34	\$1.29	26.3%
RTO Zone	2015	Dec	728,815	\$1,053,608	\$0.67	\$1.45	46.6%
RTO Zone	2015	Tot	7,038,700	\$13,785,091	\$1.15	\$1.96	58.7%
<hr/>							
MAD Subzone	2015	Jan	486,505	\$909,339	\$1.07	\$1.87	57.2%
MAD Subzone	2015	Feb	326,818	\$2,126,008	\$3.75	\$6.51	57.7%
MAD Subzone	2015	Mar	473,825	\$836,501	\$1.25	\$1.77	70.6%
MAD Subzone	2015	Apr	685,799	\$700,577	\$0.88	\$1.02	86.4%
MAD Subzone	2015	May	623,907	\$968,896	\$0.89	\$1.55	57.3%
MAD Subzone	2015	Jun	510,793	\$901,934	\$1.24	\$1.77	70.1%
MAD Subzone	2015	Jul	553,485	\$1,018,749	\$0.99	\$1.84	53.5%
MAD Subzone	2015	Aug	542,866	\$523,260	\$0.52	\$0.96	53.8%
MAD Subzone	2015	Sep	558,774	\$837,491	\$0.83	\$1.50	55.4%
MAD Subzone	2015	Oct	582,379	\$992,071	\$1.38	\$1.70	80.8%
MAD Subzone	2015	Nov	636,997	\$809,715	\$0.34	\$1.27	26.4%
MAD Subzone	2015	Dec	728,048	\$1,032,339	\$0.67	\$1.42	47.1%
MAD Subzone	2015	Tot	6,710,197	\$11,656,879	\$1.03	\$1.74	59.4%

## Secondary Reserve (DASR)

PJM maintains a day-ahead, offer based market for 30-minute day-ahead secondary reserve.<sup>29</sup> The Day-Ahead Scheduling Reserves Market (DASR) has no performance obligations.

## Market Structure

### Supply

DASR is provided by both generation and demand resources. DASR offers consist of price only. DASR MW are calculated by the market clearing engine. Available DASR MW are the lesser of the energy ramp rate for all on-line units times thirty minutes, or the economic maximum minus the day-ahead dispatch point. For off-line resources capable of being online in thirty minutes, the DASR quantity is the economic maximum. In 2015, the average available hourly DASR was 36,396.0 MW. This is a 13.3 percent reduction from 42,017 MW of 2014. The DASR MW purchased averaged 6,113.1 MW per hour for all hours in 2015, a small decrease from

6,245 MW per hour in 2014. Although there was no shortage of DASR in the market solution, the market has no requirements for or link to the availability of scheduled reserve during real-time hours. Spinning events longer than 30 minutes, while rare, do occur. The spinning events of September 10, 2013, March 27, 2014, and April 7, 2015, are examples of when secondary reserve was needed but not enough was available in real time.

All generation resources are required to offer a price for DASR.<sup>30</sup> Of the 6,245 MW hourly average DASR in 2015,

56.0 percent was from CTs, 20.3 percent was from steam, 12.0 percent was from hydro, and 9.8 percent was CCs. Load response resources which are registered in PJM's Economic Load Response and are dispatchable by PJM are eligible to provide DASR. In 2015, six demand resources offered into the DASR Market.

### Demand

DASR 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.<sup>31</sup> The RFC and Dominion secondary reserve requirements are added together to form a single RTO DASR requirement defined as a percentage of the daily peak load forecast. For 2015, the DASR requirement was 5.93 percent of daily peak load forecast. The DASR requirement is applicable for all

29 See PJM, "Manual 35: Definitions and Acronyms," Revision 23 (April 11, 2014), p. 89.

30 See PJM "Manual 11: Energy & Ancillary Services Market Operations," Revision 79 (December 17, 2015), p. 144 §11.2.3 Day-Ahead Scheduling Reserve Market Rules.

31 See PJM, "Manual 13: Emergency Operations," Revision 59 (January 1, 2016), p. 11.

hours of the operating day. If the DASR Market does not procure adequate scheduling reserves, PJM is required to schedule additional operating reserves.<sup>32</sup>

Effective March 1, 2015, the DASR requirement can be increased by PJM dispatch under conditions of “hot weather or cold weather alert or max emergency generation alert or other escalating emergency.”<sup>33</sup> The amount of additional DASR MW that may be required is the Adjusted Fixed Demand (AFD) determined by a Seasonal Conditional Demand (SCD) factor.<sup>34</sup> 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 ten peak load days from the prior year. For November 2014 through October 2015, the values for additional percent of peak load was 3.87 percent for winter, 5.36 percent for summer. For November 2015 through October 2016, the SCD values are 3.45 percent for winter and 2.88 percent for summer. PJM Dispatch may also schedule additional Day-Ahead Scheduling Reserves as deemed necessary for conservative operations.<sup>35</sup> PJM has defined conservative operations to include, potential fuel delivery issues, forest/brush fires, extreme weather events, environmental alerts, solar disturbances, unknown grid operating state.<sup>36</sup> The net result is substantial discretion for PJM to increase the demand for DASR under a variety of circumstances.

PJM invoked adjusted fixed demand during 14 days in 2015. A record of PJM’s use of adjusted fixed demand is in Table 10–25. The use of adjusted fixed demand (and other conservative operations adjustments) impacts the DASR Market in several significant ways.

**Table 10–25 Adjusted Fixed Demand Days: 2015**

Start Date	End Date	Number of Hours	Average Additional	
				MW
26-May	27-May	44		3,626
12-Jun	13-Jun	48		3,016
20-Jul	21-Jul	38		2,288
29-Jul	30-Jul	48		3,608
17-Aug	17-Aug	24		2,476
1-Sep	3-Sep	72		4,336
8-Sep	9-Sep	48		4,452

An alternative to adjusted fixed demand would be to schedule secondary reserve in the real time market. The MMU recommends that PJM replace the DASR Market with a real-time secondary reserve product that is available and dispatchable in real time.

## Market Concentration

Between January 2012 and April 2015, no hours would have failed a three pivotal supplier test in the DASR Market. Beginning in May 2015, when PJM began to invoke adjusted fixed demand for conservative operations, the DASR Market began to fail the three pivotal supplier test (Table 10–26).

**Table 10–26 DASR market three pivotal supplier test results and number of hours with DASRMCP above \$0: 2015**

Year	Month	Number of Hours When	
		DASRMCP > \$0	Percent of Hours Pivotal
2015	Jan	151	0.0%
2015	Feb	328	0.0%
2015	Mar	300	0.0%
2015	Apr	301	0.0%
2015	May	323	3.9%
2015	Jun	349	11.2%
2015	Jul	496	28.1%
2015	Aug	482	21.5%
2015	Sep	532	11.4%
2015	Oct	634	0.3%
2015	Nov	568	0.0%
2015	Dec	473	0.4%
2015	Average	411	6.4%

## Market Conduct

PJM rules allow any unit with reserve capability that can be converted into energy within 30 minutes to offer into the DASR Market.<sup>37</sup> Units that do not offer have their offers set to \$0.00 per MW.

Economic withholding remains an issue in the DASR Market. The marginal cost of providing DASR is

<sup>32</sup> PJM uses the terms “supplemental operating reserves” and “scheduling operating reserves” interchangeably.

<sup>33</sup> PJM, “Energy and Reserve Pricing Et Interchange Volatility Final Proposal Report,” <<http://www.pjm.com/~media/committees-groups/committees/mrc/20141030/20141030-item-04-erpv-final-proposal-report.ashx>>.

<sup>34</sup> See PJM, “Manual 11: Energy Et Ancillary Services Market Operations,” Revision 79, (December 17, 2015) p. 144 at 11.2.1 Day-Ahead Scheduling Reserve Market Requirement.

<sup>35</sup> See PJM “Manual 11: Energy Et Ancillary Services Market Operations,” Revision 79, (December 17, 2015) p. 144 at 11.2.1 Day-Ahead Scheduling Reserve Market Requirement.

<sup>36</sup> See PJM, “Manual 13: Emergency Operations” Revision 58, (August 1, 2015), p. 45 at 3.2 Conservative Operations

<sup>37</sup> See PJM, “Manual 11: Emergency and Ancillary Services Operations,” Revision 79 (December 17, 2015), p. 147.

zero. All offers greater than zero constitute economic withholding. Throughout 2015 daily DASR offers averaged 37.9 percent above \$0 per MW and 11.6 percent above \$5 per MW.

## Market Performance

Two changes to the DASR Market had significant impacts in 2015. In January 2015, the way that DASR available supply was estimated was reduced from day-ahead dispatch up to emergency maximum to day-ahead dispatch up to economic maximum. This reduced the DASR available supply by 13.3 percent. Between May and September 2015, the use of AFD significantly increased the demand in 366 hours. For 43.6 percent of hours in 2015, DASR cleared at a price of \$0.00 per MWh (Figure 10-17). This is a significant reduction from the 94.1 percent of hours that the DASR Market cleared at \$0 in 2014. In 2015, the weighted average DASR price for all hours when the DASRMCP was above \$0 was \$2.99. The average cleared MW in all hours when the DASRMCP was above \$0 was 5,166 MW. The highest DASR price was \$199.83 on February 19, 2015.

hours when DASRMCP was greater than \$0 and PJM dispatch did not augment the requirement.

While the new rules allow PJM dispatch 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 dispatch adds 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.

The implementation of the conservative operations adjustment to the DASR requirement in 367 hours during 2015 has significantly increased the cost of DASR as a result of increases in DASR MW cleared and corresponding increases in the DASR clearing prices (Table 10-28).

**Table 10-27 DASR Market, regular hours vs. adjusted fixed demand hours: 2015**

Year	Month	Number of Hours DASRMCP>\$0		Weighted DASRMCP		Average PJM Load		Hourly Average Cleared DASR MW		Average DASR Credits	
		Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour	Normal Hour	AFD Hour
2015	Jan	151	0	\$0.19	\$0.00	112,373	0	4,902	0	\$937	\$0
2015	Feb	328	0	\$4.03	\$0.00	113,797	0	4,868	0	\$19,610	\$0
2015	Mar	300	0	\$0.59	\$0.00	96,315	0	4,116	0	\$2,429	\$0
2015	Apr	301	0	\$0.04	\$0.00	80,798	0	4,085	0	\$155	\$0
2015	May	279	44	\$3.66	\$12.34	92,863	96,726	4,574	9,042	\$16,750	\$111,598
2015	Jun	255	94	\$0.92	\$13.82	104,388	105,190	5,152	8,895	\$4,724	\$122,908
2015	Jul	410	86	\$1.36	\$18.56	106,605	114,868	5,553	9,599	\$7,565	\$178,164
2015	Aug	459	23	\$0.95	\$14.79	105,509	110,753	5,766	9,701	\$5,483	\$143,459
2015	Sep	412	120	\$0.31	\$14.63	91,491	109,028	5,003	11,337	\$1,550	\$165,870
2015	Oct	634	0	\$0.35	\$0	77,657	0	4,231	0	\$1,500	\$0
2015	Nov	568	0	\$0.29	\$0	80,844	0	4,477	0	\$1,279	\$0
2015	Dec	473	0	\$0.13	\$0	87,166	0	4,807	0	\$617	\$0

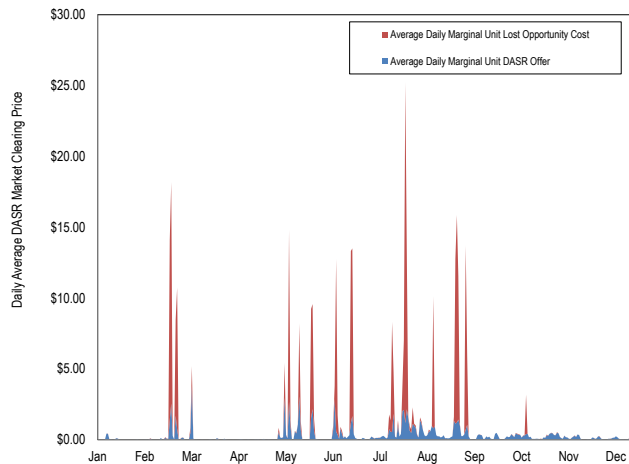
The introduction of Adjusted Fixed Demand on March 1, 2015, created a bifurcated market (Table 10-27). There were 367 hours in 2015 when PJM dispatch added an Adjusted Fixed Demand to the normal 5.93 percent of forecast load. The difference in market clearing price, MW cleared, obligation incurred, and charges to PJM load are substantial. During hours when DASRMCP was greater than \$0 and PJM dispatch augmented the requirement via Adjusted Fixed Demand the weighted average DASR price was \$15.09 compared to \$0.77 for



**Table 10-28 DASR Market all hours of DASR market clearing price greater than \$0**

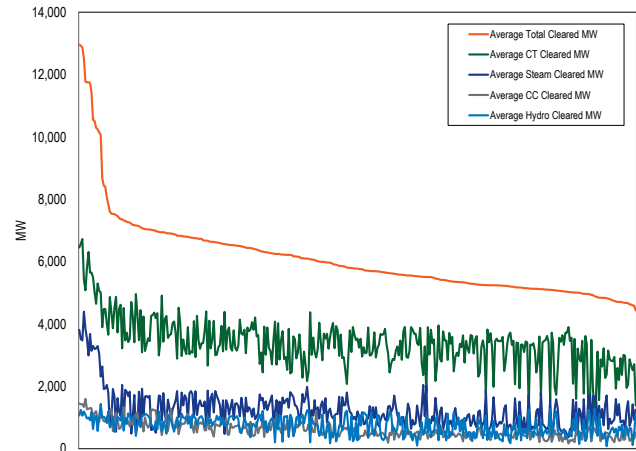
Year	Month	Number of Hours DASRMCP > \$0	Weighted DASR Market Clearing Price	Average Hourly RT Load	Total PJM Cleared DASRM MW	Total PJM Cleared Additional DASR MW	Total Charges
2015	Jan	151	\$0.19	112,373	740,268	0	\$141,561
2015	Feb	328	\$4.03	113,797	1,596,639	0	\$6,431,987
2015	Mar	300	\$0.59	96,315	1,234,905	0	\$728,829
2015	Apr	301	\$0.04	80,798	1,229,513	0	\$46,584
2015	May	323	\$5.73	93,389	1,673,983	159,559	\$9,583,568
2015	Jun	349	\$5.93	104,604	2,150,052	294,881	\$12,757,966
2015	Jul	496	\$5.94	108,038	3,102,087	260,120	\$18,423,687
2015	Aug	482	\$2.03	105,759	2,869,630	59,414	\$5,816,401
2015	Sep	532	\$6.00	95,447	3,421,690	525,883	\$20,542,872
2015	Oct	634	\$0.35	77,657	2,682,429	0	\$951,264
2015	Nov	568	\$0.29	80,844	2,542,795	0	\$726,549
2015	Dec	473	\$0.13	87,166	2,273,497	0	\$291,725
2015	Average	411	\$2.60	96,349	2,126,457	108,321	\$6,370,250

**Figure 10-17 Daily average components of DASR clearing price (\$/MW), marginal unit offer and LOC: 2015**



When the DASR requirement is increased by PJM dispatch, the reserve requirement frequently cannot be filled without redispatching online resources which significantly affects the price. Figure 10-17 shows the impact of LOC on price when online resources must be redispatched to satisfy the DASR requirement. DASR prices increase at peak loads as a result of high LOCs. Figure 10-18 shows that when total DASR MW required is at its peak, a higher percentage of MW come from on line steam and CT units. While CTs have a low DASR related cost, steam units typically incur an LOC when redispatched to provide DASR. The redispatch of steam units to provide DASR has a significant impact on DASR prices.

**Figure 10-18 Daily average DASR MW by Unit Type sorted from highest to lowest daily requirement: 2015**



## 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. Significant technical and structural changes were made to the Regulation Market in 2012.<sup>38</sup>

## Market Design

The objective of PJM's regulation market design is to minimize the cost to provide regulation using two resource types, RegA and RegD, in a single market. To

<sup>38</sup> See the 2012 State of the Market Report for PJM, Volume II, Section 9, "Ancillary Services," p. 271.

meet this objective, the marginal benefit factor (MBF) function describing the engineering substitutability between RegA and RegD must be correctly defined and consistently applied throughout the market design, from optimization to settlement. This is the only way to ensure that the engineering relationship is reflected in the relative value of RegA and RegD resources in the market price signals. That is not the case in PJM's current regulation market design. The MBF function is not correctly defined and it is not consistently applied throughout the market design, from optimization to settlement.

The result has been that the regulation market has over procured RegD relative to RegA in some hours and has provided a consistently inefficient market signal to participants regarding the value of RegD to the market in every hour. This over procurement began to degrade 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 competitive level defined by an accurate MBF function, there is an artificial incentive for inefficient entry of RegD resources. This inefficient market signal has contributed to a significant amount of storage capacity (Table 10-29) appearing in PJM's interconnection queue, despite operational evidence that the RegD market, as implemented, is saturated.

**Table 10-29 Active battery storage projects in the PJM queue system by submitted year from 2012 to 2015**

Year	Number of Storage Projects	Total Capacity (MW)
2012	3	9.1
2013	4	22
2014	11	151
2015	57	534.4

The MBF related issues with the regulation market have been raised in the PJM stakeholder process. In 2015, PJM stakeholders approved an interim, partial fix to the RegD over procurement problem which was implemented on December 14, 2015. The interim fix was designed to reduce the relative value of RegD MW in the optimization in all hours and cap RegD MW during critical performance hours, as well as provide a better measure of effective MW from cleared RegD resources. The interim fix does not address the fundamental issues in the optimization or the lack of consistency in the application of the MBF. The MMU and PJM are pursuing

a more complete fix through the Regulation Market Issues Senior Task Force.

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 and performance score translate a resource's capability (actual) MW into effective MW.

Regulation in PJM is frequently provided by fleets of resources rather than by individual units. A fleet is a set of resources owned or operated by a common entity. The regulation signals (RegA or RegD) are sent every two seconds to the fleet local control centers or, at the option of fleet owners, to their individual resources. Fleet local control centers report to PJM every two seconds the fleet response to the RegA and RegD signals.

Prior to the operating hour, fleet owners are allowed to replace an assigned regulation resource in their fleet with another resource in their fleet as long as that resource is qualified to provide regulation for the originally assigned signal, has an historic performance score close to the originally assigned resource and has notified PJM of the change.

Regulation performance scores (0.0 to 1.0) measure the response of a regulating resource to its assigned regulation signal (RegA or RegD) every ten 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.<sup>39</sup>

Figure 10-19 and Figure 10-20 show the average performance score by resource type and the signal followed for 2015. In these figures, the MW used are unadjusted regulation capability MW and the performance score is the hourly performance score of the regulation resource.<sup>40</sup> Each category (color bar) is based on the percentage of the full performance score distribution for each resource (or signal) type. As Figure 10-20 shows, 72.6 percent of RegD resources had average performance scores within the 0.91-1.00 range, and 24.1 percent of RegA resources had average performance scores within that range.

Figure 10-19 Hourly average performance score by unit type: 2015

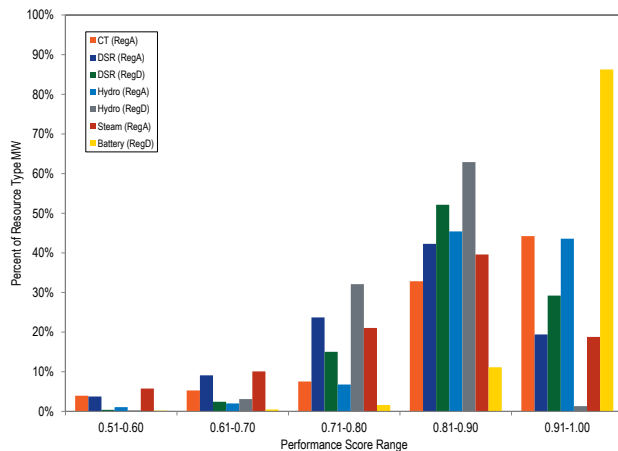
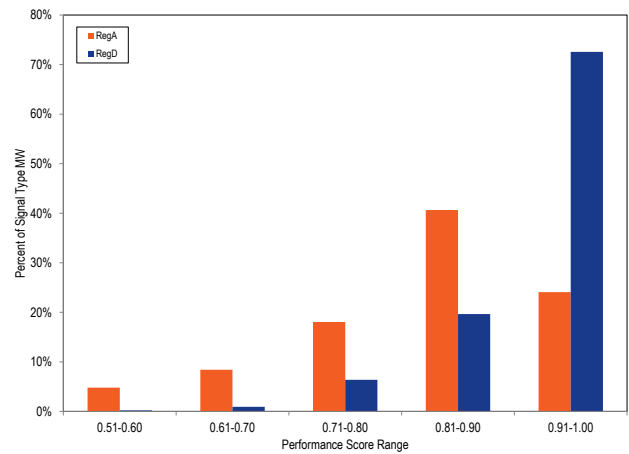


Figure 10-20 Hourly average performance score by regulation signal type: 2015



PJM creates an individual resource’s regulation signal proportionately by dividing the assigned regulation of the individual resource by the assigned regulation of the fleet. Then, PJM compares the individual resource’s regulation signal to the individual resource’s MW output (or, for DR, load) to calculate the performance score based on delay, correlation, and precision. Performance scores are calculated using data every 10 seconds, but are reported on an hourly basis for each individual regulating resource.

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. The optimization of RegA and RegD assignments is dependent on the conversion of RegA and RegD MW into a single measure. The marginal benefit factor (MBF) is the measure of substitutability of RegD resources for RegA resources in satisfying the regulation requirement.

The MBF, as the marginal rate of substitution between RegA and RegD resource MW for a given regulation requirement, defines specific combinations of RegA and RegD MW needed to meet specific regulation performance levels. The MBF should result in the selection of the least cost combination/ratio of RegA and RegD MW when the prices of RegA and RegD are known. PJM’s optimization engine has not properly implemented the MBF so that

<sup>39</sup> PJM “Manual 12: Balancing Operations” Rev. 33 (December 1, 2015); 4.5.6, p 52.  
<sup>40</sup> Except where explicitly referred to as effective MW or effective regulation MW, MW means regulation capability MW unadjusted for either marginal benefit factor or performance factor.

the market clearing combination of RegA and RegD MW is consistent with the combinations defined by the MBF curve.

For purposes of comparing effective MW to the regulation requirement, expressed in terms of effective MW of RegA, cleared regulation MW are converted to effective MW by multiplying each resource's offered capability MW by the product of the resource specific benefit factor and performance score. This resource specific block assignment approach undercounts total effective MW, which are correctly calculated as the area under the MBF curve.

Total regulation offers (made up of a \$/MW capability offer and a \$/mile based performance offer) are converted to dollars per effective MW by dividing the offer by the effective MW.

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

## Market Design Issues

### Marginal Benefit Factor Not Reflected in Market

The marginal benefit factor defines the substitutability between RegA and RegD resources in meeting the regulation requirement. If the marginal benefit factor function is incorrectly defined, the resulting combinations of RegA and RegD do not represent the least cost solution.

The marginal benefit factor 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 adhered to a FERC order that required the marginal benefit factor be fixed at 1.0 for settlement calculations only. On October 2, 2013, the FERC directed PJM to eliminate the use of the marginal benefit factor 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.<sup>41</sup>

The result of the FERC directive is that the marginal benefit factor is used in the optimization to determine the relative value of additional MW of RegD, but the marginal benefit factor is not used in the settlement for RegD.

Resources are paid Regulation Market Clearing Price (RMCP) credits and lost opportunity cost credits. 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.

Figure 10-21 compares the daily average marginal benefit factor and the mileage ratio.

**Figure 10-21 Daily average marginal benefit factor and mileage ratio: 2015**

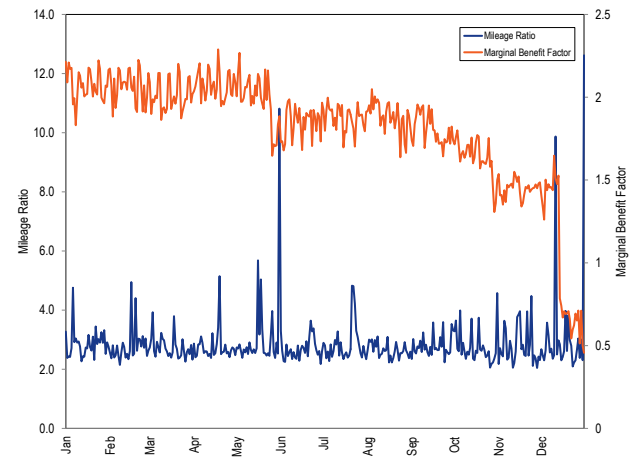
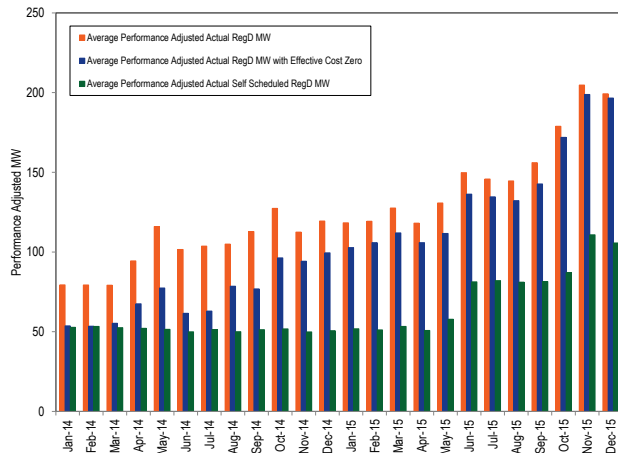


Figure 10-22 shows, by month, both an increasing amount and increasing proportion of cleared RegD MW with an effective price of \$0.00. The figure also shows a corresponding increase in the total RegD MW clearing the market in the period between January 1, 2014 and December 30, 2015. Figure 10-22 also shows that self-scheduling, bidding RegD MW at zero, has increased.<sup>42</sup>

<sup>41</sup> 145 FERC ¶ 61,011 (2013).

<sup>42</sup> See the MMU's Regulation Market Review presentation from the May 5, 2015 Operating Committee, available at <<http://www.pjm.com/~media/committees-groups/committees/oc/20150505/20150505-item-17-regulation-market-review.ashx>>

**Figure 10-22 Average cleared RegD MW and average cleared RegD with an effective price of \$0.00 by month: January 2014 through December 2015**



The current settlement process does not result in RegA and RegD resources being paid 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 marginal benefit factor is not used in settlements. When the marginal benefit factor is above one, RegD resources are generally (depending on the mileage ratio) underpaid on a per effective MW basis. When the marginal benefit factor is less than one, RegD resources are generally overpaid on a per effective MW basis.

PJM posts clearing prices for the regulation market (RMCCP, RMPCP and RMCP) in dollars per effective regulation capability MW. The regulation market clearing price (RMCP) for the hour is the simple average of the twelve 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 (\$/effective MW) is based on the marginal performance offer (RMPCP) for the hour. The capability clearing price (\$/effective MW) is equal to the difference between the RMCP for the hour and the RMPCP for the hour.

While prices are set on the basis of dollars per effective MW, only RegA receive payments (credits) that are consistent with their effective MW provided.<sup>43</sup> The current market design does not send the correct price

signal to the RegD resources as a result of the inconsistent application of the marginal benefit factor.

Figure 10-23 shows, for the period from January 1, 2015, through December 31, 2015, the maximum, minimum and average marginal benefit factor, based on PJM's incorrect marginal benefit factor curve, by month. The decrease in the average marginal benefit factor (MBF) in December is due to the changes in the marginal benefit factor curve put into place on December 14, 2015. The change in the marginal benefit factor curve reduced the relative value of RegD MW in the optimization in all hours (the slope of the benefit factor curve was altered to intercept the x axis, defined in terms of RegD MW as a percent of the regulation requirement, at 40 percent instead of 62 percent) and capped the procurement of RegD MW during what PJM has termed excursion hours (hours ending 7:00, 8:00, 18:00–21:00) at the point where the MBF on the curve is equal to 1.0 (which occurs where the x-axis is equal to 26 percent).

**Figure 10-23 Maximum, minimum, and average PJM calculated marginal benefit factor by month: 2015**

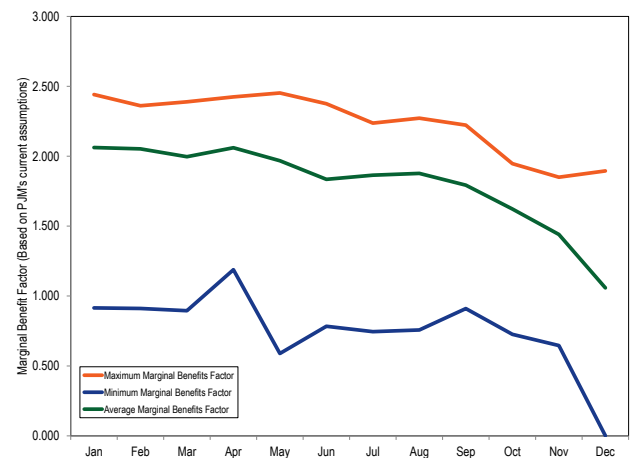
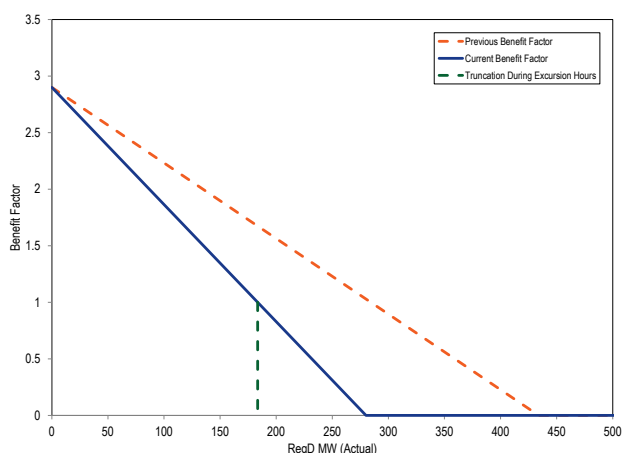


Figure 10-24 illustrates the marginal benefit factor curve before and after the December 14, 2015 modification. The modification to the marginal benefit curve reduced the amount of RegD procured, but did not correct for identified issues with the optimization engine.

<sup>43</sup> This is due to the fact that RegA resources performance adjusted MW are their effective MW.

**Figure 10-24 Benefit Factor Curve before and after December 14, 2015 revisions by PJM**



The MMU recommends that the Regulation Market be modified to incorporate a consistent application of the marginal benefit factor throughout the optimization, assignment and settlement process.<sup>44</sup>

### The Effective MW of Regulation Purchased Are Understated

In 2015, the MMU determined that the regulation market optimization/market solution was understating the amount of effective MW provided by RegD. Rather than correctly calculating the total effective MW contribution of RegD MW on the basis of the area under the marginal benefit function curve, the regulation market optimization assigns the MBF associated with the last MW of a cleared unit to every MW of that unit (“unit block”) for purposes of calculating effective MW. PJM then calculates the effective MW as the simple product of the MW and the MBF, rather than the area under the MBF curve for that number of MW. The result of this approach is that 100 MW of RegD (performance adjusted) provided by a single resource (one 100 MW unit) will appear to provide fewer effective MW than 100 MW (performance adjusted) provided by two separate 50 MW units.

In addition, the MMU determined that the regulation market optimization/market solution treats all RegD resources with the same effective price as a single resource (“price block”) for purposes of assigning a

benefit factor and calculating effective MW. This means that all of the MW associated with multiple units with the same effective price (for example a price of zero) were assigned the MBF of the last MW of the last unit of that block of resources with the same effective price. PJM then calculates the effective MW as the simple product of the MW and the MBF, rather than the area under the MBF curve for that number of MW. This resulted in an undercounting of effective MW from RegD resources cleared at an effective price of zero or self-scheduled.

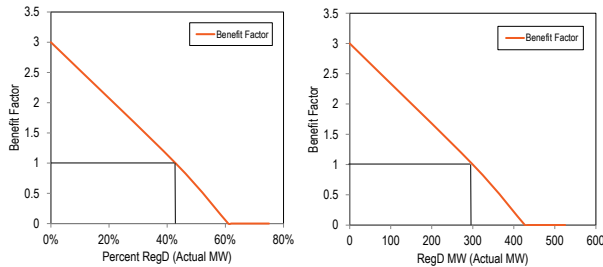
The identified effective MW measurement issue was only incompletely addressed by a modification that was put into effect on December 14, 2015. The modification rank orders self-scheduled MW and assigns the MBF of the last MW of each of these units to all MW of that unit. The result is to break up the RegD MW in the zero price or self-scheduled block into unit specific blocks of MW that are each assigned a unit specific benefit factor. The resulting effective MW calculation better approximates the area under the marginal benefit factor curve for those price block MW. A full correction of the effective MW calculation requires the use of the area under the curve.

The existing approach to calculating effective MW resulted in the purchase of more than the efficient level of regulation MW to meet PJM’s defined regulation requirement in 2015.

An example illustrates the issue. Figure 10-25 shows the marginal benefit curve, in terms of RegD percent (left diagram) and RegD MW (right diagram) in a scenario where 700 MW of effective MW are needed and the market clears 300 MW of RegD (actual MW), all priced at \$0.00, and 400 MW of RegA. Figure 10-25 shows that the 300 MW of cleared RegD are 42.9 percent of total cleared actual MW and that the marginal benefit factor is 1.0.

<sup>44</sup> See “Regulation Market Review,” presented at the May 5, 2015 Operating Committee meeting. <http://www.pjm.com/~media/committees-groups/committees/oc/20150505/20150505-item-17-regulation-market-review.ashx>

Figure 10-25 Example marginal benefit line in percent RegD and RegD MW terms



Using PJM's price block/unit block method for the calculation of effective MW from RegD resources, all RegD resources are assigned the lowest marginal benefit factor associated with the last RegD MW purchased. In this example, all 300 MW have an MBF of 1.0. PJM calculates total effective MW from RegD resources to be 300 (300MW x 1.0 = 300 effective MW).

In Figure 10-26, PJM's price block/unit block calculation of total effective MW from RegD is represented by the area of the blue rectangle which is 400 effective MW.

PJM's price block/unit block method is flawed. By assigning a single benefit value to every MW, the price block/unit block methodology undervalues the amount of effective MW provided by RegD MW. This is because the benefit curve represents a marginal rate of substitution between RegD and RegA MW, and the area under the curve, at any RegD amount, represents the total effective MW supplied by RegD at that point. In fact, RegD is providing effective MW equal to area defined by the green triangle and the blue rectangle in Figure 10-26. This corresponds to 600 effective MW being supplied by RegD resources, not 300 effective MW. This means that the actual total effective MW cleared in the market solution is 300 more effective MW than needed to meet the regulation requirement.

Figure 10-26 Illustration of correct method for calculating effective MW

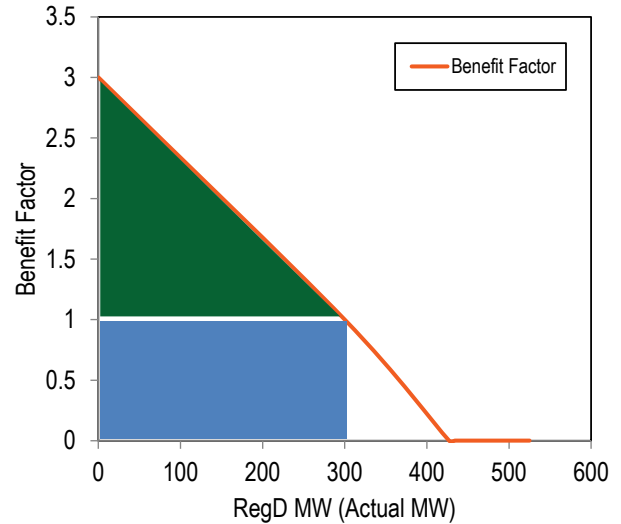


Figure 10-27 illustrates PJM's December 14, 2015, incomplete correction of the price block/unit block calculation as it applies to RegD resources that clear with an effective price of zero (\$0.00 offer or self-scheduled). In this example, the PJM market clears two self-scheduled resources, one with 100 MW and one with 83 MW, for a total of 183 MW and a market MBF of 1.0. Prior to the fix put in place on December 14, 2015, all 183 MW of RegD would be assigned the MBF of 1.0.

After December 14, 2015, zero price offer and self-scheduled resources are rank ordered by performance score and assigned unit specific MBF numbers based on the MBF associated with the last MW of each unit that cleared. Using this new approach, assuming the 83 MW resource was ranked higher than the 100 MW resource, the 83 MW resource would be assigned a unit specific benefit factor of 2.0 (see figure) and the 100 MW resource would be assigned a unit specific benefit factor of 1.0 (see figure).

PJM still calculates effective MW as the simple product of the MW and the MBF, rather than the area under the MBF curve for cleared MW, which results in an effective MW total of 269.9 MW, due to 169.9 effective MW being attributed to the 83 MW resource (83 MW times 2.0 BF) and 100 effective MW being attributed to the 100 MW resource (100 MW times 1.0 BF). This new method provides a closer approximation of the area under the curve, but this updated approach still under estimates

the effective MW from cleared RegD resources. Using the area under the curve approach would correctly result in an effective MW total of 355.9 MW being attributed to the 183 MW cleared in the market, not the 266 effective MW of the post December 14, 2015 method or the 183 effective MW of the pre December 14, 2015 method.

**Figure 10-27 Example of Pre and Post December 14, 2015, Effective MW Calculations for RegD MW offered at \$0.00 or as Self Supply**

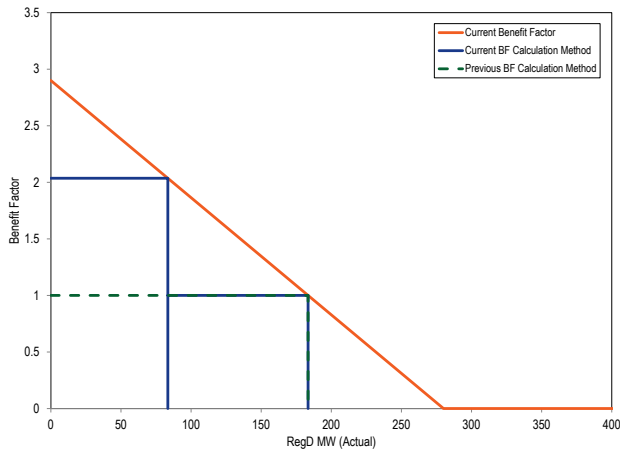
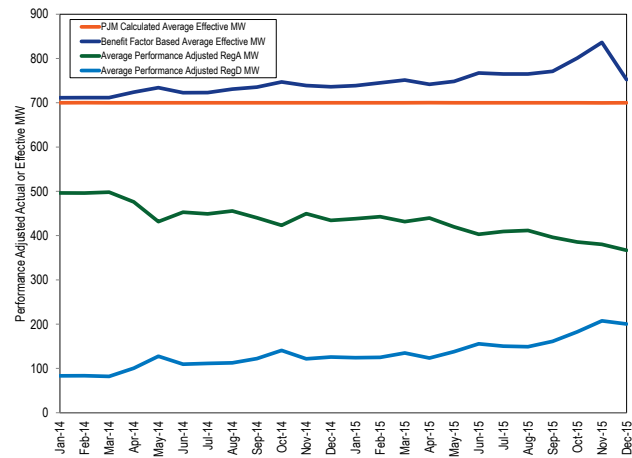


Figure 10-28 shows the average monthly peak total effective MW as calculated by PJM’s incorrect effective MW accounting method(s) and as calculated by a correctly applied marginal benefit factor for the January 2014 through December 2015 period. Figure 10-28 shows a reduction in over procurement in December of 2015. The figure also shows the monthly average actual (performance adjusted) RegA and RegD MW cleared in the regulation market for the period. Based on the assumption that the current marginal benefit function is correct, the figure shows that PJM has been clearing an increasing surplus of effective MW. As shown in Figure 10-22, this has been caused by an increasing proportion of RegD MW supply with an effective price of \$0.00 in the PJM market.

**Figure 10-28 Average monthly peak effective MW: PJM market calculated versus benefit factor based: January 2014 through December 2015**



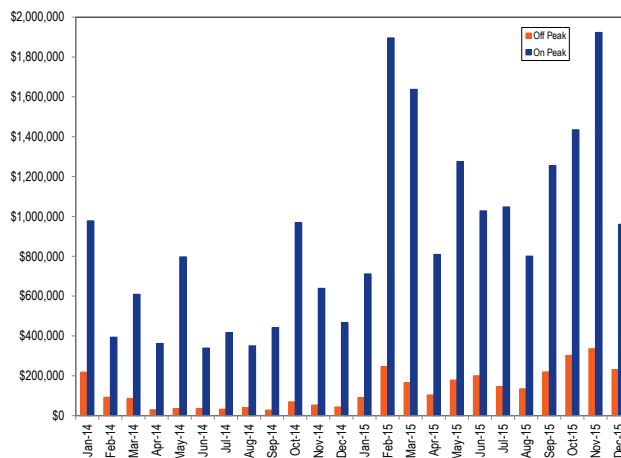
**The Cost of Purchasing Too Many Regulation MW Due to Incorrect Effective MW Calculation Approach**

Figure 10-29 shows the cost of the excess effective MW cleared by month, peak and off peak, from January 1, 2014, through December 30, 2015, caused by PJM’s incorrect approach(s) to calculating effective MW from RegD resources. To determine this excess cost, the total effective MW of RegD are correctly calculated using the full area under the Benefit Factor curve, and the difference between that value and the one used by PJM is multiplied by the price in each hour. This excess cost calculation does not take into account the fact that, if calculated correctly, the change in effective MW from RegD would alter the clearing price. The excess cost calculation also does not correct for the PJM’s flawed optimization engine which is currently clearing incorrect proportions of RegA and RegD due to an incorrect and inconsistent application of the assumed marginal benefit factor function.

In 2015, the estimated total cost of excess effective RegD MW during on peak and off peak hours was \$14.8 million and \$2.4 million. The implementation of the partial fix to the effective MW calculation and the changes in the benefit factor curve in December of 2015 reduced but did not eliminate, the excess effective MW clearing in the regulation market.



**Figure 10–29 Cost of excess effective MW cleared by month, peak and off peak: 2014 through 2015**



### Incorrect MBF and Inconsistent Application of MBF in Optimization Causing Incorrect Proportion of RegD MW Being Purchased

PJM observed issues with regulation performance when the proportion of effective MW from RegD resources exceeds 42 percent.<sup>45</sup> The system issues are a result of PJM buying too much RegD as a proportion of total regulation.

In addition, the current market clearing engine is not correctly maintaining the assumed ratios of RegA and RegD that are the basis of the MBF function describing the rate of substitution between RegA and RegD. The MBF, as a marginal rate of substitution between RegA and RegD resource MW for a given regulation requirement, assumes specific combinations/ratios of RegA and RegD MW that are needed to meet specified regulation performance goals. Properly implemented in the optimization, the use of the MBF should result in the selection of the least cost combination/ratio of RegA and RegD MW from among the specified combinations/ratios that were used to define the MBF curve. The current engine merely uses the MBF function, defined as the MBF for a given amount of RegD regardless of the amount of RegA clearing, to adjust RegD offers for purposes of rank ordering resources in the supply stack, and then clears resources in price order until the calculated effective MW target is reached. This market

clearing is done without confirming that the assumed ratios of RegA and RegD that are the basis of the MBF curve have been maintained in the market solution. The issues identified by the MMU related to the incorrect use of the MBF function, combined with an increasing proportion of RegD offering at an effective price of zero, are the reason that the market design results in too much RegD clearing relative to RegA MW in the market.

Table 10–30 illustrates, for both the previous and current benefit factor curve, the relationship between the MBF function's proportion of performance adjusted RegD MW relative to total cleared performance adjusted regulation MW and the proportion of RegD MW that would result if the RegD MW values listed in Table 10–30 were cleared before any RegA MW (due to the MBF adjusted RegD offers being less than the RegA MW offers).

For example, if the market cleared 175 MW of RegD (which would be determined to be 25 percent of the 700 performance adjusted MW needed) priced at zero, the market clearing engine would determine it would need 294.8 MW of RegA to meet the 700 MW requirement using the previous BF curve, and would need 351.1 MW using the current BF curve. The resulting proportion of RegD to total regulation cleared would be 37 percent and 33 percent for the previous and current BF curves respectively, rather than the 25 percent that was assumed by the MBF function. Although there is a smaller difference between the proportion of RegD cleared under the current BF curve and the correct amount, as compared to that of the previous BF curve, the error still persists and is not eliminated by simply adjusting the curve. A full correction will require that the proportions assumed in the curve are maintained through the market clearing process.

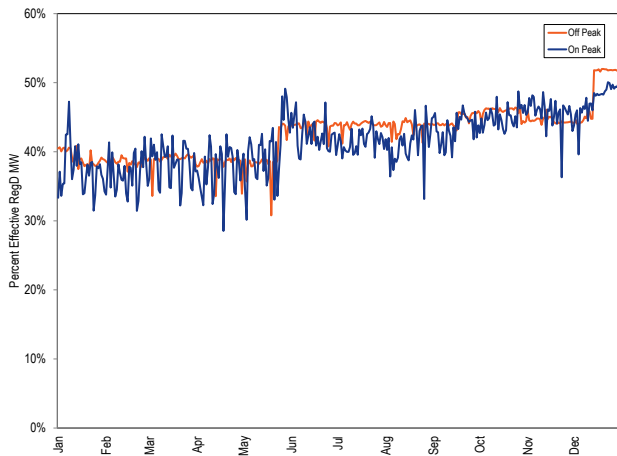
<sup>45</sup> See PJM's "Fast Response Regulation (RegD) Resources Operational Impact Problem Statement," presented at the May 5, 2015 Operating Committee meeting. <<http://www.pjm.com/~media/committees-groups/committees/oc/20150505/20150505-item-17-problem-statement-regulation.ashx>>

**Table 10-30 MBF assumed RegD proportions versus market solution realized RegD proportions<sup>46</sup>**

RegD Percent of 700 MW	RegD MW (Performance Adjusted)	MBF (Previous)	MBF (Current)	Effective MW from RegD MW (Previous)	Effective MW from RegD MW (Current)	Residual A (700 MW Target, Previous)	Residual A (700 MW Target, Current)	RegD/ (RegA+RegD, Previous)	RegD/ (RegA+RegD, Current)
5%	35	2.67	2.54	97.41	95.16	602.59	604.84	5%	5%
10%	70	2.43	2.18	186.63	177.63	513.37	522.38	12%	12%
15%	105	2.20	1.81	267.67	247.41	432.33	452.59	20%	19%
20%	140	1.96	1.45	340.52	304.50	359.48	395.50	28%	26%
25%	175	1.73	1.09	405.18	348.91	294.82	351.09	37%	33%
30%	210	1.50	0.73	461.66	380.63	238.34	319.38	47%	40%
35%	245	1.26	0.36	509.96	399.66	190.04	300.34	56%	45%
40%	280	1.03	0.00	550.06	406.00	149.94	294.00	65%	49%
45%	315	0.80	-	581.99	-	118.01	-	73%	-
50%	350	0.56	-	605.73	-	94.27	-	79%	-
55%	385	0.33	-	621.28	-	78.72	-	83%	-
60%	420	0.09	-	628.65	-	71.35	-	85%	-

The proportion of RegD resources used to satisfy the on peak (700 MW) and off peak (525 MW) regulation requirements is shown in Figure 10-30.

**Figure 10-30 Daily average percent of RegD effective MW by peak: January through December 2015**



The effect of the incorrect accounting of effective MW was exacerbated by a marginal benefit factor function that assigns too high a marginal benefit factor to RegD resources. An inflated marginal benefit factor makes incremental effective MW from RegD resources look less expensive than incremental effective MW from RegA resources.

The effect of these market flaws on the amount of Reg D clearing the market has been magnified by the increasing proportion of RegD MW with an effective

price of \$0.00 per MW (Figure 10-22). This guarantees that an increasing proportion of RegD MW in the market incorrectly appears as the cheapest source of incremental effective regulation MW.

## Market Structure

### Supply

Table 10-31 shows capability MW (actual), average daily offer MW (actual), average hourly eligible MW (actual and effective), and average hourly cleared MW (actual and effective) for all hours in 2015. Actual MW are unadjusted regulation capability MW and effective MW are adjusted by the historic 100-hour moving average performance score and resource-specific benefit factor.<sup>47</sup> A resource must be either generation or demand. A resource can choose to follow both signals. For that reason, the sum of each signal type’s capability can exceed the full regulation capability. Offered MW are calculated based on the daily offers from units that are categorized as available for the day. Eligible MW are calculated from the hourly offers from both units with daily offers and units that are categorized as unavailable for the day, but still offer MW into some hours. Additionally, units with daily offers are permitted to offer above or below their daily offer from hour to hour. Because of these hourly MW adjustments to MW offers beyond what was offered on a daily basis, the average hourly Eligible MW can be higher than the Offered MW.

<sup>46</sup> This example assumes that the calculation of effective MW from RegD was calculated correctly as the area under the MBF curve.

<sup>47</sup> 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 and future analysis will show the effect of this correction.

**Table 10-31 PJM regulation capability, daily offer and hourly eligible: January through December 2015<sup>48 49</sup>**

Metric	By Resource Type			By Signal Type	
	All Regulation	Generating Resources	Demand Resources	RegA Following Resources	RegD Following Resources
Capability MW	8,701.8	8,680.4	21.4	8,390.5	628.3
Offered MW	2,717.3	2,709.3	8.0	2,504.1	213.2
Actual eligible MW	1,157.8	1,151.7	6.1	907.9	249.9
Effective eligible MW	889.9	882.6	7.3	606.4	283.5
Actual cleared MW	640.9	637.0	3.9	477.6	163.3
Effective cleared MW	663.7	657.5	6.2	387.7	275.9

**Table 10-32 PJM regulation by source in 2014 and 2015**

Source	2014				2015			
	Number of Units	Adjusted Settled Regulation (MW)	Percent of Scheduled Regulation	Total Regulation Credits	Number of Units	Adjusted Settled Regulation (MW)	Percent of Scheduled Regulation	Total Regulation Credits
Battery	85	807,003.6	16.1%	\$29,681,876	143	1,383,557.2	27.6%	\$37,447,900
Biomass	12	16,497.6	0.3%	\$730,973	12	25,681.8	0.5%	\$799,228
Coal	998	543,018.5	10.8%	\$44,718,176	711	590,903.6	11.8%	\$32,877,595
Hydro	350	910,391.1	18.2%	\$57,492,082	356	935,039.5	18.7%	\$37,546,622
Light Oil	13	742.7	0.0%	\$597,921	0	1.0	0.0%	\$0
Natural Gas	835	2,707,792.7	54.0%	\$119,434,967	980	2,042,374.2	40.7%	\$69,891,947
DR	163	28,958.2	0.6%	\$1,301,092	157	35,731.5	0.7%	\$1,047,198
Total	2,456	5,014,404.5	100.0%	\$253,957,088	2,359	5,013,288.9	100.0%	\$179,610,489

Table 10-32 provides the scheduled regulation in MW by source, the total scheduled regulation in MW provided by all resources (including DR), and the percent of scheduled regulation provided by each fuel type. In Table 10-32 the MW have been adjusted by the actual within hour performance score since this adjustment forms the basis of payment for units providing regulation. Total regulation capability MW decreased from 5,014,404.5 MW in 2014 to 5,013,288.9 MW in 2015. The average proportion of regulation provided by battery units had the largest increase, providing 16.1 percent of regulation in 2014 and 27.6 percent of regulation in the 2015. Natural gas units had the largest decrease in average proportion of regulation provided, decreasing from 54.0 percent in 2014, to 40.7 percent in 2015. The total regulation credits in 2015 were \$179,610,489 down from \$253,957,088 in 2014.

The supply of regulation can be affected by regulating units retiring from service. Table 10-33 shows the impact on the regulation market from all units that retired in 2015. These retirements reduced the supply of regulation in PJM by less than one percent. The MW in Table 10-33 have been adjusted by the actual within hour performance score.

**Table 10-33 Impact on the PJM Regulation Market of currently regulating units retired in 2015**

Current Regulation Units, 2015	Adjusted Settled MW, 2015	Units Retired In 2015	Adjusted Settled MW of Units Retired In 2015	Percent of Regulation MW Retired In 2015
291	4,169,935.6	19	11,477.1	0.3%

Although the marginal benefit factor for RegA resources is 1.0, the effective MW of RegA resources was lower than the offered MW in 2015, because the average performance score was less than 1.00. For 2015, the MW weighted average RegA performance score was 0.81 and there were 291 resources following the RegA signal.

For RegD resources, the total effective MW vary relative to actual MW because the benefit factor at current participation levels varies from values greater than and less than 1.0. In 2015, the marginal benefit factor, based on PJM's current assumed marginal benefit factor curve, for cleared RegD following resources ranged from 0.001 to 2.452 with an average over all hours of 1.802. In 2015, the MW weighted average RegD resource performance score was 0.92 and there were 57 resources following the RegD signal.

The cost of each unit is calculated using its capability and performance offer prices, lost opportunity cost, capability MW, and the miles to MW ratio of the signal type offered, modified by resource marginal benefit factor and historic performance score. (The miles to MW

<sup>48</sup> Average Daily Offer MW excludes units that have offers but are unavailable for the day.

<sup>49</sup> Total offer capability is defined as the sum of the maximum daily offer volume for each offering unit during the period, without regard to the actual availability of the resource or to the day on which the maximum was offered.

ratio of the signal type offered is the historic 30-day moving average of requested mileage for that signal type per unadjusted regulation capability MW.)

As of October 1, 2012, a regulation resource's total offer is equal to the sum of its capability offer (\$/MW) and performance offer (\$/MW) and its estimated lost opportunity cost (\$/MW). As of October 1, 2012, the within hour five minute clearing price for regulation is determined by the total offer, including the actual opportunity cost and any applicable benefit factor, of the most expensive cleared regulation resource in each interval.

Since the implementation of regulation performance on October 1, 2012, both regulation price and regulation cost per MW are higher than they were prior to October 1, 2012, (Table 10-41). In 2015, the price and cost of regulation have remained high relative to prior years with the exception of 2014. The weighted average regulation price for 2015 was \$31.92/MW. The regulation cost for 2015 was \$38.36/MW. The ratio of price to cost is higher (83.2 percent) than in 2014 (82.6 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 in 2015.

Table 10-34 shows the average hourly required regulation by month and its relationship to the supply of regulation for both actual (unadjusted) and effective MW. The average hourly required regulation by month is an average across all of the hours in that month. The average hourly required effective MW of regulation is a weighted average of the requirement of 700 effective MW during peak hours and the requirement of 525 effective MW during off peak hours.

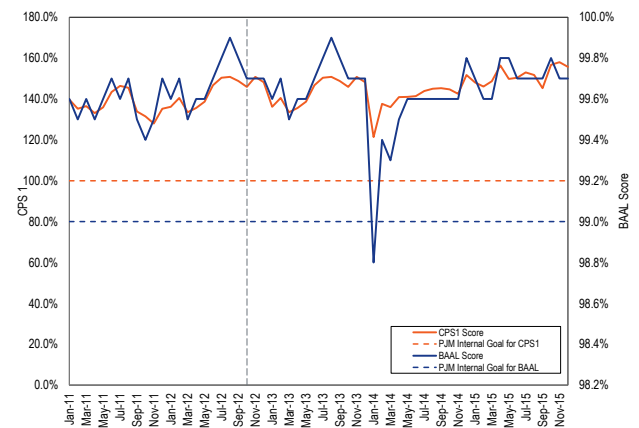
**Table 10-34 PJM Regulation Market required MW and ratio of eligible supply to requirement: January through March 2014 and 2015**

Month	Average Required Regulation (MW), 2014	Average Required Regulation (MW), 2015	Average Required Regulation (Effective MW), 2014	Average Required Regulation (Effective MW), 2015	Ratio of Supply MW to MW Requirement, 2014	Ratio of Supply MW to MW Requirement, 2015	Ratio of Supply Effective MW to Effective MW Requirement, 2014	Ratio of Supply Effective MW to Effective MW Requirement, 2015
Jan	689.9	638.3	663.6	663.7	2.05	1.86	1.60	1.35
Feb	681.7	656.3	663.6	663.5	2.00	1.74	1.51	1.37
Mar	682.8	649.8	663.8	663.8	1.99	1.73	1.48	1.35
Apr	681.8	646.0	663.7	663.7	2.04	1.83	1.55	1.34
May	658.1	650.4	663.6	663.6	1.93	1.72	1.44	1.32
Jun	647.0	632.2	663.9	663.7	1.89	1.81	1.29	1.30
Jul	642.0	627.5	663.5	663.8	1.88	1.83	1.29	1.32
Aug	649.7	631.4	663.6	663.6	1.93	1.79	1.30	1.33
Sep	643.1	638.4	663.6	663.5	1.91	1.80	1.26	1.35
Oct	655.2	632.6	663.6	663.4	1.83	1.86	1.26	1.36
Nov	660.9	655.4	663.3	663.2	1.85	1.82	1.28	1.33
Dec	636.5	634.0	663.6	663.9	1.97	1.88	1.34	1.39

PJM's performance as measured by CPS1 and BAAL standards is shown in Figure 10-31 for every month from January 2011 through December 2015 with the dashed vertical line marking the date (October 1, 2012) of the implementation of the Performance Based Regulation Market design.<sup>50</sup> The horizontal dashed lines represent PJM internal goals for CPS1 and BAAL performance. While PJM did not meet its internal goal for BAAL performance in January 2014, PJM remained in compliance with the applicable NERC standards.

Very cold weather from January 6 through January 8 and from January 17 through January 29, 2014, caused extreme system conditions, including 12 synchronized reserve events, seven RTO-wide shortage pricing events and high forced outage rates. As a result, PJM experienced several frequency excursions of between 10 and 20 minutes which caused PJM's performance on the BAAL metric, a measure of a balancing authority's ability to control ACE and frequency, to decline substantially.

**Figure 10-31 PJM monthly CPS1 and BAAL performance: January 2011 through December 2015**



## Market Concentration

Table 10-35 shows HHI results for 2014 and 2015, based on market shares of effective MW, defined as regulation capability MW adjusted by performance score and resource-specific benefit factor, consistent with the metrics used to clear the regulation market. The weighted average HHI of 1358 is classified as moderately concentrated and is lower than the HHI for the same period in 2014 of 1936. For 2015, the weighted average HHI of RegA resources was 2573 (highly concentrated, but lower than the 2014 value of 3151 and the weighted average HHI of RegD resources was 2506 (highly concentrated, but lower than the 2014 value of 4330). The HHI of RegA resources and the HHI of RegD resources are both substantially higher than the HHI of the regulation market as a result of the fact that

<sup>50</sup> See the 2014 State of the Market Report for PJM, Appendix F: Ancillary Services.

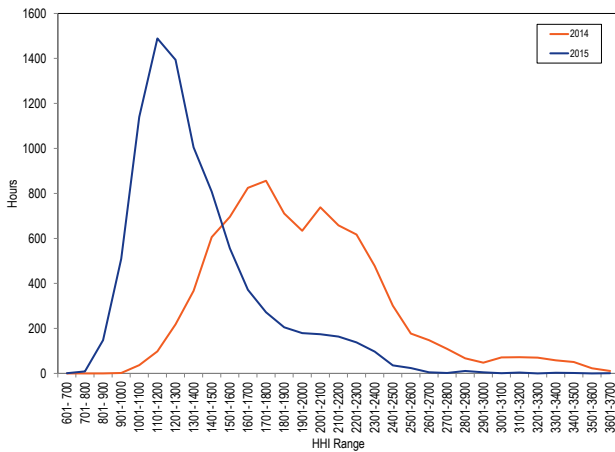
different owners have large market shares in the RegA and RegD markets.

**Table 10-35 PJM cleared regulation HHI: 2014 and 2015**

Year	Weighted Average		
	Minimum HHI	HHI	Maximum HHI
2014	915	1936	5325
2015	695	1358	3658

Figure 10-32 compares the frequency distribution of HHI for January through December 2014 and 2015. The HHI values are calculated based on effective MW cleared.

**Figure 10-32 PJM Regulation Market HHI distribution: 2014 and 2015**



The regulation market TPS test is calculated for each market hour. If an owner is pivotal, its resources are offer capped at the lower of their cost based or price based regulation offers.

Table 10-36 includes a monthly summary of three pivotal supplier results. In 2015, 97.8 percent of hours had three or fewer pivotal suppliers. The impact of offer capping in the regulation market is limited because of the role of LOC in price formation (Figure 10-34). The MMU concludes from these results, that the PJM Regulation Market in 2015 was characterized by structural market power in 97.8 percent of hours.

**Table 10-36 Regulation market monthly three pivotal supplier results: 2013 through 2015**

Month	Percent of Hours Pivotal		
	2013	2014	2015
Jan	83.0%	96.9%	97.8%
Feb	82.5%	98.7%	96.3%
Mar	97.3%	94.9%	97.3%
Apr	88.0%	89.0%	98.1%
May	93.1%	95.7%	99.3%
Jun	94.6%	99.4%	98.6%
Jul	93.5%	100.0%	98.8%
Aug	91.5%	99.7%	97.7%
Sep	90.4%	99.4%	97.1%
Oct	82.7%	99.1%	96.1%
Nov	88.6%	98.9%	99.2%
Dec	94.9%	98.1%	97.2%
Average	90.0%	97.5%	97.8%

## 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 must not allow the sum of its regulating ramp rate and energy ramp rate to exceed its economic ramp rate. When offering into the regulation market, regulating resources must submit a cost offer and, optionally, a price offer (capped at \$100/MW) by 6:00 pm the day before the operating day.

Offers in the regulation market consist of a capability component for the MW of regulation capability provided and a performance component for the miles ( $\Delta$ MW of regulation movement) provided. The capability component for cost offers is not to exceed the increased costs (specifically, increased fuel costs and lower efficiency) resulting from operating the regulating unit at a lower output level than its economically optimal output level plus a \$12.00/MW adder. The performance component for cost offers is not to exceed the increased costs (specifically, increased VOM and lower efficiency) resulting from operating the regulating unit in a nonsteady state. Batteries and flywheels have zero cost for lower efficiency from providing regulation instead of energy, as they are not net energy producers. Instead batteries and flywheels are, due to losses, net consumers of energy when providing regulation service. On April 1, 2015, PJM added an Energy Storage Loss component for batteries and flywheels as a cost component of regulation performance offers to the eMkt Regulation

Offers screen, to reflect the net energy consumed to provide regulation service.<sup>51</sup>

Up until one hour before the operating hour, the regulating resource must input or may change: 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. Resources have the option to submit a minimum level of regulation they require to regulate.<sup>52</sup>

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 10-38).<sup>53</sup> Figure 10-33 compares average hourly regulation and self scheduled regulation during on peak and off peak 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.<sup>54</sup> Self scheduled regulation during on peak and off peak hours varies from hour to hour and comprises a large portion of total effective regulation per hour (on average 40.3 percent during on peak and 54.9 percent during off peak hours in 2015).

Figure 10-33 Off peak and on peak regulation levels: 2014 through 2015

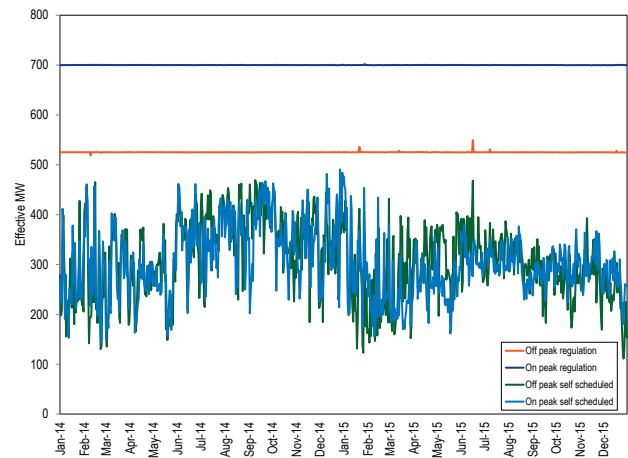


Table 10-37 shows how RegD resources have impacted the regulation market. RegD resources are both a growing proportion of the market (10.9 percent of the total effective MW at the start of the performance based regulation market design in October 2012 and 47.8 percent in December 2015) and a growing proportion of resources that self schedule (10.1 percent in October 2012 and 21.8 percent in December 2015).

<sup>51</sup> See PJM. "Manual 15: Cost Development Guidelines," Revision 26, (November 6, 2014); para 11.8, p. 60.

<sup>52</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 72, (January 16, 2015); para 3.2.2, pp 48.

<sup>53</sup> See PJM. "Manual 28: Operating Agreement Accounting," Revision 68, (January 16, 2015); para 4.1, p 15.

<sup>54</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations," Revision 72, (January 16, 2015); para 3.2.9, p 59.

Table 10-37 RegD self-scheduled regulation by month, October 2012 through December 2015

Year	Month	RegD Self Scheduled Effective MW	RegD Effective MW	Total Self Scheduled Effective MW	Total Effective MW	Percent of Total Self Scheduled	RegD Percent of Total Self Scheduled	RegD Percent of Total Effective MW
2012	Oct	66.3	71.8	264.7	658.1	40.2%	10.1%	10.9%
2012	Nov	74.4	88.3	196.5	716.5	27.4%	10.4%	12.3%
2012	Dec	82.5	88.8	188.8	701.1	26.9%	11.8%	12.7%
2013	Jan	35.7	82.5	133.6	720.0	18.6%	5.0%	11.5%
2013	Feb	84.8	90.2	212.2	724.3	29.3%	11.7%	12.5%
2013	Mar	80.1	119.3	279.8	680.7	41.1%	11.8%	17.5%
2013	Apr	82.3	106.9	266.0	594.1	44.8%	13.8%	18.0%
2013	May	74.0	109.0	268.2	616.2	43.5%	12.0%	17.7%
2013	Jun	79.6	122.7	334.9	730.6	45.8%	10.9%	16.8%
2013	Jul	77.6	120.4	303.6	822.9	36.9%	9.4%	14.6%
2013	Aug	83.6	127.6	366.0	756.8	48.4%	11.0%	16.9%
2013	Sep	112.2	152.1	381.6	669.9	57.0%	16.7%	22.7%
2013	Oct	120.2	163.7	349.6	613.3	57.0%	19.6%	26.7%
2013	Nov	133.9	175.7	396.5	663.3	59.8%	20.2%	26.5%
2013	Dec	136.5	180.7	313.6	663.5	47.3%	20.6%	27.2%
2014	Jan	132.9	193.5	261.1	663.6	39.3%	20.0%	29.2%
2014	Feb	134.3	193.4	289.0	663.6	43.5%	20.2%	29.1%
2014	Mar	131.8	193.8	287.2	663.8	43.3%	19.9%	29.2%
2014	Apr	126.8	212.4	270.8	663.7	40.8%	19.1%	32.0%
2014	May	121.7	248.5	265.6	663.6	40.0%	18.3%	37.4%
2014	Jun	123.3	231.0	365.5	663.9	55.0%	18.6%	34.8%
2014	Jul	126.4	235.5	352.7	663.5	53.2%	19.0%	35.5%
2014	Aug	117.6	229.8	368.2	663.6	55.5%	17.7%	34.6%
2014	Sep	121.0	242.6	393.8	663.6	59.3%	18.2%	36.6%
2014	Oct	116.1	255.4	352.7	663.6	53.2%	17.5%	38.5%
2014	Nov	113.5	235.1	347.5	664.2	52.3%	17.1%	35.4%
2014	Dec	116.7	254.3	353.0	663.6	53.2%	17.6%	38.3%
2015	Jan	116.4	250.1	304.8	663.7	45.9%	17.5%	37.7%
2015	Feb	111.3	245.8	242.6	663.5	36.6%	16.8%	37.0%
2015	Mar	113.8	255.2	229.9	663.8	34.6%	17.1%	38.5%
2015	Apr	110.1	248.2	283.7	663.7	42.7%	16.6%	37.4%
2015	May	121.8	265.1	266.7	663.6	40.2%	18.4%	39.9%
2015	Jun	158.9	283.1	321.2	663.7	48.4%	23.9%	42.6%
2015	Jul	161.4	278.3	314.0	663.8	47.3%	24.3%	41.9%
2015	Aug	159.5	276.0	300.7	663.6	45.3%	24.0%	41.6%
2015	Sep	155.4	289.2	286.0	663.5	43.1%	23.4%	43.6%
2015	Oct	147.1	299.0	292.8	663.4	44.1%	22.2%	45.1%
2015	Nov	164.9	302.1	298.1	664.2	44.9%	24.8%	45.5%
2015	Dec	144.6	317.2	260.7	663.9	39.3%	21.8%	47.8%
Average		114.6	100.7	296.5	398.0	44.2%	42.0%	30.1%

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 2015, 54.3 percent was purchased in the PJM market, 40.3 percent was self-scheduled, and 5.3 percent was purchased bilaterally (Table 10-38). Table 10-39 shows the total regulation by source including spot market regulation, self scheduled regulation, and bilateral regulation for each year from 2011 to 2015. Table 10-38 and Table 10-39 are based on settled (purchased) MW.



Table 10-38 Regulation sources: spot market, self-scheduled, bilateral purchases: 2014 and 2015

Year	Month	Spot Market	Spot Market	Self Scheduled	Self Scheduled	Bilateral	Bilateral	Total
		Regulation (MW)	Percent of Total	Regulation (MW)	Percent of Total	Regulation (MW)	Percent of Total	Regulation (MW)
2014	Jan	259,138.4	63.6%	125,621.0	30.8%	22,908.5	5.6%	407,668.0
2014	Feb	218,870.9	59.7%	131,302.2	35.8%	16,356.5	4.5%	366,529.6
2014	Mar	245,923.9	59.8%	147,908.6	36.0%	17,588.5	4.3%	411,421.0
2014	Apr	247,662.9	62.6%	135,878.5	34.4%	11,887.5	3.0%	395,428.9
2014	May	242,065.8	60.9%	141,875.8	35.7%	13,634.5	3.4%	397,576.2
2014	Jun	155,628.6	40.2%	207,331.0	53.6%	23,990.0	6.2%	386,949.6
2014	Jul	171,746.4	43.4%	204,360.6	51.6%	19,820.0	5.0%	395,927.0
2014	Aug	162,805.7	40.5%	221,096.7	55.0%	17,859.5	4.4%	401,761.9
2014	Sep	131,424.4	34.4%	227,891.1	59.6%	22,812.0	6.0%	382,127.5
2014	Oct	165,297.0	41.8%	210,306.7	53.2%	19,439.0	4.9%	395,042.7
2014	Nov	165,812.5	42.9%	200,058.9	51.8%	20,413.0	5.3%	386,284.4
2014	Dec	159,486.0	40.6%	208,365.0	53.1%	24,509.0	6.2%	392,359.9
2015	Jan	198,056.1	50.2%	173,319.4	44.0%	22,975.0	5.8%	394,350.5
2015	Feb	219,652.3	61.6%	116,607.5	32.7%	20,137.6	5.7%	356,397.3
2015	Mar	252,402.2	64.0%	122,001.9	30.9%	20,255.0	5.1%	394,659.0
2015	Apr	197,934.5	52.3%	159,511.3	42.1%	21,236.5	5.6%	378,682.3
2015	May	227,527.5	57.5%	148,998.3	37.7%	19,191.5	4.8%	395,717.3
2015	Jun	186,186.4	48.6%	174,157.4	45.5%	22,613.0	5.9%	382,956.8
2015	Jul	199,332.1	50.5%	172,743.7	43.7%	22,845.0	5.8%	394,920.8
2015	Aug	207,794.6	53.0%	162,197.5	41.3%	22,412.5	5.7%	392,404.7
2015	Sep	207,352.6	54.6%	150,467.7	39.6%	21,863.0	5.8%	379,683.3
2015	Oct	213,982.2	53.4%	169,283.3	42.2%	17,724.5	4.4%	400,990.0
2015	Nov	213,952.0	52.9%	172,561.3	42.7%	17,790.0	4.4%	404,303.3
2015	Dec	220,651.8	54.1%	166,189.2	40.7%	21,342.5	5.2%	408,183.5

Table 10-39 Regulation sources by year: 2011 through 2015

Year	Spot Market Regulation (MW)	Spot Market Percent of Total	Self Scheduled Regulation (MW)	Self Scheduled Percent of Total	Bilateral Regulation (MW)	Bilateral Percent of Total	Total Regulation (MW)
2011	6,445,984.6	81.8%	1,226,570.0	15.6%	209,284.0	2.7%	7,881,838.6
2012	6,149,110.0	78.6%	1,484,446.2	19.0%	193,408.0	2.5%	7,826,964.2
2013	3,087,927.5	57.6%	2,064,156.7	38.5%	204,260.5	3.8%	5,356,344.7
2014	2,325,862.6	49.3%	2,161,996.2	45.8%	231,218.0	4.9%	4,719,076.8
2015	2,544,824.4	54.3%	1,888,038.5	40.3%	250,386.1	5.3%	4,683,248.9

In 2015, DR provided an average of 3.6 MW of regulation per hour (3.1 MW of regulation per hour in the same period of 2014). Generating units supplied an average of 637.4 MW of regulation per hour (660.8 MW of regulation per hour in the same period of 2014).

## Market Performance

### Price

The weighted average RMCP for 2015 was \$31.92 per effective MW. This is a 28.2 percent decrease from the weighted average RMCP of \$44.47 per MW in 2014. The decrease in the regulation clearing price was the result of significant reduction in energy prices and the related reduction in the LOC component of RMCP in 2015. The significant increase in self supply and \$0.00 offers from RegD resources in the second half of 2015 also contributed to lower prices. Figure 10-34 shows the daily weighted average regulation market clearing price and the opportunity cost component for the marginal units in the PJM Regulation Market on an unadjusted regulation capability MW basis. This data is based on actual five minute interval operational data. As Figure 10-34 illustrates, the LOC component (blue line) is the dominant component of the clearing price.

**Figure 10-34 PJM regulation market daily weighted average market-clearing price, marginal unit opportunity cost and offer price (Dollars per MW): 2015**

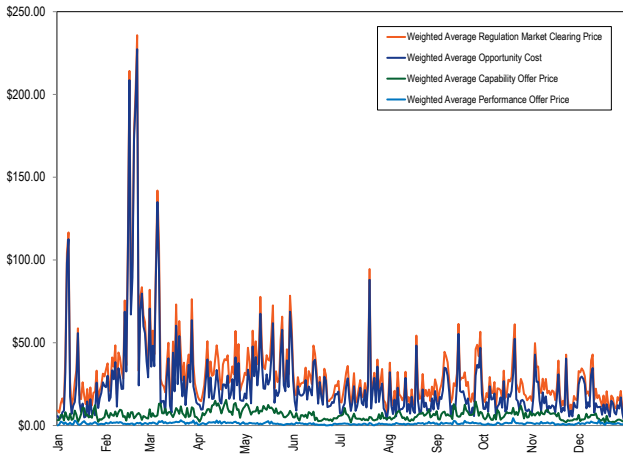


Table 10-40 shows monthly average regulation market clearing price, average marginal unit offer price, and average marginal unit LOC on an unadjusted capability MW basis. This data is based on actual five minute interval operational data.

**Table 10-40 PJM regulation market monthly weighted average market-clearing price, marginal unit opportunity cost and offer price from five minute market solution data (Dollars per MW): 2015**

Month	Weighted Average Regulation Marginal Unit LOC	Weighted Average Regulation Marginal Unit Capability Offer	Weighted Average Regulation Marginal Unit Performance Offer	Weighted Average Regulation Market Clearing Price
Jan	\$20.31	\$5.73	\$1.22	\$27.25
Feb	\$64.92	\$6.28	\$1.30	\$72.50
Mar	\$36.94	\$7.81	\$1.79	\$46.53
Apr	\$21.60	\$9.44	\$1.57	\$32.61
May	\$33.12	\$8.88	\$1.15	\$43.15
Jun	\$20.25	\$4.75	\$0.78	\$25.78
Jul	\$18.61	\$4.85	\$0.80	\$24.25
Aug	\$14.06	\$5.65	\$1.04	\$20.76
Sep	\$20.75	\$7.53	\$1.39	\$29.67
Oct	\$15.52	\$6.51	\$1.24	\$23.27
Nov	\$15.14	\$5.62	\$1.04	\$21.81
Dec	\$14.20	\$3.87	\$1.31	\$19.37

Monthly and total annual scheduled regulation MW and regulation charges, as well as monthly and monthly average regulation price and regulation cost are shown in Table 10-41. Total scheduled regulation is based on settled (unadjusted capability) MW. The total of all regulation charges for 2015 was \$179.6 million, compared to \$254.0 million for 2014.

Table 10-41 Total regulation charges: January 2014 through December 2015<sup>55</sup>

Year	Month	Scheduled Regulation (MW)	Total Regulation Charges (\$)	Weighted Average Regulation Market Price (\$/MW)	Cost of Regulation (\$/MW)	Price as Percentage of Cost
2014	Jan	407,668.0	\$65,744,697	\$132.55	\$161.27	82.2%
2014	Feb	366,529.6	\$27,509,975	\$63.12	\$75.06	84.1%
2014	Mar	411,421.0	\$39,901,162	\$80.38	\$96.98	82.9%
2014	Apr	395,428.9	\$15,208,374	\$31.74	\$38.46	82.5%
2014	May	397,576.2	\$16,927,322	\$34.40	\$42.58	80.8%
2014	Jun	386,949.6	\$14,399,445	\$30.65	\$37.21	82.4%
2014	Jul	395,927.0	\$14,458,430	\$29.75	\$36.52	81.5%
2014	Aug	401,761.9	\$9,968,110	\$20.45	\$24.81	82.4%
2014	Sep	382,127.5	\$11,906,005	\$25.10	\$31.16	80.5%
2014	Oct	395,042.7	\$15,461,162	\$32.96	\$39.14	84.2%
2014	Nov	386,284.4	\$12,615,109	\$27.50	\$32.66	84.2%
2014	Dec	392,359.9	\$9,855,652	\$21.25	\$25.12	84.6%
2014 Annual		4,719,076.8	\$253,955,442	\$44.15	\$53.41	82.7%
2015	Jan	394,350.5	\$13,054,006	\$27.13	\$33.10	81.9%
2015	Feb	356,397.3	\$31,757,444	\$73.24	\$89.11	82.2%
2015	Mar	394,659.0	\$21,887,989	\$45.79	\$55.46	82.6%
2015	Apr	378,682.3	\$14,878,908	\$32.77	\$39.29	83.4%
2015	May	395,717.3	\$21,030,737	\$43.12	\$53.15	81.1%
2015	Jun	382,956.8	\$11,544,657	\$25.94	\$30.15	86.0%
2015	Jul	394,920.8	\$11,484,271	\$24.40	\$29.08	83.9%
2015	Aug	392,404.7	\$9,913,785	\$20.85	\$25.26	82.5%
2015	Sep	379,683.3	\$13,639,604	\$29.71	\$35.92	82.7%
2015	Oct	400,990.0	\$10,904,138	\$23.12	\$27.19	85.0%
2015	Nov	404,303.3	\$10,221,684	\$21.92	\$25.28	86.7%
2015	Dec	408,183.5	\$9,323,436	\$19.58	\$22.84	85.7%
2015 Annual		4,683,248.9	\$179,640,660	\$32.30	\$38.82	83.7%

The capability, performance, and opportunity cost components of the cost of regulation are shown in Table 10-42. Total scheduled regulation is based on settled (unadjusted capability) MW.

Table 10-42 Components of regulation cost: 2015

Month	Scheduled Regulation (MW)	Cost of Regulation Capability (\$/MW)	Cost of Regulation Performance (\$/MW)	Opportunity Cost (\$/MW)	Total Cost (\$/MW)
Jan	394,350.5	\$24.34	\$3.82	\$4.94	\$33.10
Feb	356,397.3	\$69.13	\$5.98	\$14.00	\$89.11
Mar	394,659.0	\$41.41	\$6.19	\$7.86	\$55.46
Apr	378,682.3	\$28.42	\$6.07	\$4.79	\$39.29
May	395,717.3	\$39.63	\$5.02	\$8.50	\$53.15
Jun	382,956.8	\$23.58	\$3.40	\$3.17	\$30.15
Jul	394,920.8	\$22.28	\$3.07	\$3.73	\$29.08
Aug	392,404.7	\$18.21	\$3.76	\$3.30	\$25.26
Sep	379,683.3	\$26.44	\$4.90	\$4.58	\$35.92
Oct	400,990.0	\$19.91	\$5.08	\$2.20	\$27.19
Nov	404,303.3	\$19.05	\$4.52	\$1.72	\$25.28
Dec	408,183.5	\$16.81	\$4.33	\$1.71	\$22.84

Table 10-43 provides a comparison of the average price and cost for PJM regulation. The ratio of regulation market price to the actual cost of regulation in 2015 was 83.2 percent, a 0.6 percent increase from 82.6 percent in 2014.

<sup>55</sup> Weighted average market clearing prices presented here are taken from PJM settlements data, and differ from the values reported in Table 10-12, which are from five minute interval operational data. The IMM is investigating the cause of the discrepancies with PJM.

**Table 10-43 Comparison of average price and cost for PJM Regulation, 2011 through 2015**

Year	Weighted Regulation Market Price	Weighted Regulation Market Cost	Regulation Price as Percent Cost
2011	\$16.48	\$29.72	55.5%
2012	\$19.02	\$25.32	75.1%
2013	\$30.85	\$35.79	86.2%
2014	\$44.47	\$53.81	82.6%
2015	\$31.92	\$38.36	83.2%

## Black Start Service

Black start service is necessary to ensure 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 when disconnected from the grid.

PJM does not have a market to provide black start service, but compensates black start resource owners on the basis of an incentive rate or for the costs associated with providing this service.

PJM defines required black start capability zonally and ensures the availability of black start service by charging transmission customers according to their zonal load ratio share and compensating black start unit owners. Substantial rule changes to the black start restoration and procurement strategy were implemented on February 28, 2013, following a stakeholder process in the System Restoration Strategy Task Force (SRSTF) and the Markets and Reliability Committee (MRC) that approved the PJM and MMU joint proposal for system restoration. These changes give PJM substantial flexibility in procuring black start resources and make PJM responsible for black start resource selection.

On July 1, 2013, PJM initiated its first RTO-wide request for proposals (RFP) under the new rules.<sup>56</sup> PJM set a September 30, 2013, deadline for resources submitting proposals and requested that resources be able to provide black start by April 1, 2015. PJM identified zones with black start shortages, prioritized its selection process accordingly, and began awarding proposals on January 14, 2014. PJM and the MMU coordinated closely during the selection process.

<sup>56</sup> See PJM, "RTO-Wide Five-Year Selection Process Request for Proposal for Black Start Service," (July 1, 2013).

Black start payments are non-transparent payments made to units by load to maintain adequate reliability to restart the system in case of a blackout. Current rules appear to prevent publishing detailed data regarding these black start resources, hindering transparency and competitive replacement RFPs. The MMU recommends that the current confidentiality rules be revised to allow disclosure of information regarding black start resources and their associated payments.

Total black start charges are the sum of black start revenue requirement charges and black start 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. Section 18 of Schedule 6A of the OATT specifies how to calculate each component of the revenue requirement formula. 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 incremental black start equipment capital costs. Black start operating reserve charges are paid to units scheduled in the Day-Ahead Energy Market or committed in real time to provide black start service under the automatic load rejection (ALR) option or for black start testing. Total black start charges are allocated monthly to PJM customers proportionally to their zone and non-zone peak transmission use and point to point transmission reservations.

In 2015, total black start charges were \$53.6 million, a -\$6.2 million (10.4 percent) decrease from the same period of 2014 level of \$59.9 million. Operating reserve charges for black start service declined from \$32.9 million in 2014 to \$5.2 million in 2015. Table 10-44 shows total revenue requirement charges from 2010 through 2015. (Prior to December 2012, PJM did not define a black start operating reserve category.)

**Table 10-44 Black start revenue requirement charges: 2010 through 2015**

Year	Revenue Requirement Charges
2010	\$11,490,379
2011	\$13,695,331
2012	\$18,749,617
2013	\$20,874,535
2014	\$26,945,112
2015	\$48,440,990

**Table 10-45 Black start zonal charges for network transmission use: 2014 and 2015**

Zone	2014					2015				
	Revenue Requirement Charges	Operating Reserve Charges	Total Charges	Peak Load (MW-day)	Black Start Rate (\$/MW-day)	Revenue Requirement Charges	Operating Reserve Charges	Total Charges	Peak Load (MW-day)	Black Start Rate (\$/MW-day)
AECO	\$641,724	\$33,266	\$674,989	999,808	\$0.68	\$326,752	\$3,131	\$329,883	891,878	\$0.37
AEP	\$1,703,576	\$30,721,750	\$32,425,326	8,338,900	\$3.89	\$12,468,326	\$4,538,115	\$17,006,441	8,908,957	\$1.91
APS	\$284,634	\$3,027	\$287,661	3,167,251	\$0.09	\$205,796	\$69,722	\$275,518	3,412,495	\$0.08
ATSI	\$1,129,895	\$36,382	\$1,166,277	4,796,501	\$0.24	\$2,770,257	\$13,206	\$2,783,463	4,512,167	\$0.62
BGE	\$8,298,910	\$5,049	\$8,303,959	2,493,060	\$3.33	\$9,275,300	\$2,496	\$9,277,796	2,432,798	\$3.81
ComEd	\$4,245,003	\$44,049	\$4,289,052	8,128,185	\$0.53	\$5,114,530	\$49,723	\$5,164,253	7,198,238	\$0.72
DAY	\$238,564	\$6,511	\$245,075	1,244,395	\$0.20	\$236,259	\$7,929	\$244,188	1,169,387	\$0.21
DEOK	\$1,143,983	\$15,022	\$1,159,004	1,878,290	\$0.62	\$1,159,327	\$12,531	\$1,171,858	1,863,325	\$0.63
Dominion	\$1,002,604	\$4,599	\$1,007,203	6,848,495	\$0.15	\$1,014,234	\$12,719	\$1,026,953	7,221,160	\$0.14
DPL	\$569,752	\$39,708	\$609,460	1,466,826	\$0.42	\$767,906	\$19,766	\$787,673	1,414,375	\$0.56
DLCO	\$59,744	\$12,520	\$72,264	1,077,298	\$0.07	\$104,264	\$12,492	\$116,756	982,836	\$0.12
EKPC	\$414,909	\$4,439	\$419,348	924,399	\$0.45	\$425,540	\$0	\$425,540	1,250,125	\$0.34
JCPL	\$511,969	\$6,257	\$518,226	2,328,299	\$0.22	\$4,745,965	\$27,382	\$4,773,347	2,057,469	\$2.32
Met-Ed	\$841,648	\$66,776	\$908,423	1,099,490	\$0.83	\$644,821	\$72,118	\$716,939	1,028,132	\$0.70
PECO	\$1,514,472	\$13,614	\$1,528,086	3,145,716	\$0.49	\$1,598,115	\$23,957	\$1,622,072	3,013,988	\$0.54
PENELEC	\$525,451	\$3,498	\$528,949	1,126,865	\$0.47	\$543,204	\$2,881	\$546,085	1,113,834	\$0.49
Pepco	\$315,940	\$17,347	\$333,287	2,384,691	\$0.14	\$1,239,205	\$12,775	\$1,251,979	2,315,962	\$0.54
PPL	\$219,986	\$0	\$219,986	2,698,153	\$0.08	\$109,610	\$8,931	\$118,541	2,933,870	\$0.04
PSEG	\$1,776,639	\$32,643	\$1,809,283	3,801,256	\$0.48	\$3,605,402	\$12,058	\$3,617,459	3,473,048	\$1.04
RECO	\$0	\$0	\$0	NA	NA	\$0	\$0	\$0	NA	NA
(Imp/Exp/Wheels)	\$1,505,710	\$1,837,924	\$3,343,634	3,496,705	\$0.96	\$2,086,179	\$273,711	\$2,359,890	2,605,456	\$0.91
Total	\$26,945,112	\$32,904,380	\$59,849,492	61,444,579	\$0.97	\$48,440,990	\$5,175,643	\$53,616,633	59,799,496	\$0.90

Black start zonal charges in 2015 ranged from \$0.04 per MW-day in the PPL Zone (total charges were \$118,541) to \$3.81 per MW-day in the BGE Zone (total charges were \$9,277,796). For each zone, Table 10-45 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). For black start service, point-to-point transmission customers paid on average \$0.042 per MW of reserve capacity during 2015.

Table 10-46 provides a revenue requirement estimate by zone for the 2016-2017, 2017-2018 and 2018-2019 delivery years. 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, and owner provided cost estimates of incoming black start units, at the time of publication and may change significantly.

**Table 10-46 Black start zonal revenue requirement estimate: 2015/2016 through 2018/2019 delivery years**

Zone	2016-2017 Revenue Requirement	2017-2018 Revenue Requirement	2018-2019 Revenue Requirement
AECO	\$2,850,000	\$2,850,000	\$2,800,000
AEP	\$19,150,000	\$19,200,000	\$18,950,000
APS	\$4,150,000	\$4,150,000	\$4,150,000
ATSI	\$3,100,000	\$3,100,000	\$3,100,000
BGE	\$8,400,000	\$8,450,000	\$8,400,000
ComEd	\$5,100,000	\$5,200,000	\$4,750,000
DAY	\$250,000	\$300,000	\$250,000
DEOK	\$1,250,000	\$1,250,000	\$1,200,000
DLCO	\$100,000	\$100,000	\$50,000
Dominion	\$5,400,000	\$5,400,000	\$5,400,000
DPL	\$2,600,000	\$2,600,000	\$2,500,000
EKPC	\$250,000	\$250,000	\$150,000
JCPL	\$7,200,000	\$7,200,000	\$7,150,000
Met-Ed	\$700,000	\$750,000	\$600,000
PECO	\$1,750,000	\$1,900,000	\$1,550,000
PENELEC	\$4,700,000	\$4,750,000	\$4,500,000
Pepco	\$2,700,000	\$2,700,000	\$2,650,000
PPL	\$800,000	\$800,000	\$750,000
PSEG	\$4,450,000	\$4,500,000	\$4,450,000
RECO	\$0	\$0	\$0
Total	\$74,900,000	\$75,450,000	\$73,350,000

## Reactive Service

Reactive Service, Reactive Supply and Voltage Control are provided by generation and other sources (such as static VAR compensators and capacitor banks) of reactive power (measured in VAR).<sup>57</sup> Reactive power helps maintain appropriate voltages on the transmission system and is essential to the flow of real power (measured in MW).

Total reactive service charges are the sum of reactive service revenue requirement charges and reactive service operating reserve charges. Reactive service revenue requirements are based on FERC-approved filings. Reactive service revenue requirement charges are allocated monthly to PJM customers in the zone or zones where the reactive service was provided proportionally to their zone and non-zone peak transmission use and point to point transmission reservations. Reactive service operating reserve charges are paid for scheduling in the Day-Ahead Energy Market and committing in real time units that provide reactive service. These operating reserve charges are allocated daily to the zone or zones where the reactive service was provided.

In 2015, total reactive service charges were \$289.4 million, a 6.1 percent decrease from 2014 level of \$307.7 million.<sup>58</sup> Revenue requirement charges decreased from \$281.2 million to \$278.4 million and operating reserve charges fell from \$26.5 million to \$10.7 million. Total charges in 2015 ranged from \$2.5 thousand in the RECO Zone to \$38.5 million in the AEP Zone.

For each zone in 2014 and 2015, Table 10-47 shows reactive service operating reserve charges, revenue requirement charges and total charges (the sum of operating reserve and revenue requirement charges).

**Table 10-47 Reactive zonal charges for network transmission use: 2014 and 2015**

Zone	2014			2015		
	Operating Reserve Charges	Revenue Requirement Charges	Total Charges	Operating Reserve Charges	Revenue Requirement Charges	Total Charges
AECO	\$101,458	\$6,619,214	\$6,720,672	\$17,594	\$6,575,504	\$6,593,098
AEP	\$567,379	\$39,949,384	\$40,516,763	\$459,505	\$38,052,860	\$38,512,365
APS	\$258,495	\$18,526,432	\$18,784,927	\$98,962	\$16,666,745	\$16,765,707
ATSI	\$10,740,864	\$15,273,809	\$26,014,673	\$3,855,080	\$15,692,347	\$19,547,427
BGE	\$38,731	\$7,703,534	\$7,742,265	\$63,843	\$7,825,069	\$7,888,912
ComEd	\$91,551	\$25,369,783	\$25,461,334	\$180,576	\$26,029,698	\$26,210,274
DAY	\$20,416	\$8,363,678	\$8,384,093	\$34,169	\$8,495,628	\$8,529,797
DEOK	\$13,975	\$5,655,802	\$5,669,777	\$53,658	\$5,153,000	\$5,206,658
Dominion	\$4,198,879	\$29,664,589	\$33,863,468	\$2,786,438	\$29,861,486	\$32,647,924
DPL	\$7,107,245	\$10,767,853	\$17,875,098	\$2,333,403	\$11,293,877	\$13,627,280
DLCO	\$7,424	\$0	\$7,424	\$25,139	\$0	\$25,139
EKPC	\$6,773	\$2,121,517	\$2,128,289	\$29,296	\$2,154,987	\$2,184,283
JCPL	\$25,990	\$7,064,041	\$7,090,031	\$39,420	\$7,175,487	\$7,214,907
Met-Ed	\$38,160	\$7,529,560	\$7,567,720	\$63,138	\$7,730,837	\$7,793,975
PECO	\$348,912	\$17,468,722	\$17,817,634	\$73,069	\$17,744,319	\$17,817,389
PENELEC	\$2,802,590	\$6,386,846	\$9,189,436	\$312,987	\$7,406,800	\$7,719,787
Pepco	\$34,680	\$5,211,678	\$5,246,358	\$68,773	\$5,293,901	\$5,362,674
PPL	\$24,343	\$18,900,104	\$18,924,446	\$81,352	\$18,969,092	\$19,050,444
PSEG	\$35,157	\$27,028,845	\$27,064,001	\$73,242	\$28,937,473	\$29,010,715
RECO	\$756	\$0	\$756	\$2,448	\$0	\$2,448
(Imp/Exp/Wheels)	\$0	\$21,618,826	\$21,618,826	\$0	\$17,330,444	\$17,330,444
Total	\$26,463,779	\$281,224,214	\$307,687,993	\$10,652,092	\$278,389,555	\$289,041,647

<sup>57</sup> PJM OATT, Schedule 2 "Reactive Supply and Voltage Control from Generation Sources Service," (Effective Date: February 18, 2012).

<sup>58</sup> See the 2014 State of the Market Report for PJM, Volume II, Section 4, "Energy Uplift."