

## 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 incentive rates or cost.

The Market Monitoring Unit (MMU) analyzed measures of market structure, conduct and performance for the PJM Regulation Market, the two regional Synchronized Reserve and Non-Synchronized Reserve Markets, and the PJM DASR Market for January through September 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 the year because the Regulation Market had one or more pivotal suppliers which failed PJM's three pivotal supplier (TPS) test in 97.9 percent of the hours in the first nine months of 2015.
- Participant behavior in the Regulation Market was evaluated as competitive for the first nine months of 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.

<sup>1</sup> 75 FERC ¶ 61,080 (1996).

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

- Market performance was evaluated as competitive, after the introduction of the new market design, 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 results continue to include the incorrect definition of opportunity cost. The market design has failed to correctly incorporate a consistent implementation of the marginal benefit factor in optimization, pricing and settlement.

**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 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.
- 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 non-zero 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 356 hours in the first nine months of 2015.
- Participant behavior was evaluated as mixed because while most offers appeared consistent with marginal costs, a significant proportion of offers reflected economic withholding.
- Market performance was evaluated as competitive because there were adequate offers at reasonable levels in every hour to satisfy the requirement and the clearing price reflected those offers.
- Market design was evaluated as mixed because while the market is functioning effectively to provide DASR, the three pivotal supplier test, and cost-based offer capping when the test is failed, should be added to the market to ensure that market power cannot be exercised at times of system stress.

## Overview

### Primary Reserve

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

### 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 can be started 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 Reserve 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 in January through September 2015 was 2,222.6 MW. The actual demand for primary reserve in the MAD Subzone in January through June 2015 was 1,704.8 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 counts as part of PJM's primary reserve requirement 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.

- **Supply.** No offers are made for tier 1 synchronized reserve. The market solution calculates tier 1 synchronized reserve as available 10-minute ramp from the energy dispatch. In the first nine months of 2015, there was an average hourly supply of 1,491.0 MW of tier 1 for the RTO synchronized reserve zone, and an average hourly supply of 1,190.3 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.
- **Tier 1 Synchronized Reserve Event Response.** Tier 1 synchronized reserve is paid when a synchronized reserve event occurs and it responds. The synchronized reserve event response credits for tier 1 response are independent of the tier 1 estimated, independent of the synchronized

reserve market clearing price, and independent of the non-synchronized reserve market clearing price.

Of tier 1 synchronized reserve eligible for payment in Settlements, 68.1 percent actually responded during the seventeen distinct synchronized reserve events in the first nine months of 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 price 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. A tariff change included in the shortage pricing tariff changes (October 1, 2012) added the requirement to pay 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 \$26,576,359 to tier 1 resources in 2014, and \$30,361,767 in the first nine months of 2015.

## Tier 2 Synchronized Reserve Market

Tier 2 synchronized reserve is part of primary reserve (ten minute availability) 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 filled with tier 1 synchronized reserve, PJM conducts a market to satisfy 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 the first nine months of 2015, the supply of offered and eligible synchronized reserve 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 both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone.
- **Market Concentration.** In the first nine months of 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone was 4926 which is classified as highly concentrated. The MMU calculates that 39.2 percent of hours would have failed a three pivotal supplier test in the Mid-Atlantic Dominion Subzone.

In the first nine months of 2015, the weighted average HHI for cleared tier 2 synchronized reserve in the RTO Synchronized Reserve Zone was 4538 which is classified as highly concentrated. The MMU calculates that 33.1 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 the first nine months of 2015.

## Market Conduct

- **Offers.** 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 (includes all hours when a market was cleared including hours when the SRMCP was \$0) for tier 2 synchronized reserve for all cleared hours in the Mid-Atlantic Dominion (MAD) Subzone

was \$12.71 per MW in the first nine months of 2015, a decrease of \$2.71, 17.6 percent from the first nine months of 2014.

The weighted average price for tier 2 synchronized reserve for all cleared hours in the RTO Synchronized Reserve Zone was \$13.92 per MW in the first nine months of 2015, an increase of \$0.07 from the first nine months of 2014.

## Non-Synchronized Reserve Market

Non-synchronized reserve is part of primary reserve and includes the same two markets, 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.

### Market Structure

- **Supply.** In the first nine months of 2015, the supply of eligible non-synchronized reserve was 1,891.2 MW in MAD and 2,663.9 MW in the full RTO.<sup>3</sup> This supply was sufficient to cover the primary reserve requirement in both the RTO Reserve Zone (2,063 MW) and the Mid-Atlantic Dominion Reserve Subzone (1,700 MW).
- **Demand.** Demand for non-synchronized reserve is the remaining primary reserve requirement after tier 1 synchronized reserve is estimated and tier 2 synchronized reserve (if any) is scheduled. In the full RTO Zone, the market cleared an hourly average of 843.1 MW of non-synchronized reserve in the first nine months of 2015. In the MAD Subzone, the market cleared an hourly average of 424.0 MW of non-synchronized reserve.

### 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.** There are no offers for non-synchronized reserve. 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 \$1.28 per MW in the first nine months of 2015 and in 86.7 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 \$1.40 and in 86.3 percent of hours the market clearing price was \$0.

## 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>4</sup> The DASR Market has no performance obligations.

### Market Structure

- **Concentration.** In the first nine months of 2015, 356 hours in the DASR Market would have failed the three pivotal supplier test.
- **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 the first nine months of 2015, the average available hourly DASR was 36,719 MW.
- **Demand.** The DASR requirement in 2015 is 5.93 percent of peak load forecast, down from 6.27 percent in 2014. The average DASR MW purchased was 6,398 MW per hour in the first nine months of 2015.

<sup>3</sup> See PJM M-11 Energy & Ancillary services Markets, rev. 77, August 27, 2015, p. 80 "Because Synchronized Reserve may be utilized to meet the Primary Reserve requirement, there is no explicit requirement for non-synchronized reserves "

<sup>4</sup> See PJM. "Manual 35, Definitions and Acronyms," Revision 23, (April 11, 2014), p. 22.

## 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. As of September 30, 2015, 14.8 percent of resources offered DASR at levels above \$5 per MW, an increase from the 8.0 percent of resources that offered above \$5 as of June 30, of 2015.
- **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 from January through September 2015 was \$4.60 per MW. This is a significant increase from the \$1.02 per MW in the first nine months of 2014.

## Regulation Market

The PJM Regulation Market is a single 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 (actual) MW into effective MW.

## Market Structure

- **Supply.** In the first nine months of 2015, the average hourly eligible supply of regulation was 1,147.7 actual MW (885.9 effective MW). This is a decrease of 152.3 actual MW (52.1 effective MW) from the same period of 2014, when the average hourly eligible supply of regulation was 1,300.0 actual MW (938.0 effective MW).

- **Demand.** The average hourly regulation demand was 641.1 actual MW (663.7 effective MW) in the first nine months of 2015. This is a 22.9 actual MW (0 effective MW) decrease in the average hourly regulation demand of 663.9 actual MW (663.7 effective MW) from the same period of 2014.
- **Supply and Demand.** The ratio of offered and eligible regulation to regulation required averaged 1.79. This is a 8.68 percent decrease from the same period of 2014 when the ratio was 1.96.
- **Market Concentration.** In the first nine months of 2015, the PJM Regulation Market had a weighted average Herfindahl-Hirschman Index (HHI) of 1480 which is classified as moderately concentrated. In the first nine months of 2015, the three pivotal supplier test was failed in 97.9 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 along with cost parameters to verify the offer, and may optionally 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>5</sup> In the first nine months of 2015, there were 284 resources following the RegA signal and 48 resources following the RegD signal.

## Market Performance

- **Price and Cost.** The weighted average clearing price for regulation was \$35.56 per MW of regulation in the first nine months of 2015, a decrease of \$14.62 per MW of regulation, or 29.1 percent, from the same period of 2014. The cost of regulation in the first nine months of 2015 was \$43.00 per MW of regulation, a decrease of \$17.93 per MW of regulation, or 29.4 percent, from the same period of 2014. The decreases in regulation price and regulation cost resulted primarily from high prices and costs in the first nine months of 2014, particularly in January.

<sup>5</sup> See the 2014 State of the Market Report for PJM, Volume II, Appendix F "Ancillary Services Markets."

- **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 equally per effective MW.
- **Marginal Benefit Factor Function.** The marginal benefit factor measures the substitutability of RegD resources for RegA resources in satisfying the regulation requirement. The regulation market's effectiveness and efficiency depends on the marginal benefit factor function being properly defined based on the actual tradeoff between RegA and RegD MW in providing regulation. Current regulation performance indicates that the marginal benefit factor function used by PJM is incorrectly describing the operational relationship between RegA and RegD for purposes of providing regulation service.
- **Inconsistent accounting of RegD Effective MW.** The current market design does not correctly account for the amount of effective MW being provided by RegD. Rather than calculating the total effective MW contribution of RegD MW on the basis of the area under the marginal benefit function curve, the current regulation market optimization assigns all RegD resources the lowest marginal benefit factor associated with last RegD MW at that price. This incorrect accounting of effective MW results in the purchase of more than the efficient level of regulation MW necessary to meet PJM's regulation requirement.
- **Inconsistent Application of MBF in Optimization.** 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 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. This issue, combined with an increasing proportion of

RegD offering at an effective price of zero, is directly contributing to the problem of too much RegD clearing relative to RegA MW in the market.

## 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.<sup>6</sup>

In the first nine months of 2015, total black start charges were \$39.0 million with \$33.9 million in revenue requirement charges and \$5.1 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 automatic load rejection (ALR) option or for black start testing. Black start zonal charges in the first nine months of 2015 ranged from \$0.04 per MW-day in the PPL Zone (total charges were \$93,554) to \$3.99 per MW-day in the BGE Zone (total charges were \$7,256,881).

## Reactive

Reactive service, reactive supply and voltage control from generation or other sources service, is 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 the first nine months of 2015, total reactive service charges were \$217.6 million, a 4.5 percent decrease from \$227.8 million in the first nine months of 2014. Revenue requirement charges decreased from \$210.4 million to \$207.7 million and operating reserve charges fell from \$17.4 million to \$9.9 million. Total charges in the first nine months of 2015 ranged from \$2,448 in

<sup>6</sup> OATT Schedule 1 § 1.3BB.

the RECO Zone to \$29.4 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, on a per MWh of load basis. 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 also changes in total load.

**Table 10-4 History of ancillary services costs per MWh of Load: January through September, 2004 through 2015<sup>7</sup>**

Year	Scheduling, Dispatch, and System Control		Synchronized		Total
	Regulation	Reactive	Reserve		
2004	\$0.50	\$0.64	\$0.25	\$0.14	\$1.53
2005	\$0.78	\$0.47	\$0.25	\$0.11	\$1.61
2006	\$0.55	\$0.48	\$0.28	\$0.07	\$1.38
2007	\$0.65	\$0.47	\$0.29	\$0.06	\$1.47
2008	\$0.75	\$0.34	\$0.29	\$0.07	\$1.45
2009	\$0.36	\$0.36	\$0.36	\$0.05	\$1.13
2010	\$0.37	\$0.38	\$0.36	\$0.06	\$1.17
2011	\$0.35	\$0.36	\$0.39	\$0.09	\$1.19
2012	\$0.23	\$0.44	\$0.44	\$0.03	\$1.14
2013	\$0.27	\$0.41	\$0.69	\$0.04	\$1.41
2014	\$0.34	\$0.37	\$0.36	\$0.25	\$1.32
2015	\$0.25	\$0.41	\$0.36	\$0.13	\$1.15

<sup>7</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.

## 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 2013. Status: Not adopted.)
- 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. (Priority: High. First reported Q3, 2014. Status: Adopted July 2014.)
- The MMU recommends that the tier 2 synchronized reserve must-offer provision of scarcity pricing be enforced. As of September 30, 2015 compliance with the tier 2 must-offer provision was high but less than 100 percent. (Priority: Medium. First reported 2013. Status: Adopted partially.)
- 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 calculating 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. (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: Not adopted.)

- The MMU recommends that the three pivotal supplier test 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 dispatch adds additional DASR MW. 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. (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. Further, the market design has failed to correctly incorporate the marginal benefit factor in optimization, pricing and settlement. Instead, the market design makes use of 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 current 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, as currently implemented, 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. Compliance with calls to respond to actual synchronized reserve events has been an issue. Compliance with the synchronized reserve must-offer requirement has also been an issue.

The shortage pricing rule that requires market participants to pay tier 1 synchronized reserve the tier 2 synchronized reserve price when the non-synchronized reserve price is greater than zero, is inefficient and results in a 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. 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. Application of this rule added \$89.7 million to the cost of primary reserve in 2014 (Note that \$79.3 million was refunded to loads after an error in the T1 calculation was corrected, Table 10-11).

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 new 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.

## Primary Reserve

PJM has an obligation to maintain ten minute reserves (primary reserve) to ensure reliability in the event of disturbances. Primary reserve is PJM's implementation of the NERC 10-minute contingency reserve requirement.<sup>8</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>9</sup> PJM implements the NERC requirement conservatively as primary reserve available within ten minutes.

<sup>8</sup> PJM. OATT (effective 2/5/2014), p.1740; 1.3.29F Primary Reserve.

<sup>9</sup> NERC, IVGT Task 2.4 Report; Operating Practices, Procedures, and Tools, March 2011, p. 20.

## Market Structure

### Supply

In 2015, PJM's primary reserve requirement was 2,063 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 non-synchronized reserves.

Estimated tier 1 is credited against PJM's primary reserve requirement. In the MAD Subzone an average of 1,190.3 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. There was enough tier 1 to satisfy the MAD Subzone synchronized reserve requirement in 51.3 percent of hours in the first nine months of 2015. In the RTO Zone, an average of 1,491.0 MW of tier 1 was available (Table 10-6). The RTO Zone synchronized reserve requirement was satisfied by tier 1 in 55.0 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>10</sup>

There is usually enough tier 2 synchronized reserve to fulfill the synchronized reserve requirement. In the MAD Subzone, there was an average of 3,3,218 MW of eligible tier 2 synchronized reserve available (Figure 10-11) to meet

<sup>10</sup> See PJM, "Manual 11, Energy & Ancillary Services Market Operations," Revision 77 (August 27, 2015), p. 66.

the average tier 2 hourly demand of 267.6 MW (Table 10-5). In the RTO Zone, there was an average of 9,046 MW of eligible Tier 2 supply available to meet the average hourly demand of 372.5 MW (Table 10-6).

In the MAD Subzone, there was an average of 1,897.9 MW of eligible non-synchronized reserve supply available to meet the average hourly demand of 424.2 MW (Table 10-6). In the RTO Zone, an hourly average of 2,658.8 MW supply was available to meet the average hourly demand of 842.6 MW (Table 10-5).

### Demand

PJM requires that 150 percent of the largest contingency on the system be maintained as primary reserve. On January 8, 2015, the primary reserve requirement in the RTO Reserve Zone was raised from 2,063 MW to 2,175 MW. 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 (Figure 10-1).

In 11.5 percent of hours during the first nine months of 2015, PJM increased the primary reserve requirement for the RTO Zone. The actual hourly average RTO primary reserve requirement was 2,222.6 MW in the first nine months of 2015. In 38 hours during the first nine months of 2015, PJM increased the primary reserve requirement for the MAD Subzone. The actual hourly average demand for primary reserve in the MAD Subzone in the first nine months of 2015 was 1,704.8 MW.

Transmission constraints limit the deliverability of reserves within the RTO, requiring the definition of the Mid-Atlantic Dominion (MAD) Subzone.<sup>11</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).

<sup>11</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 77 (August 27, 2015), p. 68.

Figure 10-1 PJM RTO geography and primary reserve requirement: 2015



The Mid-Atlantic Dominion Reserve (MAD) Subzone is defined dynamically by the most limiting constraint separating MAD from the PJM RTO Reserve Zone. In 73.3 percent of hours in 2015, that constraint was the Bedington – Black Oak Interface. The AP South transfer interface constraint was the limiting constraint in 25.2 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: January through September 2015

Year	Month	Tier 1 Total 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	Average	1,192.9	274.5	423.6

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: January through September 2015

Year	Month	Tier 1 Total 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	Average	1,442.2	379.0	843.1

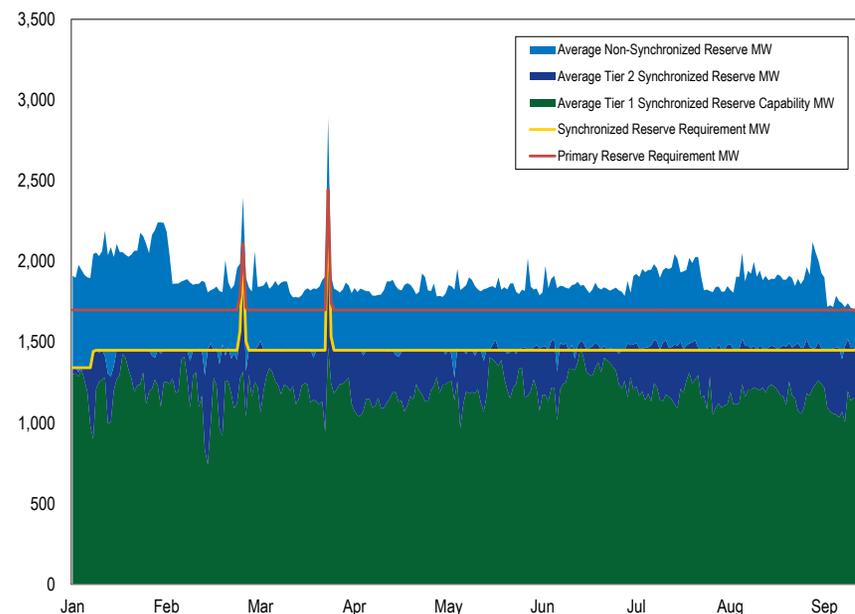
### Supply and Demand

The market solution software relevant to reserves consists of: the Ancillary Services Optimizer (ASO) solving hourly, the intermediate term security constrained economic dispatch market solution (IT-SCED) 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): January through September 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>12</sup> Figure 10-3 shows how the hour ahead ASO satisfies the primary reserve requirement for the RTO Zone.

<sup>12</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 subzone primary reserve MW by source (Daily Averages): January through September 2015**

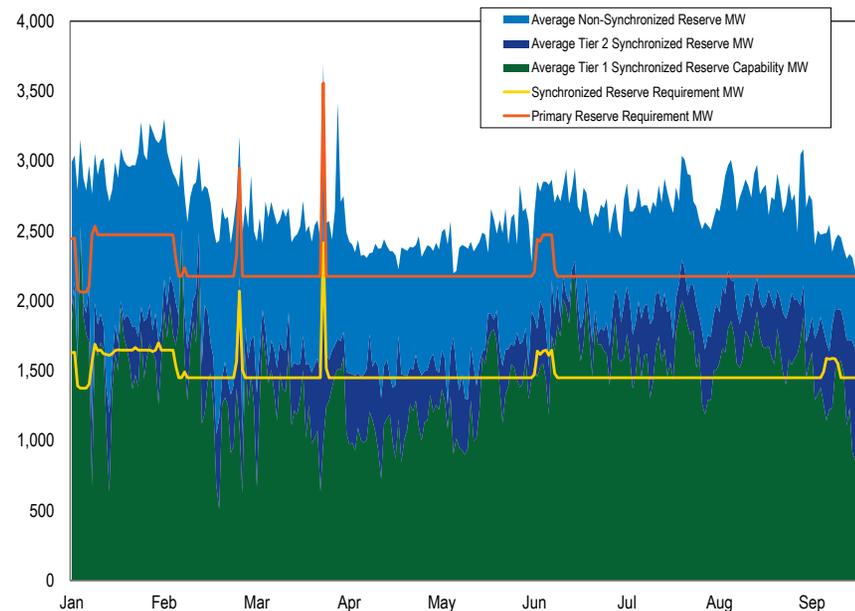


Figure 10-2 and Figure 10-3 show that tier 1 synchronized reserve remains the major contributor to satisfying the synchronized reserve requirements both in the RTO Zone and the Mid-Atlantic Dominion (MAD) Subzone.

### 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

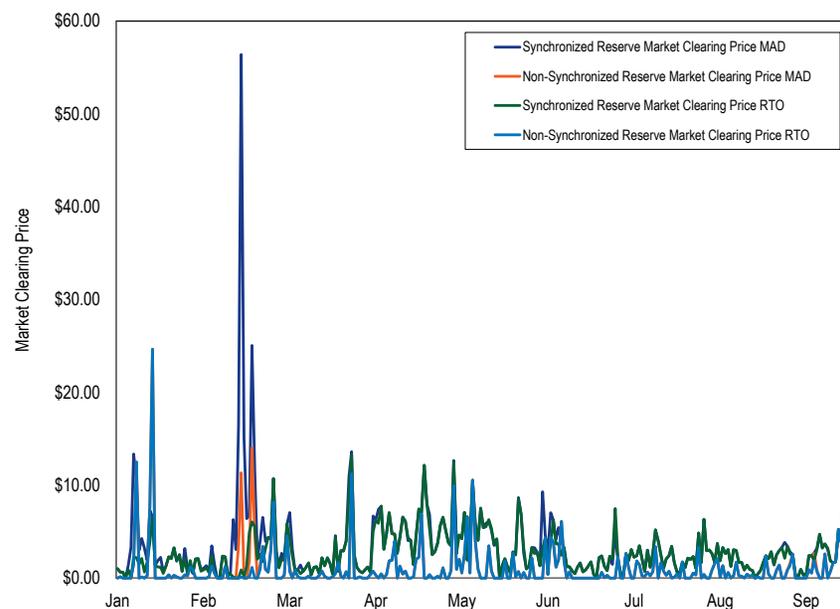
paid the tier 2 synchronized reserve market price in any hour that the non-synchronized reserve market clears with a price above \$0.

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. From June 1, 2013, through May 31, 2014, the penalty factor was \$400 per MW for both tier 2 synchronized reserve and non-synchronized reserve. 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.

Figure 10-4 shows daily average synchronized and non-synchronized market clearing prices in the first nine months of 2015.

Figure 10-4 Daily average market clearing prices (\$/MW) for synchronized reserve and non-synchronized reserve: January through September 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 (light blue area in Figure 10-2 and Figure 10-3) and tier 1 synchronized reserve (green area in Figure 10-2 and Figure 10-3). 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, full RTO Reserve Zone, January through September 2015

Product	Share of Primary Reserve					
	Requirement	MW Credited	Credits Paid	Price Per MW	Cost Per MW	All-In Cost
Tier 1 Synchronized Reserve Response	NA	6,289	\$256,083	NA	\$40.72	\$0.00
Tier 1 Synchronized Reserve	17.3%	1,505,598	\$30,673,976	\$0.00	\$20.37	\$0.05
Tier 2 Synchronized Reserve	24.4%	2,119,031	\$46,301,401	\$13.92	\$21.85	\$0.08
Non-synchronized Reserve	58.3%	5,064,150	\$10,775,867	\$1.28	\$2.13	\$0.02
Primary Reserve (total of above)	100.0%	8,688,779	\$87,751,244	\$4.14	\$10.10	\$0.15

## 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 consistent with Good Utility Practice, tier 1 resources are not financially obligated to provide their tier 1 estimated MW 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 the first nine months of 2015, in the RTO Reserve Zone the average hourly estimated tier 1 synchronized reserve was 1,442.4 MW (Table 10-6). In 903 hours (13.8 percent) 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 the first nine months of 2015, in the MAD Reserve Subzone the average hour ahead estimated tier 1 synchronized reserve was 1,193.3 MW (Table 10-5). In 161 hours the estimated tier 1 synchronized reserve local to the MAD Subzone was zero. In 138 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, January through September 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	Average	588.3	604.6	1,192.9	393.1	2,186.5

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	Average			1,442.2	21.3	3,395.8

## 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, a new metric, DGP (Degree of Generator Performance), was introduced 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>13</sup>

For the first nine months of 2015, PJM estimated tier 1 MW for an average of 156 units as part of the solution each hour. The average DGP was 84.6 percent for those 156 units.

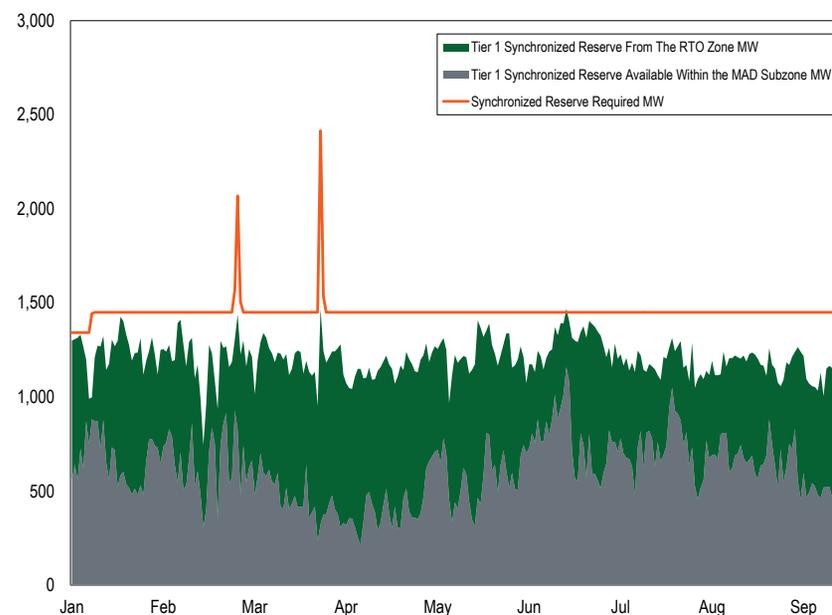
## Supply and Demand

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 (adjusted by each unit's DGP). To improve its tier 1 estimates, PJM routinely deselects certain resources from the tier 1 estimate. Tier 1 deselection is based on unit type, location and daily grid conditions.

<sup>13</sup> PJM. "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>>

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: January through September 2015**



Demand for synchronized reserve in the RTO Zone in the first nine months of 2015 was 12.1 percent higher than in the first nine months of 2014 primarily because the hourly synchronized reserve requirement was increased from 1,375 MW to 1,450 MW. In addition, there was a temporary increase 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. Usually, the synchronized reserve requirement is increased because of planned outages in the spring and fall for periods of 10 to 14 days.

## 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 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 the first nine months of 2015, tier 1 synchronized reserve synchronized reserve event response credits of \$256,083 were paid for 6,289 MW of tier 1 response at a cost per MW of \$40.72, for 17 spinning events (Table 10-9).

**Table 10-9 Tier 1 synchronized reserve event response costs: January 2014 through September 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
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
All		55	24,251.3	\$1,787,061	\$49.25	374.8

## Paying Tier 1 the Tier 2 Price

The market solutions correctly treat tier 1 synchronized reserve as having zero 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 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 synchronized reserve market clearing price of \$30.67 per MW and earned \$89,719,045 in credits. (Table 10-10) Of the \$89,719,045, \$10,406,363 was for tier 1 actually estimated by the PJM market solution and \$79,312,682 was mistakenly paid because deselected tier 1 MW were paid when they should not have been. The issue of paying for tier 1 from deselected units was corrected in July 2014. PJM continues however to pay tier 1 synchronized reserve the SRMCP when the non-synchronized reserve market clearing price is above \$0. In the first nine months of 2015, PJM paid \$30,673,976 in credits for tier 1 estimated during the 889 hours when the non-synchronized reserve market clearing price was above \$0.

**Table 10-10 Weighted price of tier 1 synchronized reserve attributable to a non-synchronized reserve price above zero: January 2014 to September 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	706,479	\$64,956,018	4,557.9
2014	Feb	15	\$40.18	65,332	\$2,625,303	4,355.4
2014	Mar	67	\$44.56	240,625	\$10,665,198	3,591.4
2014	Apr	99	\$16.07	308,759	\$4,959,232	3,118.8
2014	May	61	\$15.85	253,076	\$4,012,285	4,148.8
2014	Jun	4	\$35.46	15,970	\$566,292	3,992.4
2014	Jul	5	\$17.02	9,150	\$155,744	1,829.9
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
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	\$3,265,956	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	1,061.1
Total		1417	\$28.42	3,311,605	\$120,474,541	2,293.3

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. Only 63.9 percent of the market solution's estimated tier 1 resource MWh actually responded during synchronized reserve events of greater than ten minutes in the first nine months of 2015. Thus, 36.1 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 effective price of all tier 1 MW increases significantly.

In the first nine months of 2015, tier 1 MW were paid \$256,083 for responding to synchronized reserve events and were paid \$30.7 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 September 2015

Year	Month	Synchronized Reserve Events			Hours When NSRMCP > \$0			Corrected Payments for Hours When NSRMCP > \$0 (After Refund)	
		Total MWh	Total Credits	Average MWh Per Event	Total MW	Total Credits	Average MW Per Hour	Correct Tier 1 Credits	Overpayment
2014	Jan	7,828	\$965,846	522	706,479	\$64,956,018	4,558	\$4,874,314	\$60,081,704
2014	Feb	273	\$11,153	273	65,332	\$2,625,303	4,355	\$337,903	\$2,287,400
2014	Mar	3,030	\$175,902	606	240,625	\$10,665,198	3,591	\$1,513,636	\$9,151,562
2014	Apr	389	\$6,378	195	308,759	\$4,959,232	3,119	\$916,275	\$4,042,957
2014	May	717	\$34,906	239	253,076	\$4,012,285	4,149	\$799,911	\$3,212,374
2014	Jun	0	\$0	0	15,970	\$566,292	3,992	\$118,273	\$448,019
2014	Jul	616	\$35,179	308	9,150	\$155,744	1,830	\$67,078	\$88,666
2014	Aug	0	\$0	0	0	\$0	0	\$0	\$0
2014	Sep	1,936	\$143,574	645	0	\$0	0	\$0	\$0
2014	Oct	1,132	\$83,901	566	2,146	\$46,319	715	\$46,319	\$0
2014	Nov	1,350	\$38,895	337	38,188	\$599,147	1,364	\$599,147	\$0
2014	Dec	258	\$12,897	129	163,552	\$1,133,507	1,740	\$1,133,507	\$0
2015	Jan	397	\$8,198	397	274,996	\$3,727,945	1,858	\$3,727,945	\$0
2015	Feb	218	\$9,634	109	369,111	\$9,164,267	1,903	\$9,164,267	\$0
2015	Mar	2,446	\$105,505	611	305,967	\$4,985,446	1,690	\$4,985,446	\$0
2015	Apr	1,399	\$69,399	280	102,117	\$2,587,076	1,547	\$2,587,076	\$0
2015	May	0	\$0	0	106,027	\$2,158,080	1,473	\$2,158,080	\$0
2015	Jun	0	\$0	0	182,417	\$3,183,436	1,961	\$3,183,436	\$0
2015	Jul	502	\$25,540	502	64,516	\$2,265,614	1,403	\$2,265,614	\$0
2015	Aug	648	\$7,730	324	48,479	\$1,078,199	1,276	\$1,078,199	\$0
2015	Sep	678	\$30,077	226	51,968	\$1,522,913	1,061	\$1,522,913	\$0
Total		23,817	\$1,764,714	369	3,308,873	\$120,392,021	2,294	\$41,079,339	\$79,312,682

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 plus \$50/MW, termed the Synchronized Energy Premium Price.

A summary of 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 * calculated 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.

In 2015, PJM used tier 1 estimate biasing in the MAD Subzone ASO and the RTO Zone ASO (Table 10-14). Tier 1 biasing is not used in any IT-SCED solutions.

Table 10-14 MAD Subzone ASO tier 1 estimate biasing, January 2014 through September, 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	NA
2014	May	23	(909.8)	0	NA
2014	Jun	17	(1,179.4)	3	666.7
2014	Jul	36	(1,011.1)	0	NA
2014	Aug	31	(891.9)	1	750.0
2014	Sep	15	(1,206.7)	0	NA
2014	Oct	67	(1,285.8)	1	500.0
2014	Nov	193	(1,125.4)	6	475.0
2014	Dec	163	(1,238.9)	1	300.0
2015	Jan	51	(1,731.4)	6	600.0
2015	Feb	62	(1,641.1)	0	NA
2015	Mar	25	(794.0)	3	1,000.0
2015	Apr	31	(430.7)	0	NA
2015	May	46	(582.6)	8	812.5
2015	Jun	25	(694.0)	1	1,000.0
2015	Jul	9	(588.9)	0	NA
2015	Aug	1	(750.0)	1	750.0
2015	Sep	4	(475.0)	1	2,000.0
Total		917	(1,031.5)	39	693.2

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.

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 calculating 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 energy price based 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. 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 redispaches 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>14</sup> This rule is intended to increase the accuracy of estimates of available synchronized reserve and primary reserve.

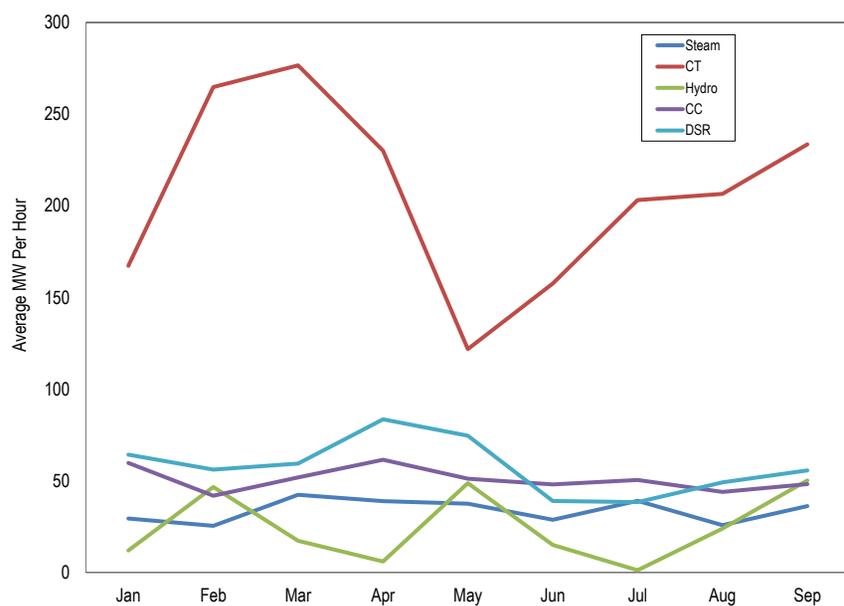
In the first nine months of 2015, the Mid Atlantic Dominion Subzone averaged 3,217.8 MW in synchronized reserve offers, and the RTO Zone averaged 9,045.9 MW of synchronized reserve offers (Figure 10-11).

The supply of tier 2 synchronized reserve in the first nine months of 2015 was sufficient to cover the requirement in both the RTO Reserve Zone and the Mid-Atlantic Dominion Reserve Subzone. In addition the availability of on-line resources was sufficient to meet the synchronized reserve requirement and shortage pricing was not reached.

<sup>14</sup> See PJM. "Manual 11: Energy & Ancillary Services Market Operations" Revision 77, (August 27, 2015), p. 65.

The largest portion of cleared tier 2 synchronized reserve in the first nine months of 2015 is from CTs (Figure 10-6), 55.3 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 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 Market was 15.5 percent in the first nine months of 2015.<sup>15</sup> This is an increase from the 14.3 percent share of the tier 2 market in the first nine months of 2014.

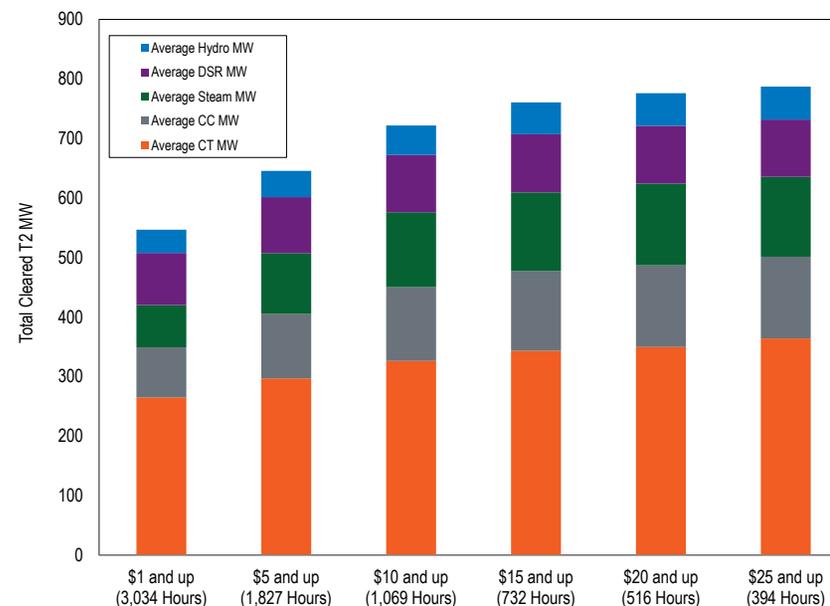
**Figure 10-6 Cleared tier 2 synchronized reserve average hourly MW per hour by unit type, full RTO Zone: January through September 2015**



<sup>15</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.

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

**Figure 10-7 Average hourly MW contribution by unit type to total cleared tier 2 synchronized reserve MW / SRMCP; January through September 2015**



### 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>16</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.

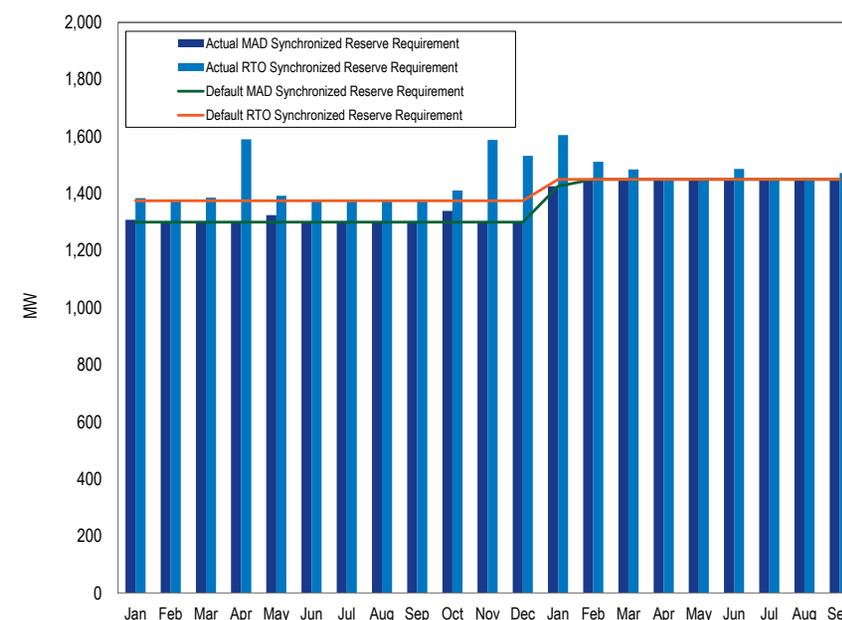
**Table 10-15 Default Tier 2 Synchronized Reserve Markets required MW, RTO Zone and Mid-Atlantic Dominion Subzone**

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 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 average actual synchronized reserve requirement in the MAD Subzone was 1,453.4 MW. The average actual synchronized reserve requirement in the RTO Reserve Zone was 1,484.8 MW.

<sup>16</sup> PJM Manual 11 Energy & Ancillary Services Market Operations, Rev 77 August 27, 2015, pp. 69.

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

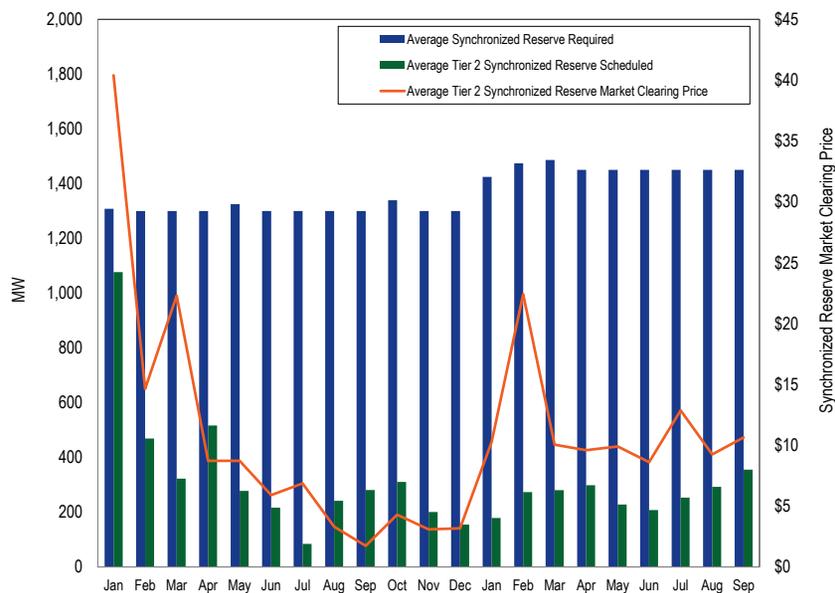


The market demand for tier 2 synchronized reserve in the Mid-Atlantic Dominion Subzone is determined by subtracting the amount of forecast tier 1 synchronized reserve available in the subzone from the subzone requirement each five-minute period. Market demand is also reduced by subtracting the amount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

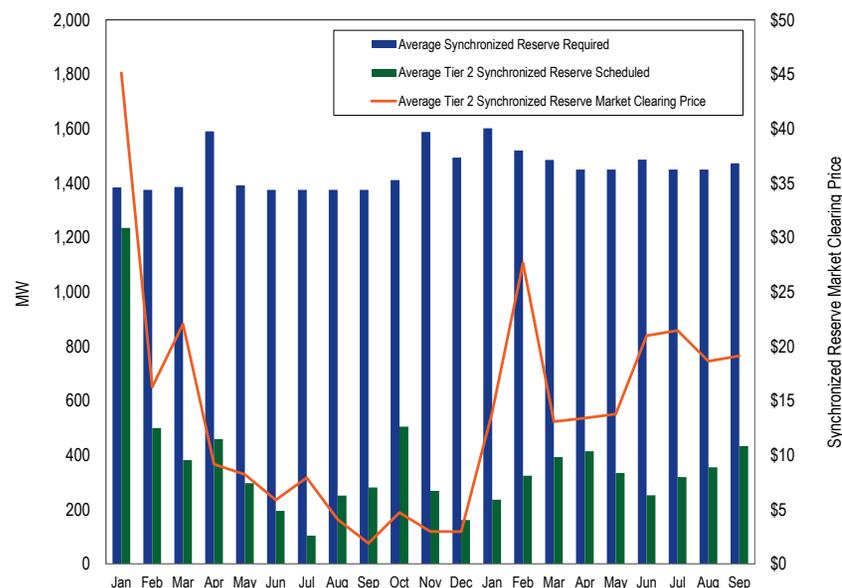
In the RTO Reserve Zone, 47.6 percent of hours cleared a Tier 2 Synchronized Reserve Market in the first nine months of 2015 averaging 378.1 MW. This compares with 32.9 percent of hours averaging 751.0 MW in the first nine months of 2014. In the MAD Reserve Subzone, 93.7 percent of hours cleared a Tier 2 Synchronized Reserve Market in the first nine months of 2015 averaging 273.6 MW. This compares with 97.1 percent of hours cleared, averaging 390.0 MW in the first nine months of 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 from January 2014 through September 2015, for the RTO Zone and MAD Subzone. The month of January 2014 was unusual in that much more tier 2 synchronized reserve was cleared than prior years as a result of extreme weather.

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



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



### Market Concentration

The HHI for all settled tier 2 synchronized reserve during cleared hours of the Mid-Atlantic Dominion Subzone Tier 2 Synchronized Reserve Market from the first nine months of 2015 was 4926, which is defined as highly concentrated. This is a decrease from the 5427 HHI of the first nine months of 2014. The largest hourly market share was 100 percent and 65.0 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 the first nine months of 2015 was 4538, which is defined as highly concentrated. The largest hourly market share was 100 percent and 67.3 percent of cleared hours had a maximum market share greater than or equal to 40 percent.

In the MAD Subzone, flexible synchronized reserve was 4.4 percent of all tier 2 synchronized reserve in the first nine months of 2015. In the RTO Zone, flexible synchronized reserve assigned was 5.4 percent of all tier 2 synchronized reserve in the first nine months of 2015.

The MMU calculates that 39.2 percent of hours failed the three pivotal supplier test in the MAD Subzone from January through September 2015 for the inflexible Synchronized Reserve Market (excluding self-scheduled synchronized reserve) in the hour ahead market (Table 10-16) and 33.1 percent of hours failed a three pivotal supplier test in the RTO Zone from the first nine months of 2015.

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

Year	Month	Mid Atlantic Dominion Reserve Subzone Pivotal Supplier Hours	RTO Reserve Zone Pivotal 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%
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	45.2%	19.1%
2015	Average	43.4%	36.6%

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

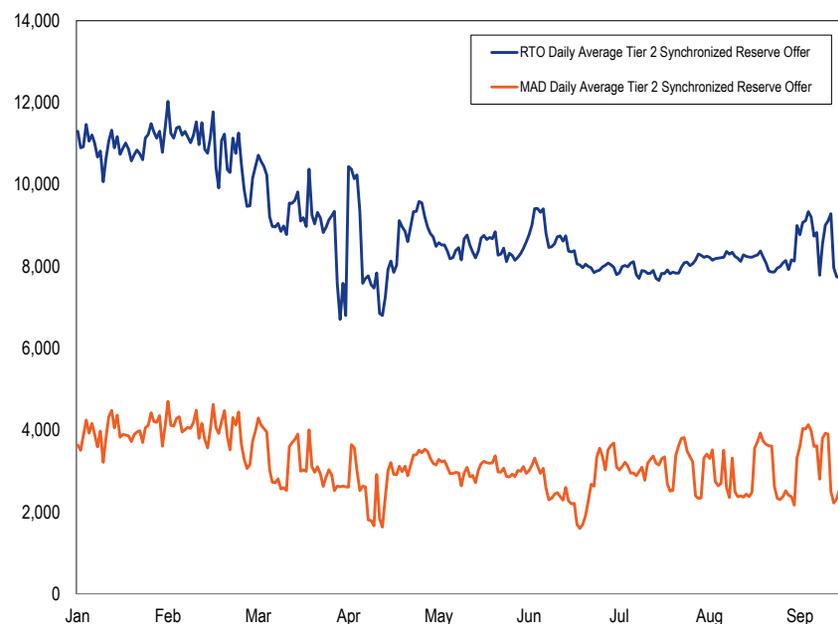
### Offers

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 includes the synchronized reserve offer quantity (MW). The offer quantity is limited to the economic maximum or less if a spin maximum value 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 the first nine months of 2015, the ratio of on-line and eligible tier 2 synchronized reserve to synchronized reserve required in the Mid-Atlantic Dominion Subzone was 3.70 averaged over all hours. For the full RTO Synchronized Reserve Zone the ratio was 15.91.

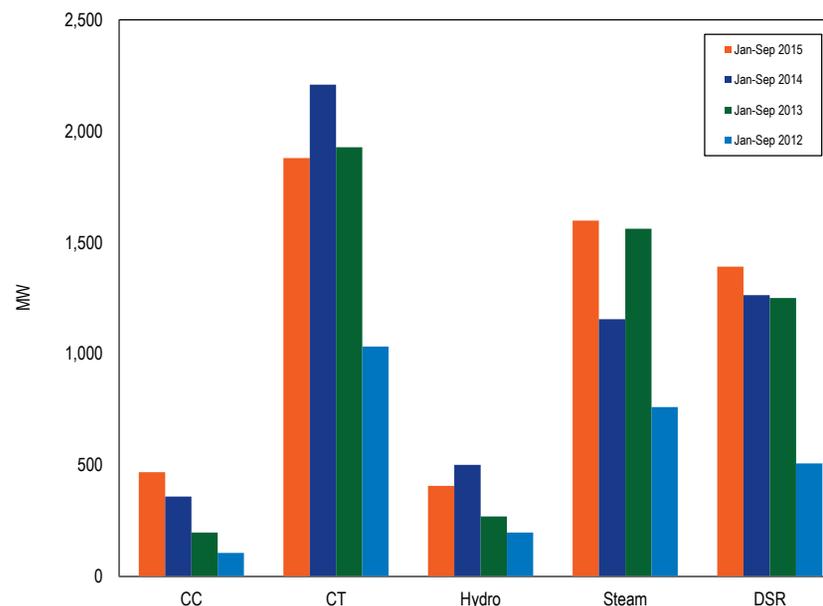
After October 1, 2012, PJM adopted a new rule creating a must offer requirement for synchronized reserve for all generation that is online, non-emergency, and available to produce energy. Changes to hourly and daily offer levels are the result of on-line status, minimum/maximum runtimes, minimum notification times, maintenance status and grid conditions including constraints. Compliance with this requirement is high but less than 100 percent.

**Figure 10-11 Tier 2 synchronized reserve daily average offer and eligible volume (MW): January through September 2015**

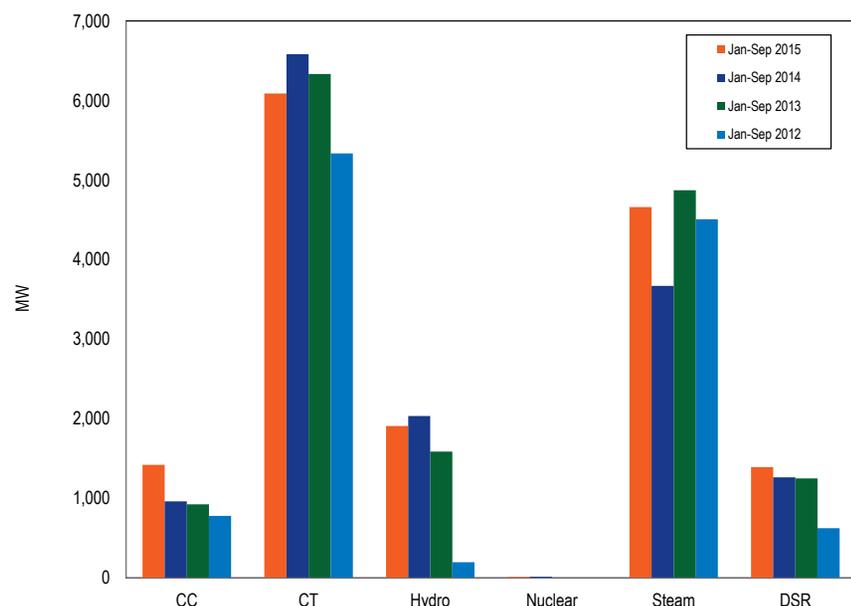


Synchronized reserve is offered by steam, CT, CC, hydroelectric and DR resources. Figure 10-12 shows average offer MW volume by market and unit type for the MAD Subzone and Figure 10-13 shows average offer MW volume by market and unit type for the RTO Zone.

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



**Figure 10-13 RTO Zone average daily tier 2 synchronized reserve offer by unit type (MW): January through September 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 273.6 MW (including self-scheduled) with a price greater than \$0 in 93.7 percent of hours in the first nine months of 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 378.1 MW (including self-scheduled) with a price greater than \$0 in 47.6 percent of hours in the first nine months of 2015.

In the first nine months of 2015, the weighted average Tier 2 synchronized reserve market clearing price in the MAD Subzone for all cleared hours was \$12.71. In the first nine months of 2014, the weighted average synchronized reserve market clearing price in the MAD Subzone was \$15.42.

In the first nine months of 2015, the weighted average Tier 2 Synchronized Reserve Market clearing price in the full RTO Zone for all cleared hours was \$13.92. In the first nine months of 2014, the weighted average synchronized reserve market clearing price in the RTO Zone was \$13.85.

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): January through September 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	165.3
2015	Jul	\$12.87	1,444.8	41.1	225.9
2015	Aug	\$9.25	1,498.7	50.2	249.4
2015	Sep	\$10.69	1,091.7	74.3	309.1

**Table 10-18 RTO zone weighted SRMCP and cleared MW (excludes self-scheduled): January through September 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	\$12.24	1,417.5	164.8	345.5
2015	Feb	\$24.68	1,618.3	46.3	362.5
2015	Mar	\$12.37	1,285.0	60.8	381.9
2015	Apr	\$11.53	1,228.6	85.0	354.5
2015	May	\$11.22	1,239.8	76.0	298.8
2015	Jun	\$12.95	1,636.6	54.5	280.1
2015	Jul	\$15.28	1,618.0	41.1	293.9
2015	Aug	\$11.20	1,637.1	50.8	308.9
2015	Sep	\$12.44	1,431.8	79.7	388.7

## 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 the first nine months of 2015, the price to cost ratio of the full RTO Zone Tier 2 Synchronized Reserve Market averaged 63.7 percent (Table 10-19); the price to cost ratio of the RTO Zone excluding MAD averaged 68.0 percent; the price to cost ratio of the MAD Subzone averaged 61.7 percent.

**Table 10–19 Full RTO, RTO, Mid-Atlantic Subzone tier 2 synchronized reserve MW, credits, price, and cost: January through September 2015**

Tier 2 Synchronized Reserve Market	Year	Month	Total		Weighted Synchronized Reserve Market		Price Cost/ Ratio
			MW	Total Credits	Clearing Price	Cost	
Full RTO Zone	2015	Jan	225,741	\$5,089,807	\$12.24	\$22.55	54.3%
Full RTO Zone	2015	Feb	272,371	\$12,065,569	\$24.68	\$44.30	55.7%
Full RTO Zone	2015	Mar	301,564	\$7,323,630	\$12.37	\$24.29	50.9%
Full RTO Zone	2015	Apr	278,562	\$4,896,351	\$11.53	\$17.58	65.6%
Full RTO Zone	2015	May	244,947	\$4,231,841	\$11.22	\$17.28	65.0%
Full RTO Zone	2015	Jun	174,039	\$2,916,195	\$12.95	\$16.76	77.3%
Full RTO Zone	2015	Jul	194,178	\$3,435,731	\$15.28	\$17.69	86.4%
Full RTO Zone	2015	Aug	173,869	\$2,329,804	\$11.20	\$13.40	83.6%
Full RTO Zone	2015	Sep	253,762	\$4,012,473	\$12.44	\$15.81	78.9%
Full RTO Zone	2015	Total	2,119,031	\$46,301,401	\$13.92	\$21.85	63.7%
RTO Only	2015	Jan	81,527	\$1,635,137	\$13.91	\$20.06	69.4%
RTO Only	2015	Feb	63,834	\$3,324,613	\$26.51	\$52.08	50.9%
RTO Only	2015	Mar	104,025	\$2,835,300	\$13.44	\$27.26	49.3%
RTO Only	2015	Apr	81,339	\$1,312,673	\$13.39	\$16.14	83.0%
RTO Only	2015	May	72,479	\$1,280,635	\$13.77	\$17.67	77.9%
RTO Only	2015	Jun	50,566	\$1,230,802	\$19.43	\$24.34	79.8%
RTO Only	2015	Jul	54,485	\$1,342,278	\$21.46	\$24.64	87.1%
RTO Only	2015	Aug	36,206	\$795,826	\$18.63	\$21.98	84.8%
RTO Only	2015	Sep	53,504	\$1,179,825	\$19.12	\$22.05	86.7%
RTO Only	2015	Total	597,964	\$14,937,090	\$16.99	\$24.98	68.0%
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	Total	1,521,067	\$31,364,311	\$12.71	\$20.62	61.7%

## 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>17</sup> When synchronized reserve resources self schedule or clear the

<sup>17</sup> See the 2011 State of the Market Report for PJM, Volume II, Section 9, "Ancillary Services" at pg. 250.

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>18</sup> Tier 2 resources are obligated to sustain their final output for the shorter of the length of the event or 30 minutes.<sup>19</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 the first nine months of 2015 there were seventeen spinning events of which seven were 10 minutes or longer.

**Table 10–20 Synchronized reserve events greater than 10 minutes, Tier 2 response compliance, RTO Reserve Zone: January through September 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>20</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

<sup>18</sup> See PJM, "Manual 11, Energy & Ancillary Services Market Operations," Rev. 75, April 9, 2015 4.2.12 Non-Performance, p. 77.

<sup>19</sup> See PJM, "Manual 11, Energy & Ancillary Services Market Operations," Rev. 75, April 9, 2015 4.2.11 Non-Performance, p. 77.

<sup>20</sup> See PJM, "Manual 11, Energy & Ancillary Services Market Operations," Rev. 75, April 9, 2015 4.2.12 Non Performance, p. 77.

reserve events of ten minutes or longer that occurred in the first nine months of 2015, 24.5 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>21</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>22</sup>

### History of Synchronized Reserve Events

Synchronized reserve is designed to provide relief for disturbances.<sup>23 24</sup> 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 have been declared for low ACE thus far in 2015. 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. The risk of using synchronized reserves for energy or any non-disturbance 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 a secondary reserve is the appropriate response.

From January 2010 through September 2015, PJM experienced 169 synchronized reserve events (Table 10-21), approximately three events per month. Synchronized reserve events had an average length of 13 minutes.

<sup>21</sup> See PJM “M-28 Operating Agreement Accounting,” Rev. 71, June 1, 2015, p. 45. See also “Manual 11, Energy & Ancillary Services Market Operations,” Rev. 75, April 9, 2015 4.2.12 Non-Performance, p. 77.

<sup>22</sup> Report to PJM Operating Committee, “Synchronized Reserve Event Performance and Penalty Days,” Dec 3, 2014.

<sup>23</sup> 2013 State of the Market Report for PJM, Appendix F – PJM’s DCS Performance, pp 451-452.

<sup>24</sup> See PJM, “Manual 12, Balancing Operations,” Revision 32 (April 6, 2015), 4.1.2 Loading Reserves pp. 36.

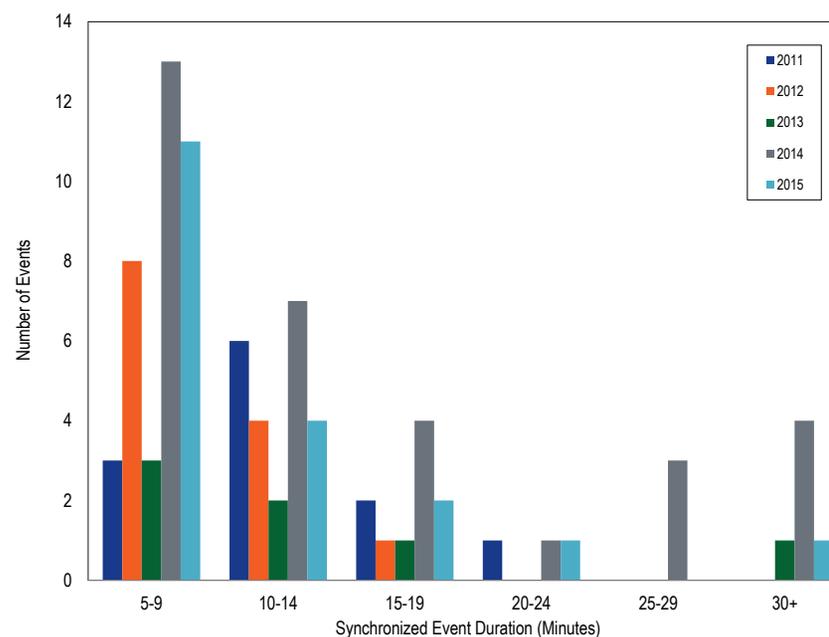
Table 10-21 Synchronized reserve events: January 2010 through September 2015

Effective Time	Region	Duration (Minutes)	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	JAN-22-2013 08:34	RTO	8
MAR-18-2010 11:02	RFC	27	FEB-02-2011 01:21	RFC	5	JAN-06-2012 23:25	RFC	8	JAN-25-2013 15:01	RTO	19
MAR-23-2010 20:14	RFC	13	FEB-08-2011 22:41	Mid-Atlantic	11	JAN-23-2012 15:02	Mid-Atlantic	8	FEB-09-2013 22:55	RTO	10
APR-11-2010 13:12	RFC	9	FEB-09-2011 11:40	Mid-Atlantic	16	MAR-02-2012 19:54	RFC	9	FEB-17-2013 23:10	RTO	13
APR-28-2010 15:09	Mid-Atlantic	8	FEB-13-2011 15:35	Mid-Atlantic	14	MAR-08-2012 17:04	RFC	6	APR-17-2013 01:11	RTO	11
MAY-11-2010 19:57	Mid-Atlantic	9	FEB-24-2011 11:35	Mid-Atlantic	14	MAR-19-2012 10:14	RFC	10	APR-17-2013 20:01	RTO	9
MAY-15-2010 03:03	RFC	6	FEB-25-2011 14:12	RFC	10	APR-16-2012 00:20	Mid-Atlantic	9	MAY-07-2013 17:33	RTO	8
MAY-28-2010 04:06	Mid-Atlantic	5	MAR-30-2011 19:13	RFC	12	APR-16-2012 11:18	RFC	8	JUN-05-2013 18:54	RTO	20
JUN-15-2010 00:46	RFC	34	APR-02-2011 13:13	Mid-Atlantic	11	APR-19-2012 11:54	RFC	16	JUN-08-2013 15:19	RTO	9
JUN-19-2010 23:49	Mid-Atlantic	9	APR-11-2011 00:28	RFC	6	APR-20-2012 11:08	Mid-Atlantic	7	JUN-12-2013 17:35	RTO	10
JUN-24-2010 00:56	RFC	15	APR-16-2011 22:51	RFC	9	JUN-20-2012 13:35	RFC	7	JUN-30-2013 01:22	RTO	10
JUN-27-2010 19:33	Mid-Atlantic	15	APR-21-2011 20:02	Mid-Atlantic	6	JUN-26-2012 17:51	RFC	7	JUL-03-2013 20:40	RTO	13
JUL-07-2010 15:20	RFC	8	APR-27-2011 01:22	RFC	8	JUL-23-2012 21:45	RFC	18	JUL-15-2013 18:43	RTO	29
JUL-16-2010 20:45	Mid-Atlantic	19	MAY-02-2011 00:05	Mid-Atlantic	21	AUG-03-2012 12:44	RFC	10	JUL-28-2013 14:20	RTO	10
AUG-11-2010 19:09	RFC	17	MAY-12-2011 19:39	RFC	9	SEP-08-2012 04:34	RFC	12	SEP-10-2013 19:48	RTO	68
AUG-13-2010 23:19	RFC	6	MAY-26-2011 17:17	Mid-Atlantic	20	SEP-27-2012 17:19	Mid-Atlantic	7	OCT-28-2013 10:44	RTO	33
AUG-16-2010 07:08	RFC	17	MAY-27-2011 12:51	RFC	6	OCT-17-2012 10:48	RTO	10	DEC-01-2013 11:17	RTO	9
AUG-16-2010 19:39	Mid-Atlantic	11	MAY-29-2011 09:04	RFC	7	OCT-23-2012 22:29	RTO	19	DEC-07-2013 19:44	RTO	7
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						

Table 10-21 Synchronized reserve events: January 2010 through September 2015 (continued)

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

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. 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 software evaluates all eligible resources and schedules them economically. 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. The non-synchronized reserve market clearing price is determined at the end of the hour as the highest LOC among all non-synchronized reserve committed units. Examples of equipment that generally qualifies as non-synchronized reserve are run of river hydro, pumped hydro, combustion turbines, combined cycles and diesels.<sup>25</sup> In the first nine months of 2015, an average of 424.0MW of non-synchronized reserve was scheduled hourly out of 1,891.2 eligible

<sup>25</sup> See PJM. "Manual 11, Energy & Ancillary Services Market Operations" Revision 77 (August 27, 2015), p. 80.

MW as part of the primary reserve requirement in the Mid-Atlantic Dominion Subzone.<sup>26</sup> In the first nine months of 2015, an average of 843.1 MW of non-synchronized reserve was scheduled hourly out of 2,663.8 MW eligible MW in the full RTO Zone.

CTs provided 51.5 percent and hydro 44.8 percent of cleared non-synchronized reserve MW in the first six months of 2015. The remaining 3.5 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. The supply of non-synchronized reserves in the RTO Zone was also highly concentrated.

**Table 10-22 Non-synchronized reserve market HHIs: January through September 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	Average	3856	4475

<sup>26</sup> The State of the Market Report for PJM, Q2, 2015 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: January through September 2015**

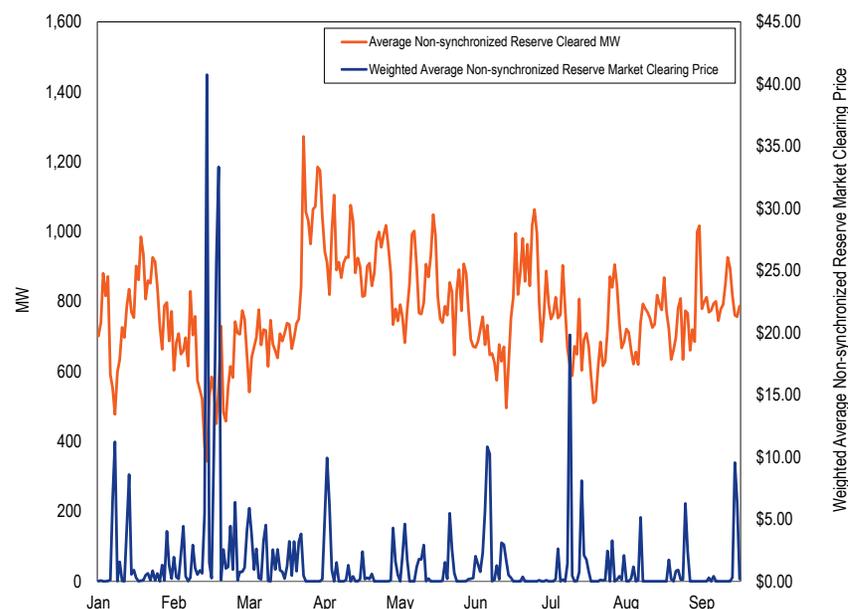
Year	Month	Mid Atlantic Dominion Three Pivotal Supplier Hours	RTO Three Pivotal Supplier Hours
2015	Jan	100.0%	98.0%
2015	Feb	95.0%	98.9%
2015	Mar	100.0%	95.8%
2015	Apr	100.0%	94.7%
2015	May	98.9%	97.9%
2015	Jun	97.2%	93.7%
2015	Jul	96.5%	93.2%
2015	Aug	97.4%	98.8%
2015	Sep	97.1%	95.9%
2015	Average	98.0%	96.3%

## Price

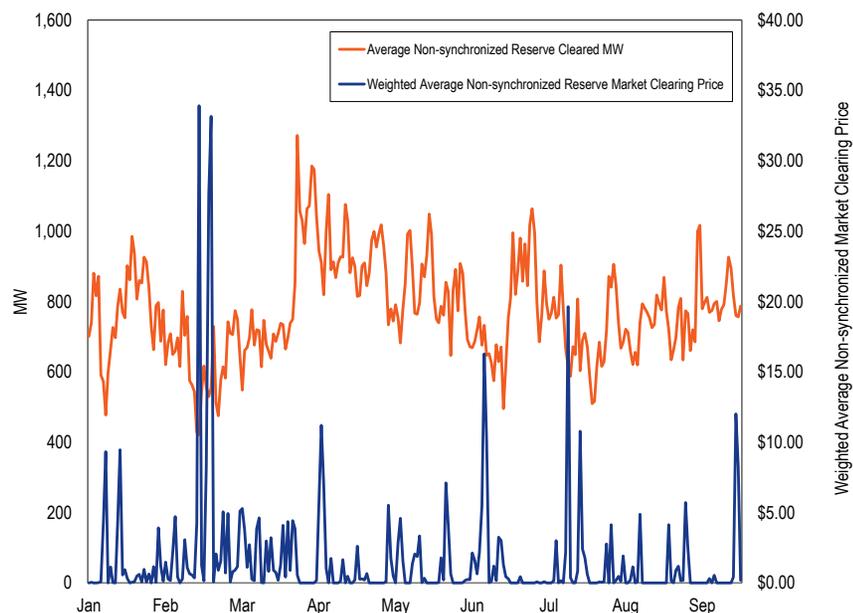
The price of non-synchronized reserve is calculated in real time every five minutes and averaged each hour for the RTO Reserve Zone and the Mid Atlantic Dominion Reserve Subzone. Resources eligible for non-synchronized reserve make no price offer or MW offer.

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 896 (13.7 percent) hours in the first nine months of 2015, at a weighted average price of \$10.87 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 \$1.40 per MW. The maximum 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 873 (13.3 percent) hours in the first nine months of 2015, at a weighted average price of \$10.69. The weighted non-synchronized reserve market clearing price for all hours in the RTO Zone including cleared hours when the price was zero, was \$1.28.

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



**Figure 10-16 Daily average RTO zone non-synchronized reserve market clearing price and MW purchased: January through September 2015**



### Price and Cost

In satisfying the primary reserve requirement there is often a large supply of non-synchronized reserve available at zero cost. When the most economic next MW of primary reserve can be met by backing down a resource from its economic operating point for energy, the non-synchronized reserve market price is equal to the LOC of that resource and is greater than zero.

As a result of changing grid conditions, load forecasts, and unexpected generator performance, prices sometimes do not cover the full cost and final LOC for 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 the first nine months of 2015, the price to cost ratio of the full RTO Zone Non-Synchronized Reserve Market averaged 60.1 percent; the price to cost ratio of the RTO Zone excluding MAD averaged 80.4 percent; the price to cost ratio of the MAD Subzone averaged 45.3 percent.

**Table 10-24 Full RTO, RTO, Mid-Atlantic Subzone non-synchronized reserve MW, credits, price, and cost: January through September 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
Full RTO Zone	2015	Jan	576,746	\$667,159	\$1.16	\$2.13	54.3%
Full RTO Zone	2015	Feb	415,396	\$1,690,416	\$4.07	\$6.77	60.1%
Full RTO Zone	2015	Mar	548,931	\$832,808	\$1.52	\$2.53	60.0%
Full RTO Zone	2015	Apr	688,202	\$618,177	\$0.90	\$1.07	84.2%
Full RTO Zone	2015	May	634,454	\$592,776	\$0.93	\$1.67	55.9%
Full RTO Zone	2015	Jun	526,389	\$711,124	\$1.35	\$1.93	70.0%
Full RTO Zone	2015	Jul	564,010	\$581,313	\$1.03	\$1.88	54.8%
Full RTO Zone	2015	Aug	546,739	\$295,022	\$0.54	\$1.01	53.6%
Full RTO Zone	2015	Sep	563,284	\$494,392	\$0.88	\$1.65	53.3%
Total	2015	Total	5,064,150	\$6,483,185	\$1.28	\$2.13	60.1%
RTO Only	2015	Jan	347,839	\$383,124	\$1.10	\$1.59	69.4%
RTO Only	2015	Feb	244,284	\$858,177	\$3.51	\$4.43	79.3%
RTO Only	2015	Mar	330,187	\$482,694	\$1.46	\$2.39	61.1%
RTO Only	2015	Apr	423,312	\$374,924	\$0.89	\$0.94	94.7%
RTO Only	2015	May	385,646	\$347,019	\$0.90	\$1.04	86.5%
RTO Only	2015	Jun	315,402	\$411,695	\$1.31	\$1.42	92.1%
RTO Only	2015	Jul	330,969	\$334,379	\$1.01	\$1.03	98.4%
RTO Only	2015	Aug	322,143	\$172,392	\$0.54	\$0.58	92.9%
RTO Only	2015	Sep	338,693	\$292,659	\$0.86	\$1.04	83.1%
Total	2015	Total	3,038,474	\$3,657,063	\$1.20	\$1.50	80.4%
MAD Subzone	2015	Jan	228,907	\$284,035	\$1.24	\$2.96	41.9%
MAD Subzone	2015	Feb	171,112	\$832,238	\$4.86	\$10.11	48.1%
MAD Subzone	2015	Mar	218,744	\$350,114	\$1.60	\$2.73	58.6%
MAD Subzone	2015	Apr	264,890	\$243,252	\$0.92	\$1.28	71.9%
MAD Subzone	2015	May	248,808	\$245,757	\$0.99	\$2.65	37.2%
MAD Subzone	2015	Jun	210,987	\$299,429	\$1.42	\$2.70	52.6%
MAD Subzone	2015	Jul	233,041	\$246,934	\$1.06	\$3.09	34.3%
MAD Subzone	2015	Aug	224,596	\$122,629	\$0.55	\$1.62	33.6%
MAD Subzone	2015	Sep	224,591	\$201,733	\$0.90	\$2.56	35.1%
Total	2015	Total	2,025,676	\$2,826,122	\$1.40	\$3.08	45.3%

## Secondary Reserve (DASR)

PJM maintains a day-ahead, offer based market for 30-minute secondary reserve.<sup>27</sup> The Day-Ahead Scheduling Reserves Market (DASR) has no performance obligations. The MMU recommends elimination of the Day-Ahead Scheduling Reserve Market and its replacement with a Real-Time Energy Market for a dispatchable reserve product beyond the 30-minute limit for primary reserves.

## Market Structure

### Supply

On January 1, 2015, PJM began using economic maximum MW minus dispatch MW to calculate hourly DASR MW by resource. Before January 1, 2015, PJM had used emergency maximum MW minus dispatch MW to calculate hourly DASR MW. The amount of DASR available is 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. The change in January 2015 reduced the supply of DASR. In the first nine months of 2015, the average available hourly DASR was 36,719 MW. This is a 13.1 percent reduction from 42,261 MW of the first nine months of 2014. The DASR MW purchased averaged 6,401 MW per hour for all hours in the first nine months of 2015, a small increase from 6,379 MW per hour in the first nine months of 2014. Although there was no shortage of DASR in the market solution, the market does not guarantee the availability of scheduled reserve during real-time hours. Spinning events longer than 30 minutes while rare do occur (September 10, 2013, March 27, 2014, and April 7, 2015) when secondary reserve was needed but not enough was available in real time.

All generation resources are required to offer DASR.<sup>28</sup> In the first nine months of 2015 an average of 6,401 MW was cleared hourly of which 55.7 percent was from CTs, 31.2 percent was from steam, and 11.5 percent was from hydro. Load response resources which are registered in PJM's Economic Load Response

<sup>27</sup> See PJM, "Manual 35, Definitions and Acronyms," Revision 23, (April 11, 2014), p. 89.

<sup>28</sup> See PJM "Manual 11, Energy & Ancillary Services Market Operations" Revision 77, (August 27, 2015) p. 144 at 11.2.3 Day-Ahead Scheduling Reserve Market Rules.

and are dispatchable by PJM are eligible to provide DASR. In the first nine months of 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>29</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, currently 5.93 percent. The DASR requirement is applicable for all hours of the operating day. If the DASR Market does not procure adequate scheduling reserves, PJM is required to schedule additional operating reserves.<sup>30</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>31</sup> The amount of additional DASR MW that may be required is the adjusted fixed demand determined by a seasonal conditional demand factor. The seasonal conditional demand factor is calculated separately for the winter (November through March) and summer (April through October) seasons. The seasonal conditional demand 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 are 3.87 percent for winter, 5.36 percent for summer. PJM Dispatch may also schedule additional Day-Ahead Scheduling Reserves as deemed necessary for conservative operations.<sup>32</sup> PJM has further defined conservative operations<sup>33</sup> to include, potential fuel delivery issues, forest/brush fires, extreme weather events, environmental alerts, solar disturbances, unknown grid operating state. The net result is substantial discretion for PJM to increase the demand for DASR.

<sup>29</sup> See PJM, “Manual 13, Emergency Operations,” Revision 58 (August 1, 2015), p. 11.

<sup>30</sup> PJM uses the terms “supplemental operating reserves” and “scheduling operating reserves” interchangeably.

<sup>31</sup> PJM, “Energy and Reserve Pricing & Interchange Volatility Final Proposal Report,” <<http://www.pjm.com/~media/committees-groups/committees/mre/20141030/20141030-item-04-erpiv-final-proposal-report.ashx>>.

<sup>32</sup> See PJM “Manual 11, Energy & Ancillary Services Market Operations” Revision 77, (August 27, 2015) p. 141 at 11.2.1 Day-Ahead Scheduling Reserve Market Requirement.

<sup>33</sup> See PJM Manual 13, Emergency Operations, Revision 58, (August 1, 2015), p. 45 at 3.2 Conservative Operations

On May 26 and 27, 2015, PJM dispatch invoked this authority to adjust DASR for the first time adding an average of 3,626 MW for 44 hours. The authority was again invoked on June 12 and June 13 adding an average 3,263 MW for 46 hours. On June 22 and June 23, the DASR requirement was again raised, this time by an average of 3,016 MW for 48 consecutive hours. On July 20 and July 21 the DASR requirement was raised an average of 2,302 MW. On July 29 and July 30 the DASR requirement was raised an average of 3,807 MW. On August 17 the DASR requirement was raised to 3,319 MW. On September 1, 2, and 3 the DASR requirement was raised an average of 4,336 MW. On September 8 and 9 the DASR requirement was raised an average of 4,452 MW. The use of adjusted fixed demand (and other conservative operations adjustments) impacts the DASR Market in several significant ways.

## 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 10-25).

**Table 10-25 DASR market three pivotal supplier test results and number of hours with DASRMCP above \$0: January through September, 2015**

Year	Month	Number of Hours When DASRMCP > \$0	Percent of Hours Pivotal
2015	Jan	151	0%
2015	Feb	323	0%
2015	Mar	304	0%
2015	Apr	301	0%
2015	May	330	4%
2015	Jun	347	11%
2015	Jul	495	28%
2015	Aug	483	22%
2015	Sep	533	11%
2015	Average	363	8%

## 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>34</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 direct marginal cost of providing DASR is zero. All offers greater than zero constitute economic withholding. As of September 30, 2015, 14.8 percent of resources offered DASR at levels above \$5 per MW. This is an increase from the 9.7 percent of resources that offered above \$5 in the first nine months of 2014.

## Market Performance

DASR offer prices are calculated as the sum of the direct offer price plus the opportunity cost. For 50.1 percent of hours in the first nine months of 2015, DASR cleared at a price of \$0.00 per MWh (Figure 10-17). This is a significant reduction from the 92.3 percent of hours that the DASR Market cleared at \$0 in the first nine months of 2014. The January 1, 2015, change in the calculated DASR MW<sup>35</sup> from dispatch to emergency maximum to dispatch to economic maximum significantly reduced the amount of DASR offered. In the first nine months of 2015, the weighted average DASR price for all hours when the DASRMCP was above \$0 was \$4.60. The average cleared MW in all hours when the DASRMCP was above \$0 was 6,398 MW. The highest DASR price was \$199.83 on February 19, 2015.

The introduction of adjusted fixed demand created a bifurcated market. The effect of conservative operation's adjustment of the DASR requirement on the market is significant (Table 10-26). In all, there were 367 hours from March 1, 2015, through September 30, 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 PJM dispatch augmented the requirement via adjusted fixed demand the weighted average DASR price was

\$15.27 compared to \$0.69 for hours when 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 normal 5.93 percent of forecast load. 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.

**Table 10-26 DASR Market, regular hours vs. adjusted fixed demand hours: January 1, 2015 through September 30, 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

The implementation of the conservative operations adjustment to the DASR requirement 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 10-27).

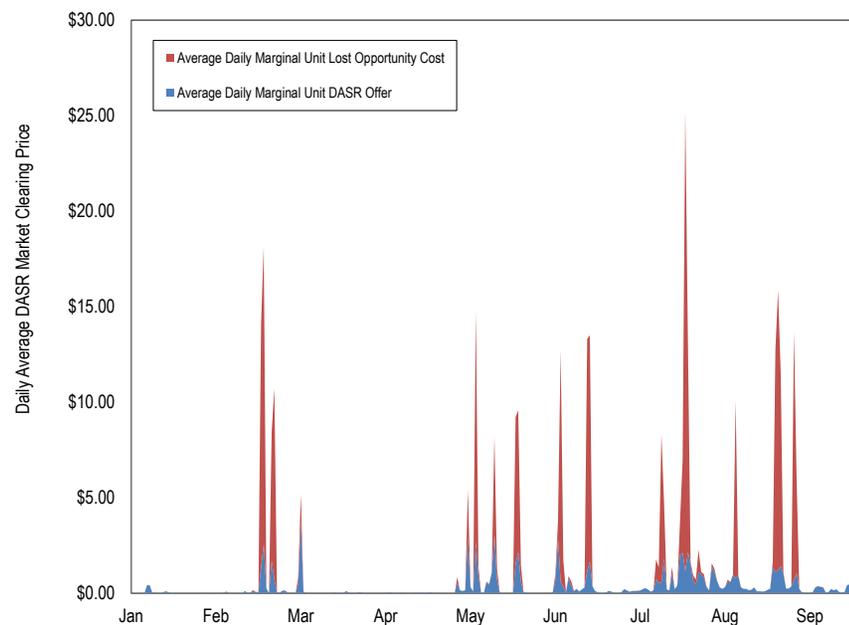
<sup>34</sup> See PJM, "Manual 11, Emergency and Ancillary Services Operations," Revision 75 (April 9, 2015), p. 143.

<sup>35</sup> Market participants do not offer DASR MW amounts. Available DASR MWs is computed at market solution time. It related to the economic maximum and the current economic dispatch.

**Table 10-27 DADR Market all hours of DADR market clearing price greater than \$0**

Year	Month	Number of Hours DADR MCP > \$0	Weighted DADR Market Clearing Price	Average Hourly RT Load	Total PJM Cleared DADR MW	Total PJM Cleared Additional DADR 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	Average	362	\$3.39	101,169	2,002,085	144,429	\$8,274,829

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



When the DADR requirement is increased by PJM dispatch, the reserve requirement 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 DADR requirement. DADR prices increase very suddenly at peak loads as a result of high LOCs. Figure 10-18 shows that when total DADR MW required is at its peak, a higher percentage of MW come from on-line steam and CT units. While CTs have a low DADR related cost, steam units typically incur an LOC when redispatched to provide DADR. The redispatch of steam units to provide DADR has a significant impact on DADR prices.

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

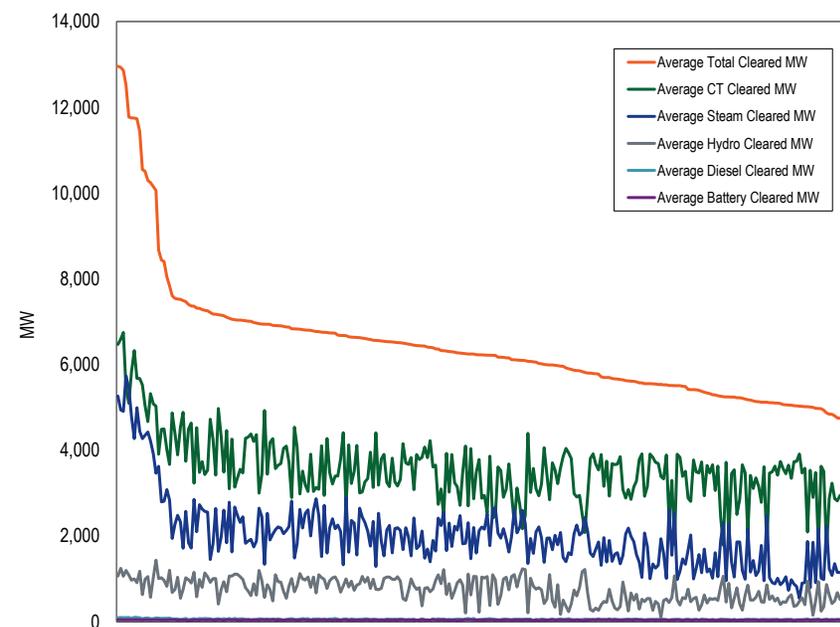


Table 10-27 shows the impact of the 367 hours when additional DADR was scheduled on both the market price and market concentration.

## 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>36</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 meet this objective, the marginal benefit factor function (MBF) defining the substitutability between RegA and RegD must be correctly defined and consistently applied throughout the market construct, from optimization to settlement. That is not the case in PJM's current regulation market design.

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 has begun to degrade the ability of PJM to control ACE in some hours while at the same time increasing the cost of regulation to the PJM market. When the price paid for RegD is above the competitive level defined by an accurate marginal benefit 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 10-28) appearing in PJM's interconnection queue, despite operational evidence that the RegD market, as currently implemented, is saturated.

**Table 10-28 Active storage projects (pumped storage hydro and battery) in the PJM queue system by submitted year from 2012 to 2015**

Year	Number of Storage Projects	Total Capacity (MW)
2012	2	4.6
2013	9	80.4
2014	13	189.0
2015	46	384.1

The MBF related issues with the Regulation Market have been raised in the PJM stakeholder process. The PJM stakeholders recently approved an interim, partial fix to the RegD over procurement problem which will be implemented in December. The interim fix is 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 all of the 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 a senior task force that reports to the Market and Reliability Committee (MRC).

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, but with limited ramp rates. RegD is PJM's fast-oscillation regulation signal and is designed for resources with the ability to quickly adjust energy output, but with limited ability to sustain energy output for periods of time. Resources must qualify to follow the RegA and RegD signals. Resources must qualify for one signal or both signals, but will be assigned by the market clearing engine to follow only one signal within a given market hour. 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 (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

<sup>36</sup> See the 2012 State of the Market Report for PJM, Volume II, Section 9, "Ancillary Services," p. 271.

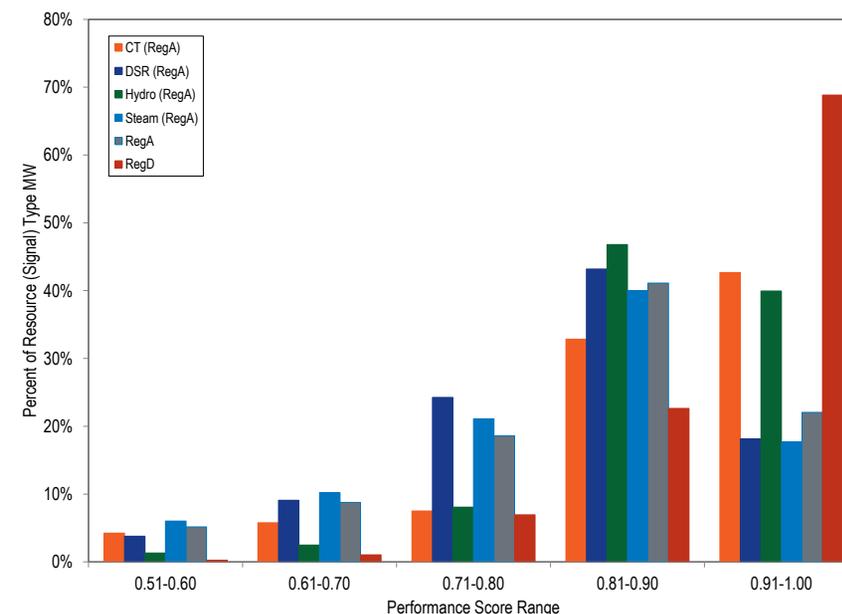
common entity. The regulation signals (RegA or RegD) are sent every two seconds to the fleet local control centers or, at the option of fleet owners, to their individual resources. Fleet local control centers report to PJM every two seconds the fleet response to the RegA and RegD signals.

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>37</sup>

Figure 10-19 shows the average performance score by resource type and signal followed for the first nine months of 2015. In this figure, the MW used are unadjusted regulation capability MW and the performance score is the actual within hour (as opposed to the historic 100-hour moving average) performance score of the regulation resource.<sup>38</sup> Each category (color bar) adds up to 100 percent so that the full performance score distribution for each resource (or signal) type is shown. RegD resources tend to have higher performance scores. As the figure shows, 68.8 percent of RegD resources have average performance scores within the 0.91-1.00 range, whereas only 22.0 percent of RegA resources have average performance scores within that range.

Figure 10-19 Hourly average performance score by unit type and regulation signal type: January through September 2015



Performance scores measure the regulating response of individual resources, regardless of whether they were originally assigned or replaced (with notification) by a fleet owner. 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

<sup>37</sup> PJM "Manual 12: Balancing Operations" Rev. 31 (August 21, 2014); 4.5.6, p 52.  
<sup>38</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.

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 resources into a common unit of measure via a marginal benefit factor (MBF).<sup>39</sup> The marginal benefit factor is a measure of the substitutability of RegD resources for RegA resources in satisfying the regulation requirement. The marginal benefit factor and the performance score of the resource are used to convert offers of RegA and RegD resource regulation capability MW into comparable units, termed effective MW and dollars per effective MW.

Resource specific benefit factors are defined for each resource separately while the market marginal benefit factor is the marginal benefit factor of the last RegD resource cleared in the market.

Effective MW, supplied from RegA or RegD resources, are defined in terms of effective RegA MW. For purposes of calculating total effective MW contribution towards the total regulation requirement, cleared regulation MW are converted to effective MW by multiplying offered capability MW by the product of the resource specific benefit factor and performance score. This approach undercounts effective MW. The assigned benefit factor of a RegA resource is always 1.0.

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 MW RegD resource with an total offer price (the sum of the capability and performance offers) 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, in terms of dollars per effective MW, would be \$4 per effective MW (\$2/MW offer divided by the 0.5 effective MW).

<sup>39</sup> See the 2013 State of the Market Report for PJM, Volume II, Section 10, "Issues Related to the Marginal Benefit Factor," pp. 294-8.

## 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. The effectiveness and efficiency of the regulation market depends on the marginal benefit factor function being defined by the actual tradeoff between RegA and RegD MW in providing regulation. If the marginal benefit factor function is incorrectly defined, the resulting combinations of RegA and RegD would not represent the least cost solution.

The absence of the marginal benefit factor from PJM's settlement process is the result of 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 one 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 RegD to RegA mileage ratio in the performance credit paid to RegD resources, effective November 1, 2013, and retroactively to October 1, 2012.<sup>40</sup>

The result of the current 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 ultimate settlement for RegD. Instead, PJM uses a mileage ratio (RegD/RegA) to adjust the performance component (RMPCP) of price paid to RegD resources.

Resources are paid RMCP credits (the sum of RMCCP credits and RMPCP 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.

RMCCP (capability related) credits are calculated as MW of regulation capability times performance score times RMCCP (the regulation capability price per effective MW).

<sup>40</sup> 145 FERC ¶ 61,011 (2013).

Figure 10-20 compares the daily average marginal benefit factor and the mileage ratio.

Figure 10-20 Daily average marginal benefit factor and mileage ratio: 2015

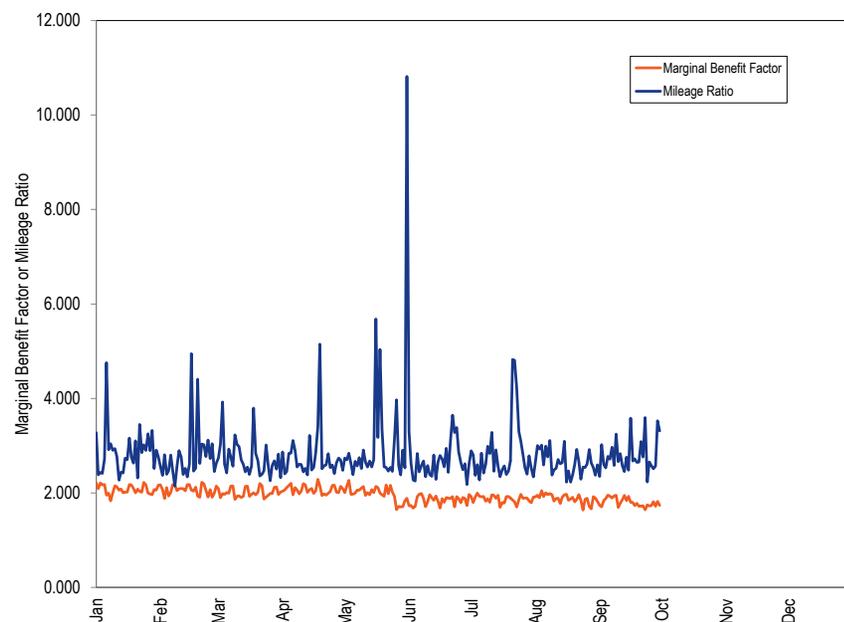


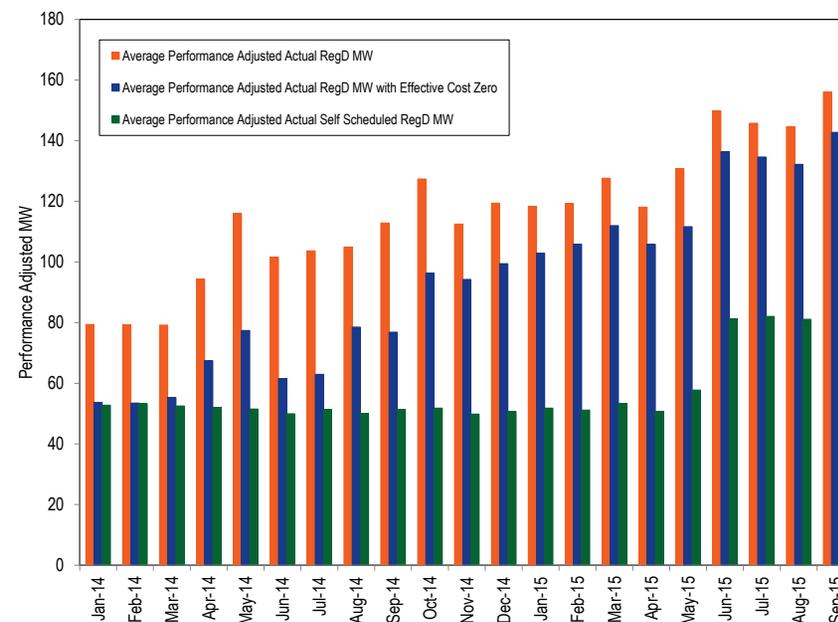
Figure 10-21 shows, by month, both an increasing amount and increasing proportion of cleared RegD MW with an effective price of \$0.00. The figure also shows a corresponding increase in the total RegD MW clearing the market in the period between January 2014 and September 2015.

As shown in Figure 10-21, self-scheduling or bidding RegD MW at zero has increased.<sup>41</sup> Between the end of the second quarter, June 30, 2015, and the end of the third quarter, September 30, 2015, there was a 3.0 percent increase in the amount of performance adjusted actual RegD MW with an effective cost of \$0.00, and a 7.2 percent increase in the amount of performance adjusted

<sup>41</sup> See MMU's Regulation Market Review presentation from the May 5, 2015 Operating Committee See <<http://www.pjm.com/committees-and-groups/committees/oc.aspx>>, accessed May 4, 2015

actual RegD that is self scheduled. This is reflected in the average decrease of MBF seen in Figure 10-20 after June 1, 2015, due to the incorrect method of assigning benefit factors to entire price blocks of offered MW by PJM.

Figure 10-21 Average cleared RegD MW and average cleared RegD with an effective price of \$0.00 by month: January 2014 through September 2015



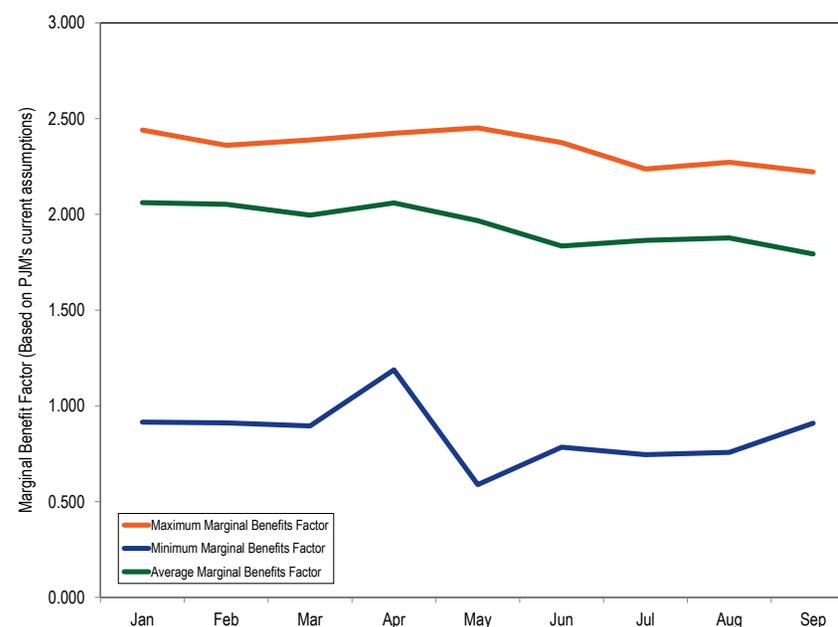
The current settlement process does not result in RegA and RegD resources being paid a uniform amount per effective MW. Only RegA resources are paid on the basis of dollars per effective MW of RegA. RegD resources are not paid in terms of dollars per effective MW of RegA because the marginal benefit factor is not used. When the marginal benefit factor is above one, this means that RegD resources are generally underpaid on a per effective MW basis relative to RegA resources. When the marginal benefit factor is less than one, this means that RegD resources are generally overpaid on a per effective MW basis relative to RegA resources.

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 of the twelve five-minute interval within a market hour, based on the marginal offer (including lost opportunity costs) in each of interval. The five-minute RMCP is the sum of the performance clearing price (RMPCP) and the capability clearing price (RMCCP). The performance clearing price (\$/effective MW) is equal to the most expensive performance offer (RMPCP) cleared 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>42</sup> The current market design does not send the correct price signal to the RegD resources as the price realized by RegD resources in settlement is inconsistent with the effective MW based prices used in the optimization. This is due to an inconsistent application of the marginal benefit factor.

Figure 10-22 shows, for the period from January 1, 2015; through September 30, 2015; the maximum, minimum and average PJM calculated marginal benefit factor, based on PJM's incorrect marginal benefit factor curve, by month.

**Figure 10-22 Maximum, minimum, and average PJM calculated marginal benefit factor by month: January through September of 2015**



The MMU recommends that the marginal benefit factor function used in the Regulation Market be reviewed as part of incorporating a consistent application of the marginal benefit factor in the Regulation Market and that PJM correct the calculation of effective MW attributed to RegD MW in the regulation market solution.<sup>43</sup>

### The Effective MW of Regulation Purchased Are Understated

The MMU has determined that the current market optimization/market solution understates the amount of effective MW provided by RegD. Rather than calculating the total effective MW contribution of RegD MW on the basis of the area under the marginal benefit function curve, the current regulation

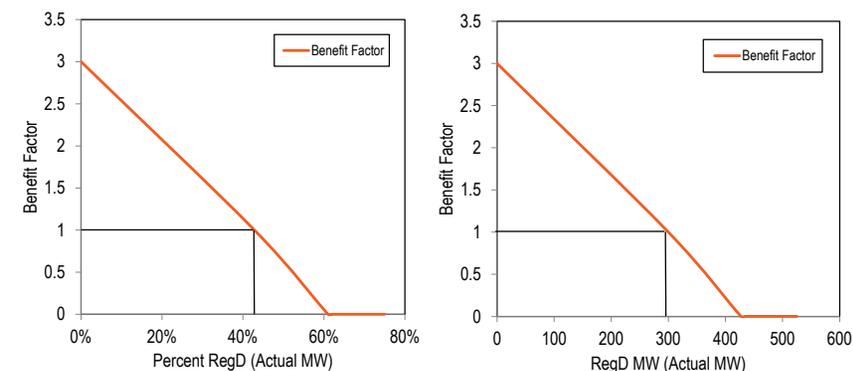
<sup>42</sup> This is due to the fact that RegA resources performance adjusted MW are their effective MW.

<sup>43</sup> See "Fast Response Regulation (RegD) Resources Operational Impact Problem Statement," and the MMU's "Regulation Market Review" presentation which were presented at the May 5, 2015 Operating Committee See <<http://www.pjm.com/committees-and-groups/committees/oc.aspx>>, accessed May 4, 2015.

market optimization assigns all RegD resources with the same effective price the lowest marginal benefit factor associated with last RegD MW purchased at that price. This means that the MBF associated with the last MW of a cleared unit is assigned to every MW of that unit for purposes of calculating effective MW from that unit. The result of this approach is that 100 MW of RegD (performance adjusted) provided by a single unit (a single unit's MW are associated with a single offer price) will provide fewer effective MW than 100 MW (performance adjusted) provided by two separate 50 MW units. Similarly, all of the MW associated with multiple units with the same effective price (for example a price of zero) are assigned the MBF of the last MW of the last unit of that block of resources with the same effective price. This results in an undercounting of effective MW from RegD resources cleared at an effective price of zero or self scheduled. Assuming the correct definition and implementation of the MBF function in the market, the flawed approach to calculating effective MW has resulted in the purchase of more than the efficient level of regulation MW to meet PJM's defined regulation requirement.

Figure 10-23 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 10-23 shows that the 300 MW of cleared RegD makes up 42.9 percent of total cleared actual MW and resulting marginal benefit factor of 1.0.

**Figure 10-23 Example marginal benefit line in percent RegD and RegD MW terms**

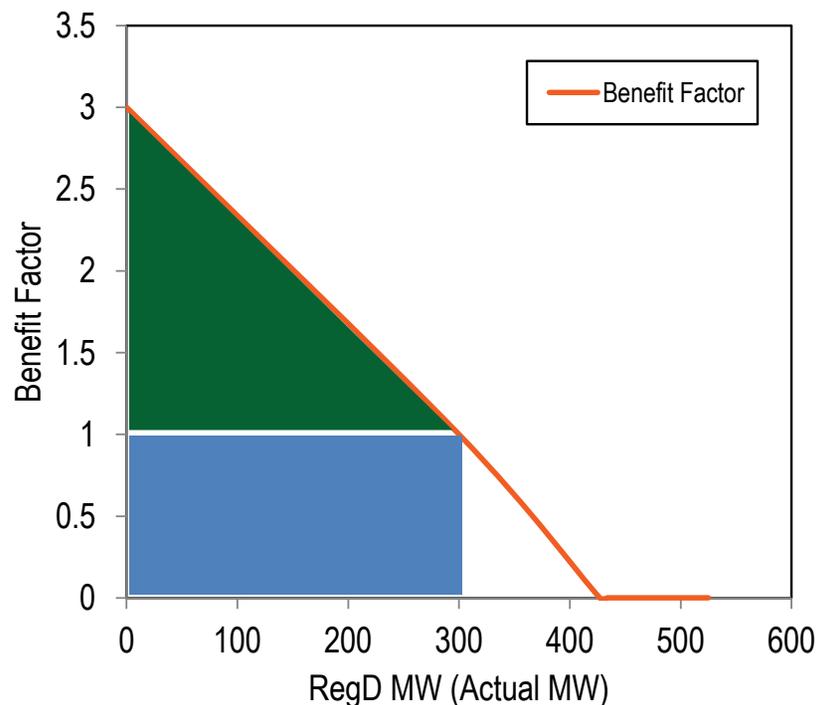


Using PJM's method for the calculation of effective MW from RegD resources, all RegD resources are assigned the lowest marginal benefit factor associated with the last RegD MW purchased. In this example, all 300 MW have an MBF of 1.0 for determining the total effective MW provided by RegD resources. PJM calculates total effective MW from RegD resources to be 300 ( $300\text{MW} \times 1.0 = 300$  effective MW).

In Figure 10-24, PJM's calculation of total effective MW from RegD is represented by the area of the blue rectangle which is 400 effective MW.

PJM's current method is flawed. By assigning a single benefit value to every MW, PJM's methodology undervalues the amount of effective MW provided by RegD MW (assuming the benefit curve is properly defined). 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 10-24. 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 10-24 Illustration of correct method for calculating effective MW



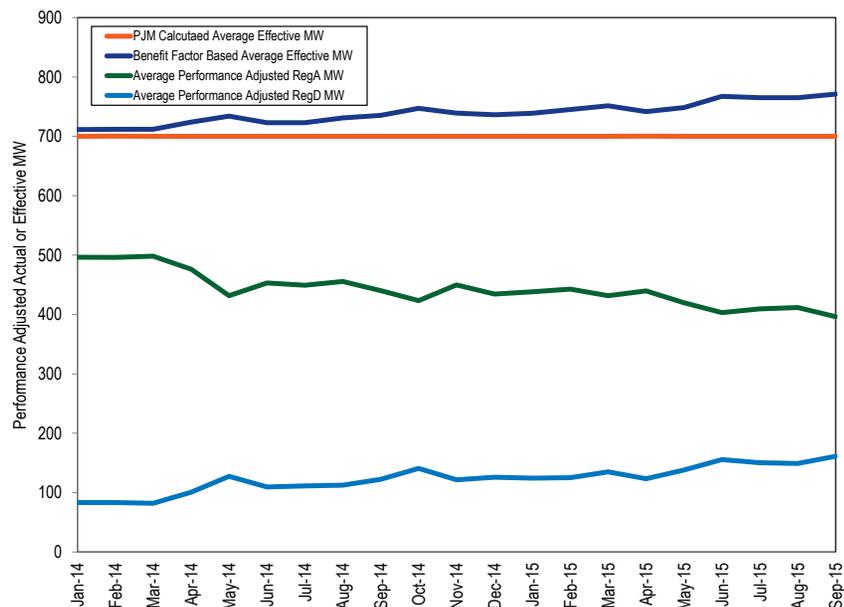
The MRC approved a partial solution to the issue caused by zero priced/self-scheduled resources being treated as a single resource for purposes of assigning an MBF and calculating effective MW. PJM's approved partial solution identifies the individual units within the price block and assigns a unit specific MBF to each unit based on its performance score based rank in the supply stack. This partial fix is due to be implemented in December of this year. This approach will reduce but not eliminate the undercounting issues caused by the failure to calculate effective MW from RegD as the area under the MBF curve for a given amount of cleared RegD resources.

Figure 10-25 shows the average monthly peak total effective MW as calculated by PJM's current incorrect effective MW accounting method and as calculated

by a correctly applied marginal benefit factor for the January 2014 through September 2015 period. The portion of this over purchase associated with price block assignment of MBF (assignment of the same MBF to all RegD MW clearing at a zero effective price) will be eliminated with the interim fix due to go into effect in December 2015. This partial fix to the undercounting issue adds an additional term to the Adjusted Total Cost formula, which allows RegD resources offered at \$0.00 to be ranked for purposes of assigning unit specific MBFs based on their performance score. This additional term is only used for the purposes of ranking the offers, and does not get factored into the actual Adjusted Total Cost value.<sup>44</sup> The figure also shows the monthly average actual (performance adjusted) RegA MW and RegD 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 10-21, this has been caused by an increasing proportion of RegD MW supply with an effective price of \$0.00 in the PJM market.

<sup>44</sup> See "Proposed Revision to the Adjusted Total Cost Formulation and the Benefits Factor Curve" PJM Presentation to the Regulation Performance Impacts Operating Committee (August 17, 2015) <<http://www.pjm.com/~media/committees-groups/committees/oc/20150817-rpi/20150817-item-02-03-proposed-revision-to-the-adjusted-total-cost-formulation.ashx>>.

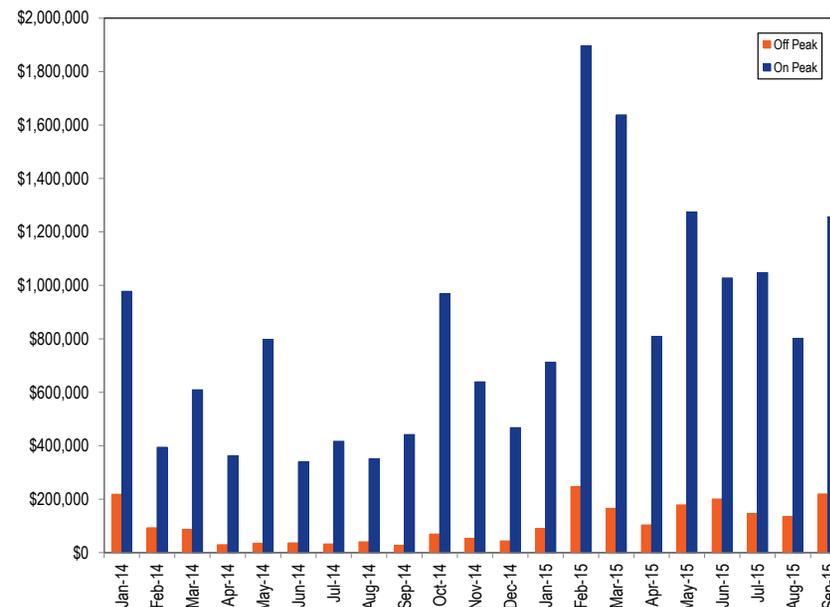
Figure 10-25 Average monthly peak effective MW: PJM market calculated versus benefit factor based



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

Figure 10-26 shows the cost of the excess effective MW cleared by month, peak and off peak, from January 1, 2014 through September 30, 2015 caused by PJM’s current incorrect approach 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. In the first nine months of 2015, the total cost of excess effective RegD MW during on peak and off peak hours was \$10.5 million and \$1.5 million.

Figure 10-26 Cost of excess effective MW cleared by month, peak and off peak: January 1, 2014 through September 30, 2015



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

PJM has 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. The issues also indicate that the marginal benefit factor function used by PJM is incorrectly describing the operational relationship between RegA and RegD. PJM’s current marginal benefit factor function is, at least in some hours, overvaluing RegD as a substitute for RegA in the optimization.

<sup>45</sup> "Fast Response Regulation (RegD) Resources Operational Impact Problem Statement," Presented at the May 5, 2015 Operating Committee. See <<http://www.pjm.com/committees-and-groups/committees/oc.aspx>>, accessed May 4, 2015.

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 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. This issue, combined with an increasing proportion of RegD offering at an effective price of zero, is directly contributing to the problem of too much RegD clearing relative to RegA MW in the market.

Table 10-29 illustrates the relationship between the MBF function's assumed proportion of performance adjusted RegD MW relative to total cleared performance adjusted regulation MW (RegD MW + RegA MW) and the proportion of RegD MW that would result if the listed number of RegD MW 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 only need 294.82 MW of RegA to meet the 700 MW requirement. The resulting proportion of RegD to total regulation cleared would be 37 percent, rather than the 25 percent that was assumed by the MBF function.

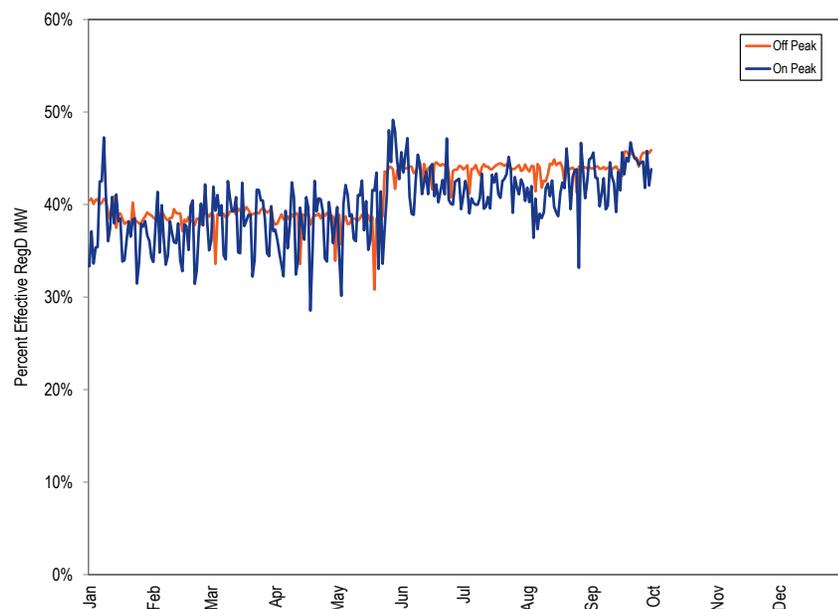
**Table 10-29 MBF assumed RegD proportions versus market solution realized RegD proportions<sup>46</sup>**

RegD Percent of 700 MW	RegD MW (Performance Adjusted)	MBF	Effective MW from RegD MW	Residual A (700 MW Target - Effective MW from RegD)	RegD/(RegA+RegD)
5%	35	2.67	97.41	602.59	5%
10%	70	2.43	186.63	513.37	12%
15%	105	2.20	267.67	432.33	20%
20%	140	1.96	340.52	359.48	28%
25%	175	1.73	405.18	294.82	37%
30%	210	1.50	461.67	238.33	47%
35%	245	1.26	509.96	190.04	56%
40%	280	1.03	550.07	149.93	65%
45%	315	0.80	582.00	118.00	73%
50%	350	0.56	605.74	94.26	79%
55%	385	0.33	621.30	78.70	83%
60%	420	0.09	628.67	71.33	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 10-27.

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

Figure 10-27 Daily average percent of RegD effective MW by peak: January through September 2015



The effect of the incorrect accounting of effective MW is 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 10-21). This guarantees that an increasing proportion of RegD MW in the market appears as the cheapest source of incremental effective regulation MW.

## Market Structure

### Supply

Table 10-30 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 the first nine months of 2015. In this table, 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. But a resource can (and several resources currently do) 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.

Table 10-30 PJM regulation capability, daily offer and hourly eligible: January through September 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	8,441.4	8,422.5	18.9	8,300.1	455.4
Offered MW	3,571.8	3,564.3	7.5	3,386.9	184.9
Actual eligible MW	1,147.7	1,142.0	5.7	923.2	224.5
Effective eligible MW	885.9	878.6	7.3	612.3	273.5
Actual cleared MW	641.0	637.4	3.6	493.8	147.2
Effective cleared MW	663.7	657.3	6.3	397.9	265.8

<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.

<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.

Table 10-31 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 10-31 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 3,769,729.8 MW in the first nine months of 2014 to 3,675,518.3 MW in the first nine months of 2015. The average proportion of regulation provided by battery units had the largest increase, providing 15.5 percent of regulation in the first nine months of 2014 and 23.8 percent of regulation in the first nine months of 2015. Natural gas units had the largest decrease in average proportion of regulation provided, decreasing from 53.7 percent in the first nine months of 2014, to 43.0 percent in the first three months of 2015. The total regulation credits in the first nine months of 2015 were \$149,160,801, down from \$216,024,609 in the first nine months of 2014. The decrease in revenues was a result of the high regulation market clearing prices and out of market opportunity cost credits in January 2014.

**Table 10-31 PJM regulation by source in the first nine months of 2014 and 2015**

Source	2014 (Jan-Sep)				2015 (Jan-Sep)			
	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	61	583,742.0	15.5%	\$24,221,392	96	874,798.9	23.8%	\$27,356,213
Biomass	9	10,523.7	0.3%	\$535,432	9	23,526.0	0.6%	\$752,592
Coal	787	411,056.6	10.9%	\$38,819,255	586	493,527.7	13.4%	\$29,350,285
Hydro	280	717,104.6	19.0%	\$50,272,925	256	678,259.1	18.5%	\$31,470,963
Light Oil	13	742.7	0.0%	\$597,921	0	0.0	0.0%	\$0
Natural Gas	632	2,024,178.7	53.7%	\$100,445,341	766	1,581,452.8	43.0%	\$59,429,740
DR	163	22,381.5	0.6%	\$1,132,343	157	23,953.7	0.7%	\$801,008
Total	1,945	3,769,729.8	100.0%	\$216,024,609	1,870	3,675,518.3	100.0%	\$149,160,801

The supply of regulation can be affected by regulating units retiring from service. Table 10-32 shows what the impact on the Regulation Market would be if all units retire that are requesting retirement through the end of 2015. These retirements will reduce the supply of regulation in PJM by less than one

percent. The MW in Table 10-32 have been adjusted by the actual within hour performance score.

**Table 10-32 Impact on PJM Regulation Market of currently regulating units scheduled to retire through 2015**

Current Regulation Units, 2015	Adjusted Settled MW, 2015	Units Scheduled to Retire Through 2015	Adjusted Settled MW of Units Scheduled to Retire Through 2015	Percent of Regulation MW to Retire Through 2015
291	4,169,932.4	19	11,477.1	0.3%

Although the marginal benefit factor for slow (RegA) resources is 1.0, the effective MW of RegA following resources was lower than the offered MW in the first nine months of 2015, because the average performance score was less than 1.00 For the first nine months of 2015, the MW weighted average RegA performance score was 0.81 and there were 284 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 the first nine months of 2015, the marginal benefit factor, based on PJM's current assumed marginal benefit factor curve, for cleared RegD following resources ranged from 0.589 to 2.452 with an average over all hours of 1.945. In the first nine months of 2015, the MW weighted average RegD resource performance score was 0.91 and there were 48 resources following the RegD signal.

The cost of each unit is calculated using its offer price, 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 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 10-40). In the first nine months of 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 the first nine months of 2015 was \$35.56/MW. The regulation cost for the first nine months of 2015 was \$43.00/MW. The ratio of price to cost is higher (82.7 percent) than in the same period in 2014 (82.4 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 1, 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 the first nine months of 2015.

Table 10-33 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.

PJM's performance as measured by CPS1 and BAAL standards is shown in Figure 10-28 for every month from January 2011 through September 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.

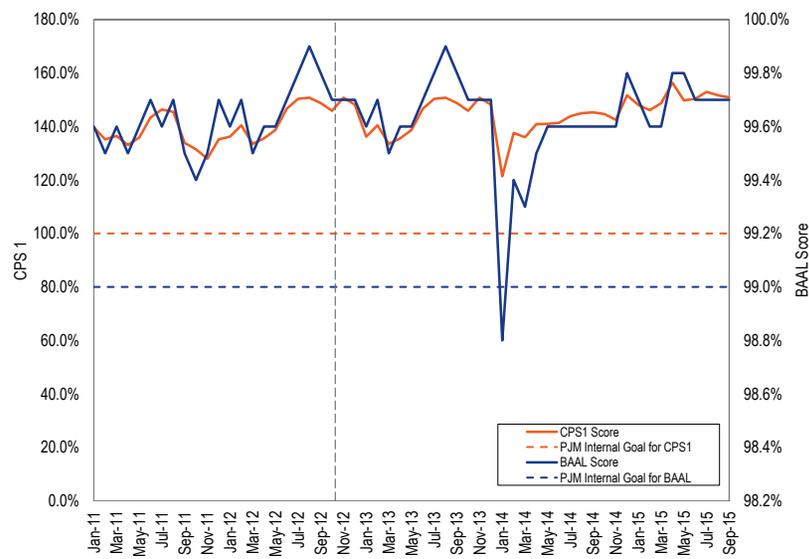
<sup>50</sup> See the 2014 State of the Market Report for PJM, Appendix F: Ancillary Services.

Table 10-33 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

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 10-28 PJM monthly CPS1 and BAAL performance: January 2011 through September 2015



## Market Concentration

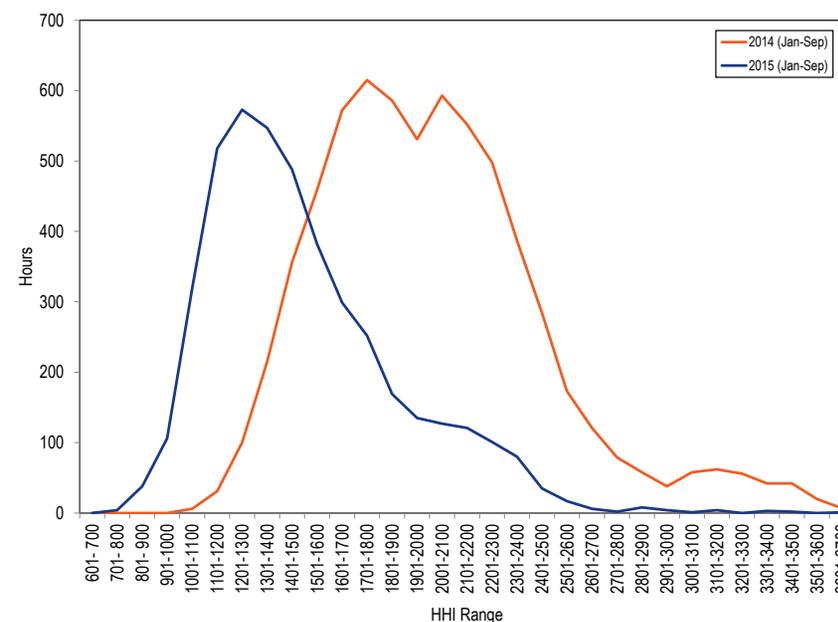
Table 10-34 shows Herfindahl-Hirschman Index (HHI) results for January through September 2014 and 2015, based on market shares of effective MW, defined as regulation capability MW adjusted by performance score and resource-specific benefit factor, consistent with the metrics used to clear the regulation market. The weighted average HHI of 1,480 is classified as moderately concentrated and is lower than the HHI for the same period in 2014 of 1,991. For the first nine months of 2015, the weighted average HHI of RegA resources was 2,529 (highly concentrated, but lower than the January through September 2014 value of 2,635 and the weighted average HHI of RegD resources was 2,865 (highly concentrated, but lower than the January through September 2014 value of 5,150). 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 different owners have large market shares in the RegA and RegD markets.

**Table 10-34 PJM cleared regulation HHI: 2014 and 2015**

Year (Jan-Sep)	Minimum HHI	Weighted Average HHI	Maximum HHI
2014	1,034	1,991	3,943
2015	717	1,480	3,658

Figure 10-29 compares the frequency distribution of HHI for January through September 2014 and 2015. The HHI values are calculated based on effective MW cleared.

**Figure 10-29 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 10-35 includes a monthly summary of three pivotal supplier results. In the first nine months of 2015, 97.9 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 10-31). The MMU concludes from these results that the PJM Regulation Market in the first nine months of 2015 was characterized by structural market power in 97.9 percent of hours.

**Table 10-35 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%	
Nov	88.6%	98.9%	
Dec	94.9%	98.1%	
Average	90.0%	97.5%	97.9%

## Market Conduct

### Offers

Resources seeking to regulate must qualify to follow a regulation signal by passing a test for that signal with at least a 75 percent performance score. The regulating resource must be able to supply at least 0.1 MW of regulation and 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 non-steady state. For batteries and flywheels only,

there is zero cost for lower efficiency. Instead, on April 1, 2015, PJM added an Energy Storage Loss component for batteries and flywheels only as a cost component of regulation performance offers to the eMkt Regulation Offers screen reflecting 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, if already inputted, may change the following: 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 10-37).<sup>53</sup> Figure 10-30 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 43.6 percent during on peak and 60.1 percent during off peak hours in the first nine months of 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.

Figure 10-30 Off peak and on peak regulation levels: 2014 through 2015

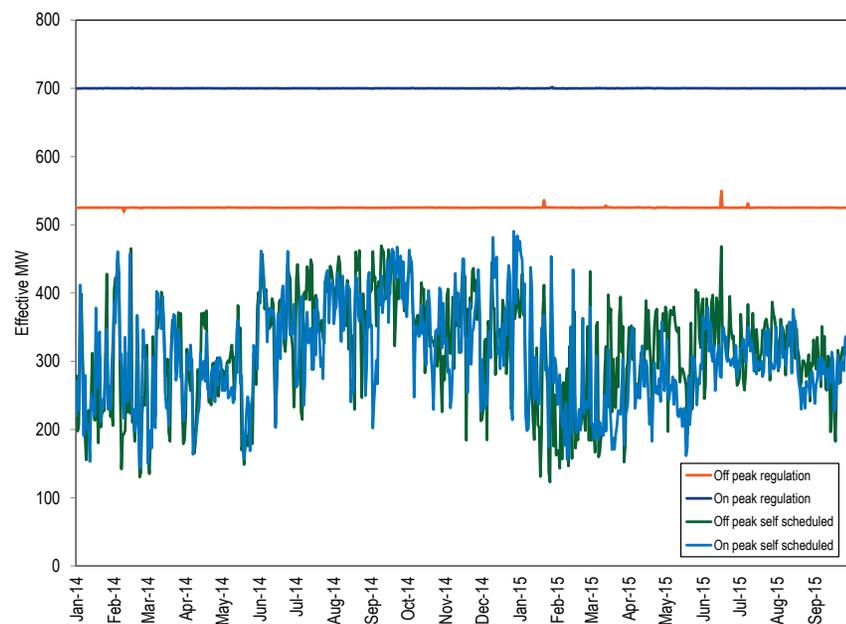


Table 10-36 shows how RegD resources have impacted the Regulation Market. RegD resources are both a growing proportion of the market (10.9 percent at the start of the Performance Based Regulation Market design in October 2012 versus 43.6 percent in September 2015) and a growing proportion of resources that self schedule (10.1 percent in October 2012 versus 23.4 percent in September 2015). This has resulted in an increase in the proportion of the regulation requirement that is self scheduled.

Table 10-36 RegD self scheduled regulation by month, October 2012 through September 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%
Average		104.9	175.9	298.0	676.2	44.3%	15.7%	26.3%

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 the first nine months of 2015, 54.7 percent was purchased in the PJM market, 39.7 percent was self-scheduled, and 5.6 percent was purchased bilaterally (Table 10-37). Table 10-38 shows the total regulation by market regulation, self-scheduled regulation, and bilateral regulation for the first nine months of each year. These tables are based on settled (purchased) MW, but are not adjusted for either performance score or benefit factor to maintain consistency with years 2010 through 2012 when these constructs were not part of the Regulation Market.

**Table 10-37 Regulation sources: spot market, self-scheduled, bilateral purchases: 2014 and 2015**

Year	Month	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)
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

**Table 10-38 Regulation sources by year: 2011 through 2015**

Year (Jan-Sep)	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	5,033,232.8	84.2%	784,300.8	13.1%	157,659.0	2.6%	5,975,192.6
2012	5,110,747.9	79.7%	1,122,671.9	17.5%	180,121.0	2.8%	6,413,540.8
2013	2,528,830.3	60.8%	1,478,608.5	35.5%	152,328.5	3.7%	4,159,767.3
2014	1,835,267.1	51.8%	1,543,265.7	43.5%	166,857.0	4.7%	3,545,389.8
2015	1,896,238.3	54.7%	1,380,004.7	39.8%	193,529.1	5.6%	3,469,772.1

In the first nine months of 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 January through September 2015 was \$35.55 per MW. This is the average price per unadjusted capability MW. This is a 29.2 percent decrease from the weighted average RMCP of \$50.18/MW in the same period of 2014. The decrease in regulation price resulted from very high prices in the first nine months of 2014, primarily January. Figure 10-31 shows the daily 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.

**Figure 10-31 PJM regulation market daily weighted average market-clearing price, marginal unit opportunity cost and offer price (Dollars per MW): 2015**

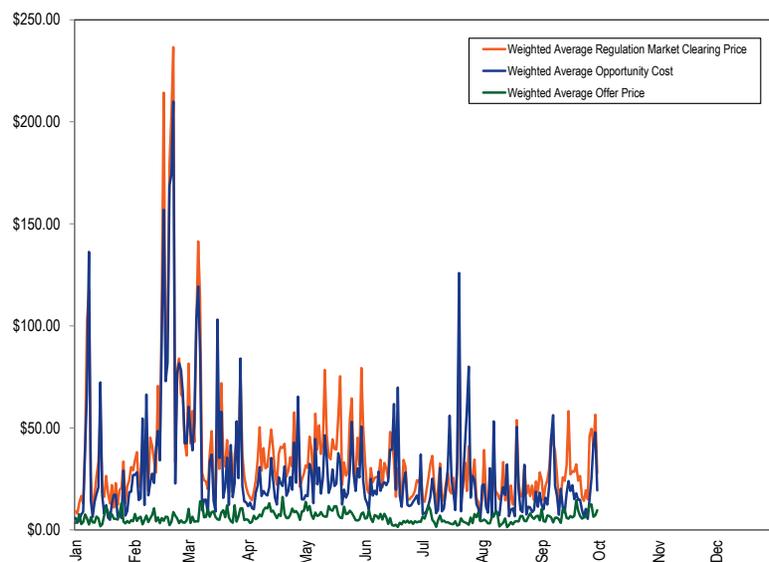


Table 10-39 shows monthly average regulation market clearing price, average marginal unit offer price, and average marginal unit LOC on an unadjusted capability MW basis.

**Table 10-39 PJM regulation market monthly weighted average market-clearing price, marginal unit opportunity cost and offer price (Dollars per MW): 2015**

Month	Weighted Average Regulation Market Clearing Price	Weighted Average Regulation Marginal Unit Offer	Weighted Average Regulation Marginal Unit LOC
Jan	\$27.13	\$5.60	\$22.67
Feb	\$73.24	\$5.40	\$57.07
Mar	\$45.79	\$7.09	\$41.78
Apr	\$32.77	\$7.77	\$21.60
May	\$43.12	\$8.24	\$27.37
Jun	\$25.94	\$4.50	\$25.96
Jul	\$24.40	\$4.79	\$26.92
Aug	\$20.85	\$4.66	\$17.83
Sep	\$29.71	\$7.20	\$19.83

Total scheduled regulation MW, total regulation charges, regulation price and regulation cost are shown in Table 10-40. Total scheduled regulation is based on settled (unadjusted capability) MW. The total of all regulation charges for the first nine months of 2015 was \$149.2 million, compared to \$216.0 million for the same time period in 2014.

**Table 10-40 Total regulation charges: January 2014 through September 2015**

Year	Month	Scheduled Regulation (MW)	Total Regulation Charges (\$)	Weighted Average Regulation Market Price (\$/MW)	Cost of Regulation (\$/MW)	Price as Percent 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%
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%

The capability, performance, and opportunity cost components of the cost of regulation are shown in Table 10-41. Total scheduled regulation is based on settled (unadjusted capability) MW.

**Table 10-41 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

Table 10-42 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 the first nine months of 2015 was 82.7 percent, a 0.3 percent increase from 82.4 percent in the same period of 2014.

**Table 10-42 Comparison of average price and cost for PJM Regulation, January through March, 2009 through 2015**

Year (Jan-Sep)	Weighted Regulation Market Price	Weighted Regulation Market Cost	Regulation Price as Percent Cost
2011	\$17.04	\$32.70	52.1%
2012	\$15.16	\$21.07	71.9%
2013	\$33.29	\$38.49	86.5%
2014	\$50.18	\$60.93	82.4%
2015	\$35.56	\$43.00	82.7%

## 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>55</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. (The selection process was completed in the first half of 2014.) PJM and the MMU coordinated closely during the selection process.

PJM issued two incremental RFPs in 2014. On April 11, 2014, PJM sought additional black start in the AEP Zone and one proposal was selected. On November 24, 2014, PJM sought additional black start in northeastern Ohio and western Pennsylvania but no proposals have been selected yet.

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 is 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 the first nine months of 2015, total black start charges were \$39.0 million, a -\$6.10 million (13.5 percent) decrease from the same period of 2014 level of \$45.1 million. Operating reserve charges for black start service declined from \$26.66 million in 2014 to \$5.06 million in 2015. Table 10-43 shows total revenue requirement charges from 2010 through 2015. (Prior to December 2012, PJM did not define a black start operating reserve category.)

**Table 10-43 Black start revenue requirement charges: January through September, 2010 through 2015**

Year (Jan-Sep)	Revenue Requirement Charges
2010	\$8,527,000
2011	\$9,996,898
2012	\$13,288,491
2013	\$15,728,447
2014	\$18,395,320
2015	\$33,890,859

Black start zonal charges in the first nine months of 2015 ranged from \$0.04 per MW-day in the PPL Zone (total charges were \$93,554) to \$3.99 per MW-day in the BGE Zone (total charges were \$7,256,881). For each zone, Table 10-44 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 \$0.044 per MW of reserve capacity during the first nine months of 2015.

<sup>55</sup> See PJM, "RTO-Wide Five-Year Selection Process Request for Proposal for Black Start Service," (July 1, 2013).

Table 10-44 Black start zonal charges for network transmission use: January through September, 2014 and 2015

Zone	2014 (Jan - Sep)					2015 (Jan - Sep)				
	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	\$477,125	\$33,266	\$510,390	\$747,802	\$0.68	\$275,890	\$3,131	\$279,021	\$667,076	\$0.42
AEP	\$663,227	\$24,880,441	\$25,543,668	\$6,237,040	\$4.10	\$8,299,373	\$4,526,548	\$12,825,921	\$6,663,411	\$1.92
APS	\$211,845	\$3,027	\$214,872	\$2,368,930	\$0.09	\$180,899	\$69,722	\$250,621	\$2,552,359	\$0.10
ATSI	\$494,771	\$32,487	\$527,258	\$3,587,520	\$0.15	\$2,007,896	\$13,206	\$2,021,102	\$3,374,853	\$0.60
BGE	\$5,564,956	\$5,049	\$5,570,005	\$1,864,672	\$2.99	\$7,254,385	\$2,496	\$7,256,881	\$1,819,600	\$3.99
ComEd	\$3,161,530	\$20,220	\$3,181,750	\$6,079,437	\$0.52	\$3,270,367	\$28,968	\$3,299,335	\$5,383,888	\$0.61
DAY	\$179,835	\$6,511	\$186,345	\$930,739	\$0.20	\$176,923	\$7,929	\$184,852	\$874,637	\$0.21
DEOK	\$856,598	\$15,022	\$871,619	\$1,404,858	\$0.62	\$867,587	\$12,531	\$880,118	\$1,393,665	\$0.63
Dominion	\$752,079	\$4,599	\$756,678	\$5,122,299	\$0.15	\$758,363	\$10,434	\$768,797	\$5,401,032	\$0.14
DPL	\$424,047	\$17,593	\$441,640	\$1,097,105	\$0.40	\$501,367	\$7,059	\$508,426	\$1,057,875	\$0.48
DLCO	\$44,492	\$0	\$44,492	\$805,760	\$0.06	\$81,598	\$0	\$81,598	\$735,107	\$0.11
EKPC	\$301,997	\$4,439	\$306,436	\$691,400	\$0.44	\$315,106	\$0	\$315,106	\$935,025	\$0.34
JCPL	\$378,821	\$6,257	\$385,078	\$1,741,440	\$0.22	\$3,024,606	\$27,382	\$3,051,988	\$1,538,874	\$1.98
Met-Ed	\$638,333	\$58,205	\$696,538	\$822,358	\$0.85	\$499,189	\$27,745	\$526,934	\$768,986	\$0.69
PECO	\$1,124,950	\$13,614	\$1,138,564	\$2,352,823	\$0.48	\$1,191,177	\$19,741	\$1,210,918	\$2,254,298	\$0.54
PENELEC	\$388,241	\$3,498	\$391,738	\$842,833	\$0.46	\$408,350	\$2,881	\$411,231	\$833,087	\$0.49
Pepco	\$235,155	\$17,347	\$252,502	\$1,783,618	\$0.14	\$598,704	\$10,932	\$609,636	\$1,732,212	\$0.35
PPL	\$164,317	\$0	\$164,317	\$2,018,071	\$0.08	\$84,623	\$8,931	\$93,554	\$2,194,374	\$0.04
PSEG	\$1,287,063	\$32,643	\$1,319,706	\$2,843,131	\$0.46	\$2,542,009	\$12,058	\$2,554,067	\$2,597,650	\$0.98
RECO	\$0	\$0	\$0	NA	NA	\$0	\$0	\$0	NA	NA
(Imp/Exp/Wheels)	\$1,045,939	\$1,505,088	\$2,551,027	\$2,671,946	\$0.95	\$1,552,447	\$269,370	\$1,821,817	2,065,969	\$0.88
Total	\$18,395,320	\$26,659,305	\$45,054,625	46,013,781	\$0.98	\$33,890,859	\$5,061,064	\$38,951,923	44,843,977	\$0.87

Table 10-45 provides a revenue requirement estimate by zone for the 2015-2016, 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. They are based on the best available data (i.e. 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 in either direction as actual costs become known and finalized.

**Table 10-45 Black start zonal revenue requirement estimate: 2015/2016 through 2018/2019 delivery years**

Zone	2015-2016		2016-2017		2017-2018		2018-2019	
	Revenue Requirement							
AECO	\$1,550,000		\$2,850,000		\$2,850,000		\$2,800,000	
AEP	\$15,650,000		\$19,150,000		\$19,200,000		\$18,950,000	
APS	\$4,200,000		\$4,150,000		\$4,150,000		\$4,150,000	
ATSI	\$3,150,000		\$3,100,000		\$3,100,000		\$3,100,000	
BGE	\$8,400,000		\$6,700,000		\$1,900,000		\$500,000	
ComEd	\$5,550,000		\$5,100,000		\$5,200,000		\$4,400,000	
DAY	\$250,000		\$250,000		\$300,000		\$200,000	
DEOK	\$1,250,000		\$1,250,000		\$1,250,000		\$500,000	
DLCO	\$150,000		\$100,000		\$100,000		\$50,000	
Dominion	\$4,000,000		\$5,400,000		\$5,400,000		\$4,600,000	
DPL	\$1,800,000		\$2,600,000		\$2,600,000		\$2,500,000	
EKPC	\$500,000		\$250,000		\$250,000		\$200,000	
JCPL	\$7,150,000		\$7,200,000		\$7,200,000		\$7,150,000	
Met-Ed	\$650,000		\$700,000		\$750,000		\$600,000	
PECO	\$1,650,000		\$1,750,000		\$1,900,000		\$1,550,000	
PENELEC	\$4,650,000		\$4,700,000		\$4,750,000		\$4,600,000	
Pepco	\$2,250,000		\$2,700,000		\$2,700,000		\$2,650,000	
PPL	\$650,000		\$800,000		\$800,000		\$750,000	
PSEG	\$4,450,000		\$4,450,000		\$4,500,000		\$4,450,000	
RECO	\$0		\$0		\$0		\$0	
Total	\$67,900,000		\$73,200,000		\$68,900,000		\$63,700,000	

## Reactive Service

Reactive Service, Reactive Supply and Voltage Control from Generation or Other Sources Service, is provided by generation and other sources (such as static VAR compensators and capacitor banks) of reactive power (measured in VAR).<sup>56</sup> Reactive power helps maintain appropriate voltages on the transmission system and is essential to the flow of real power (measured in MW). Without Reactive Service in the necessary amounts across the RTO footprint, transmission system voltages fall, generating units and transmission lines shut down, and no real power flows.

<sup>56</sup> PJM OATT, Schedule 2 "Reactive Supply and Voltage Control from Generation Sources Service," (Effective Date: February 18, 2012).

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 the first nine months of 2015, total reactive service charges were \$217.6 million, a 4.5 percent decrease from the first nine months of 2014 level of \$227.8 million.<sup>57</sup> Revenue requirement charges decreased from \$210.4 million to \$207.7 million and operating reserve charges fell from \$17.4 million to \$9.9 million. Total charges in the first nine months of 2015 ranged from \$1.8 thousand in the RECO Zone to \$20.6 million in the AEP Zone.

For each zone in the first nine months of 2014 and 2015, Table 10-46 shows Reactive Service operating reserve charges, revenue requirement charges and total charges (the sum of operating reserve and revenue requirement charges).

<sup>57</sup> See the 2014 State of the Market Report for PJM, Volume II, Section 4, "Energy Uplift."

Table 10-46 Reactive zonal charges for network transmission use: January through September, 2014 and 2015

Zone	2014 (Jan - Sep)			2015 (Jan - Sep)		
	Operating Reserve Charges	Revenue Requirement Charges	Total Charges	Operating Reserve Charges	Revenue Requirement Charges	Total Charges
AECO	\$105,349	\$4,672,195	\$4,777,544	\$17,594	\$5,292,735	\$5,310,329
AEP	\$810,230	\$29,925,304	\$30,735,534	\$448,415	\$28,915,175	\$29,363,590
APS	\$287,907	\$14,409,373	\$14,697,280	\$96,205	\$12,467,253	\$12,563,458
ATSI	\$1,794,455	\$11,580,909	\$13,375,364	\$3,843,352	\$11,182,818	\$15,026,170
BGE	\$55,337	\$5,770,567	\$5,825,904	\$63,843	\$5,853,399	\$5,917,242
ComEd	\$146,656	\$18,243,345	\$18,390,001	\$180,547	\$18,667,106	\$18,847,653
DAY	\$29,971	\$6,265,068	\$6,295,039	\$33,388	\$6,354,999	\$6,388,387
DEOK	\$29,412	\$4,276,336	\$4,305,748	\$52,469	\$3,854,607	\$3,907,076
Dominion	\$3,407,126	\$22,221,164	\$25,628,290	\$2,637,311	\$22,540,135	\$25,177,446
DPL	\$6,946,178	\$8,055,957	\$15,002,135	\$1,817,220	\$8,212,146	\$10,029,366
DLCO	\$15,711	\$0	\$15,711	\$25,139	\$0	\$25,139
EKPC	\$12,873	\$1,589,187	\$1,602,060	\$29,296	\$1,611,999	\$1,641,295
JCPL	\$24,410	\$5,291,535	\$5,315,945	\$39,420	\$5,367,492	\$5,406,912
Met-Ed	\$46,086	\$5,619,871	\$5,665,957	\$63,138	\$5,782,911	\$5,846,049
PECO	\$369,727	\$13,085,479	\$13,455,206	\$73,069	\$13,273,313	\$13,346,382
PENELEC	\$2,813,308	\$4,607,834	\$7,421,142	\$290,358	\$5,438,052	\$5,728,410
Pepco	\$50,912	\$3,903,966	\$3,954,878	\$68,773	\$3,960,005	\$4,028,778
PPL	\$45,113	\$14,214,314	\$14,259,427	\$81,352	\$14,189,481	\$14,270,833
PSEG	\$389,323	\$20,246,780	\$20,636,103	\$73,242	\$21,276,072	\$21,349,314
RECO	\$1,679	\$0	\$1,679	\$2,448	\$0	\$2,448
(Imp/Exp/Wheels)	\$0	\$16,412,204	\$16,412,204	\$0	\$13,449,392	\$13,449,392
Total	\$17,381,763	\$210,391,388	\$227,773,151	\$9,936,579	\$207,689,090	\$217,625,669

