Working to Perfect the Flow of Energy

PJM Manual 11:

Energy & Ancillary Services Market Operations

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- Revisions to Section 3: Overview of PJM Regulation Market: Incorporation of RMISTF Solution Package

Section 3: Overview of the PJM Regulation Market

Welcome to the Overview of the PJM Regulation Market section of the PJM Manual for Energy & Ancillary Services Market Operations. In this section you will find the following information:

- An overview description of the PJM Regulation Market (see "Overview of PJM Regulation Market").
- A list of the PJM Regulation Market Business Rules (see "PJM Regulation Market Business Rules").

3.1 Overview of the PJM Regulation Market

The PJM Regulation Market provides PJM participants with a market-based system for the purchase and sale of the Regulation ancillary service. Resource owners submit specific offers for Regulation Capability and Regulation Performance, and PJM utilizes these offers together with energy offers and resource schedules from the Markets Gateway System, as input data to the Ancillary Service Optimizer (ASO) which is an hour-ahead Market Clearing Engine. ASO then optimizes the RTO dispatch profile and forecasts LMPs to determine hourly commitments of Regulation to meet the requirement. In real-time PJM jointly optimizes the Regulation committed simultaneously with energy and reserve and calculates the Regulation Market Clearing Price (RMCP) and, Regulation Market Performance Clearing Price (RMPCP), which are used to derive the Regulation Market Capability Clearing Price (RMCCP)) every 5 minutes based on the current system conditions. All 5 minute, real-time, Regulation prices will be averaged to calculate the hourly Regulation Market Performance Clearing Price (RMPCP) and the Regulation Market Capability Clearing Price (RMCCP). These clearing prices are then used in market settlements to determine the credits awarded to providers and charges allocated to purchasers of the Regulation service.

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.

At the inception of the regulation market, regulation was provided by resources following the RegA signal. Since regulation service originated with resources following the RegA signal, performance adjusted RegA MW are used as the common unit of measure, called Effective MW, of regulation service currently provided in the PJM Regulation Market. The regulation requirement (the amount of regulation MW needed to control for ACE) is defined in terms of a total Effective MW required to provide an expected amount of area control error (ACE) control.

The Regulation Market functions by converting performance adjusted RegD MW into their marginal effective MW equivalent using a marginal rate of technical substitution (MRTS) called Regulation Marginal Rate of Technical Substitution (RMRTS). The RMRTS is used to convert incremental additions of RegD MW into incremental effective MW. The total effective MW for a

given amount of RegD MW are determined by the area under the RMRTS curve (the sum of the incremental effective MW contributions). This conversion into a common unit of measure allows a direct comparison of RegA and RegD offers. The RMRTS reflects the fact that each incremental MW of RegD has a progressively smaller effective MW value. Total regulation provided by a given combination of RegA and RegD is defined in terms of total effective MW.

Based on the resource signal design (RegA and RegD) and the expected response of resources following their selected signal, PJM defines an expected engineering relationship between different combinations of RegA following resources and RegD following resources and the expected level of correction of area control error (ACE) by each combination of RegA and RegD. Combinations of RegD and RegA MW quantities (quantity pairs of RegD MW and RegA MW) that provide a constant expected level of ACE control performance define isoquants of expected regulation control.[1] A regulation service isoquant defines a set of RegD MW and RegA MW pairs that provide a fixed level of expected ACE control performance. The objective of the Regulation Market is to find the least cost combination of RegA and RegD MW along the isoquant that provides the desired level of expected ACE control performance.

PJM uses resource schedules, regulation, and energy offers from the Markets Gateway System as input data to the ASO to provide the lowest cost alternative for the procurement of Regulation for each hour of the operating day. The lowest cost alternative for this service is achieved through a simultaneous co-optimization with Synchronized Reserve, Non-Synchronized Reserve and energy. Within the co-optimization, an RTO dispatch profile is forecasted along with LMPs for the market hour and adjacent hours. Using the dispatch profile and forecasted LMPs, an opportunity cost, adjusted by applicable performance score and ~~benefits factor~~Regulation Rate of Techincal Substitution, is estimated for each resource that is eligible to provide regulation. The estimated opportunity cost for demand resources will be zero. The adjusted lost opportunity cost is added to the adjusted regulation capability cost and the adjusted regulation performance cost to make the adjusted total regulation offer cost. The adjusted total regulation offer cost is then used to create the merit order price. Resource owners may self-schedule Regulation on any qualified resource. The merit order price for any self-scheduled Regulation resource is zero. All available regulating resources are then ranked in ascending order of their merit order prices, and the lowest cost set of resources necessary to simultaneously meet the PJM Regulation Requirement, PJM Synchronized Reserve Requirement, PJM Primary Reserve Requirement and provide energy in that hour is determined. If there is an excess of self-scheduled and zero-cost offers over and beyond the Regulation requirement, PJM uses resource-specific historic performance scores, selecting those resources with the highest performance scores, as a tie-breaker to determine which set of

[1] An isoquant is a curve that shows all the combinations of inputs that yield the same level of output.

resources to commit to meet the Regulation requirement. The least cost set of regulation resources identified through this process are then committed. Prices for Regulation will be calculated simultaneously with energy and reserve every 5 minutes for the 12 intervals of the hour by the Locational Pricing Calculator (LPC). The highest merit order price associated with this lowest cost set of resources awarded regulation becomes the RMCP. The RMPCP is calculated as the highest adjusted performance offer from the set of cleared resources. The RMCCP is the difference between RMCP and RMPCP.

In the after-the-fact settlement, any resources self-scheduled to provide Regulation are compensated based on the processes described in Manual 28.

3.2 PJM Regulation Market Business Rules

3.2.1 Regulation Market Eligibility

Regulation offers may be submitted only for those resources electrically within the PJM RTO.

To regulate, a resource must meet the following criteria:

- Generation resources must be able to provide 0.1 MW of Regulation Capability in order to participate in the Regulation Market. Demand Resources must be able to provide 0.1 MW of Regulation Capability in order to participate in the Regulation Market.
- Generation resources must have a governor capable of AGC control.
- Resources must be able to receive an AGC signal. Resources MW output must be telemetered to the PJM control center in a manner determined to be acceptable by PJM.
- New resources must pass an initial performance test (minimum 75% compliance required).
- Resources must demonstrate minimum performance standards, as set forth in the PJM Manual 12: Balancing Operations, Section 4: Providing Ancillary Services.
- Resources should give priority to the regulation signal by not allowing the sum of the regulating ramp rate and energy ramp rate to exceed the economic ramp rate. Only after a regulating resource has accounted for the regulation capability, may a generator use net of the economic base point and the regulation ramp rate to follow the energy signal.
- Demand Resources must complete initial and continuing training on Regulation and Synchronized Reserve Market as documented in Manual 40: Certification and Training Requirements, Section 2.6: Training Requirements for Demand Response Resources Supplying Regulation and Synchronized Reserve.
- When a Demand Resource that is eligible for the Regulation Market is called for a mandatory Emergency or Pre-Emergency Load Management Event, it will be de-

assigned from Regulation for any intervals that overlap with the Load Management Event, starting from the notice time of the Load Management Event, unless otherwise approved by PJM. PJM will not assign the resource to Regulation for the remainder of the mandatory portion of the Load Management Event.

The following information must be supplied through the Markets Gateway System:

- Resource Regulating Status (available, unavailable, self-scheduled)
- Regulation Capability (above and below regulation midpoint, MW)
- Regulation Maximum and Minimum values, considering any necessary offsets (MW)
- Demand Resource must submit valid Economic and Regulation Maximum and Minimum MW limits respectively
- Regulation Signal Type – RegA or RegD
- Cost-Based Regulation Offer ($/MWh): This value will be validated using the unit-specific operating parameters submitted with the regulation offer and the applicable $12/MWh regulation margin adder. The portions of the cost based offer are split into:
    - Regulation Capability portion capturing the Fuel Cost Increase and Unit Specific Heat Rate Degradation due to Operating at Lower Loads. The margin adder may only be added to the Regulation Capability portion; and,
    - Regulation Performance portion representing Cost Increase due to Heat Rate Increase during non-steady state operation and Cost Increase in VOM.
        - The $/MW value determined in this step will be converted to $/ΔMW by dividing the value by mileage ΔMW/MW for the applicable signal for that offer.
- Price-Based Regulation Offer ($/MWh, optional): This value is capped at $100/MWh, and its submission is optional on the part of the market participant. The portions of the price-based offer are split into:
    - Regulation Capability portion the capturing the resource owner's price to reserve MWs for regulation in $/MW; and,
    - Regulation Performance portion capturing the resource owner's price to provide regulation movement in $/ΔMW.

The $/MW value determined in this step will be converted to $/ΔMW by dividing the value by mileage ΔMW/MW for the applicable signal for that offer.

In addition to the cost-based regulation offer price, each market participant may also submit additional information to support the cost-based offer price. Using the calculations in Manual M-15: Cost Development Guidelines, PJM will validate the cost-based regulation offer price to

ensure that it does not exceed actual regulating cost as determined by this manual, plus the applicable regulation margin adder. Any cost-based offer prices that exceed this value will be rejected by the Markets Gateway System. An example of this calculation is available on the PJM website in the 'Regulation Two Part Cost-Based Offer' document, located at http://www.pjm.com/markets-and-operations/ancillary-services.aspx.

Regulation offers cannot be negative.

If a market participant does not submit a cost-based regulation offer price they will not be permitted to participate in the PJM Regulation Market until such offer has been validated. Any participants that do not submit any of the supporting parameters below will have their cost-based regulation offer price capped at the margin adder of $12/MWh.

The following optional parameters may be submitted in the Markets Gateway System to support the cost-based regulation offer price. If any of these parameters are not submitted they will default to zero.

- **Heat Rate @ EcoMax [BTU/kWh]:** The heat rate at the default economic maximum for a resource. The economic maximum that will correspond to this rate value will be the default economic maximum that is shown on both the Daily Regulation Offers and Unit Details pages.

- **Heat Rate @ RegMin [BTU/kWh]:** The heat rate at the default regulation minimum for a resource. The regulation minimum that will correspond to this rate value will be the default regulation minimum that is shown on both the Daily Regulation Offers and Unit Details pages.

- **VOM Rate [$/MWh of Regulation]:** The increase in VOM resulting from operating the regulating resource at a higher heat rate than is otherwise economic for the purpose of providing regulation.

- **Fuel Cost [$/MBTU]:** The fixed fuel costs of the resource. This value will be used to determine the heat rate adjustments during steady-state and non steady-state operation for the purpose of providing regulation.

Regulation resources that are dual certified as RegA and RegD may submit a set of offers for each signal type. In such case, the market clearing engine evaluates both offers but will clear the resource for either one or neither of the two signal types based on economics and system needs. A dual certified resource offering both signal types in a given hour, if cleared for regulation, will be assigned one signal type for that the entire hour. The signal type assigned may vary from one hour to another during the course of the day if both signal types are made available consistently.

- If a dual certified resource submits self-scheduled regulation offers as both RegA and RegD signal types in the same hour, the market clearing engine will only evaluate the RegA self-schedule offer and then either commit the resource or not based on system needs.

- If a resource submits offers into both the Regulation and Synchronized Reserve Markets in the same hour, the regulation offer receives higher priority in the market clearing process, meaning if economic for both markets, the unit will be committed for Regulation rather than Synchronized Reserve.

3.2.2 Regulation Market Data Timeline

Cost-based and Price-Based Regulation Offer(s) and any applicable cost information must be supplied prior to 1415 day-ahead and is applicable for the entire 24-hour period for which it is submitted. Resource Regulating Status, Regulation Capability, and Regulation Maximum and Regulation Minimum information may be submitted or changed up until sixty (60) minutes prior to the beginning of the operating hour, at which time the Regulation market closes.

In the event that the Regulation Maximum and Regulation Minimum limits are not the most restrictive for a given resource (i.e. the Regulation Maximum the lowest of all the high limits and the Regulation Minimum the highest of all the low limits), the regulation software will utilize the most restrictive minimum and maximum of all applicable limits for real time.

- Should a resource wish not to participate in the regulation market in any given hour on the operating day, the following update should be made at least 60 minutes prior to the operating hour in the Regulation Updates screens of the Markets Gateway System:
    - Set Offer MW to zero and
    - Set Available status to Not Available.
- Should a resource's regulation operating parameters change after the regulation market closes for an hour, the following changes may be made through direct communication with the PJM Scheduling Coordinator:
    - Resource Regulating Status
        - Available to unavailable
        - Self-scheduled to unavailable
    - High Regulation Limit may be decreased but not increased and Low Regulation Limit may be increased but not decreased.
    - Regulating capability may be decreased but not increased.
    - Regulation Maximum capability may be decreased but not increased and Regulation Minimum capability may be increased but not decreased.

3.2.3 Regulation Bilateral Transactions

Bilateral regulation transactions may be reported to PJM. Such reported bilateral regulation transactions must be for the physical transfer of regulation and must be reported by the buyer and subsequently confirmed by the seller through the Markets Gateway System no later than 1330 the day after the transaction starts. Bilateral transactions that have been reported and confirmed may not be changed; they must be deleted and re-reported. Deletion of a reported

bilateral transaction is interpreted as a change in the end time of the transaction to the current hour, unless the transaction has not yet started.

The buyer on the transaction submits the MW amount, the seller, and the start and end time of the transaction via the Markets Gateway System. The seller confirms the transaction via the Markets Gateway System by 1330 the day after the start date of the bilateral transaction.

Payments and related charges associated with the bilateral regulation transactions reported to PJM shall be arranged between the parties to the bilateral contract.

A buyer under a bilateral regulation contract reported to PJM agrees that it guarantees and indemnifies PJM, PJM Settlement, and the market participants for the costs of any purchases by the seller in the Regulation Market, as determined by PJM, to supply the reported bilateral transaction and for which payment is not made to PJM Settlement by the seller.

Upon any default in obligations to PJM or PJM Settlement by a Market Participant, PJM shall not accept any new bilateral reporting by the Market Participant and shall terminate all of the market participant's reporting of Markets Gateway schedules associated with its bilateral regulation transactions previously reported to PJM for all days where delivery had not yet occurred.

3.2.4 Regulation Requirement Determination

The total PJM Regulation Requirement for the PJM RTO is determined in whole MW for the ramp and non-ramp periods each day. Further detail can be found in Manual 12, Section 4.4.3 - Determining Regulation Assignment.

Demand Resources will be limited to providing 25% of the regulation requirement.

3.2.5 Regulation Obligation Fulfillment

LSEs may fulfill their regulation obligations by:

- Self-scheduling the entity's own resources;
- Entering contractual arrangements with other market participants; or
- Purchasing regulation from the regulation market.

3.2.6 Regulation Offer Period

Resource owners wishing to sell regulation service must at least supply a cost-based regulation offer reflecting both Regulation capability offer cost and the Regulation performance cost of the resource by 1415 the day prior to operation, and the remainder of the necessary data prior to Regulation market closing as stated above in the Regulation Market Date Timeline section.

Regulation offers are locked as of 1415 the day prior to operation. The Markets Database is generally unavailable for updates to offers for the next Operating Day between 1030 and the time the office of interconnection posts the results of the Day-ahead Energy Market for that

Operating Day while the Day-ahead market is being cleared. All resources listed as available for regulation with no offer price have their offer prices set to zero.

3.2.7 Regulation Market Clearing

PJM clears the regulation market simultaneously with the synchronized reserve market, and posts the results no later than 30 minutes prior to the start of the operating hour.

Dispatch

Economic ramp rate must be adjusted when resources provide regulation to minimize the conflict between energy and regulation products. The segment specific ramp rates should be calculated from the economic ramp rate as follows:

$$Reduced\ Energy\ Ramp\ Rate = \max\left(0, Economic\ Ramp\ Rate - \frac{Cleared\ Regulation\ Capacity\ (AREG)}{5\ Minutes}\right)$$

To increase consistency in the Individual Generator Dispatch (IGD) set point sent by PJM while a unit is regulating, the IGD set point will only move up when the RT-SCED LMP justifies raising the resource and the resource has a non-zero reduced energy ramp rate entered. The IGD set point will only move down when the RT-SCED LMP justifies lowering the resource and the resource has a non-zero reduced energy ramp rate entered. The reduced energy ramp rate is a member-entered, unit-specific percentage of the bid-in energy ramp rate for each resource. If no value is entered in the Market Gateway system for the resource, a default of zero will be used.

Regulating Capability

For each resource, PJM will calculate an adjusted Capability Cost, as

$$Adjusted\ Regulating\ Capability\ \ Cost\ (\$) = \frac{\left(\begin{matrix}Capability\\ Offer\ \left(\frac{\$}{MW}\right)\end{matrix}\right)}{\left(\begin{matrix}Benefits\ Factor\\ of\\ Offered\ Resource\end{matrix}\right)} * \frac{\left(\begin{matrix}Capability\\ (MW)\end{matrix}\right)}{\left(\begin{matrix}Historic\\ Performance\\ Score\end{matrix}\right)}$$

$$Adjusted\ Regulating\ Capability\ Cost\ (\$) = \left(\frac{Capability\ Offer\ \left(\frac{\$}{MW}\right)}{RRTS\ of\ Offered\ Resource}\right) * \left(\frac{Capability(MW)}{Historic\ Performance\ Score}\right)$$

The Adjusted Regulating Capability Offer is adjusted by the ~~benefits factor~~Regulation Rate of Technical Substitution (RRTS) of the specific offered resource and the historic performance score of the resource. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource.

Mileage and the Performance Offer

Mileage is the summation of movement requested by the regulation control signal a resource is following. It is calculated for the duration of the market hour for each regulation control signal (i.e. RegA and RegD).

$$Mileage_{RegA} = \sum_{i=0}^{n} |RegA_i - RegA_{i-1}|$$

$$Mileage_{RegD} = \sum_{i=0}^{n} |RegD_i - RegD_{i-1}|$$

PJM calculates the performance-adjusted Performance Cost, as

$$Adjusted\ Performance\ Cost\ (\$) = \frac{\begin{pmatrix} Performance \\ Offer\ (\$/\Delta MW) \end{pmatrix} * \begin{pmatrix} Mileage \\ of \\ Offered\ Resource \\ Signal\ Type\ (\Delta MW/MW) \end{pmatrix}}{\begin{pmatrix} ~~Benefits\ Factor~~RRTS \\ of \\ Offered\ Resource \end{pmatrix} * \begin{pmatrix} Historic \\ Performance \\ Score \end{pmatrix}} * \begin{pmatrix} Capability \\ (MW) \end{pmatrix}$$

Similar to the Adjusted Regulating Capability Offer, the Adjusted Performance Offer is adjusted by the ~~benefits~~ RRTS ~~factor~~ of the specific offered resource and the historic performance score of the resource. ~~Benefits factor~~The RRTS ~~-~~is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource. The performance offer is priced on a $ per change in MW, to normalize the performance between signal types, the historical mileage is a rolling 30-day average by the signal type that the resource has qualified to follow.

Lost Opportunity Cost

Estimated resource opportunity cost is calculated as follows:

- The Market Clearing Engine (MCE) optimizes resource energy schedules and forecasts LMPs for the operating hour while respecting appropriate transmission constraints and Ancillary Service requirements.

- The MCE utilizes the schedule on which the resource was committed ~~on~~ for online generating resources or, for offline resources, the cheapest ~~lesser~~ of the available price-based energy schedule or ~~most expensive available~~ cost-based energy schedules ~~(the "lost opportunity cost energy schedule")~~, and forecasted LMPs to determine the estimated opportunity cost each resource would incur if it adjusted its output as necessary to provide its full amount of regulation.

Regulation opportunity cost is divided into three components.

- The lost opportunity cost incurred in the shoulder hour preceding the initial regulating hour while the unit moves uneconomically into its regulating band to comply with the next hour's regulation assignment.

- The lost opportunity cost incurred in the actual regulating hour from reducing or raising the unit's output uneconomically for the purpose of providing regulation.

- The lost opportunity cost incurred in the shoulder hour following the final hour of the regulation assignment while the unit moves from its uneconomic regulation set point back to its economic set point.

The approximate formula for the lost opportunity incurred during the shoulder hours can be defined as:

$$|LMP_{SH} - ED| * GENOFF * TIME, \text{ where:}$$

a. LMP_{SH} is the forecasted shoulder hour LMP at the generator bus,

b. ED is the price from the lost opportunity cost energy schedule associated with the setpoint the resource must maintain to provide its full amount of regulation, and

c. GENOFF is the MW deviation between economic dispatch and the regulation setpoint.

d. TIME is the percentage of the hour it would take the unit to reduce GENOFF MWs using the applicable offer-in ramp rate.

- The approximate formula for the lost opportunity cost incurred during the regulating hour is:

$$|LMP - ED| * GENOFF, \text{ where:}$$

a. LMP is the forecasted hourly LMP at the generator bus,

b. ED is the price from the lost opportunity cost energy schedule associated with the setpoint the resource must maintain to provide its full amount of regulation, and

c. GENOFF is the MW deviation between economic dispatch and the regulation setpoint.

All unit-specific lost opportunity costs will be divided by the ~~benefits~~ RRTS ~~factor~~ of the specific offered resource and the resource's historic performance score for the purposes of commitment and setting the regulation market clearing prices. ~~Benefits~~ The RRTS~~)~~ ~~factor~~ is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource.

$$Adjusted\ Lost\ Opportunity\ \ Cost\ (\$) = \frac{\left(\begin{matrix}Estimated\ Lost\ Opportunity\\ \left(\frac{\$}{MW}\right)\end{matrix}\right)}{\left(\begin{matrix}Benefits\ Factor\\ of\\ Offered\ Resource\end{matrix}\right)} * \frac{\left(\begin{matrix}Capability\\ (MW)\end{matrix}\right)}{\left(\begin{matrix}Historic\\ Performance\\ Score\end{matrix}\right)}$$

$$Adjusted\ Lost\ Opportunity\ Cost\ (\$) = \left(\frac{\left(\begin{matrix}Estimated\ Lost\ Opportunity\\ \left(\frac{\$}{MW}\right)\end{matrix}\right)}{\begin{matrix}RRTS\ \ of\\ Offered\ Resource\end{matrix}}\right) * \left(\frac{Capability\ (MW)}{Historice\ Performnace\ Score}\right)$$

Both lost opportunity cost calculations are defined simplistically for the purpose of the manual. The actual calculations are integrations that may be visualized as the area on a graph enclosed by the lost opportunity cost energy schedule, the points on that curve corresponding to the resource's desired economic dispatch and the setpoint necessary to provide the full amount of regulation, and the LMP. A sample calculation can be found on PJM website at http://pjm.com/~/media/markets-ops/ancillary/regulation-uplift-and-lost-opportunity-cost.ashx.

PJM may call on resources not otherwise assigned in order to provide regulation, in accordance with PJM's obligation to minimize the total cost of energy, operating reserves, regulation, and other ancillary services. If a resource is called on by PJM for the purpose of providing regulation, the resource is eligible for recovery of Regulation lost opportunity costs as well as start-up, no-load, and energy costs. Please refer to Manual 28: Operating Agreement Accounting for additional settlements details.

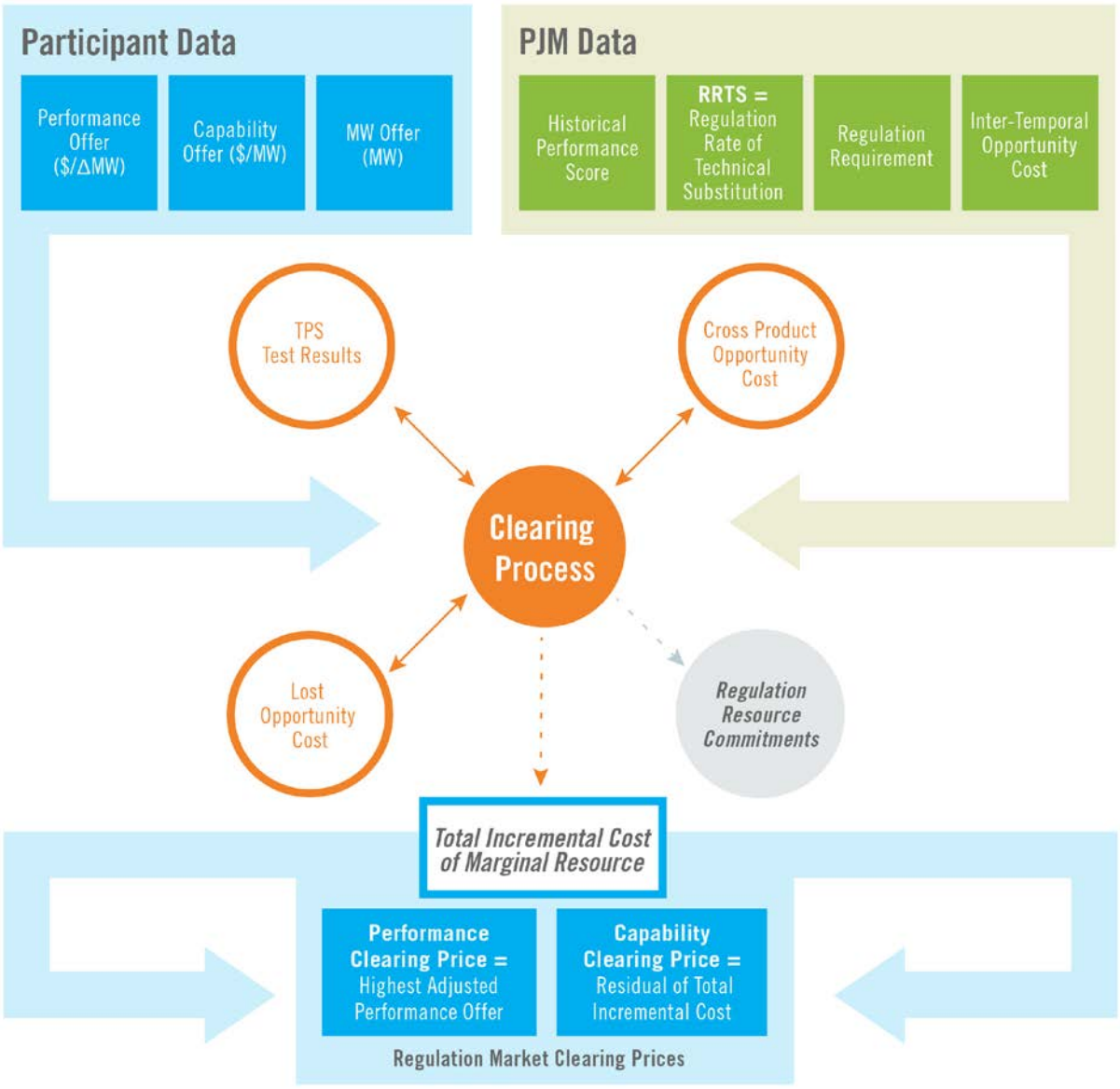
Resources not eligible or with no lost opportunity associated with providing regulation:

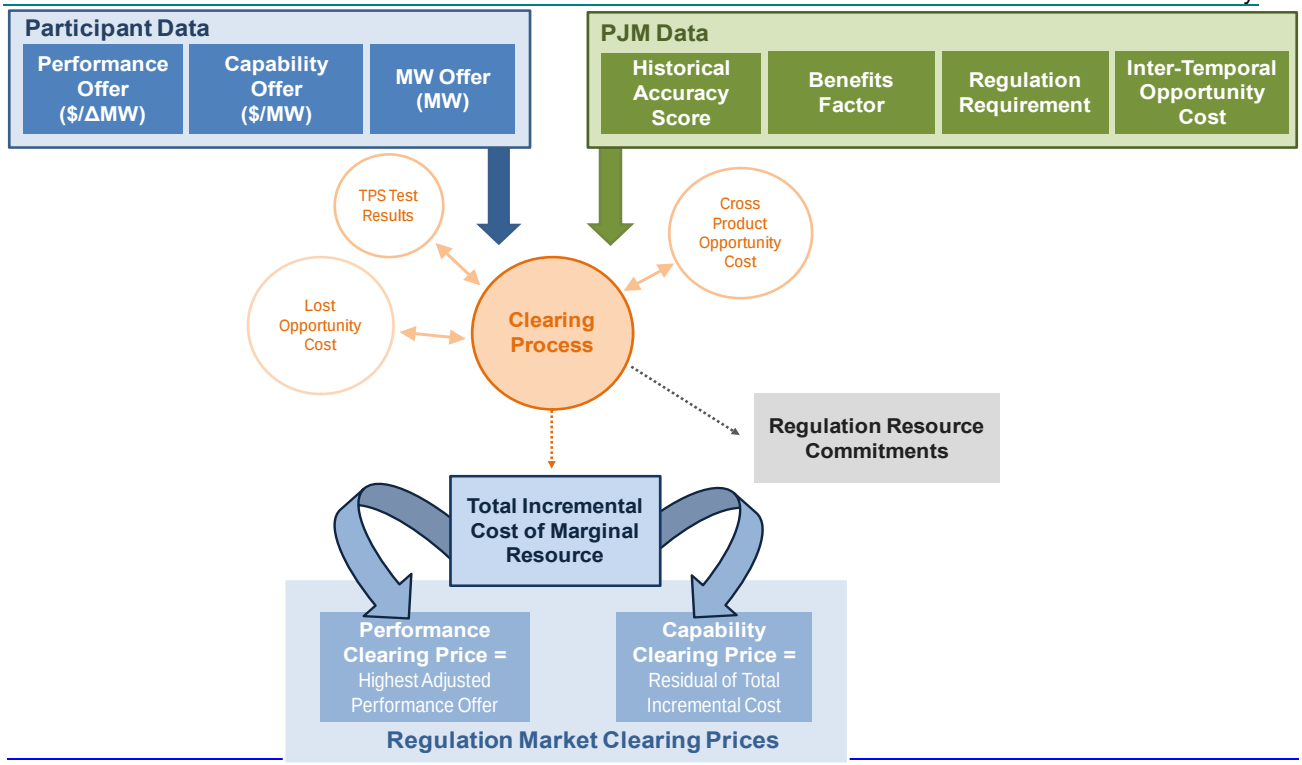
- Energy resources that are self-scheduled to provide energy and do not supply an energy offer.
- Demand Resources
- Notwithstanding the above, resources that do not submit an energy offer curve will have a Lost Opportunity Cost of zero.

Total Offer

Each resource must be ranked based on the total expected cost of that resource regulating. PJM calculates the Adjusted Total Offer of the resource as follows

$$Adjusted\ Total\ Offer\ Cost\ (\$) = \left(\begin{matrix}Adjusted\\ Regulation\\ Capability\\ Cost\\ (\$)\end{matrix}\right) + \left(\begin{matrix}Adjusted\\ Lost\\ Opportunity\\ Cost\\ (\$)\end{matrix}\right) + \left(\begin{matrix}Adjusted\\ Performance\\ Cost\\ (\$)\end{matrix}\right)$$


Participant Data
Performance Offer ($/ΔMW)
Capability Offer ($/MW)
MW Offer (MW)
PJM Data
Historical Performance Score
RRTS = Regulation Rate of Technical Substitution
Regulation Requirement
Inter-Temporal Opportunity Cost
TPS Test Results
Cross Product Opportunity Cost
Clearing Process
Lost Opportunity Cost
Regulation Resource Commitments
Total Incremental Cost of Marginal Resource
Performance Clearing Price = Highest Adjusted Performance Offer
Capability Clearing Price = Residual of Total Incremental Cost
Regulation Market Clearing Prices



MCE ranks all available regulating resources in ascending merit order price, and simultaneously determines the least expensive set of resources necessary to provide energy, regulation and synchronized reserve for the operating hour taking into account any resources self-scheduled to provide any of these services. The Rank price is determined as follows:

$$Rank\ Price = \frac{Adjusted\ Total\ Offer\ Cost\ (\$)}{Capability\ \ (MW)}$$

Should the MCE application be unable to fulfill both the Regulation and Synchronized Reserve requirements, regulation receives the higher priority.

PJM will clear the market to meet the Regulation Capability Requirement. The Regulation Capability Requirement sets the amount of regulating capability that PJM believes it would need to absorb sustained RTO ACE deviations adjusted by the ~~benefits~~ RRTS ~~factor~~ of a specific offered resource and the resource's historic performance score. ~~Benefits~~ The RRTS ~~factor~~ is discussed later in this section. The historic performance score is discussed in Manual 12 – Balancing Operations, Section 4.5.5 Disqualification and Requalification of a Resource. The market will assign resources until the constraint is met, by

$$Regulation\ Capability\ Requirement\ MW \leq \sum_{i=0}^{n} Capability\ (MW)_i * RRTS\ of\ Offered\ Resource_i * Historic\ Performance\ Score_i$$

$$\begin{matrix} Regulation\ Capability\ Requirement \\ MW \end{matrix} \leq \sum_{i=0}^{n} Capability\ (MW)_{i*} * Benefits\ Factor\ of\ Offered\ Resource_i * Historic\ Performance\ Score_i$$

With the Regulation Capability constraint satisfied, the Rank Price ($/MW) of the last assigned resource sets the Regulation Market Clearing Price (RMCP). This RMCP is used to derive the clearing price for the Regulation Capability and Regulation Performance components. First the Regulation Market Performance Clearing Price (RMPCP) is calculated by finding the maximum performance offer from the set of all cleared resources' performance offers as follows:

$$Regulation\ Market\ Performance\ Claering\ Price\ \frac{\$}{MW} = \max_{Assigned\ Resources} \left(\frac{\begin{pmatrix} Performance \\ Offer \\ \left(\frac{\$}{\Delta MW}\right) \end{pmatrix} * \begin{pmatrix} Actual\ Mileage \\ of \\ Offered\ Resource\ Signal\ Type \frac{\Delta MW}{MW} \end{pmatrix}}{\begin{pmatrix} RRTS \\ of \\ Offered\ Resource \end{pmatrix} * \begin{pmatrix} Historic \\ Performance \\ Score \end{pmatrix}} \right)$$

$$\begin{matrix} Regulation\ Market\ Performance \\ Clearing\ Price \\ \$/MW \end{matrix} = \max_{Assigned\ \ Resources} \left(\frac{\begin{pmatrix} Performance \\ Offer \\ (\$/\Delta MW) \end{pmatrix} * \begin{pmatrix} Actual\ Mileage \\ of \\ Offered\ Resource\ Signal\ Type\ \Delta MW/MW \end{pmatrix}}{\begin{pmatrix} Benefits\ Factor \\ of \\ Offered\ Resource \end{pmatrix} * \begin{pmatrix} Historic \\ Performance \\ Score \end{pmatrix}} \right)$$

Then the RMPCP is subtracted from the RMCP for the Regulation Market Capability Clearing Price (RMCCP), which is the residual between the RMCP and RMPCP.

$$\begin{matrix} Regulation\ Market\ Capability \\ Clearing\ Price \\ \$/MW \end{matrix} = \begin{pmatrix} Regulation\ Market \\ Clearing\ Price \\ \$/MW \end{pmatrix} - \begin{pmatrix} RM\ Performance \\ Clearing\ Price \\ \$/MW \end{pmatrix}$$

The five minute regulation clearing prices are posted in the Data Viewer user interface public view. RMCP(s) and other billing determinant information is also available on the PJM website at

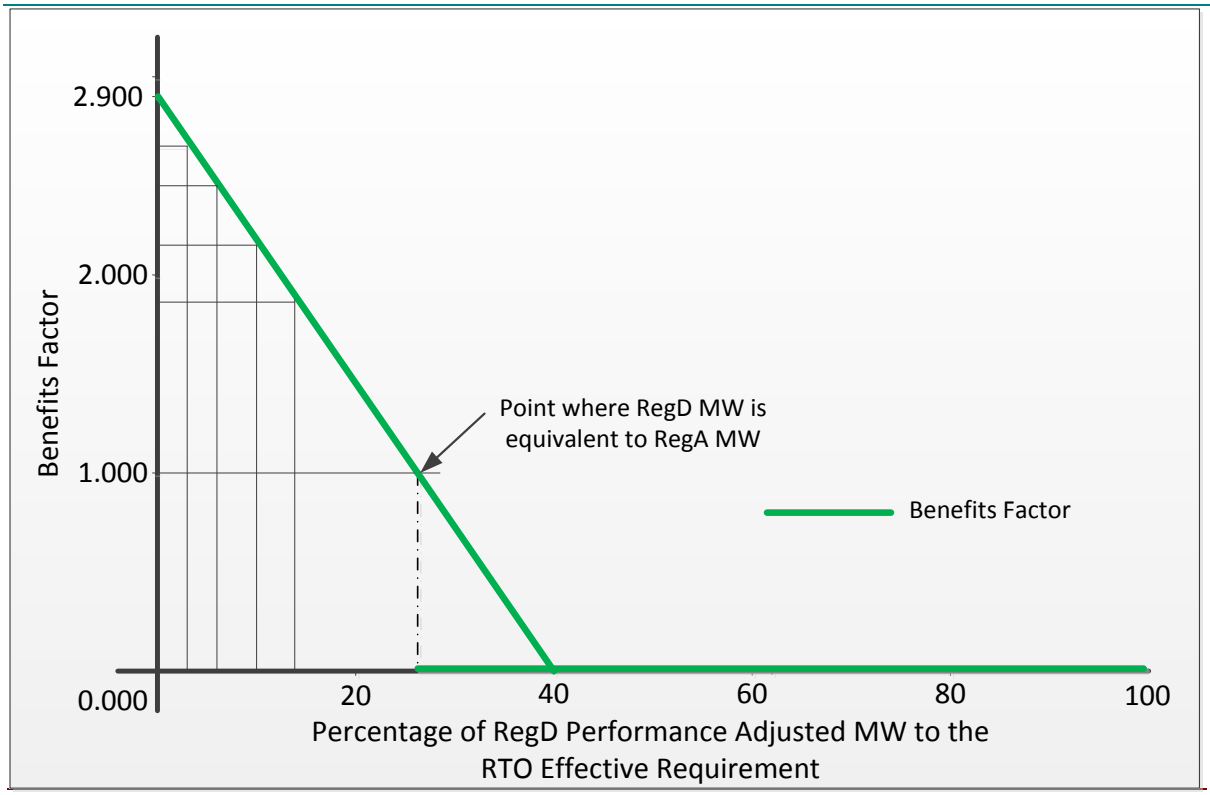
http://www.pjm.com/markets-and-operations/billing-settlements-and-credit/preliminary-billing-reports/pjm-reg-data.aspx.

If no Regulation Market Results are posted to the Markets Gateway MUI for an hour, PJM will continue the current assignments, as needed, into the un-posted hour. There will be no impact to the price calculation. The Regulation Clearing Prices will continue to be calculated every five minutes in real-time and the hourly integrated clearing price will be used for settlement.

~~Benefits~~ Regulation Rate of Technical Substitution ~~Factor Function~~Curve ~~Function~~

Regulating resources can follow either a RegA (traditional) or RegD (dynamic) signal based on their resources' limitation and business practices. The regulating resources cleared in any hour can be any set of or mix of both traditional and dynamic resources. There is an operational relationship between the regulating resource mix and how the regulation requirement is satisfied. This relationship is included in the market clearing process as the ~~Benefits~~ Regulation Rate of Technical Substitution (RRTS) ~~Factor Function~~ Curve. ~~because the relationship is depicted as a curve.~~

The ~~benefits~~ RRTS ~~factor~~ translates a fast moving resource's performance adjusted MWs into traditional performance adjusted MWs ~~or~~ expressed as Effective MWs. These Effective MWs reflect the rate of substitution between resources following the different regulation signals. For market clearing, each dynamic resource will be assigned a decreasing and unique ~~benefits~~ RRTS. ~~factor.~~ The ~~benefits~~ RRTS ~~factor~~ of the offered resource or resource specific ~~benefits~~ RRTS ~~factor~~ is the marginal point on the ~~benefits~~ RRTS ~~factor~~ function that aligns with the last MW, adjusted by historical performance, that specific resource will add to the dynamic resource stack.



The ~~benefits~~ RRTS ~~factor~~ curve will be defined on a seasonal, ramp and non-ramp basis, derived from engineering performance analysis. PJM will review the RRTS Curve as operational conditions warrant to re-evaluate the relationship when needed. These operational conditions could include, among other factors, changes to the regulation signal tuning parameters, changes in the set of resources providing regulation service, and changes to the regulation requirement.. These curves will be posted on PJM.com at http://www.pjm.com/markets-and-operations/ancillary-services.aspx.

~~ranges from 2.9 to 0 where a benefits factor of 1 is equivalent to a traditional resource. PJM will review the benefits factor as operational conditions warrant to re-evaluate the relationship when needed. These operational conditions could include, among other factors, changes to the regulation signal tuning parameters, changes in the set of resources providing regulation service, and changes to the regulation requirement.~~

PJM determines the ~~benefits~~ RRTS ~~factor~~ based on the expected impact that fast-following resources have on the NERC reliability criteria. The RRTS Curve is defined where an RRTS of 1 is equivalent to a traditional resource. A RRTS value greater than 1 indicates the RegD resource can replace more than 1 equivalent MW of a traditional resource, and a RRTS value less than 1 indicates the RegD resource can replace less than 1 equivalent MW of a traditional resource.

Determination of expected response will be based a combination of off-line models, analysis of the regulation signals, and the historical operational data as it accumulates. Historical operational data will be given increasing weight to the ~~benefits~~RRTS ~~factor~~ determination over time. Changes to the ~~benefits~~ RRTS ~~factor function~~Curve will be made periodically after review at the Operating Committee.

The net impact of the use of the ~~benefits~~ RRTS ~~factor~~ is to increase the likelihood of dynamic resources being selected in the clearing process, up to the point of diminishing returns. Beyond the point of diminishing returns (1 to 0), the ~~benefits~~ RRTS ~~factor~~ will decrease the likelihood of fast-following resources getting clearing.

~~During identified hours where more sustaining regulation (RegA) and less fast following regulation (RegD) is warranted, RegD resources with a benefits factor less than 1 will not be considered in the regulation clearing because of its reduced benefits. A cap will be implemented at BF = 1 during these hours. Capped hours will be reviewed on a quarterly basis at the Operating Committee.~~

The ~~benefits~~ RRTS ~~factor~~ is calculated in ASO one hour ahead in real time for each qualified RegD resource participating in the Regulation Market. Also, the ~~benefits~~RRTS ~~factor~~ is re-calculated for each RegD resource that is committed and providing regulation service in real-time for every 5 minute interval of the hour. The recalculation accounts for changes in the resource's adjusted total offer cost due to potential change in LMP at its bus which may affect its lost opportunity cost value. The ~~benefits~~ RRTS ~~factor~~ of RegA resources is always 1.

The ~~benefits~~ RRTS ~~factor~~ calculation steps include:

- Step 1: Calculation of the Performance Adjusted MW

$$Performance\ Adjusted\ MW = Capability\ (MW) * Historical\ Performance\ Score$$

- Step 2: Calculation of the Initial Adjusted Total Offer Cost

$$Initial\ Adjusted\ Total\ Offer\ Cost\ (\$) = \begin{pmatrix} Adjusted \\ Regulation \\ Capability \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Lost \\ Opportunity \\ Cost \\ (\$) \end{pmatrix} + \begin{pmatrix} Adjusted \\ Performance \\ Cost \\ (\$) \end{pmatrix}$$

$$in\ this\ step, the\ resource\ \sout{benefits\ factor}RRTS\ is\ assumed\ to\ be\ 1$$

RegD resources with initial adjusted total offer cost equal to zero will still be given priority in the ranking, but will instead be ordered using the resource specific historical performance score as a tie-breaker.

- Step 3: Calculation of the rolling performance adjusted MW based on the initial adjusted total cost in ascending rank order

- Step 4: Calculation of the resource specific ~~benefits~~ RRTS ~~factor~~ based on the defined ~~benefits~~ RRTS ~~factor~~ curve

- Step 5: Calculation of the resource specific Effective MW towards the regulation requirement. The effective MW will be calculated as the area under the portion of the RRTS Curve bounded by the resource's performance adjusted MW

Regulation Rate of Technical Substitution Curve –Transition Operations

A 24 month transition period has been identified starting on the first day of implementation of the Regulation Rate of Technical Substitution Curve

The first 12 months of the transition period will have a minimum (floor) RRTS value of 0.65. This will allow the maximum amount of RegD performance adjusted MW allowed to provide regulation service in a given hour to exist~~,~~ at the point on the RRTS Curve where the l Regulation Marginal Rate of Technical Substitution (RMRTS) value = 0.65.

The second 12 months of the transition period will have a minimum (floor) RRTS value of 0.50. This will allow the maximum amount of RegD performance adjusted MW allowed to provide regulation service in a given hour to exist ~~,~~ at the point on the RRTS Curve where the RMRTS value = 0.50.

All minimum (floor) RRTS values will be removed following the 24 month transition period. The applicable RRTS Curves for the identified transition period will be available on PJM.com at http://www.pjm.com/markets-and-operations/ancillary-services.aspx

Three Pivotal Supplier Test

PJM utilizes the Three Pivotal Supplier (TPS) Test in the regulation market to mitigate market power as detailed in section 3.2.2A.1 of the PJM Tariff. Each supplier, from 1 to n, is ranked from the largest to the smallest offered MW of eligible regulation supply adjusted by the resource-specific ~~benefits~~ RRTS ~~factor~~ and the resource specific performance score in each hour. Suppliers are then tested in order, starting with the three largest suppliers. In each iteration of the test, the two largest suppliers adjusted by the ~~benefits~~ RRTS ~~factors~~ of the offered resources and the resource specific performance scores are combined with a third supplier adjusted by the ~~benefits~~ RRTS ~~factor~~ of the offered resource and the resource specific performance score, and the resulting combined supply is subtracted from total effective supply adjusted by the ~~benefits~~ RRTS ~~factors~~ of all offered resource and their resource specific performance scores. The resulting net amount of eligible supply is divided by the regulation requirement for the hour adjusted by the resource-specific ~~benefits~~ RRTS ~~factors~~ and the resource specific performance scores (D). Where j defines the supplier being tested in combination with the two largest suppliers (initially the third largest supplier with j=3). Equation 0-1 shows the formula for the residual supply index for three pivotal suppliers (RSI3):

$$RSI3_j = \frac{\sum_{i=1}^{n} S_i - \sum_{i=1}^{2} S_i - S_j}{D}.$$

Where j=3, if RSI3j is less than or equal to 1.0, then the three suppliers are jointly pivotal and the suppliers being tested fail the three pivotal supplier test. Iterations of the test continue until the combination of the two largest suppliers and a supplier j result in RSI3j greater than 1.0. When the result of this process is that RSI3j is greater than 1.0, the remaining suppliers pass the test. Any resource owner that fails the TPS Test will be offer-capped.

- Regulating resources are offer-capped at the lesser of their cost-based or market-based regulation offer price.

- An offer-capped resource will only be offer-capped for a single hour at a time as the TPS Test is rerun for each hour of the day.

- Resource merit order price ($/MWh) = Resource regulation offers + estimated resource opportunity cost per MWh ~~of capability~~both ~~-~~adjusted by the resource-specific ~~benefits~~ RRTS ~~factor -~~and the resource specific performance score.

3.2.8 Hydro Units

Since hydro units operate on a schedule and do not have an energy bid, opportunity cost for these units is calculated as follows:

- During those hours when a hydro unit is in spill, the ED value is set to zero such that the opportunity cost is based on the full value of LMP. During the operating day, the operating company is responsible for communicating this condition to the PJM Scheduling Coordinator, and indicating this condition on the Regulation Updates page of the Markets Gateway System.

- If a hydro unit is committed day-ahead with MW greater than zero, the formula is the same as Section 3.2.7.Regulation Market Clearing and Dispatch above, except the ED value is an average of the LMP at the hydro unit bus for the appropriate on-peak (0700 - 2259) or off-peak (0000 – 0659, 2300 - 2359) period, excluding those hours during which all available units at the hydro plant were operating. If this average LMP value is higher than the actual LMP at the generator bus, the opportunity cost is zero. Day-ahead LMPs are used for the purpose of estimating opportunity costs for hydro units, and actual LMPs are used in the lost opportunity costs for settlement.

- If a hydro unit is brought on out of schedule to provide regulation or not committed in day-ahead market with MWs greater than 0, the opportunity cost is equal to the average LMP (calculated as stated above) minus the actual LMP at the generator bus. If the actual LMP is higher than the average, the opportunity cost is zero.

- When determined to be economically beneficial, PJM maintains the authority to adjust hydro unit schedules for those units scheduled by the owner if the owner has also submitted a regulation offer for those units and made the units available for regulation.

- An example of Regulation Hydro Lost Opportunity Cost Calculations can be found on the PJM website at http://pjm.com/~/media/markets-ops/ancillary/regulation-uplift-and-lost-opportunity-cost.ashx

3.2.9 Regulation Market Operations

The PJM Operator periodically evaluates the set of resources providing regulation, and makes any adjustments to regulation assignments deemed necessary and appropriate to minimize the overall cost of regulation.

In the event of a regulation excess, the PJM dispatcher ~~deselects~~ de-assign resources beginning with the highest cost resource currently providing regulation and moving downward.

In the event of a regulation deficiency, the PJM dispatcher uses the Intermediate-Term Security Constrained Economic Dispatch (IT SCED) application to select resources to provide regulation beginning with the lowest cost resource currently not providing regulation and moving upward.

The RMCP and therefore RMPCP and RMCCP may change based upon regulating resource adjustments made in real time. Any opportunity costs that exceed the RMCP are credited after the fact on a resource-specific basis.

The PJM Energy Management System (EMS) will send a RTO based signal(s) to each Local Control Center (LCC), as well as signals to individual resources or plants as requested by the owner.

The PJM Operator communicates any change in resource regulating assignments to individual Local Control Centers. Company total in-service regulating capabilities are then telemetered back to the PJM EMS via the PJM data link.

Resource regulation assignment changes during transitions between on-peak and off-peak periods begin 30 minutes prior to the new period, and are completed no later than 30 minutes after the period begins.

For a dual qualified regulation resource, should the assignment change within the operating hour, the resource will continue to be committed or re-committed on the regulation signal type that the resource was initially committed on.

3.2.10 Settlements

Please refer to Manual 28: Operating Agreement Accounting, Section 4: Regulation Accounting for settlement details.

Regulation settlement is a zero-sum calculation based on the regulation provided to the market by generation owners and purchased from the market by LSEs.

A resource's regulation performance score for the hour or the portion of the hour it is regulating will determine the resource's eligibility for regulation credit and lost opportunity cost for that hour. A resource whose performance score for the hour or the portion of the hour is below 25% will forfeit regulation credit and Lost Opportunity for that hour.

Opportunity cost is calculated as shown above in Section 3.2.7 Market Clearing and Dispatch using actual integrated LMPs as opposed to that which was forecasted. PJM then adjusts the opportunity cost calculated for each resource based on the actual hourly integrated value of the real-time PJM regulation signal to account for the fact that the resource may have been held above or below its regulation set point for greater than half the hour and also adjusted by the resource-specific ~~benefits~~ RRTS ~~factor~~ and the resource specific performance score. Energy resources that are self-scheduled to provide energy and do not supply an energy offer are not eligible to collect opportunity cost credits.

For market settlement, regulating~~These~~ resources will receive credit equal to the RMPCP and RMCCP times the amount of regulation self-scheduled on or assigned to them adjusted by the ~~mileage ratio~~ Regulation Marginal Rate of Technical Substitution (RMRTS)~~n, if applicable between the requested mileage for the regulation dispatch signal assigned to the resource and the mileage for the traditional regulation signal~~ and the resource's actual performance score for an hour. This means that all resources, either RegA or RegD, are paid the same price per marginal effective MW provided.

~~For market settlement, regulating resources are compensated with consideration toward the resource's Regulation performance, and where applicable, the mileage ratio between the requested mileage for the regulation dispatch signal assigned to the resource and the mileage for the traditional regulation signal.~~