

PJM/IMM Proposed Changes to Regulation Market
April 27, 2017
Markets and Reliability Committee Meeting

Proposed New Definitions

Regulation Rate of Technical Substitution Curve: The “Regulation Rate of Technical Substitution Curve” shall mean a function that defines the operational relationship between traditional and dynamic Regulation resources utilized to meet the Regulation Requirement. The Regulation Rate of Technical Substitution Curve is calculated in accordance with the PJM Manuals.

Regulation Rate of Technical Substitution: The “Regulation Rate of Technical Substitution” shall mean a value along the Regulation Rate of Technical Substitution Curve that translates a dynamic Regulation resource into a traditional Regulation resource. The Regulation Rate of Technical Substitution is calculated in accordance with the PJM Manuals.

Regulation Marginal Rate of Technical Substitution: The “Regulation Marginal Rate of Technical Substitution” shall mean the Regulation Rate of Technical Substitution assigned to the last dynamic Regulation resource committed to provide Regulation service in a given hour.

Regulation Requirement: The “Regulation Requirement” shall mean the calculated Regulation Effective Megawatts required to be maintained in a Regulation Zone, absent any increase to account for additional Regulation scheduled to address operational uncertainty. The Regulation Requirement is defined in accordance with the PJM Manuals.

Regulation Effective Megawatts: “Regulation Effective Megawatts” shall equal the area under the Regulation Rate of Technical Substitution Curve given 1) the amount of Regulation that a resource is providing in a given hour, 2) the resource’s historic performance score, and 3) the resource’s Regulation Rate of Technical Substitution.

Regulation Signal: The Regulation control signals are utilized to optimize system control and maintain reliability by minimizing Area Control Error. The traditional control signal and dynamic control signal are developed with consideration to each resources limitations, when possible, while still minimizing Area Control Error and are further set forth in the PJM Manuals.

Tariff, Schedule 3

Regulation and Frequency Response Service is necessary to provide for the continuous balancing of resources with load and for maintaining scheduled Interconnection frequency at sixty cycles per second (60 Hz). Regulation and Frequency Response Service is accomplished by committing on-line resources whose output is raised or lowered (predominantly through the use of automatic generating control equipment) and by other non-generation resources capable of providing this service as necessary to follow the moment-by-moment changes in load.

Regulation control signals are utilized to optimize system control and maintain reliability by minimizing Area Control Error. The traditional control signal and dynamic control signal are further described in the PJM Manuals, and consider each resource's operational limitations, when possible, while still minimizing Area Control Error.

The obligation to maintain this balance between resources and load lies with the Transmission Provider. The Transmission Provider must offer this service when the transmission service is used to serve load within its Control Area. The Transmission Customer must either purchase this service from the Transmission Provider or make alternative comparable arrangements to satisfy its Regulation and Frequency Response Service obligation. The Transmission Provider will take into account the speed and accuracy of Regulation resources in its determination of Regulation and Frequency Response reserve requirements, including as it reviews whether a self-supplying Transmission Customer has made alternative comparable arrangements. Upon request by the self-supplying Transmission Customer, the Transmission Provider will share with the Transmission Customer its reasoning and any related data used to make the determination of whether the Transmission Customer has made alternative comparable arrangements. The amount of and charges for Regulation and Frequency Response Service are set forth below. The Transmission Provider shall administer the purchases of Regulation Service in the PJM Interchange Energy Market. PJMSettlement shall be the Counterparty to the purchases by customers of Regulation Service in the PJM Interchange Energy Market; provided however, that PJMSettlement shall not be the contracting party to bilateral transactions between market participants or with respect to a self-schedule or self-supply of resources by a customer to satisfy its Regulation obligation.

Tariff, Attachment K-Appendix and Operating Agreement, Schedule 1

3.2.2 Regulation.

(a) Each Internal Market Buyer that is a Load Serving Entity in a Regulation Zone shall have an hourly Regulation objective equal to its pro rata share of the Regulation requirements of such Regulation Zone for the hour, based on the Internal Market Buyer's total load (net of operating Behind The Meter Generation, but not to be less than zero) in such Regulation Zone for the hour ("Regulation Obligation"). An Internal Market Buyer that does not meet its hourly Regulation obligation shall be charged the following for Regulation dispatched by the Office of the Interconnection to meet such obligation: (i) the capability Regulation

market-clearing price determined in accordance with subsection (h) of this section; (ii) the amounts, if any, described in subsection (f) of this section; and (iii) the performance Regulation market-clearing price determined in accordance with subsection (g) of this section.

(b) Each Market Seller and Generating Market Buyer shall be credited for each of its resources supplying Regulation in a Regulation Zone at the direction of the Office of the Interconnection such that the calculated credit for each increment of Regulation provided by each resource shall be the higher of: (i) the Regulation market-clearing price; or (ii) the sum of the applicable Regulation offers for a resource determined pursuant to Section 3.2.2A.1 of this Schedule, the unit-specific shoulder hour opportunity costs described in subsection (e) of this section, the unit-specific inter-temporal opportunity costs, and the unit-specific opportunity costs discussed in subsection (d) of this section.

(c) The total Regulation market-clearing price in each Regulation Zone shall be determined at a time to be determined by the Office of the Interconnection which shall be no earlier than the day before the Operating Day. In accordance with the PJM Manuals, the total Regulation market-clearing price shall be calculated by optimizing the dispatch profile to obtain the lowest cost combination set of resources that satisfies the Regulation ~~R~~requirement. The market-clearing price for each regulating hour shall be equal to the average of all 5-minute clearing prices calculated during that hour. The total Regulation market-clearing price shall include: (i) the performance Regulation market-clearing price in a Regulation Zone that shall be calculated in accordance with subsection (g) of this section; (ii) the capability Regulation market-clearing price that shall be calculated in accordance with subsection (h) of this section; and (iii) a Regulation resource's unit-specific opportunity costs during the 5-minute period, determined as described in subsection (d) below, divided by the unit-specific ~~benefits factor~~Regulation Rate of Technical Substitution, described in subsection (k) of this section and divided by the historic ~~accuracy-performance~~ score of the resource from among the resources selected to provide Regulation. A resource's Regulation offer by any Market Seller that fails the three-pivotal supplier test set forth in section 3.2.2A.1 of this Schedule shall not exceed the cost of providing Regulation from such resource, plus twelve dollars, as determined pursuant to the formula in section 1.10.1A(e) of this Schedule.

(d) In determining the Regulation 5-minute clearing price for each Regulation Zone, the estimated unit-specific opportunity costs of a generation resource offering to sell Regulation in each regulating hour, except for hydroelectric resources, shall be equal to the product of (i) the deviation of the set point of the generation resource that is expected to be required in order to provide Regulation from the generation resource's expected output level if it had been dispatched in economic merit order times, (ii) the absolute value of the difference between the expected Locational Marginal Price at the generation bus for the generation resource and (a) for offline resources that will be brought online solely for regulation, the lesser-cheapest of the available market-based or ~~highest-available~~-cost-based energy schedules energy offer from the generation resource ~~(at the megawatt level of the Regulation set point for the resource)~~ in the PJM Interchange Energy Market or (b) for online resources, the schedule on which the resource was committed for energy.

For hydroelectric resources offering to sell Regulation in a regulating hour, the estimated unit specific opportunity costs for each hydroelectric resource in spill conditions as defined in the PJM Manuals will be the full value of the Locational Marginal Price at that generation bus for each megawatt of Regulation capability.

The estimated unit-specific opportunity costs for each hydroelectric resource that is not in spill conditions as defined in the PJM Manuals and has a day-ahead megawatt commitment greater than zero shall be equal to the product of (i) the deviation of the set point of the hydroelectric resource that is expected to be required in order to provide Regulation from the hydroelectric resource's expected output level if it had been dispatched in economic merit order times (ii) the difference between the expected Locational Marginal Price at the generation bus for the hydroelectric resource and the average of the Locational Marginal Price at the generation bus for the appropriate on-peak or off-peak period as defined in the PJM Manuals, excluding those hours during which all available units at the hydroelectric resource were operating. Estimated opportunity costs shall be zero for hydroelectric resources for which the average Locational Marginal Price at the generation bus for the appropriate on-peak or off-peak period, excluding those hours during which all available units at the hydroelectric resource were operating is higher than the actual Locational Marginal Price at the generator bus for the regulating hour.

The estimated unit-specific opportunity costs for each hydroelectric resource that is not in spill conditions as defined in the PJM Manuals and does not have a day-ahead megawatt commitment greater than zero shall be equal to the product of (i) the deviation of the set point of the hydroelectric resource that is expected to be required in order to provide Regulation from the hydroelectric resource's expected output level if it had been dispatched in economic merit order times (ii) the difference between the average of the Locational Marginal Price at the generation bus for the appropriate on-peak or off-peak period as defined in the PJM Manuals, excluding those hours during which all available units at the hydroelectric resource were operating and the expected Locational Marginal Price at the generation bus for the hydroelectric resource. Estimated opportunity costs shall be zero for hydroelectric resources for which the actual Locational Marginal Price at the generator bus for the regulating hour is higher than the average Locational Marginal Price at the generation bus for the appropriate on-peak or off-peak period, excluding those hours during which all available units at the hydroelectric resource were operating.

For the purpose of committing resources and setting Regulation market clearing prices, the Office of the Interconnection shall utilize day-ahead Locational Marginal Prices to calculate opportunity costs for hydroelectric resources. For the purposes of settlements, the Office of the Interconnection shall utilize the real-time Locational Marginal Prices to calculate opportunity costs for hydroelectric resources.

Estimated opportunity costs for Demand Resources to provide Regulation are zero.

(e) In determining the credit under subsection (b) to a Market Seller or Generating Market Buyer selected to provide Regulation in a Regulation Zone and that actively follows the Office of the Interconnection's Regulation signals and instructions, the unit-specific opportunity cost of a generation resource shall be determined for each hour that the Office of the Interconnection requires a generation resource to provide Regulation, and for the percentage of the preceding

shoulder hour and the following shoulder hour during which the Generating Market Buyer or Market Seller provided Regulation. The unit-specific opportunity cost incurred during the hour in which the Regulation obligation is fulfilled shall be equal to the product of (i) the deviation of the generation resource's output necessary to follow the Office of the Interconnection's Regulation signals from the generation resource's expected output level if it had been dispatched in economic merit order times (ii) the absolute value of the difference between the Locational Marginal Price at the generation bus for the generation resource and ~~the lesser of the available market based or highest available cost based energy offer from the generation resource~~ the schedule on which the resource was committed at the actual megawatt level of the resource when the actual megawatt level is within the tolerance defined in the PJM Manuals for the Regulation set point, or at the Regulation set point for the resource when it is not within the corresponding tolerance in the PJM Interchange Energy Market. Opportunity costs for Demand Resources to provide Regulation are zero.

The unit-specific opportunity costs associated with uneconomic operation during the preceding shoulder hour shall be equal to the product of (i) the deviation between the set point of the generation resource that is expected to be required in the initial regulating hour in order to provide Regulation and the resource's expected output in the preceding shoulder hour times (ii) the absolute value of the difference between the Locational Marginal Price at the generation bus for the generation resource in the preceding shoulder hour and ~~the lesser of the available market based or highest available cost based energy offer from the generation resource~~ the schedule on which the resource was committed at the megawatt level of the Regulation set point for the resource in the initial regulating hour in the PJM Interchange Energy Market times (iii) the percentage of the preceding shoulder hour during which the deviation was incurred, all as determined by the Office of the Interconnection in accordance with procedures specified in the PJM Manuals.

The unit-specific opportunity costs associated with uneconomic operation during the following shoulder hour shall be equal to the product of (i) the deviation between the set point of the generation resource that is expected to be required in the final regulating hour in order to provide Regulation and the resource's expected output in the following shoulder hour times (ii) the absolute value of the difference between the Locational Marginal Price at the generation bus for the generation resource in the following shoulder hour and ~~the lesser of the available market based or highest available cost based energy offer from the generation resource~~ the schedule on which the resource is committed at the megawatt level of the Regulation set point for the resource in final regulating hour in the PJM Interchange Energy Market times (iii) the percentage of the following shoulder hour during which the deviation was incurred, all as determined by the Office of the Interconnection in accordance with procedures specified in the PJM Manuals.

(f) Any amounts credited for Regulation in an hour in excess of the Regulation market-clearing price in that hour shall be allocated and charged to each Internal Market Buyer in a Regulation Zone that does not meet its hourly Regulation obligation in proportion to its purchases of Regulation in such Regulation Zone in megawatt-hours during that hour.

(g) To determine the ~~performance~~-Regulation market performance-clearing price for the each

Regulation Zone, the Office of the Interconnection shall adjust the submitted performance offer for each resource in accordance with the historical performance of that resource, the amount of Regulation that resource will be dispatched based on the ratio of control signals calculated by the Office of the Interconnection, and the unit-specific Regulation Rate of Technical Substitution benefits factor described in subsection (kj) of this section for which that resource is qualified. The maximum adjusted performance offer of all cleared resources will set the performance Regulation market performance-clearing price.

The owner of each Regulation resource that actively follows the Office of the Interconnection's Regulation signals and instructions, will be credited for Regulation performance by multiplying the assigned MW(s) by the performance Regulation market performance-clearing price, by the Regulation Marginal Rate of Technical Substitution ratio between the requested mileage for the Regulation dispatch signal assigned to the Regulation resource and the Regulation dispatch signal assigned to traditional resources, and by the Regulation resource's accuracy performance score calculated in accordance with subsection (lk) of this section.

(h) The Office of the Interconnection shall divide each Regulation resource's capability offer by the unit-specific Regulation Rate of Technical Substitution benefits factor described in subsection (jk) of this section and also divided by the historic accuracy performance score of for the resource for the purposes of committing resources and setting the market clearing prices. The Office of the Interconnection shall calculate the capability Regulation market capability-clearing price for the each Regulation Zone by subtracting the performance Regulation market performance-clearing price described in subsection (g) from the total Regulation market clearing price described in subsection (c). This residual sets the capability Regulation market capability-clearing price for that market hour. The owner of each Regulation resource that actively follows the Office of the Interconnection's Regulation signals and instructions will be credited for Regulation capability based on the assigned MW and the capability Regulation market capability-clearing price multiplied by the Regulation Marginal Rate of Technical Substitution, and the Regulation resource's accuracy performance score calculated in accordance with subsection (kl) of this section.

(i) In accordance with the processes described in the PJM Manuals, the Office of the Interconnection shall: (i) calculate inter-temporal opportunity costs for each applicable resource; (ii) include such inter-temporal opportunity costs in each applicable resource's offer to sell frequency Regulation service; and (iii) account for such inter-temporal opportunity costs in the Regulation market-clearing price.

(j) As further detailed in PJM Manuals, the Regulation Rate of Technical Substitution Curve shall be calculated using engineering models to determine the combinations of the dynamic Regulation signal and traditional Regulation signal that provide equivalent system control.

(jk) The Office of the Interconnection shall calculate a unit-specific benefits factor Regulation Rate of Technical Substitution for each resource assigned to the of the dynamic Regulation signal and the traditional Regulation signal based on their order in the merit order stack for the applicable Regulation signal, in accordance with the PJM Manuals. Each resource shall be assigned a unit-specific Regulation Rrate of Ttechnical Ssubstitution benefits factor based on

~~their order in the merit order stack for the applicable Regulation signal.~~ The unit-specific Regulation Rate of Technical Substitution benefits factor is the point on the Regulation Rate of Technical Substitution benefits factor Curve that aligns with the last megawatt, adjusted by historical performance, that resource will add to the dynamic resource stack. The unit-specific Regulation Rate of Technical Substitution benefits factor for the traditional Regulation signal shall be equal to one.

(k) The Office of the Interconnection shall calculate each Regulation resource's performance accuracy score. The performance accuracy score shall be calculated as a function of the difference in the energy provided by the Regulation resource versus the energy requested by the Regulation signal. For each interval in which a resource is assigned Regulation, PJM calculates the performance score in accordance with the following equation:

Error

$$= \text{MIN}_{t_0-t_{10}} \left(\text{Avg of Abs} \left| \frac{(\text{Response} - \text{Regulation Signal})}{0.5 * \text{Hourly Average Regulation Signal} + 0.5 * \text{Assigned Regulation (MW)}} \right. \right)$$

$$\text{Performance Score} = 1 - \frac{1}{n} \sum |Error|$$

~~the average of a delay score, correlation score, and energy score for each ten second interval. For purposes of setting the interval to be used for the correlation score and delay scores, PJM will use the maximum of the correlation score plus the delay score for each interval.~~

~~The Office of the Interconnection shall calculate the correlation score using the following statistical correlation function (r) that measures the delay in response between the Regulation signal and the resource change in output:~~

$$\text{Correlation Score} = r_{\text{Signal,Response}(\delta, \delta+5 \text{ Min})};$$

$\delta=0 \text{ to } 5 \text{ Min}$

~~where δ is delay.~~

~~The Office of the Interconnection shall calculate the delay score using the following equation:
Delay Score = Abs(($\delta - 5 \text{ Minutes}$) / (5 Minutes)).~~

~~The Office of the Interconnection shall calculate a energy score as a function of the difference in the energy provided versus the energy requested by the Regulation signal while scaling for the number of samples. The energy score is the absolute error (e) as a function of the resource's Regulation capacity using the following equations:~~

$$\text{Energy Score} = 1 - 1/n \sum \text{Abs}(\text{Error});$$

$$\text{Error} = \text{Average of Abs} ((\text{Response} - \text{Regulation Signal}) / (\text{Hourly Average Regulation$$

Signal)); and
n = the number of samples in the hour and the energy.

~~The Office of the Interconnection shall calculate an accuracy score for each Regulation resource that is the average of the delay score, correlation score, and energy score for a five-minute period using the following equation where the energy score, the delay score, and the correlation score are each weighted equally:~~

~~Accuracy Score = max ((Delay Score) + (Correlation Score)) + (Energy Score).~~

The historic accuracy performance score will be based on a rolling average of the hourly accuracy performance scores, with consideration of the qualification score, as defined in the PJM Manuals.

3.2.2A Offer Price Caps.

3.2.2A.1 Applicability.

(b) For the purposes of conducting the three-pivotal supplier test pursuant to this section, the following applies:

(i) The three-pivotal supplier test will include in the definition of available supply all offers from resources capable of satisfying the Regulation ~~R~~ requirement of the PJM Region multiplied by the historic accuracy score of the resource and multiplied by the unit-specific ~~benefits factor~~ Regulation Rate of Technical Substitution for which the capability cost-based offer plus the performance cost-based offer plus any eligible opportunity costs is no greater than 150 percent of the clearing price that would be calculated if all offers were limited to cost (plus eligible opportunity costs).