Generation Initial Training Program

PJM Regulation Market

PJM State & Member Training Dept.

Objectives

Students will be able to:

- Identify the process and procedures for participating in the Real-Time Regulation Market

What is Regulation?

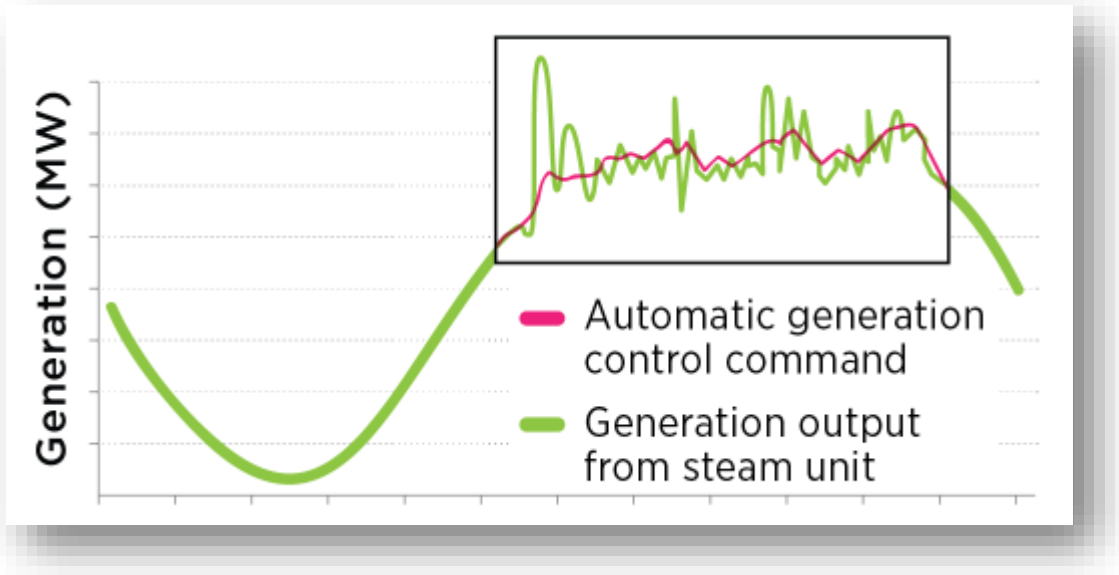
- Reliability product that corrects for short-term changes in electricity use that might affect stability of power system
- Variable amount of generation under automatic control obtainable within 5 minutes
- Main goal is to keep system's area control error, also called ACE, within acceptable bounds
- ACE is difference between scheduled and actual electrical generation, accounting for variations in system's frequency

- Necessary to provide for continuous balancing of resources (generation and interchange) with load and for maintaining scheduled Interconnection frequency at 60 cycles/ second (60 Hz)
- PJM commits on-line resources whose output is raised or lowered as necessary to follow moment-to-moment changes in load
- Regulation is predominantly achieved using automatic generation control equipment
- Regulating resources include both generators and demand side response resources

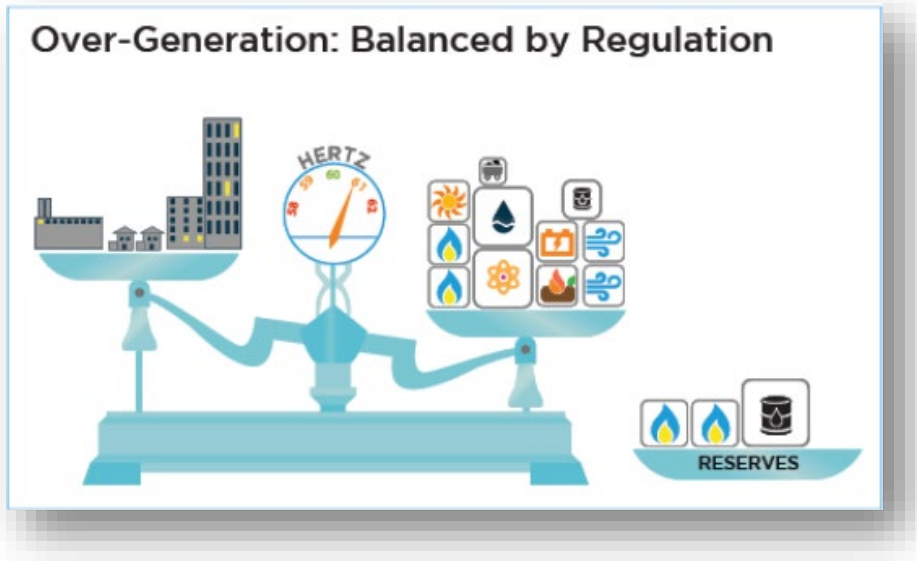
Regulation

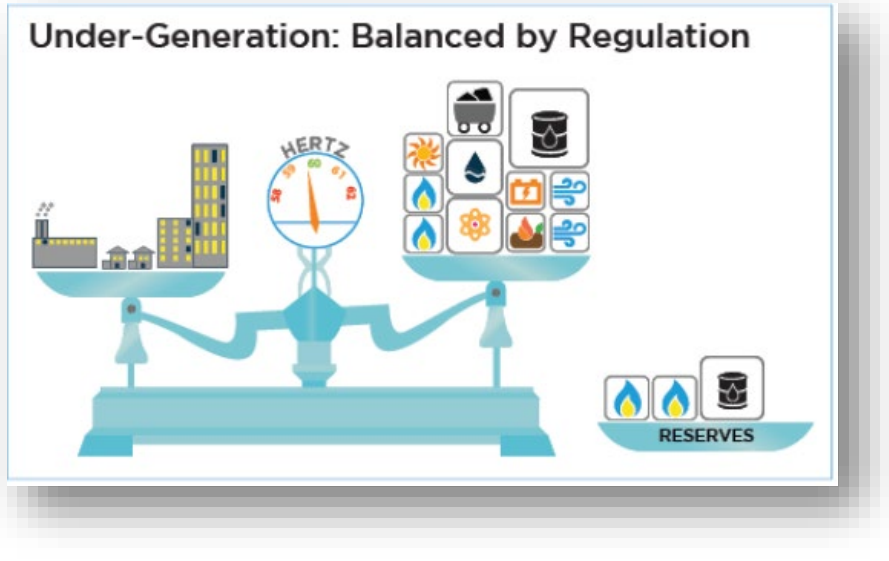
Regulation helps match generation and demand to keep grid functioning normally by …

- Maintaining system frequency of 60 Hertz
- Tracking moment-to-moment fluctuations in customer electricity use
- Correcting for unintended fluctuations in generation (such as a large generating unit disconnecting from the system)
- Managing differences between forecasted or scheduled power flow and actual power flow on system



Balancing Generation & Load





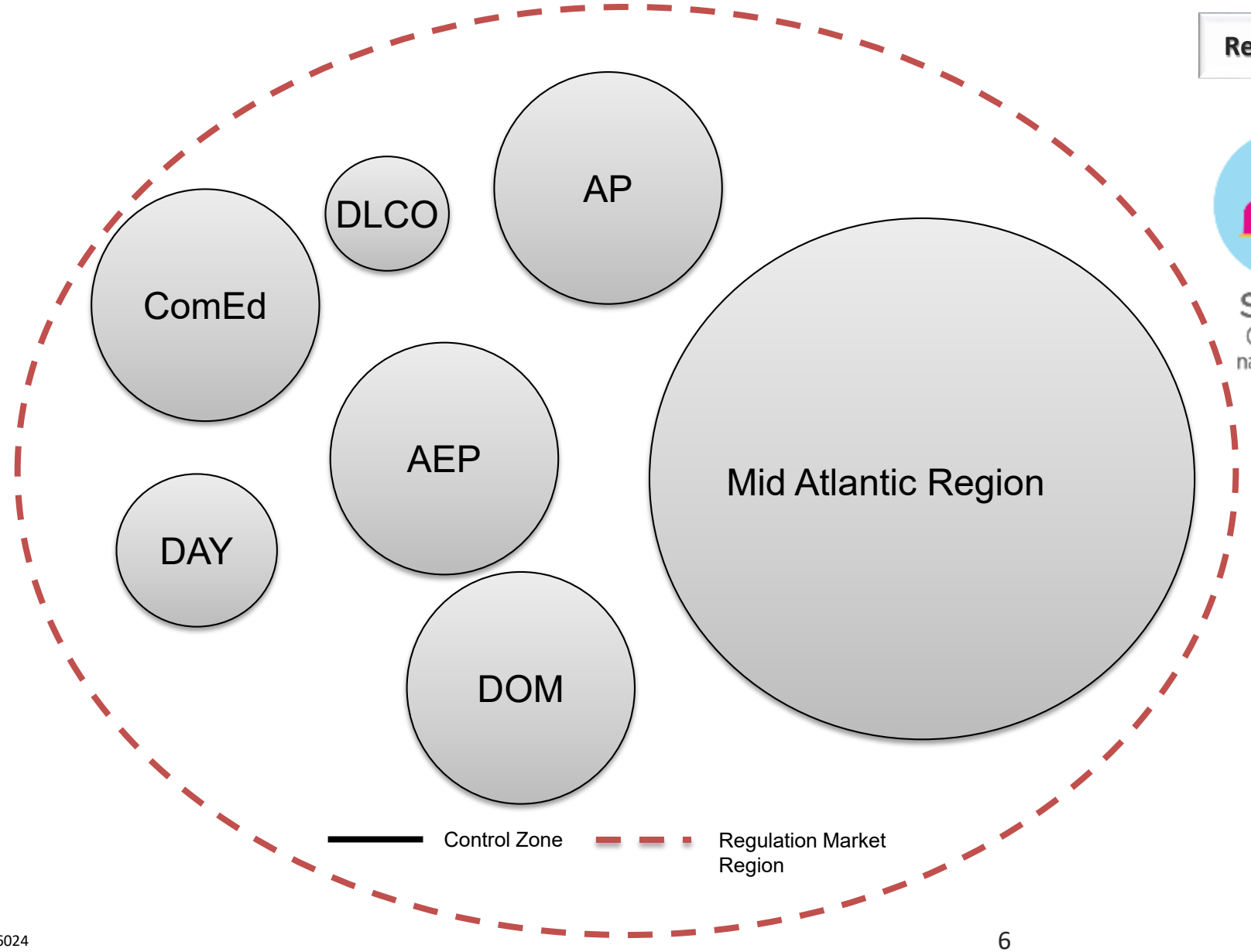
Over-Generation

- Total Generation > Total Demand
- Frequency > 60 Hertz
- Generators momentarily speed up

Under-Generation

- Total Generation < Total Demand
- Frequency < 60 Hertz
- Generators momentarily slow down

Single Regulation Market Region



Resources Types that Participate in Regulation Market

Steam
(coal and natural gas)

Combustion Turbines (natural gas oil, methane and biomass)

Hydro

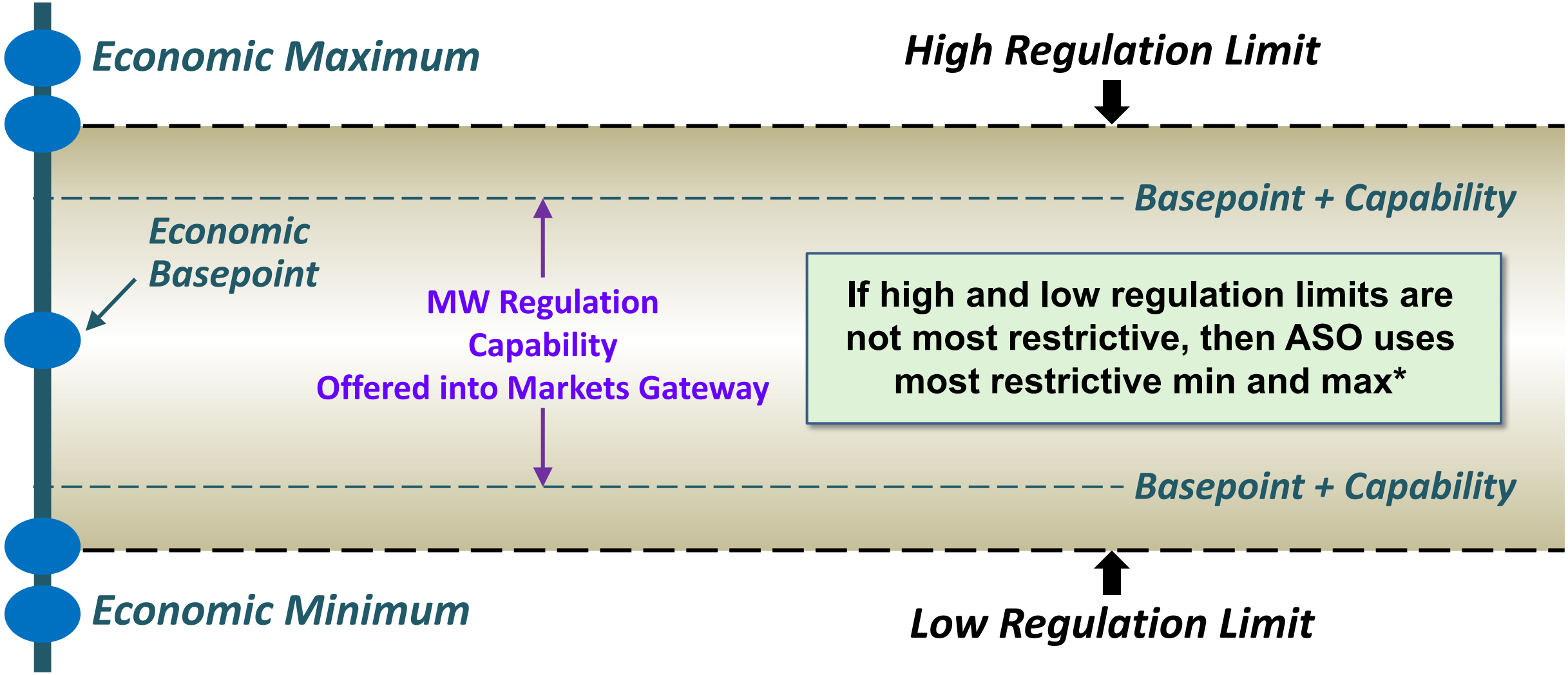
Storage
(batteries, flywheels and hot water heaters)

Demand Response

Characteristic Differences Between Resources

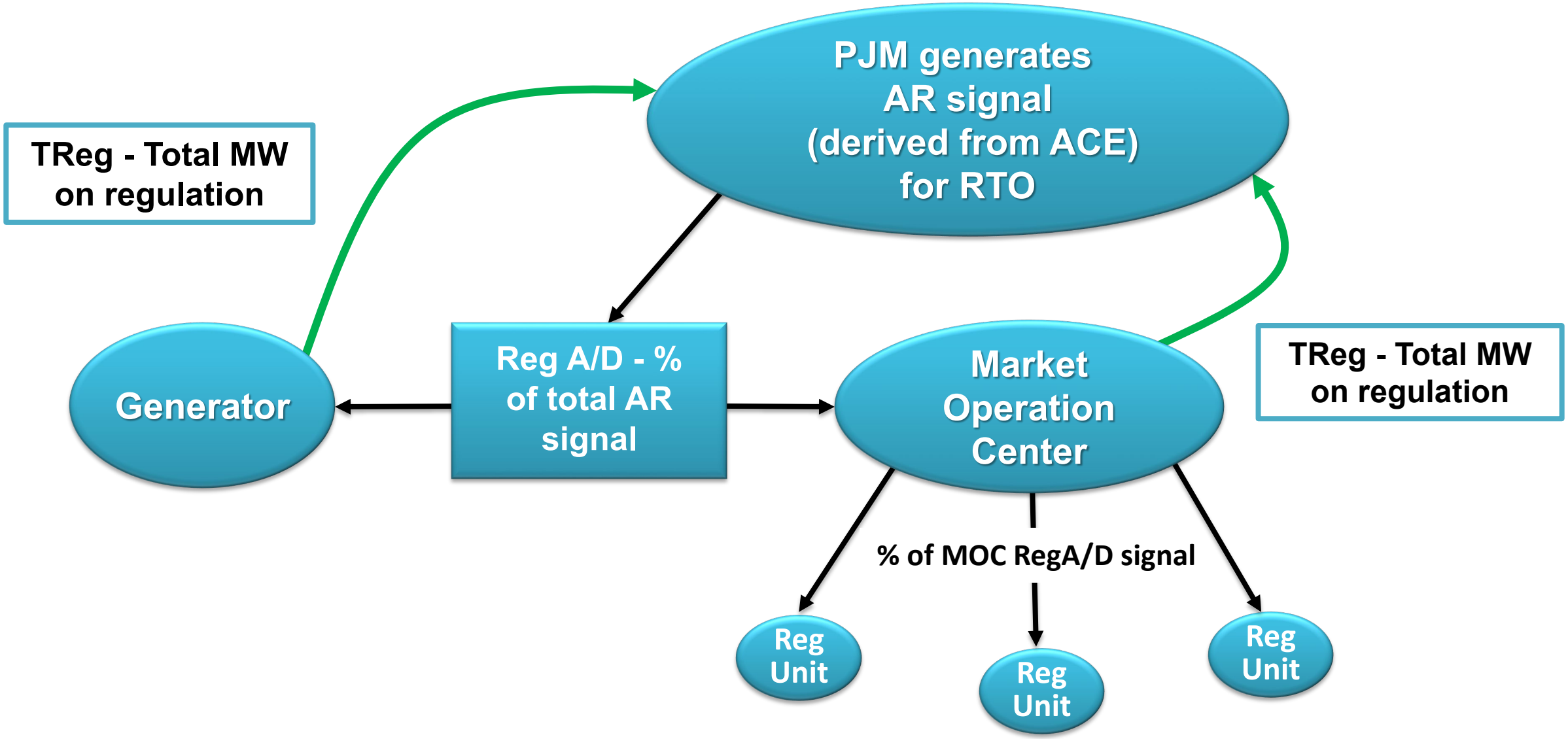
- **Ramp-Limited Resources**
  - Examples include Steam, Combustion Turbine (CT), Combined Cycle (CC), Hydroelectric Dams
  - Fuel-burning results in hours of operation at all deployment levels (sustain full raise/lower)
  - Energy output rate-of-change limited by mechanical processes
  - Operates on Traditional Regulation Signal
- **Energy-Limited Resources**
  - Examples include Batteries and Flywheels
  - Sub-second matching of control signal (infinite ramp rate)
  - Energy output determined by state of charge, storage capacity
  - Operates on Dynamic Regulation Signal

Band of Regulation for Generator



* Band of regulation must fall within the economic limits of the generating unit

Regulation in Real-Time Operations



Regulation Requirement

Season	Dates	Non-Ramp Hours	Ramp Hours	Effective MW Requirement
Winter	Dec 1 – Feb 29	HE1 – HE4, HE10 – HE16	HE5 – HE9, HE17 – HE24	Non-Ramp = 525MW Ramp = 800MW
Spring	Mar 1 – May 31	HE1 – HE5, HE9 – HE17	HE6 – HE8, HE18 – HE24	Non-Ramp = 525MW Ramp = 800MW
Summer	Jun 1 – Aug 31	HE1 – HE5, HE15 – HE18	HE6 – HE14, HE19 – HE24	Non-Ramp = 525MW Ramp = 800MW
Fall	Sep 1 – Nov 30	HE1 – HE5, HE9 – HE17	HE6 – HE8, HE18 – HE24	Non-Ramp = 525MW Ramp = 800MW

Market-Based Regulation

- Creates market for regulation
- Provides Market Clearing Prices for regulation
- Protects supplier by providing opportunity cost of energy
- Provides more incentive to provide regulation
- LSE Obligation

- Hourly Regulation obligations are determined after-the-fact, based on LSE's total real time hourly load
- LSEs can estimate their share of PJM Regulation Requirement in advance by comparing their hourly load forecast to PJM hourly load forecasts provided by PJM

LSEs can meet their obligation to provide regulation to grid by …

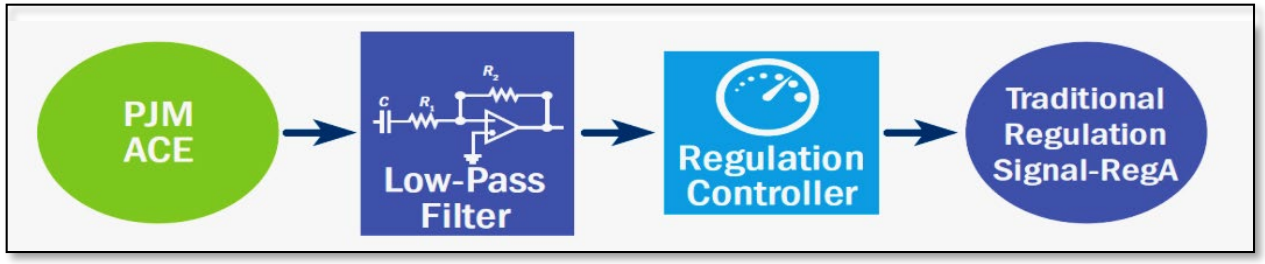
- Self-scheduling own generation
- Purchasing required regulation under contract with another party
- Purchasing from PJM Regulation Market

Fulfilling Obligation: Bilateral Transactions

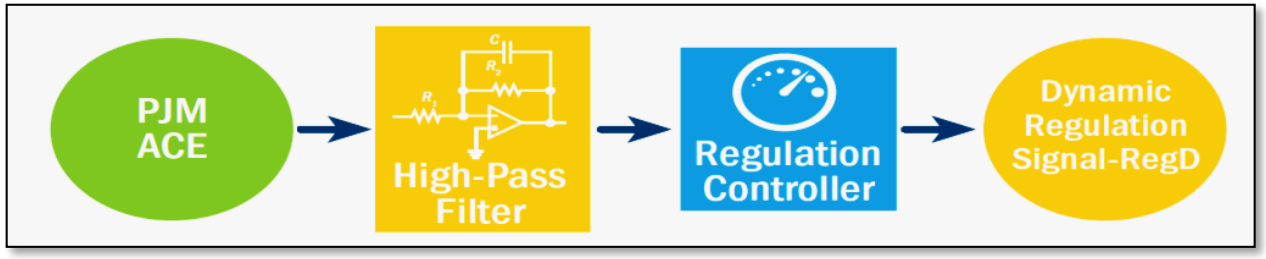
- Entered by Buyer using Markets Gateway
  - Entered as a MW amount to be transacted
- Confirmed by Seller in Markets Gateway
- Data entered and confirmed no later than 13:30 the day after the transaction starts
  - Transaction that have been reported and confirmed may not be changed; they must be deleted and re-reported
  - Deletion of a reported transaction after its start time has passed will result in a change in the end time to the current hour
  - Confirmation after 13:30 will default the transaction to starting the day of confirmation

Regulation Signals

- **Traditional Regulation Signal (REGA)***
  - A function of slow filter of RTO Area Control Error (ACE)
  - Can remain full raise or lower for extended periods

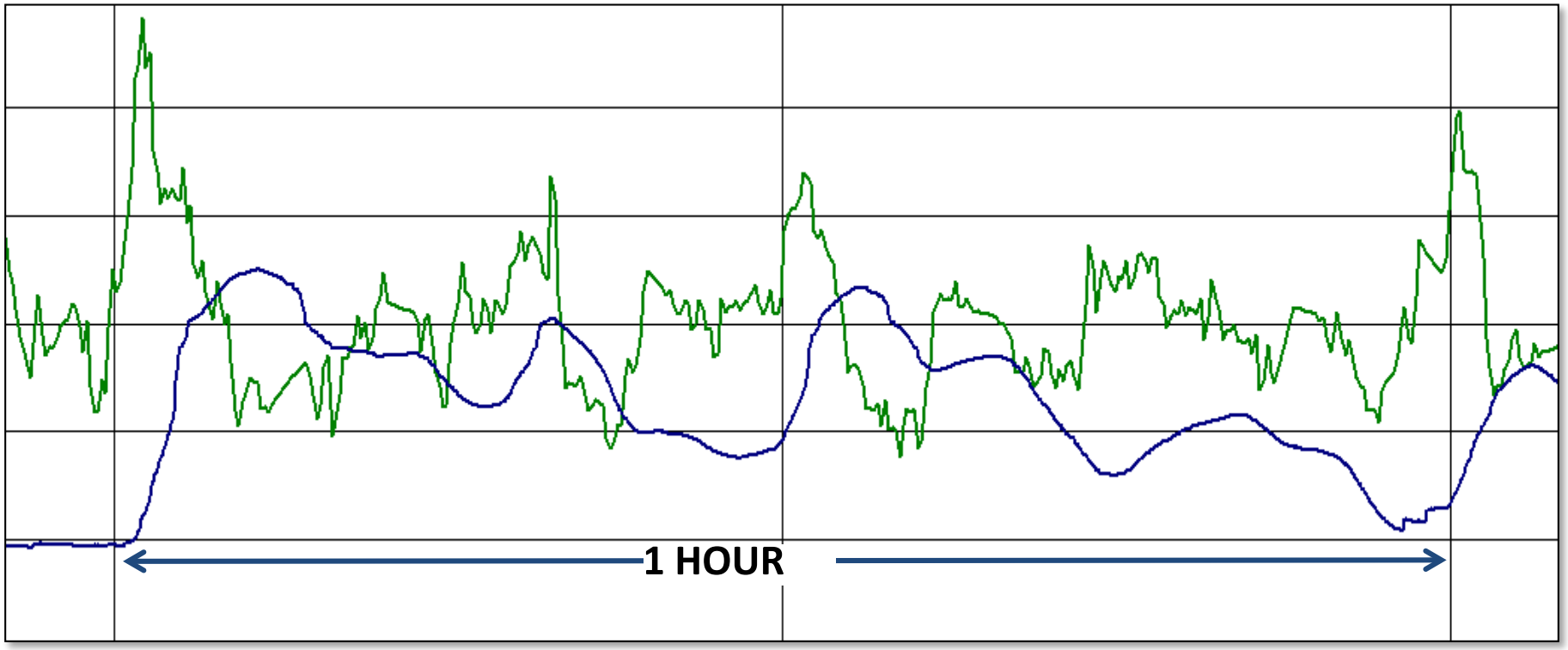


- **Dynamic Regulation Signal (REGD)***
  - A function of fast filter of RTO ACE



* Which signal the resource operates on is determined by how the company operates the resource

Regulation Signals



RegA (blue) – fleet level regulation signal sent by PJM to ramp-limited resources

RegD (green) – fleet level regulation signal sent by PJM to fast moving units

Regulation Offer Parameters

- **Reg Type** – The regulation type (Reg A or Reg D). For a unit with both Reg A and Reg D offers, two rows will display
- **Offer MW** – The amount of regulation MW offered for the unit
  - This field is required if the unit is either Available or Self-Scheduled to provide regulation
- **Price Offer** – Cannot be more than $100/MW total
  - **Capability Offer Price** – resource owner's price to reserve MWs for regulation in $/MW
  - **Performance Offer Price** – $/ΔMW price to provide regulation movement
    - The $/MW value determined in this step is converted to $/ΔMW by dividing the value by mileage ΔMW/MW for the applicable signal for that offer.

Regulation Cost-Based Offers

- **Cost-Based Regulation Offer** – Mandatory offer (Must Meet Manual 15 Guidelines*)
  - **Capability Offer Cost** – cost to reserve MW in $/MW
  - Must be ≤ (fuel cost increase and unit specific heat rate degradation due to operating at lower loads) + optional $12/MWh adder
  - **Performance Offer Cost** – $/ΔMW cost increase due to Heat Rate increase during non-steady state operation and Cost increase in VOM
    - The $/MW value determined in the performance offer will be converted to cost per mileage $/ΔMW by dividing the value by the mileage ΔMW/MW for the applicable signal
    - Regulation Cost Validation Spreadsheet
  - Regulation Two-Part Cost based offer
  - http://www.pjm.com/markets-and-operations/ancillary-services.aspx

*Cost offers that exceed the cost development guidelines will be rejected

Regulation Cost-Based Offers

- **Heat Rate @ Eco Max [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
  - This is an optional parameter that may be submitted in the Markets Gateway System to support the cost-based regulation offer price

- **Heat Rate @ Reg Min [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
  - This is an optional parameter that may be submitted in the Markets Gateway System to support the cost-based regulation offer price

Regulation Cost-Based Offers

- **Variable Operating and Maintenance (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.
  - This is an optional parameter that may be submitted in the Markets Gateway System to support the cost-based regulation offer price
- **Energy Storage Loss [$/MWh of Regulation]** - The value is used to account for the energy losses experienced by an energy storage device while providing regulation service
  - This field is valid only for energy storage resources

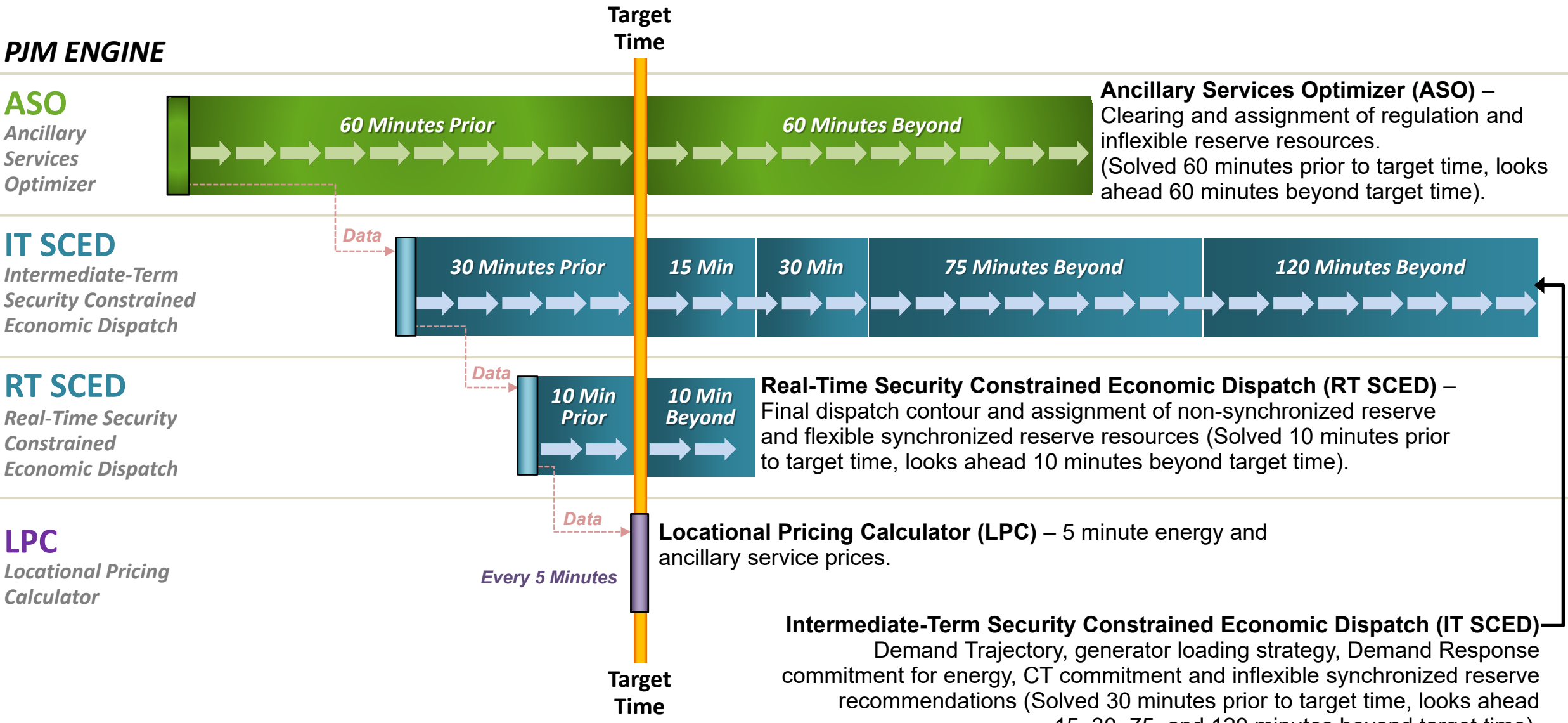
Regulation Price-Based Offer

- **Price-Based Offer** – Optional offer which cannot be more than $100/MW total
  - **Capability Offer Price** – resource owner's price to supply MWs for regulation in $/MW
  - **Performance Offer Price** – $/ΔMW price to provide regulation movement
    - Converted to $/MW by multiplying the value by the ratio of ΔMW/MW for the applicable signal for that offer

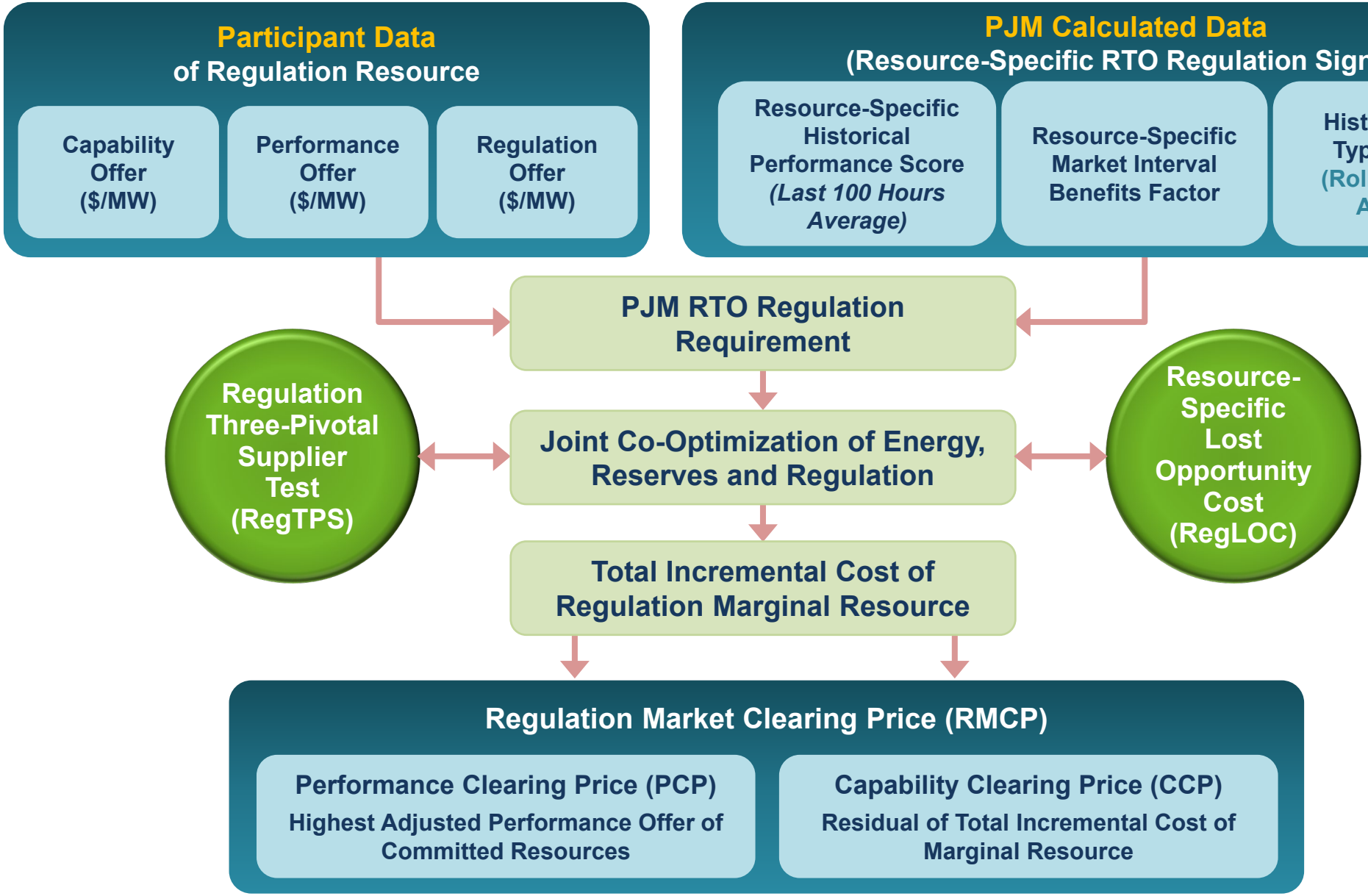
Regulation Offers

- **Eco Max MW** - Maximum generation limit when unit is providing regulation. This value is entered on the Unit Detail page and can only be edited there
- **Reg. Min MW** - Minimum generation limit when unit is providing regulation. This value is entered on the Unit Detail page and can only be edited there
- **Min Offer MW** - Minimum MW for assignment. The value should not be greater than the Offer MW
- **Available Status** - availability of unit
  - Available
  - Not Available
- **Self Scheduled** - indication the resource is self scheduled
- **Rolling Avg. Performance Score** - The average performance score for the last 100 operating hours. It is used to adjust the capability and performance offer

Market Clearing, Dispatching and Pricing Engines

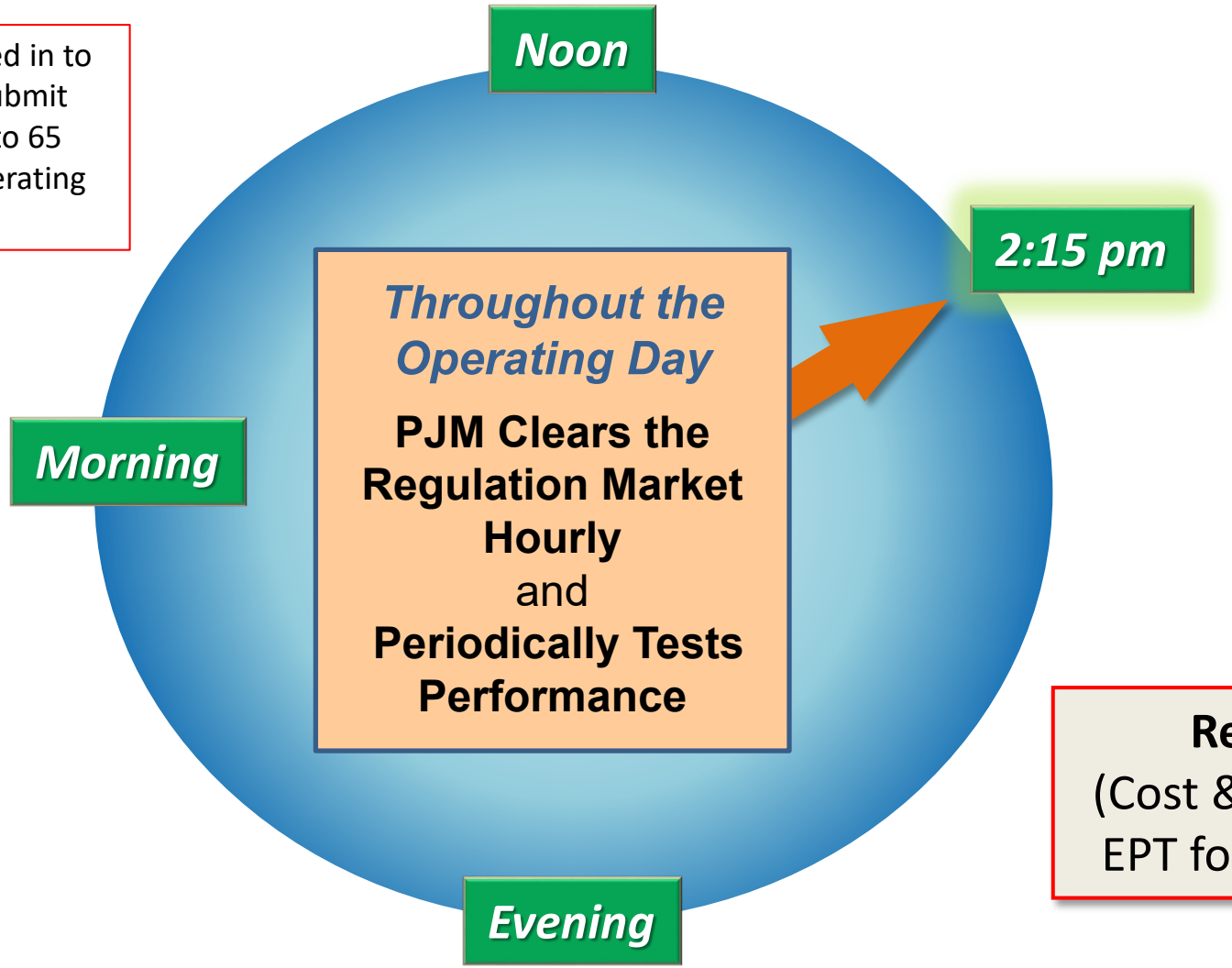


Regulation Market Clearing Process



Regulation Market Time Line

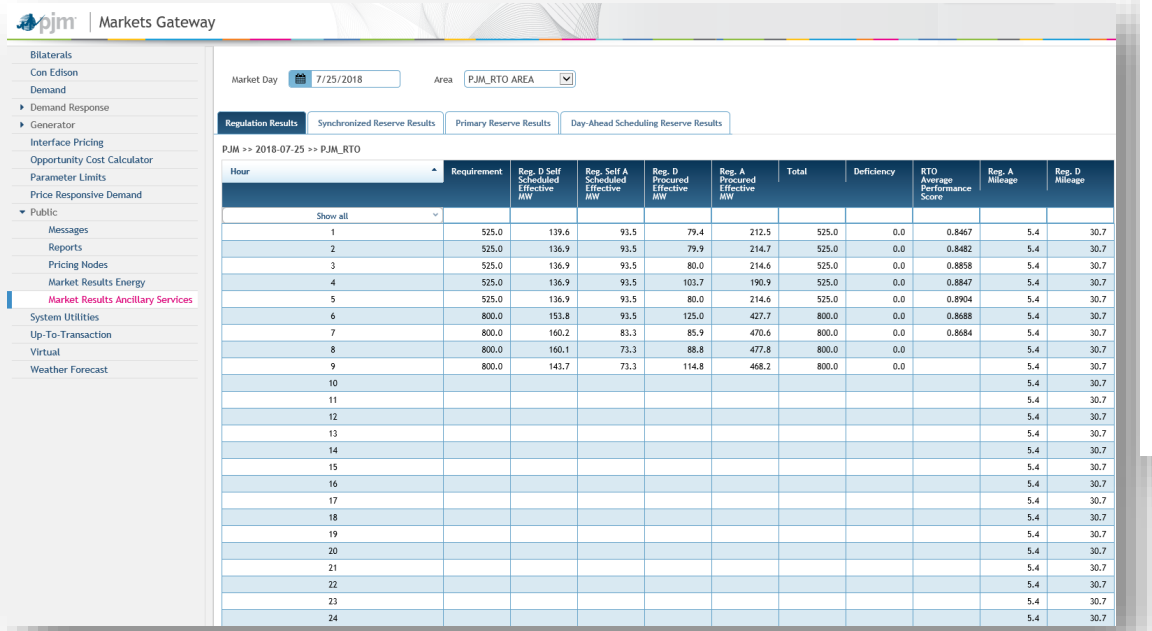
Resources that are opted in to intraday offers may submit Regulation offers up to 65 minutes before the operating hour



Regulation Offers
(Cost & Price) due by 14:15 EPT for next operating day

Regulation Market Timing

Regulation Market Results



Hour	Requirement	Reg. D Self Scheduled Effective MW	Reg. Self A Scheduled Effective MW	Reg. D Procured Effective MW	Reg. A Procured Effective MW	Total	Deficiency	RTO Average Performance Score	Reg. A Mileage	Reg. D Mileage
Show all										
1	525.0	139.6	93.5	79.4	212.5	525.0	0.0	0.8467	5.4	30.7
2	525.0	136.9	93.5	79.9	214.7	525.0	0.0	0.8482	5.4	30.7
3	525.0	136.9	93.5	80.0	214.6	525.0	0.0	0.8858	5.4	30.7
4	525.0	136.9	93.5	103.7	190.9	525.0	0.0	0.8847	5.4	30.7
5	525.0	136.9	93.5	80.0	214.6	525.0	0.0	0.8904	5.4	30.7
6	800.0	153.8	93.5	125.0	427.7	800.0	0.0	0.8688	5.4	30.7
7	800.0	160.2	83.3	85.9	470.6	800.0	0.0	0.8684	5.4	30.7
8	800.0	160.1	73.3	88.8	477.8	800.0	0.0		5.4	30.7
9	800.0	143.7	73.3	114.8	468.2	800.0	0.0		5.4	30.7
10									5.4	30.7
11									5.4	30.7
12									5.4	30.7
13									5.4	30.7
14									5.4	30.7
15									5.4	30.7
16									5.4	30.7
17									5.4	30.7
18									5.4	30.7
19									5.4	30.7
20									5.4	30.7
21									5.4	30.7
22									5.4	30.7
23									5.4	30.7
24									5.4	30.7

What	Frequency	Location	When
Assignment	Hourly	Markets Gateway	30 min prior to top of hour
Clearing Price	Every 5 minutes	Data Viewer	Every 5 min

Public results in Markets Gateway under:

Public >> Market Results A/S >> Regulation Results

Private Generator Results under:

Generator >> Market Results >> Regulation and Reserve Award

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Performance Scores

- A ***performance score*** is calculated for each regulation resource for each regulating hour
  - Performance scores reflect the benefits each resource provides to system control by focusing on the resource's response to PJM control signals
  - PJM will provide continuous feedback to the regulation resources of their performance using near real time reporting
  - Data posting for each resource through Markets Gateway

Regulation Adjusted Offers

Adjusted Regulation Capability Cost ($)

$$\frac{\left(\text{Capability Offer } \left(\frac{\$}{MW}\right)\right)}{\left(\text{Benefits Factor of Offered Resource}\right)} * \frac{\left(\text{Capability } (MW)\right)}{\left(\text{Historic Performance Score}\right)}$$

Adjusted Lost Opportunity Cost ($)

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

Adjusted Total Cost ($)

$$\underbrace{\left(\text{Adjusted Regulation Capability Cost } (\$)\right) + \left(\text{Adjusted Lost Opportunity Cost } (\$)\right)}_{\text{Capability Component}} + \underbrace{\left(\text{Adjusted Performance Cost } (\$)\right)}_{\text{Performance Component}}$$

Historical Performance Score

- Average of last 100 hours of resource's performance scores

Historical Mileage

- 30 days average of PJM regulation control signal-type mileage

Benefits Factor

- RegD resources are scaled factor, Reg A resources use 1.0

Adjusted Regulation Performance Cost ($)

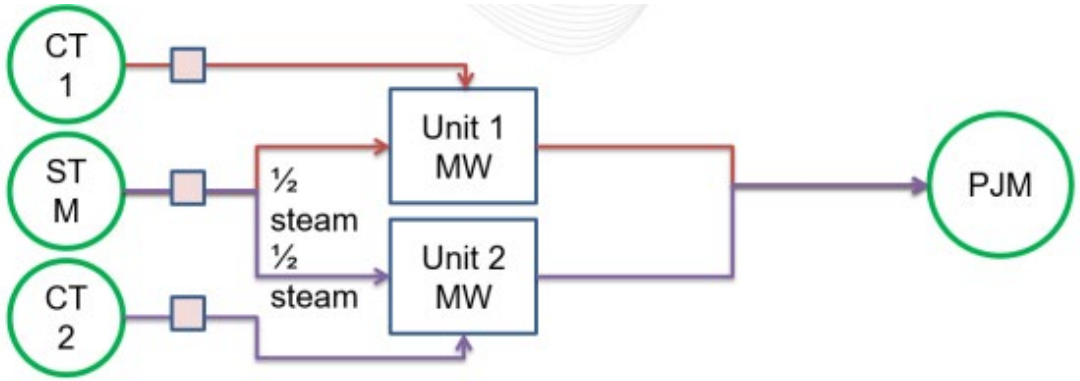
$$\frac{\left(\text{Performance Offer } \left(\frac{\$}{\Delta MW}\right)\right)}{\left(\text{Benefits Factor of Offered Resource}\right)} * \frac{\left(\text{Historic Mileage of Offered Resource Signal Type } \left(\frac{\Delta MW}{MW}\right)\right)}{\left(\text{Historic Performance Score}\right)} * \left(\text{Capability } (MW)\right)$$

Regulation Effective MW

$$\text{Regulation MW} * \text{Benefits Factor} * \text{Performance Score}$$

Performance Score for Combined Cycle Modeling

- Combined Cycle can be modeled as multiple virtual Market units
- There is a possibility for unbalanced or unequal regulation awards to each “unit”
- This is a result from the “units” having different performance scores, which results in unequal regulation awards



Mitigating Unequal Awards for CCs

- To minimize the frequency of unbalanced regulation market awards:
  - Market Sellers may submit identical MW and price offers in both the regulation and energy markets
  - Resources may use Performance Groups for equal Historic Performance Scores

$$\text{Adjusted Total Offer Cost (\$)} = \frac{\left(\text{Capability Cost} + \text{Performance Cost} + \text{Lost Opportunity Cost}\right)}{\left(\text{Benefits Factor of Offered Resource}\right) * \left(\text{Historic Performance Score}\right)}$$

Performance Group Scoring

- Extend the logic of the Regulation performance group performance sharing to the historic performance score (100 hour rolling average). This will ensure resources in performance groups have the same historic performance score for clearing purposes.

Optimization

- Resources cannot be committed (during the same interval) for more than one of:
  - Non-synchronized reserve
  - Synchronized reserve
  - Regulation products

Real-Time Regulation Data/Terms

PJM >> Member

AReg – Assigned Regulation

- Static for hour as a result of market
- Sent by PJM for each resource capable of regulation

RegA – Regulation Control Signal

- Automated Generator Control signal sent by PJM to Resource owner
- Sent every 2 seconds
- Bounded by TReg

RegD – Fast Regulation

- Automated Generator Control signal sent by PJM to Resource owner
- Dynamic signal moves with the frequency deviation component of ACE
- Increases the “utilization” of the energy storage devices

Member >> PJM

TReg – Total Regulation

- Resource owner sends one number for the fleet regulation capability

CReg – Current Regulation

- Calculated value where fleet is operating relative to regulation band
- Fleet-wide value sent from Resource owner to PJM
- Sent every 4 seconds

Unit Reg – Resource allocation

- Allocation should be sent as percent allocation for each individual regulating resource of the resource AReg

Load BP – Operational Midpoint

- The point around which the regulating resource (unit, plant or registration) operates

Managing Regulation Data

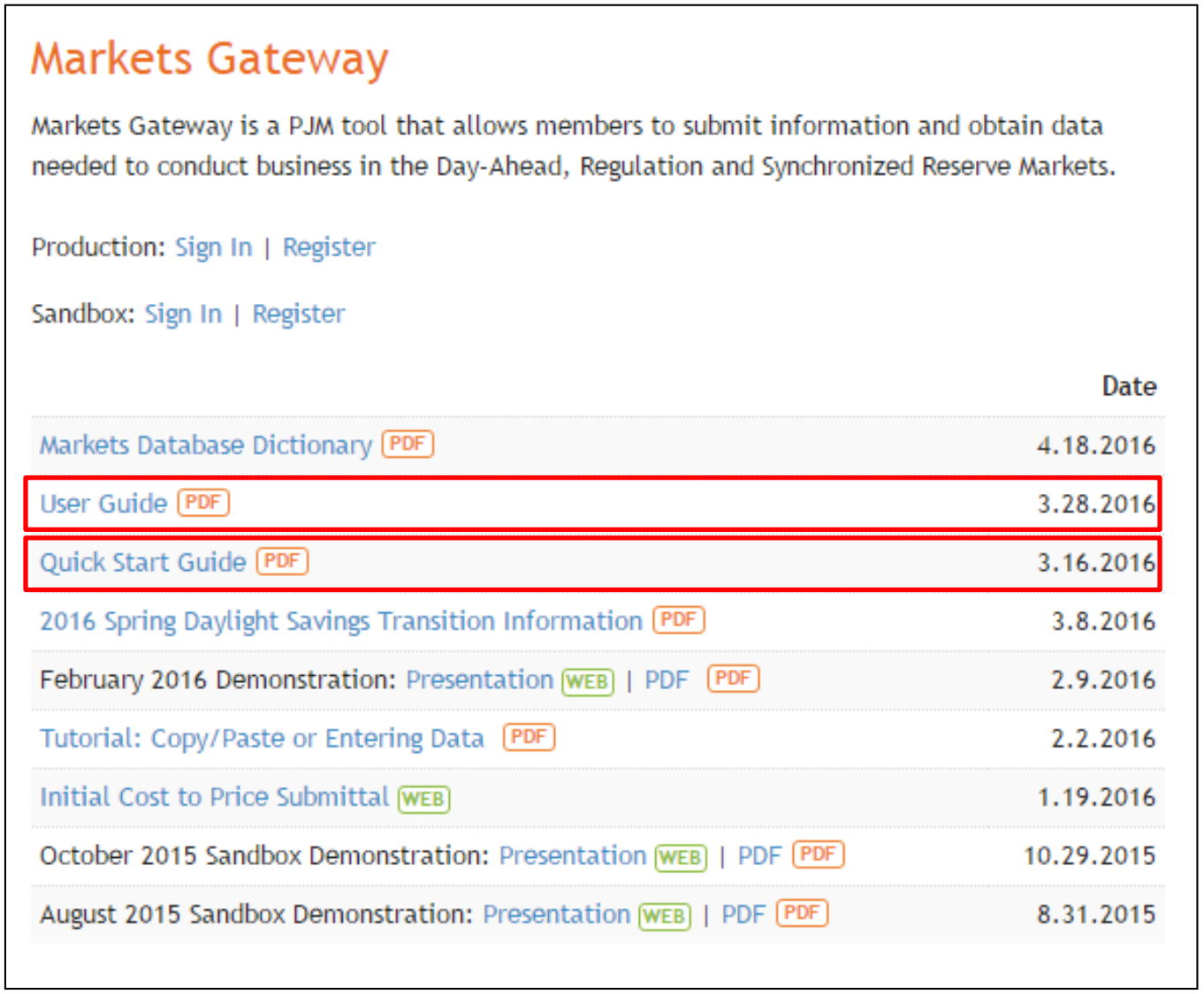
The following Markets Gateway pages are used to manage the Regulation Offers:

- **Unit Detail** - use this web page to enter regulating high and low limits
- **Regulation Offer** - use this web page to create regulation offers and modify the status of the regulation offer
- **Regulation Updates** - use this web page to update regulation resource availability and parameters on an hourly basis. (up to 65 minutes prior to the beginning of the desired operating hour)
- **Regulation Bilateral Transactions** - use this web page to facilitate a regulation bilateral transaction

Regulation Parameters in Unit Detail

- **Regulation Max MW:** Maximum generation limit when unit is providing regulation
- **Regulation Min MW:** Minimum generation limit when unit is providing regulation
- **Reduced Ramp Rate (%)** **= Minimum Reduced Ramp Rate Floor Percent** - Minimum percentage of the bid-in ramp rate used for the reduced energy ramp rate logic when a unit is providing both energy and regulation
  - If zero (the default value), then 100% of the assigned Regulation MW (divided by 5) will reduce the bid-in energy ramp rate for SCED
  - Note: Hourly updates are made on the Regulation Update Screen, not the Unit Hourly Screen

Markets Gateway Materials



Markets Gateway

Markets Gateway is a PJM tool that allows members to submit information and obtain data needed to conduct business in the Day-Ahead, Regulation and Synchronized Reserve Markets.

Production: Sign In | Register

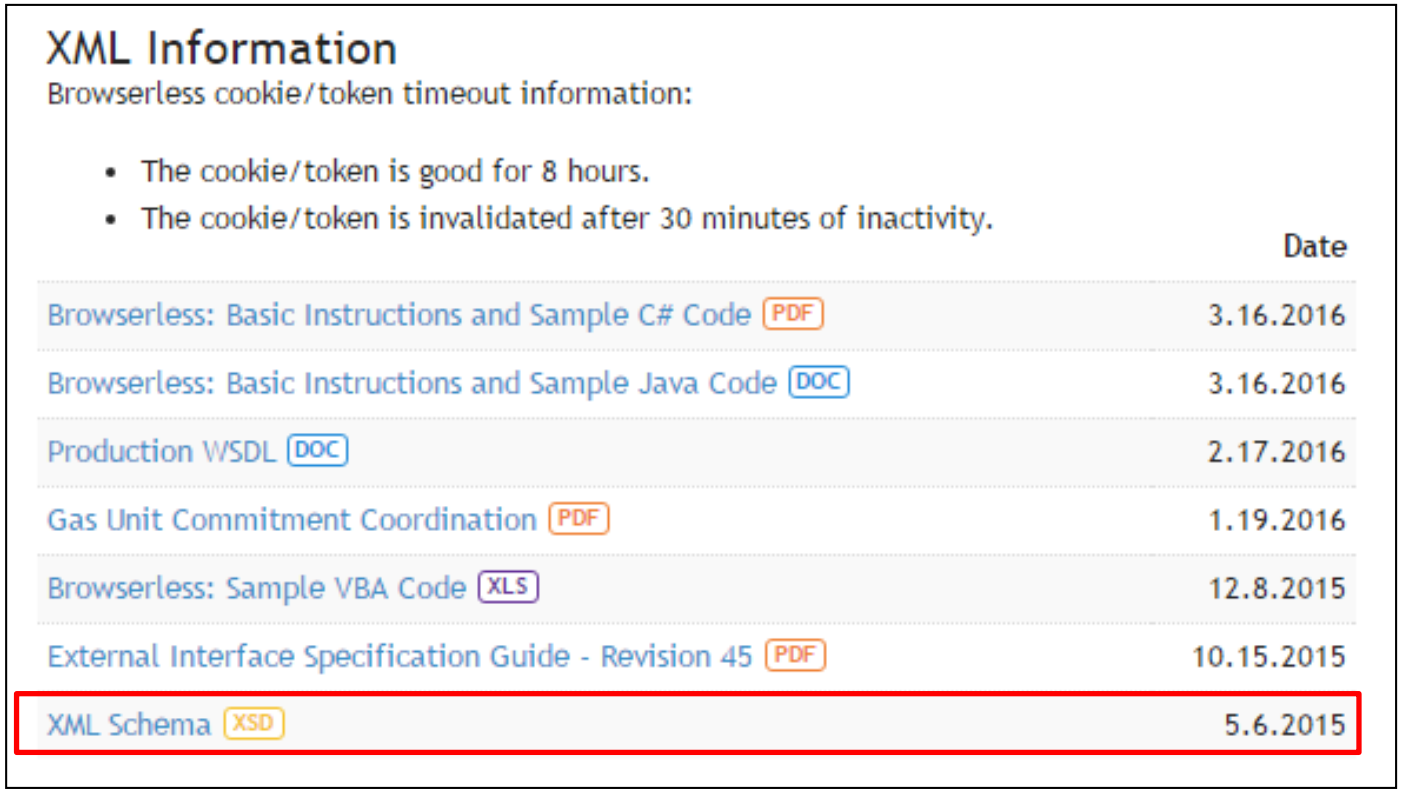
Sandbox: Sign In | Register

	Date
Markets Database Dictionary PDF	4.18.2016
User Guide PDF	3.28.2016
Quick Start Guide PDF	3.16.2016
2016 Spring Daylight Savings Transition Information PDF	3.8.2016
February 2016 Demonstration: Presentation WEB | PDF PDF	2.9.2016
Tutorial: Copy/Paste or Entering Data PDF	2.2.2016
Initial Cost to Price Submittal WEB	1.19.2016
October 2015 Sandbox Demonstration: Presentation WEB | PDF PDF	10.29.2015
August 2015 Sandbox Demonstration: Presentation WEB | PDF PDF	8.31.2015

Markets Gateway Documentation

http://www.pjm.com/markets-and-operations/etools/markets-gateway.aspx

Markets Gateway Materials



XML Information

Browserless cookie/token timeout information:

- The cookie/token is good for 8 hours.
- The cookie/token is invalidated after 30 minutes of inactivity.

	Date
Browserless: Basic Instructions and Sample C# Code PDF	3.16.2016
Browserless: Basic Instructions and Sample Java Code DOC	3.16.2016
Production WSDL DOC	2.17.2016
Gas Unit Commitment Coordination PDF	1.19.2016
Browserless: Sample VBA Code XLS	12.8.2015
External Interface Specification Guide - Revision 45 PDF	10.15.2015
XML Schema XSD	5.6.2015

Markets Gateway Documentation

http://www.pjm.com/markets-and-operations/etools/markets-gateway.aspx

Questions?

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Website: www.pjm.com

The Member Community is PJM's self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services