History of Regulation Market Reform Efforts

Regulation Market Design Senior Task Force

March 22, 2022

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Agenda

1. Regulation History Pre-2011
2. Regulation Performance Senior Task Force (RPSTF) and FERC Order 755: Performance Based Regulation
3. Regulation Performance Impact in 2015
4. Regulation Market Issue Senior Task Force (RMISTF) in 2017
5. Other Issues and Fixes Post-RMISTF
6. Regulation Status Quo – Challenges & Opportunities

Regulation History Through 2005

PJM has two regulation signals: Regulation A and Regulation B (for hydroelectric units)

Moved to an RTO regulation market
- Between 2002–2005 PJM footprint expansions, calculated regulation by zones and aggregate zones
- Requirement was 1% of on/off peak load forecast

2002 AP
2004 AEP,CE,DAY
2005 DUQ, DOM
2011 ATSI
2012 DEOK
2013 EKPC

COST-BASED
48,444 MW
PEAK
LOAD

MARKET-BASED →
133,974 MW
154,388 MW

PJM implemented the Regulation Market on June 1

- All regulation merged to one signal type (Regulation A)
- Market-Based Regulation Requirements

Dawn of Energy Storage – 2008

2008: the "Reg Battery"

- 1 MW, 250 kWh
- 8-sec DNP TCP/IP Latency
- 200 ms Response

What signal to send?

- REGB?
- Frequency Error?
- "Dynamic" Regulation!

Three Pivotal Supplier Task Force (TPSTF) in 2008

On December 1, 2008, the TPS test was implemented in the Regulation Market in FERC Docket No. ER09-13-000.

- PJM and its stakeholders addressed the issue of market power mitigation for the Regulation Market in the TPSTF, which was convened pursuant to PJM's 2007 Strategic Report to review market power mitigation issues.
- The TPSTF achieved a consensus supporting the application of the three pivotal supplier (TPS) test to the Regulation Market, provided that three adjustments to the rules were included.
  - increasing the margin on cost-based offers from $7.50 to $12.00 per MW
  - modifying the calculation of opportunity costs to use the lower of cost-based or price-based offers rather than the current dispatch schedule as the reference
  - eliminating the netting of regulation revenues from make-whole balancing operating reserve payments

Regulation History 2011 – RPSTF and FERC Order 755

PJM has two regulation signals: Regulation A and Regulation D (Dynamic for fast responding energy limited resources) with no commensurate compensation

- Regulation Performance Senior Task Force (RPSTF) on Feb 16, 2011
- Commissioned KEMA study to analyze trade-offs for A/D signals

FERC Order 755, Performance Based Regulation (PBR)

- October 1, 2012, implementation of performance based regulation
- Implementation of Regulation A and Regulation D
- Able to decrease regulation requirement from enhanced regulation performance

FERC Order 755 Compliance Filings and Implementation Issues

FERC conditionally accepted PJM proposal to be effective on Oct. 1, 2012, subject to additional compliance filing.

- PJM proposed to adjust the capability and performance payments in settlement by a ***marginal benefits factor*** in the Regulation clearing process to reflect the operational relationship between the RegA signal and the RegD signal.

PJM submitted a compliance filing in January 2013.

- However, in proposing these changes in compliance with the Commission's directives, PJM cautioned that removal of the marginal benefits factor from settlement ***would result in an unsustainable market structure***.

  The compliance filing was accepted.

Performance Credit **=** *MW x Performance Score x Performance Clearing Price x Mileage Ratio*

Significant Market Design Changes With PBR

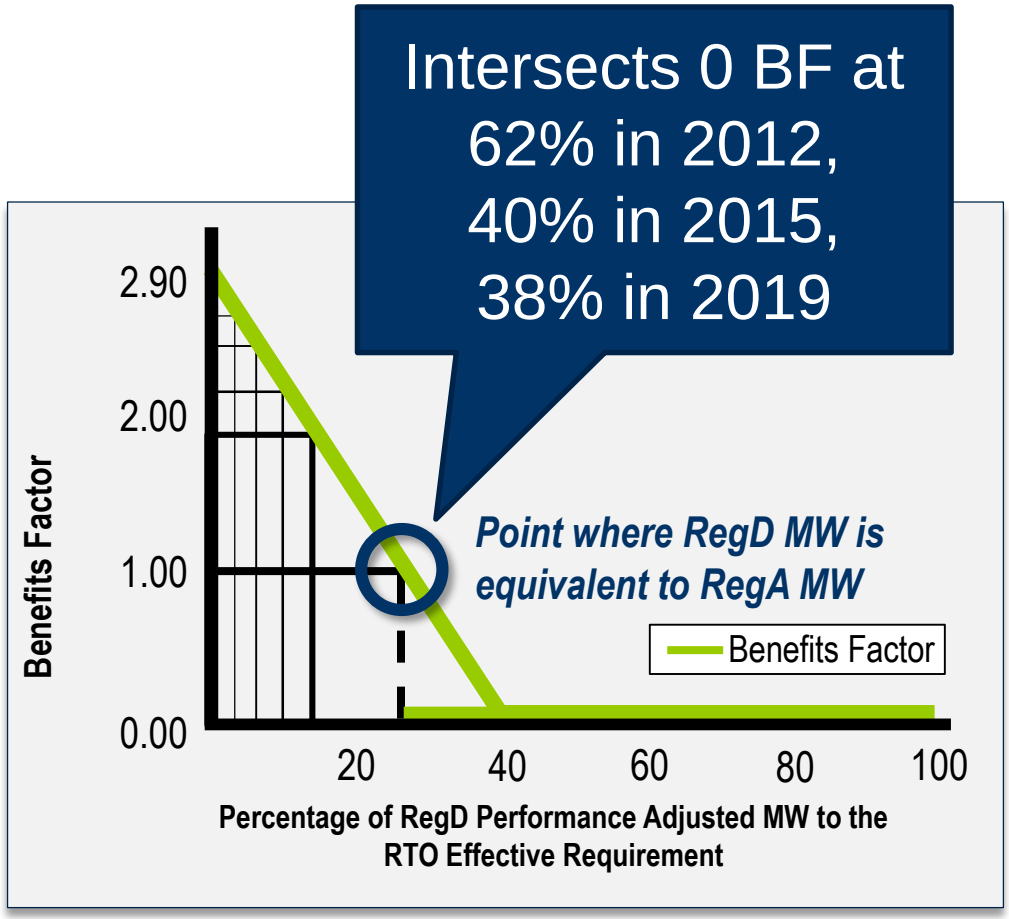
- Market clears to a single requirement in “effective MW”
  - *Mileage (signals A or D) measures how much a regulation signal is moving*
  - *Mileage Ratio measures relative movement of RegD to RegA*
  - *Performance Scoring [0, 1]* measures how well a resource follows the signal it is given
  - A *Benefit Factor [2.9, 0] models the declining rate of MW substitution between RegA and RegD*
  - Market Offers are scaled by to *$/effective-MW* in clearing
- Regulation requirement MW lowered from 1% of valley/peak load forecast for off-/on-peak period each day to 0.7%
- 5-min Regulation pricing through co-optimization with Energy and Reserve in LPC

Impact of RegD in Operations – 2014

- In 2014, Hydro resources began to qualify for RegD
  - RegD payment structure incentivizes participation
- By Summer 2014, PJM Dispatch began noticing deviations
  - RegD signal moving to zero when ACE persists
- By Fall 2014, PJM Real-Time Market Operations observed that in some hours, more than 70% of the requirement was composed of RegD, well beyond the original benefit factor design

Impact of RegD in Operations and the RPI in 2015

- Regulation Performance Impacts (RPI)
  - OC Special Session in 2015
- Benefits Factor Curve Adjustment
  - Shift Benefits Factor Curve to the left (BF=0 at 40%)
  - During identified excursion hours implement a RegD “cap” at 26.2%
- Tie Breaker in Benefits Factor Ranking to allow resource-specific benefits factor be assigned to all RegD Self-Scheduled and $0 cost resources based on resource performance



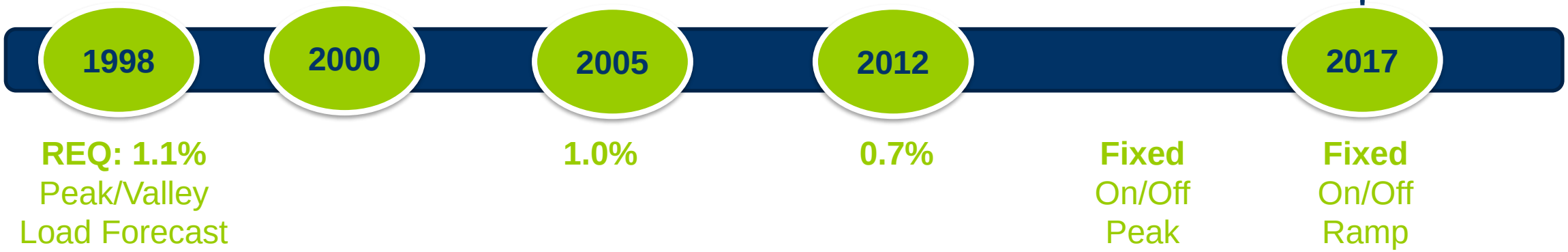
Regulation History – RMISTF in 2017

PJM put new 30-minute conditional neutrality regulation signals and dynamic requirements in operations

- Regulation requirement revised based on historic observed system operations
- RegA and RegD signals work together to provide regulation control

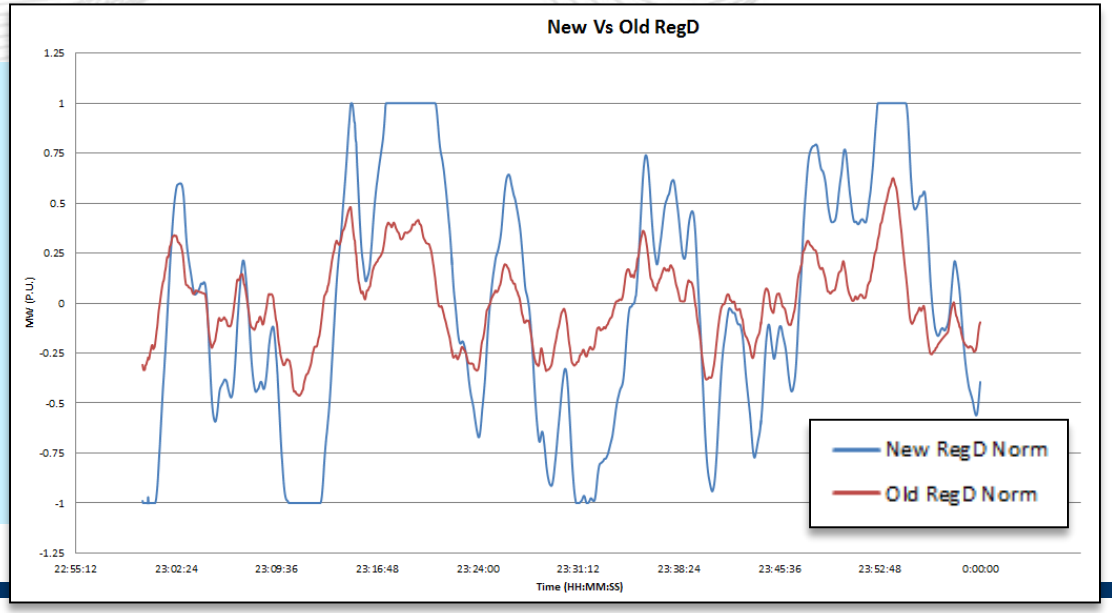
Regulation Market issues Senior Task Force

- MRC endorsed the joint PJM/IMM package to use Marginal Rate of Technical Substitution (MRTS) instead of the BF
- Submitted a 205 filing but rejected by FERC, and the solutions were never implemented



Regulation Signals Redesign in 2017

In support of the RMISTF, a new regulation signal design and regulation requirement was implemented into PJM operations on January 9, 2017.



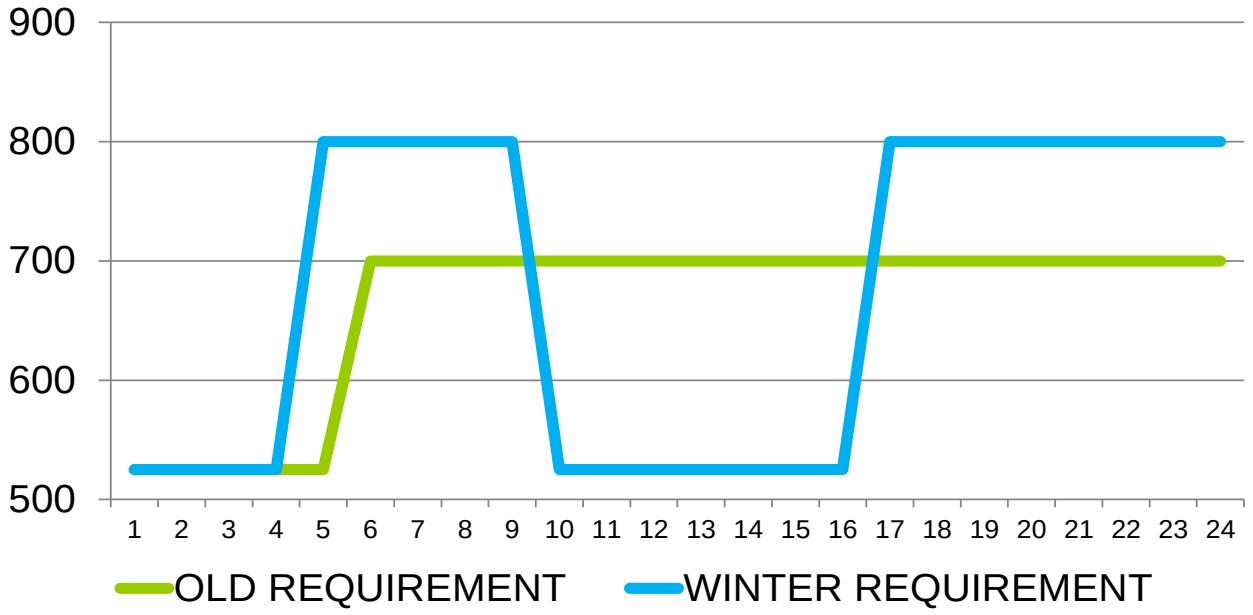
The **Conditional Neutrality** controller:

- Slows the REGA signal *was accelerated*
- Utilizes the full range of REGD *was 60%*
- Removes REGD neutrality logic *oscillated around 0 MW*
- Tracks historical REGD utilization *simulates MWh storage*
- Biases REGA to “recharge” REGD after pegging events

Regulation Requirement Redesign of 2017

- Requirement based on system conditions and variability
  - Increase requirement when CPS/BAAL are *low*
- An increase in signal and unit performance drives need for ***lower*** regulation requirement
- Dynamic/variable requirement improved system economics (not carrying extra regulation for all hours)

Off-Peak / Non-Ramp Hours	On-Peak / Ramp Hours
525	700 / 800



Regulation Market Issues Senior Task Force (RMISTF)

- RMISTF met 18 times from September 2015 through February 2017
- Developed seven proposals, including a joint PJM/IMM proposal, to address the problem statement
- The PJM/IMM joint proposal received the most votes and was endorsed by the Markets and Reliability Committee on June 22, 2017
- Submitted a 205 filing with the FERC on Oct. 17, 2017, in Docket No. ER18-87-000 but rejected by FERC
- Proposed solutions were never implemented

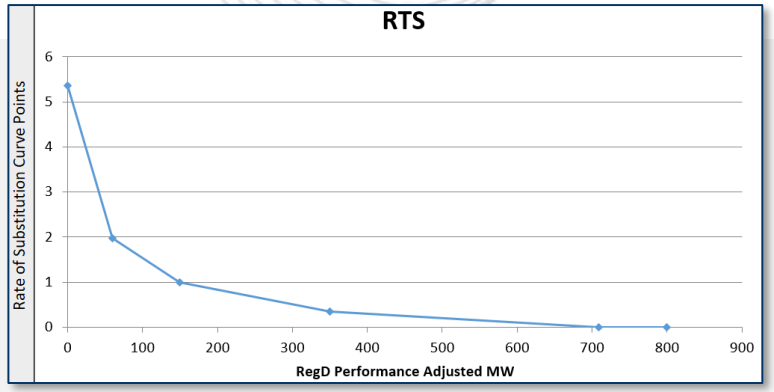
Summary of Solutions From RMISTF

- **Benefit Factor – Application and Clearing**
  - Replace Benefit Factor with Regulation Rate of Technical Substitution
  - Effective MW calculation as area under the Regulation Rate of Technical Substitution curve
- **Performance Scoring**
  - Precision-only calculation
  - Minimum allowable participation threshold to be raised from status quo 40% to 50%
- **Settlements**
  - Replace Mileage Ratio from the Regulation Performance Credit with Marginal Rate of Technical Substitution
  - Marginal Rate of Technical Substitution added also to the Regulation Capability Credit

Regulation Rate of Technical Substitution (RRTS) – Overview

RRTS translates a fast-moving resource's performance-adjusted MW into traditional performance-adjusted MW expressed as Effective MW.

RTS function is used to convert incremental additions of RegD MW into incremental effective MW.



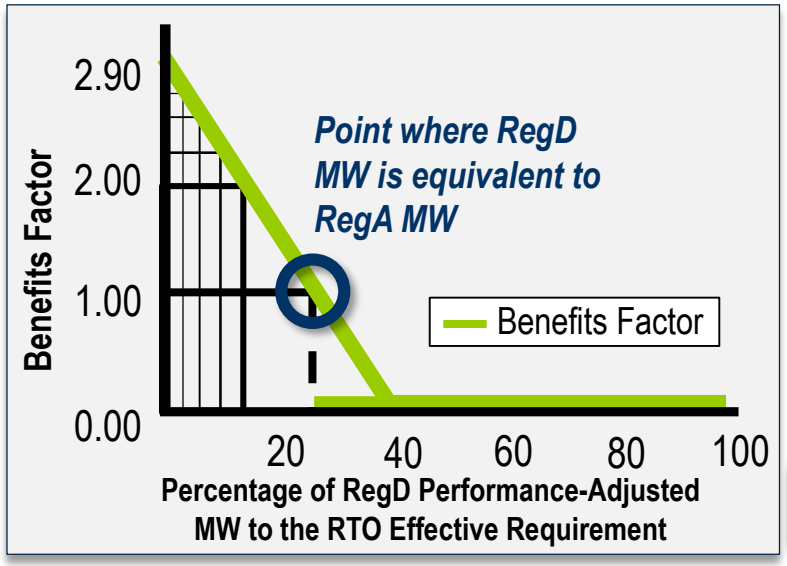
		Current	MRTS Framework
Rate of Substitution between Signals	RegA RegD	1 Benefits factor (BF)	1 Rate of Technical Substitution (RTS)
Performance-Adjusted MW		Reg MW * Performance Score, That Is MW * PS	Reg MW * Performance Score, That Is MW * PS
Effective MW		MW * PS * BF	(MW * PS * RTS) + Δ (Area under the curve)
Initial Adjusted Cost	Capability Performance LOC	Cap$ / (PS) (Per$ * Mileage) / (PS) LOC / (PS)	Cap$ / (PS) (Per$ * Mileage) / (PS) LOC / (PS)
Adjusted Total Cost	Capability Performance LOC	Cap$ / (PS * BF) (Per$ * Mileage) / (PS * BF) LOC / (PS * BF)	Cap$ / (PS * RTS) (Per$ * Mileage) / (PS * RTS) LOC / (PS * RTS)
RegD Offer$ in Term of RegA		RegD($) = RegA($) * BF RegA($) = RegD($) / BF	RegD($) = RegA($) * RTS RegA($) = RegD($) / RTS
Regulation Market Clearing Price (RMCP)		Max{[(Cap$(A) + Per$(A) + LOC$(A))/(PS * MBF)], [(Cap$(D) + Per$(D) + LOC$(D) / (PS * MBF)}	Max{[(Cap$(A) + Per$(A) + LOC$(A))/(PS * MRTS)], [(Cap$(D) + Per$(D) + LOC$(D) / (PS * MRTS)}
RMCP Components	PCP CCP	Max(Adjusted Performance Cost) RMCP minus max(Adjusted Performance Cost)	None None
Settlement Credit(s)	PCP CCP	RegMW * PCP * PS * Mileage Ratio RegMW * CCP * PS	RegMW * RMCP *PS * MRTS

Other Endorsed Changes From RMISTF

- Procurement floor: Floor BF at 0 for all hours (following transition)
- Schedule used for LOC: Use the schedule the resource is committed on
- Qualification testing: Uprate testing once per month; uprate testing is categorized as two attempts at an updated capability (one failed test and one retest) per month
- Change in cleared commitment-performance score: Self de-selection results in zero score for remainder of hour
  - PJM dispatcher de-selection does not impact performance
- Calculation of mileage: Status quo

Price Spike Issue Due to Low Benefits Factor (BF)

- RegD BF ranged from 2.9 to 0, and RegA BF = 1
- MRC/MC of Oct. 25, 2018, approved Floor BF in market clearing at .1 instead of 0
  - The solution limited 10 MW of RegD to provide 1 MW of RegA
  - FERC accepted Tariff revision on Jan. 18, 2019 – ER19-383-000



$$\text{RMCP} = \frac{Capability\ Offer}{Benefits\ Factor * Performance\ Score} = \frac{\$0/MWh}{0.001 * 0.80} = \$0/MWh$$

$$+ \frac{Performance\ Offer * Mileage}{Benefits\ Factor * Performance\ Score} = \frac{\$0/MWh * 34.14}{0.001 * 0.80} = \$0/MWh$$

$$+ \frac{LMP - Marginal\ Cost}{Benefits\ Factor * Performance\ Score} = \frac{\$15/MWh - \$10/MWh}{0.001 * 0.80} = \frac{\$5/MWh}{0.0008} = \$6{,}250/MWh$$

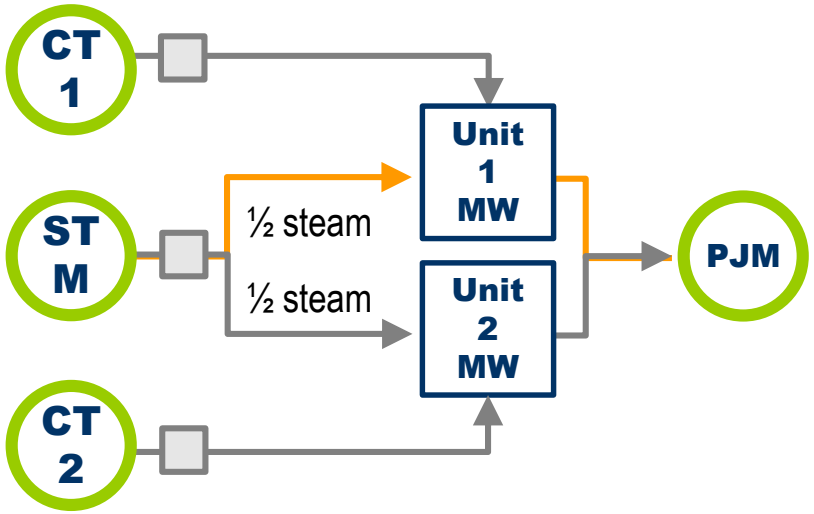
Offer prices of $0 and a difference of $5 in LOC can create a $6,250 Clearing Price.

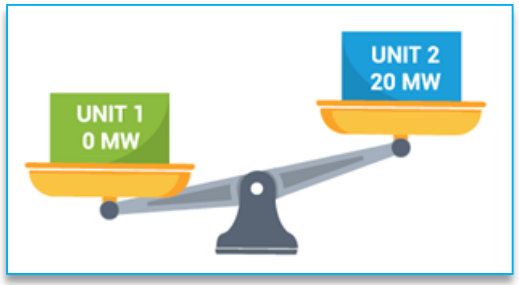
2017 Signal Change – RegD Battery Settlement in 2020

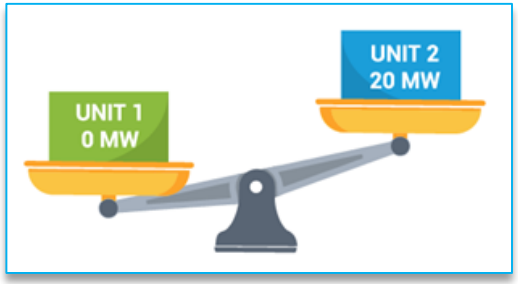
- On January 14, 2017, PJM implemented a 30-minute conditional neutrality Regulation signal to correct the operational impact of Regulation D resources moving in the opposite direction of ACE (Area Control Error) control
  - The implementation of the new signal increased the energy throughput of storage assets, which in turn impacted the life of the storage bank
  - ESA (Energy Storage Association), RES and Invenergy filed separate complaints in April 2017 (EL17-64, EL17-65), resulting in a settlement proceeding commencing in May 2018 facilitated by a FERC-appointed settlement judge

- On March 26, 2020, FERC approved settlement (ER19-1651)
  - Term of the settlement commenced on July 1, 2020
  - Duration of settlement term is 42 months

Virtual Combined Cycle Units Regulation Clearing Issue – 2021







Before March 2022	From March 2022

Hourly PS – Markets Gateway

Performance Group PG = hourly score
Copy down PG hourly score to resource(s) that provided regulation in that hour

Resource 1 = PG Hourly Score | Resource 2 = PG Hourly Score

Daily PS – Regulation Clearing

Resource 1 (R1) = rolling 100 hours average for R1

Resource 2 (R2) = rolling 100 hours average for R2

Daily scores can be different if R1 and R2 didn't always provide regulation together.

Performance Group (PG) = rolling 100 hours average for PG

Copy down to resource(s) in PG

Resource 1 (R1) = PG daily score
Resource 2 (R2) = PG daily score

PJM will calculate the performance group historic performance score and extend it to each market resource in the performance group.

Regulation Undefined Mileage Ratio Issue – 2021

Regulation Market **Performance Clearing Price** (PCP) Credit =

5-min integrated Regulation MW x 5-min Actual Performance Score x **Mileage Ratio** x 5-min PCP /12

Mileage Ratio (RegA) = $\frac{RegA\ Hourly\ Mileage}{RegA\ Hourly\ Mileage}$

Mileage Ratio (RegD) = $\frac{RegD\ Hourly\ Mileage}{RegA\ Hourly\ Mileage}$

If the RegA Hourly Mileage = 0, then Mileage Ratio for the hour cannot be calculated

PJM Proposed Solution

Substitute 0.1 only when RegA Hourly Mileage is 0

- Applied to only one hour since 2012 with no impact because PCP was $0

IMM Proposed Solution

A cap of 5.5 on the realized mileage ratio in all hours

- Would affect about 50% of hours based on data from 1/1/2020 through 3/31/2021

Both the PJM and the IMM proposals failed the minimum threshold at the October 2021 MRC

Regulation Settlement

Year	CCP Credit	PCP Credit	LOC Credit	Total Credit	PCP % of Total
2019	$68,926,127	$12,129,990	$9,539,138	$90,595,254	13.4
2020	$60,145,244	$8,408,813	$8,314,396	$76,868,453	10.9
2021	$115,792,915	$13,496,204	$15,106,853	$144,395,972	9.3

Settlement went to 5-min interval pricing on April 1, 2018

FERC Filing Update for Undefined Mileage Ratio

- June 10, 2021 – FERC filing in 206 for the purpose of establishing refund effective date for the eventual replacement calculation (EL21-83)
  - Pending outcome of stakeholders process
- At the October 20, 2021, MRC, both the PJM and the IMM package to address the undefined mileage ratio failed
  - PJM could not file FPA section 205
- On February 14, 2022 – PJM updated FERC, asked to refrain from acting on the proceeding until after the stakeholder process is complete and reforms are submitted.
  - RMDSTF outcome is expected to address the issue among others

Ongoing challenges in the Regulation Market & Operations

1. Mileage definition – A flat signal does not mean no ACE correction is being provided; it means that the signals are saturated and energy-limited resources are at risk!
   - Should a signal mileage ever be zero when flat?
2. Extended signal saturation at full raise/lower
   - Is this RTSCED energy dispatch the issue or lack of sufficient regulation?
3. PJM's fixed requirements were designed to keep total Regulation procurement (MWh) predictable for Load
   - Should the targeted hours be more dynamic?
4. Lost Opportunity Cost calculation formulation
5. Others?

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