Regulation Overview

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RMDSTF

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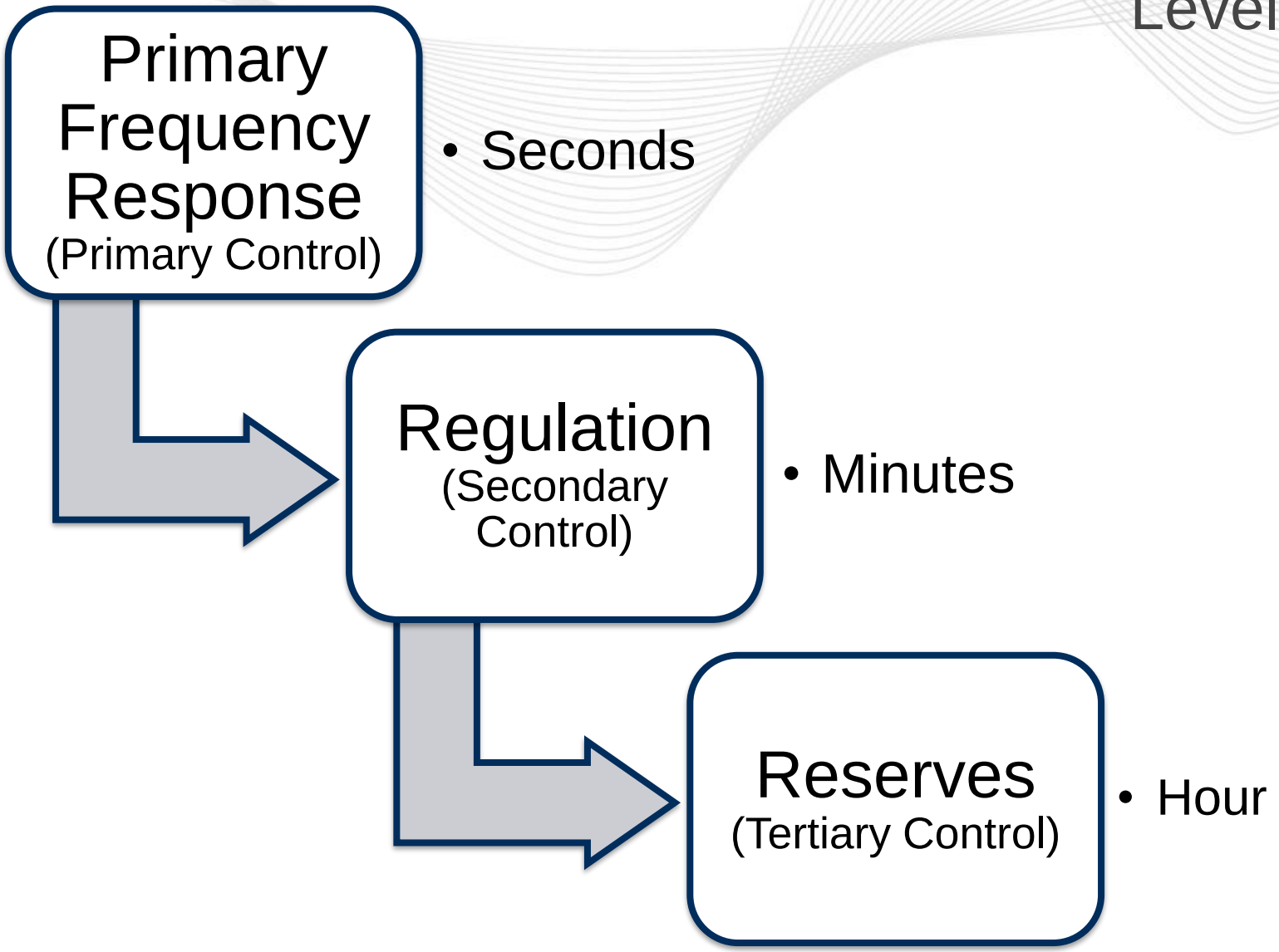
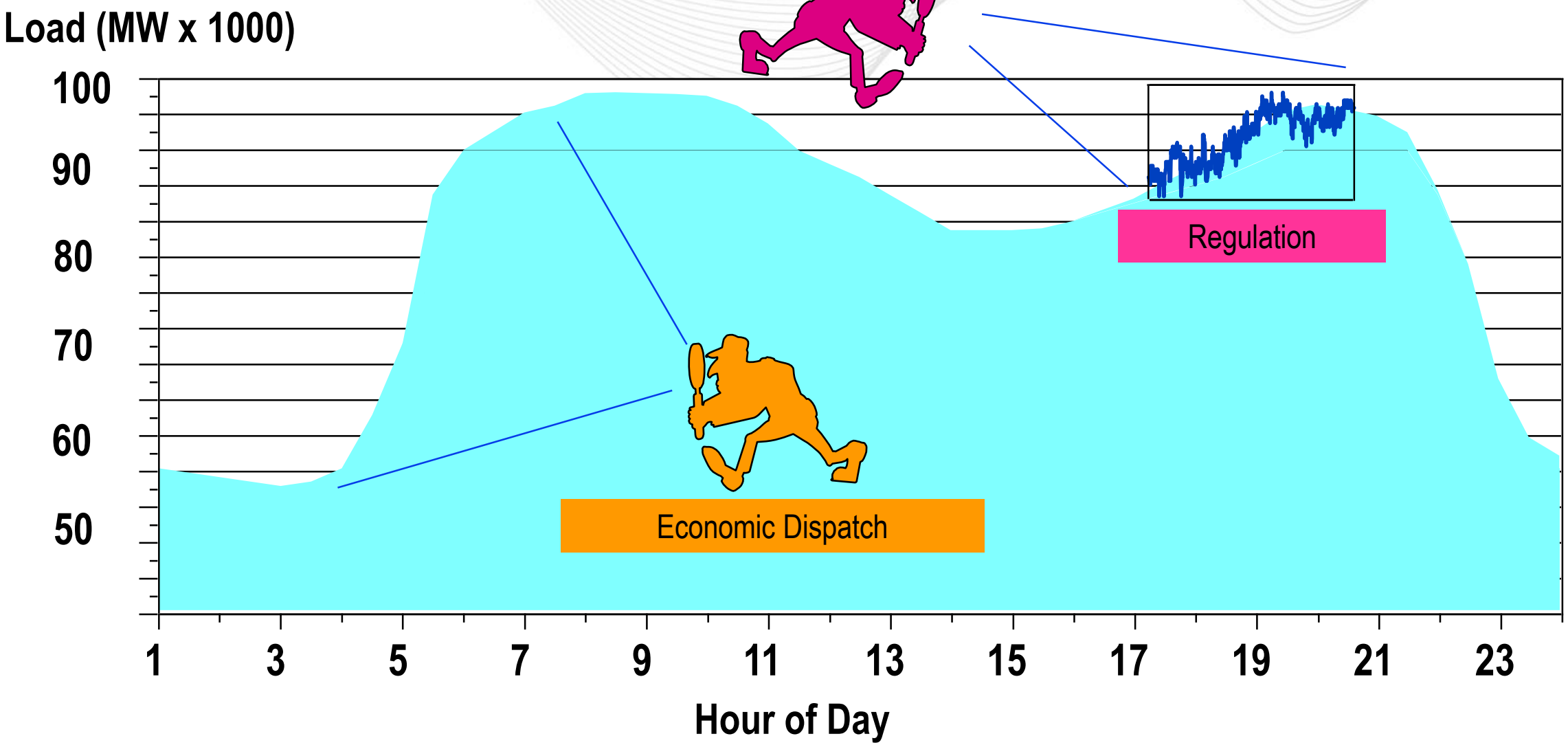
What are Ancillary Services?

- Ancillary services help balance the transmission system as it moves electricity from generating sources to ultimate consumers.
- PJM operates several markets for ancillary services: the Synchronized Reserve Market, the Non-Synchronized Reserve Market, the Day-ahead Scheduling Reserve Market and the Regulation Market.
- There are also several other non-markets for ancillary services such as black start service and reactive service. These services are paid through credits.
- Primary frequency response (PFR) is another non-markets ancillary service. Resources are not getting paid for providing PFR.
- **Regulation** is the capability of a specific resource with appropriate telecommunications, control and response capability to increase or decrease its output in response to a regulating control signal to control for frequency deviations.

Levels of Control

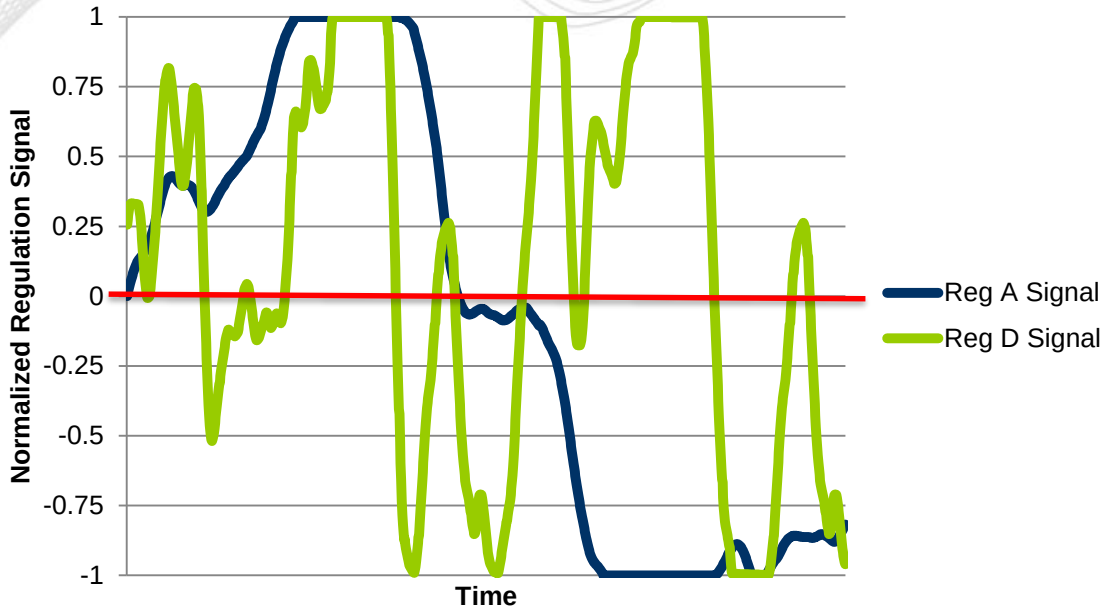


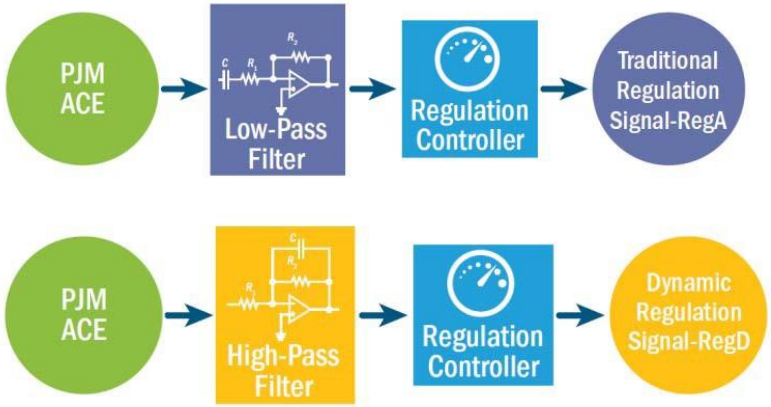
Regulation vs. Economic Dispatch



Types of Regulation Signals

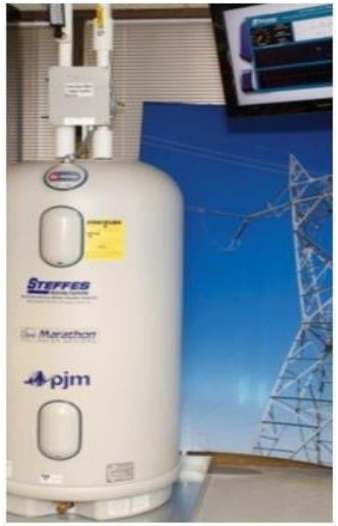
- Reg A – Traditional Regulation Signal
  - Used for traditional regulating resources with physical characteristics that limit ramp rate.
  - Followed by steam units, hydros, and CTs
- Reg D – Dynamic Regulation Signal
  - Used for regulating resources with no physical characteristics that limit ramp rate. This signal is derived from the same algorithms as the Reg A, however, the main difference is the use of a dynamic time constants that allow for faster cycling
  - Followed by hydros, CTs, Energy Storage, and DSR





Regulation Resource Types

- What types of Resource can provide regulation:
  - *Generation* : Steam, Hydroelectric, Combustion Turbines, Combined Cycle
  - *Grid Energy Storage* : Batteries, Flywheels
  - *Behind-the-meter Storage*: Water Heaters, Plug-in Hybrid Electric Vehicles
  - *Demand Response* : Variable Speed Pumps, Ceramic Thermal Storage



Regulation Performance – Recent Example

MW	Steam	Hydro	CT	DSR
Regulation A				
Avg. Performance Score (2/2022)	80%	89%	90%	80%
Regulation A Qualified MW (2/2022)	4205.5	838	1649.4	5.4
Regulation D				
Avg. Performance Score (2/2022)	79%	87%	92%	83%
Regulation D Qualified MW (2/2022)	334.0	132.4	175.5	24.2

*Data through 2/22/22

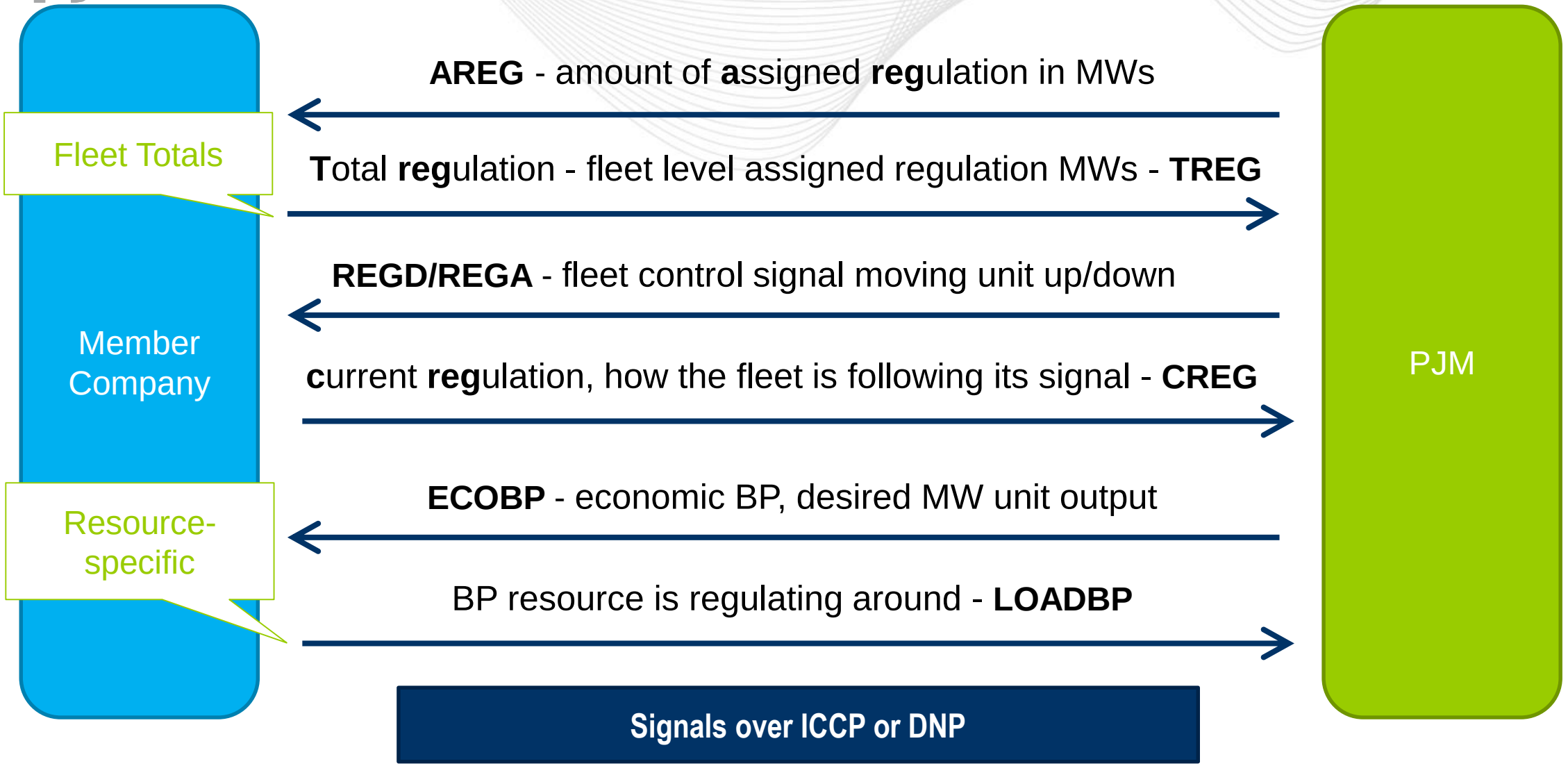
Dual Qualified Resources and Performance Groups

- Dual Qualified Resources
  - Can follow Reg A and Reg D signals
  - Hydro, CT/Diesel, DSR
- Performance Groups
  - Must satisfy one of the following criteria:
    - Resources not eligible for LOC and total to less than or equal to 10 MW across Transmission Owner boundaries
    - A performance group can be any number of resources not eligible for LOC inside a Transmission Owner's boundary
    - Resources within a fleet with equivalent applicable offers and point of interconnection
  - Each resource is metered independently

Resources can be scored individually or as groups

- ***Individual***
  - Market resource with distinct actual and desired output (basepoint)
  - Proportionally allocated from the fleet signal
- ***Performance Groups***
  - Many market resources acting as a single virtual resource
  - Hydro plants, distributed generation, DSR

Regulation Signal/Telemetry Requirements



Regulation Market Eligibility

- Generation and Demand Resources:
  - Must be located electrically within the PJM RTO
  - Must be able to provide 0.1 MW of Regulation Capability
  - Must be able to receive and respond to an AGC signal
  - MW output must be telemetered to the PJM control center
  - Must pass an initial performance test (3 consecutive successful tests, minimum of 75% compliance required and reaching upward and downward signals).
    - Resources that pass are enabled in the markets databases by PJM personnel
  - Must demonstrate minimum performance standards (must maintain 40% historic performance score), as set forth in the PJM Manual 12
    - Resources that score less than 40% are disqualified from the Regulation market by PJM personnel

Regulation Market Eligibility

- Generation Resources:
  - Must have a governor capable of AGC control
- Demand Resources (DR):
  - Must complete initial and continuing training on the Regulation Market as documented in PJM Manual 40
  - If DR is called for a mandatory Emergency or Pre-Emergency Load management Event, it is automatically de-assigned from Regulation for any intervals that overlap with the Load Management Event.

Regulation Qualification Test

- An Area Regulation (AR) test is used for both certifying and verifying regulation capability for a resource
- Certifying and Verifying Regulating Resource of PJM Manual 12 Section 4.5:
  - Member notifies PJM Performance Compliance and PJM Dispatch at least 24 hours before the test through RegulationTesting@pjm.com.
  - Member includes following information for a test request:
    - Resource Name and Market ID Number
    - Date and Time of Test
    - Amount of MW being tested (+/- TREG)
    - MW-value of Basepoint (The resource will be regulating around)
    - Signal Type: Reg A or Reg D
    - Reason for testing

Regulation Testing

Regulation Testing (Must hit full regulation range @ >75%)

3 tests

1 test

New Resources

Disqualified Resources

Uprate

Change in Communication Path – Existing Owner

Change in Communication Path – New Owner

Regulation Qualification Test

- 3 Tests:
  - Self-scheduled test
    - The first of three tests may be performed internally by the Member
    - Member must use the PJM test shape posted on PJM's website
      - Markets and Operations > Ancillary Services > Market Based Regulation page
    - Member must set testing unit to unavailable during the test, other units may continue to regulate
    - Up to 3 self-administered tests may be performed on a resource each day
  - PJM-administered test
    - The remaining tests should be performed by PJM Dispatch
    - All resources within the Fleet will be taken out of the Regulation market for the specific signal
    - Only one PJM-administered tests may be performed on a resource each day
- 1 Test:
  - Only PJM-administered tests are allowed to be performed

Regulation Qualification Test

- Testing requirements to verify the resource:
  - Was providing Regulation for the duration of the test (40 minutes)?
  - Can achieve its full Regulation testing range (+/- TREG)?
  - Has held its Regulation base loading for the full duration of the test?
  - That no other resources within the testing fleet were in the Regulation market during the testing period
  - Has a Performance score >= 75%
- PJM will send results of test to resource within 3 business days
- New performance scores are set for resources except for Changes to the Signal Path Re-Test – Existing Owner (historic performance score is maintained)
- Enable resource into Regulation market within one business day

Regulation Qualification Test

- Certifying Multiple Combustion Turbines or Hydro Units operating under a single plant control system:
  - Must have a minimum of 3 tests of the control system
  - Performance of each of the units being certified must be demonstrated in at least one of these tests.
- Resources must continue to demonstrate minimum performance requirements once in the Regulation Market:
  - Individual hour performance must be greater than 25% to be compensated
  - Historical performance score must be greater than 40% (100 hour rolling average)
    - If < 40%, PJM disqualifies the resource from Regulation market and notifies the Member
    - Member must have 3 consecutive successful tests in order to qualify back for Regulation Market

Performance Score Calculation

PJM scores resources on 3 components:

Accuracy: *The correlation or degree of relationship between control signal and response*

Delay: *The time delay between control signal and point of highest correlation*

Precision: *The instantaneous error between the control signal and the regulating unit's response*

A resource's performance score is calculated as :

$$\textbf{Performance Score} = \frac{1}{3} * \textbf{Accuracy} + \frac{1}{3} * \textbf{Delay} + \frac{1}{3} * \textbf{Precision}$$

Performance Score Calculation Engine

The Regulation Market **Performance Score Calculation Engine** (PSCE) calculates many things:

- 5-minute and Hourly after-the-fact resource performance scores
- Daily 100-day rolling average resource performance scores
- 5-minute Interval regulation signal mileage
- Hourly regulation signal mileage
- Daily regulation signal mileage

How are the Performance Scores Used?

- **5-Minute Scores** are calculated and used in Settlements for service credits
- **Hourly Scores** are calculated and posted to Markets Gateway 15 minutes after the end of the operating hour
- At midnight, **Daily Scores** are calculated from the average performance over the last 100 assigned hours:
  - Posted to the NEXT operating day for bid adjustments
  - Used in ASO for hourly clearing of assignments

Regulation Market Timeline

REGULATION MARKET

Throughout the operating day **PJM clears the Regulation Market hourly and makes intra-hour adjustments as necessary.**

REAL-TIME MARKET

Regulation offers due

Due a day ahead of the operating day by 11:00 a.m.:

- **Energy schedule for LOC calculation to qualify units**

Due a day ahead by 2:15 p.m.:

- **Daily Cost based offer**
  (capped at actual cost + $12 adder)
  Required for clearing
- **Daily Price based offer**
  (optional – capped at $100/MWh)
- **All other regulation data can be revised up till 60 minutes before the operating hour**

Up to 1 hour prior to the operating hour:

- **Regulating status**
  (available, unavailable, SS)
- **Regulating capability**
  (MW above and below reg midpoint)
- **Reg min and max**
- **Reg signal type**
  (A or D)
- **Hourly Cost and Price based offer**
  (If opted in to IDO)

Data submitted to Markets Gateway

Performance Based Regulation Concepts

- Benefits Factor - translates a RegD MW into a RegA MW
  - All RegA resources have a BF = 1
  - Value ranges from 2.9 to 0, however resources with a BF < 0.1 are not considered in the regulation clearing
- Mileage - the absolute sum of movement of the regulation signal in a given time period. Resources following the dynamic signal (RegD) will likely move much more than those on the traditional signal (RegA)
- Performance Score – evaluation of how a regulating resource closely follows the regulation signal. Value ranges from 1 to 0.
  - Resources with an hourly performance score of <=.25 will not receive compensation
  - Resources with a historical performance score of <=.40 will be removed from the market

Effects of Performance Based Regulation

- Resource offers (capability and performance), and Lost Opportunity Cost are adjusted based on:
  - Resource specific Benefit Factor
  - Resource specific Historic Performance Score
  - System-wide Historic Mileage
- Good performing resources look less expensive and poor performing look more expensive to the Market Clearing Engine:
  - Currently not true for self-scheduled resources.

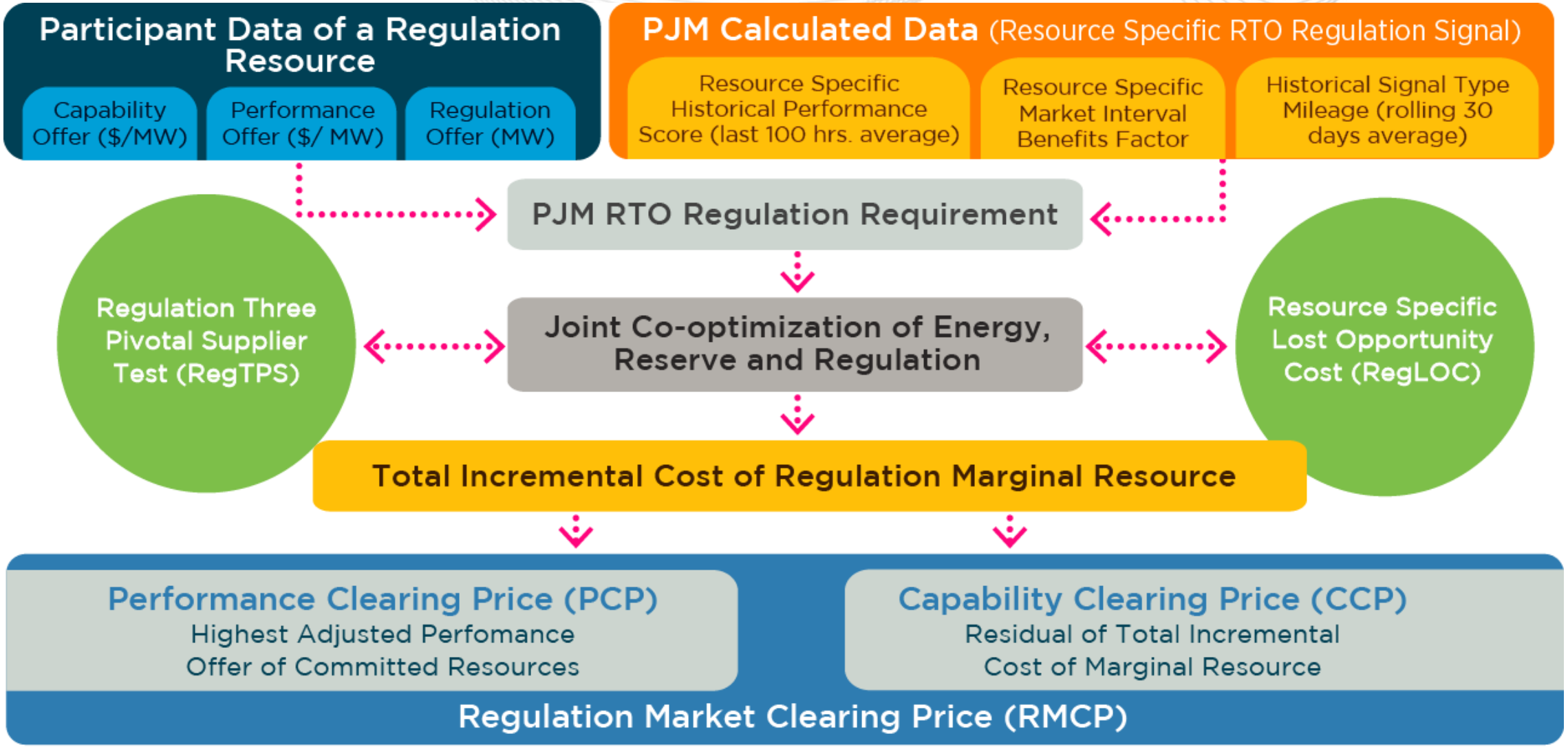
$$Effective\ MW = RegMW * Performance\ Score * Benefits\ Factor$$

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

http://pjm.com/~/media/markets-ops/ancillary/regulation-requirement-definition.ashx

Regulation Market Clearing Process



Regulation Market Clearing

- Regulation is cleared every hour for one hour look-ahead:
  - Pricing is done every 5 minutes along with energy LMP in real-time
  - Co-optimized with energy
- Regulation is cleared to meet the established requirements:
  - 525 Effective MW for Non-Ramp (hours vary by season)
  - 800 Effective MW for Ramp (hours vary by season)
  - Clear the most economic mix of RegA and RegD resources
- One RTO Regulation market and therefore one uniform clearing price (RMCP):
  - Clearing is based on merit (cost, performance, and benefits to the system)
  - Clearing price separates into capability and performance clearing prices (CCP and PCP)
  - No clearing price based on signal type (RegA, RegD)

Clearing (ASO) vs. Pricing (LPC)

ASO
Ancillary Services Optimizer

Runs one hour in advance of operating hour to procure least cost set of resources

- Input:
- Regulation Offers from Markets Gateway
- Historical Performance Score
- Historical Mileage

- Output:
- MW assignment
- Forecasted LMP (for LOC calculation)
- Rank Price (not financially binding)

LPC
Locational Pricing Calculator

Runs every 5 minutes in Real-Time to price assigned resources

- Input:
- Assignment from ASO
- Intra-hour commitments
- Historical Performance Score
- Actual Mileage

- Output:
- Actual 5 minute LMP (for LOC calculation)
- Regulation Market Clearing Price (comprised of the Regulation Market Capability Clearing Price and the Regulation Market Performance Clearing Price) used in Settlements

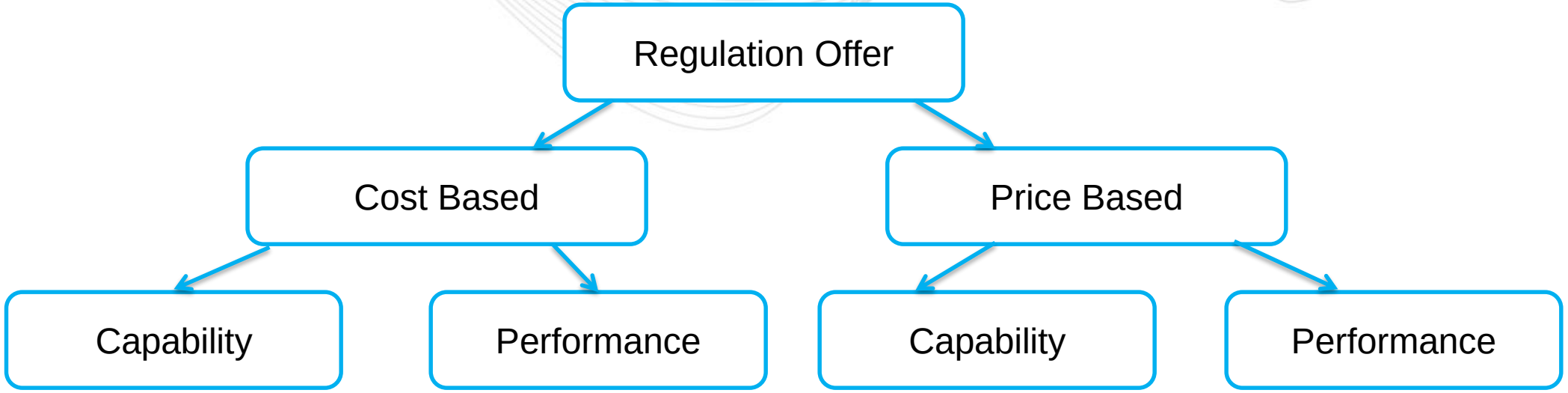
Regulation Market Clearing

Rank = Adjusted Capability Offer Cost
+ Adjusted Performance Offer Cost
+ Adjusted Lost Opportunity Cost

- Rank is used by ASO to stack resources in order to determine the least cost set of resources to meet the requirement:
  - RegA and RegD resources are evaluated simultaneously
- Rank price is not financially binding
- The term “adjusted” means factoring in the performance-based regulation measures of Benefits Factor, Mileage, and Performance Score

Regulation Offers

Rank = Adjusted Capability Offer Cost + Adjusted Performance Offer Cost + Adjusted Lost Opportunity Cost



Clearing starts at:

Least of [(Capability Cost + Performance Cost), (Capability Price + Performance Price)]

The cheaper offer is used for Regulation TPS Test:

- Regulation Three Pivotal Supplier (RegTPS) Test is used to mitigate market power
- If supplier PASSES, price based offer is used for remainder of clearing process

Cost Based Offer is required for clearing

Capability Offer Cost Example

Rank = Adjusted Capability Offer Cost + Adjusted Performance Offer Cost + Adjusted Lost Opportunity Cost

$$Adjusted\ Capability\ Offer\ Cost\ (\$/\mathrm{MW}) = \frac{Capability\ Offer\ (\$/MW)}{Benefits\ Factor\ *\ Historic\ Performance\ Score}$$

Resource	Offer Type	Signal Type	Capability	Performance	Benefits Factor	Performance Score	Adjusted Capability Offer
A	Self-Scheduled	A	$1.00	$0.50	1	0.5	$0.00
B	Self-Scheduled	D	$2.00	$1.00	1.8	0.85	$0.00
C	Economic	A	$0.00	$0.00	1	0.6	$0.00
D	Economic	D	$0.00	$0.00	2	0.9	$0.00
E	Economic	A	$5.00	$0.50	1	0.75	5/(1*0.75) = $6.67
F	Economic	D	$1.00	$0.25	1.5	0.8	1/(1.5*0.8) = $0.83

Performance Offer Cost Example

Rank = Adjusted Capability Offer Cost + Adjusted Performance Offer Cost + Adjusted Lost Opportunity Cost

$$Adjusted\ Performance\ Offer\ Cost\ (\$/\mathrm{MW}) = \frac{Performance\ Offer\ (\$/\Delta\ MW)\ *\ Mileage\ of\ Offered\ Resource\ Signal\ Type\ (\Delta\ MW/MW)}{Benefits\ Factor\ *\ Historic\ Performance\ Score}$$

Resource	Offer Type	Signal Type	Capability	Performance	Benefits Factor	Performance Score	Mileage	Adjusted Performance Offer
A	Self-Scheduled	A	$1.00	$0.50	1	0.5	5	$0.00
B	Self-Scheduled	D	$2.00	$1.00	1.8	0.85	15	$0.00
C	Economic	A	$0.00	$0.00	1	0.6	5	$0.00
D	Economic	D	$0.00	$0.00	2	0.9	15	$0.00
E	Economic	A	$5.00	$0.50	1	0.75	5	(0.5*5)/(1*0.75) = $0.67
F	Economic	D	$1.00	$0.25	1.5	0.8	15	(2*15)/(1.5*0.8) = $3.13

Historic mileage is used for clearing, actual mileage is used for pricing

Regulation Lost Opportunity Cost (RegLOC)

- RegLOC – is the foregone revenue or increase in costs relative to the energy market for providing regulation:
  - Calculated only for pool scheduled generators
  - Is $0 for DSR and self-scheduled generators
  - RegLOC is calculated relative to the cheaper of available priced-based energy schedule or the most expensive cost-based energy schedule

$$\text{RegLOC Schedule} = \text{Least}\left\{\begin{matrix}\text{available priced-based energy schedule,}\\ \text{greatest(available cost-based energy schedule)}\end{matrix}\right\}$$

- In the clearing process – RegLOC is calculated as the difference between forecasted LMP and price at the Reg base-point on RegLOC schedule
- In the pricing – RegLOC is calculated as the difference between Real-Time LMP and price at the Reg base-point on RegLOC schedule

Adjusted Lost Opportunity Cost Example

Rank = Adjusted Capability Offer Cost + Adjusted Performance Offer Cost + Adjusted Lost Opportunity Cost

$$\text{Adjusted RegLOC} = \left[\frac{|\text{LMP} - \text{MC}|}{\text{Resource BFactor} \times \text{Resource Historical Performance Score}} \right]$$

where MC is the price of Reg set point on the RegLOC schedule

Resource	Offer Type	Signal Type	Benefits Factor	Performance Score	Mileage	Adjusted Capability Offer	Adjusted Performance Offer	Adjusted LOC
A	Self-Scheduled	A	1	0.5	5	$0.00	$0.00	$0.00
B	Self-Scheduled	D	1.8	0.85	15	$0.00	$0.00	$0.00
C	Economic	A	1	0.6	5	$0.00	$0.00	$10.00
D	Economic	D	2	0.9	15	$0.00	$0.00	$0.00
E	Economic	A	1	0.75	5	$6.67	$0.67	$2.00
F	Economic	D	1.5	0.8	15	$0.83	$3.13	$0.00

Rank Example

Rank = Adjusted Capability Offer Cost + Adjusted Performance Offer Cost + Adjusted Lost Opportunity Cost

Example requirement = 90 MW

Rank Order Low to High

Resource	Offer Type	Signal Type	Adjusted Capability Offer	Adjusted Performance Offer	Adjusted LOC	Rank	Effective Offer MW	Cleared MW
C	Economic	A	$0.00	$0.00	$10.00	$10.00	20	0
E	Economic	A	$6.67	$0.67	$2.00	$9.34	20	10
F	Economic	D	$0.83	$3.13	$0.00	$3.96	20	20
A	Self-Scheduled	A	$0.00	$0.00	$0.00	$0.00	20	20
B	Self-Scheduled	D	$0.00	$0.00	$0.00	$0.00	20	20
D	Economic	D	$0.00	$0.00	$0.00	$0.00	20	20

Rank Price (ASO) vs. RMCP (LPC)

- Calculating the Rank in ASO and the RMCP in LPC:
  - The same steps are performed except Reg TPS Test (only done in ASO)

- Real-Time conditions affect regulation pricing:
  - System conditions change:
    - Resources needed for constraint control
    - Impacts to LOC
  - Forecasted LMP vs. 5 minute LMP
  - Historical mileage vs. actual mileage

RMCP Example

Regulation Market Clearing Price = Regulation Market Capability Clearing Price + Regulation Market Performance Clearing Price
RMCP = RMCCP + RMPCP

Resource	Offer Type	Signal Type	Adjusted Capability Offer	Adjusted Performance Offer	Adjusted LOC	Rank	Effective Offer MW	Cleared MW
C	Economic	A	$0.00	$0.00	$15.00	$15.00	20	0
E	Economic	A	$6.67	$0.67	$20.00	**$27.34**	20	10
F	Economic	D	$0.83	**$3.13**	$0.00	$3.96	20	20
A	Self-Scheduled	A	$0.00	$0.00	$0.00	$0.00	20	20
B	Self-Scheduled	D	$0.00	$0.00	$0.00	$0.00	20	20
D	Economic	D	$0.00	$0.00	$0.00	$0.00	20	20

- Regulation Market Clearing Price (RMCP) = highest rank of cleared resources = **$27.34**
- Regulation Market Performance Clearing Price (RMPCP) = highest adjusted performance offer from cleared resources = **$3.13**
- Regulation Market Capability Clearing Price (RMCCP) = RMCP – RMPCP = **$24.21**

Regulation Settlements

- Capability Credit = Five minute-integrated Raw Regulation MW * Five minute Performance Score * Five minute Regulation Market Capability Clearing Price (RMCCP) / 12

- Performance Credit = Five minute-integrated Raw Regulation MW * Five minute Performance Score * Mileage Ratio * Five minute Regulation Market Performance Clearing Price (RMPCP) / 12

- Five minute performance score must be above 0.25 to receive compensation
- Mileage Ratio is $\frac{RegD\ Mileage}{RegA\ Mileage}$ for a Reg D resource and $\frac{RegA\ Mileage}{RegA\ Mileage}$ = 1 for a Reg A resource
- Manual 28 Section 4 has more details on Regulation Accounting

Presenters/SMEs

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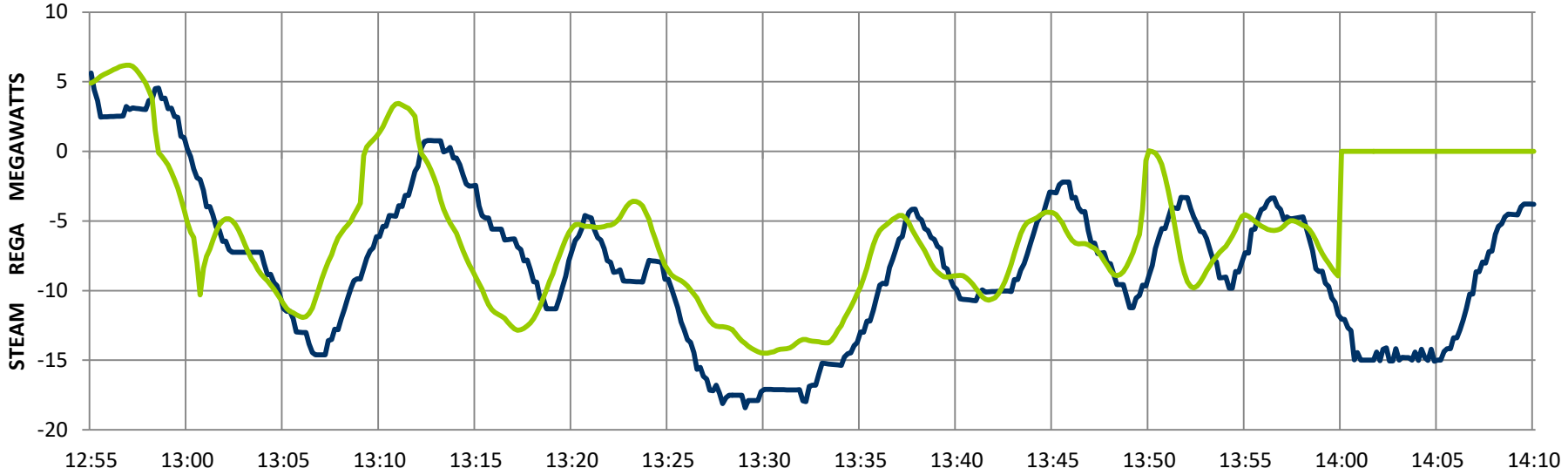
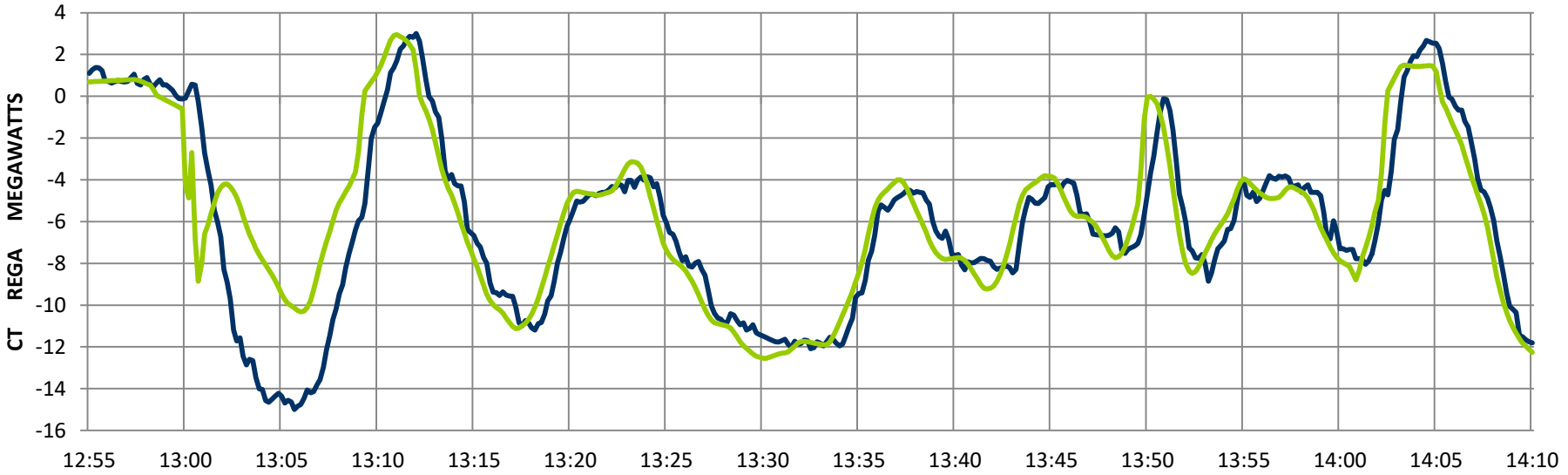
APPENDIX

Example Resources Following REGA Signal

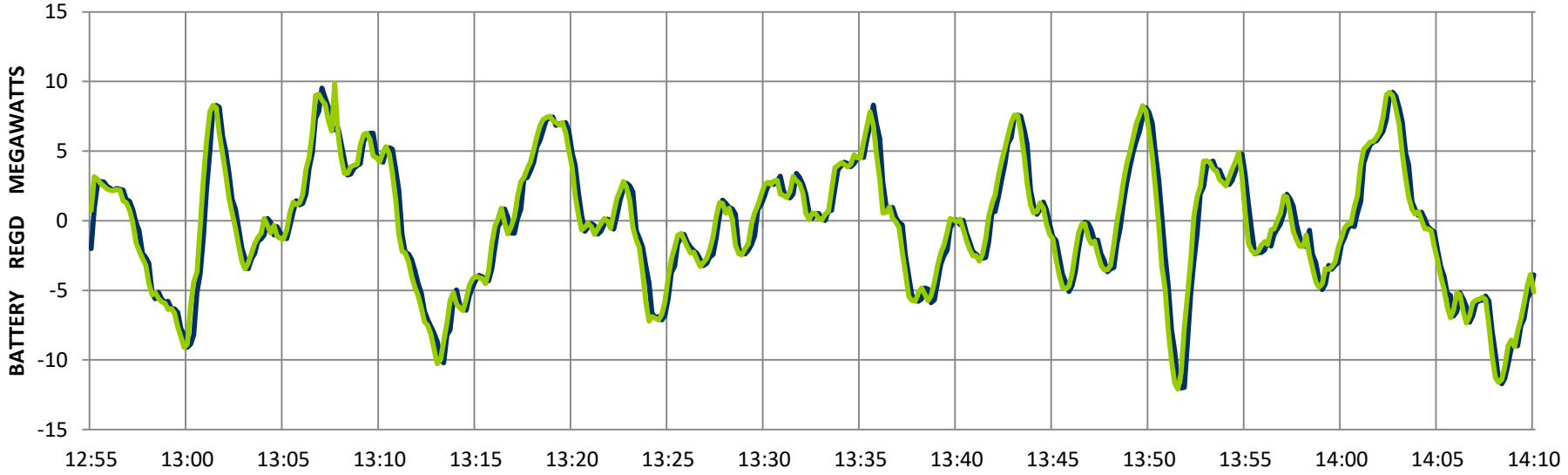


REGA
79.5%

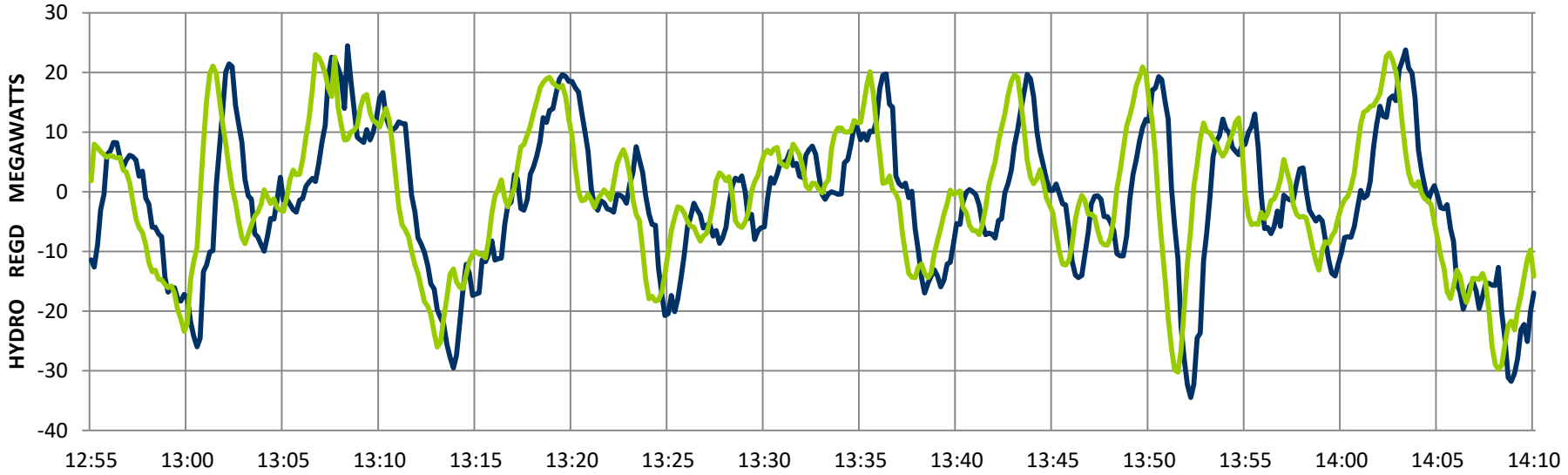


REGA
90.6%

Example Resources Following REGD Signal



REGD
97.7%



REGD
74.7%