PJM Regulation Study Update

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Acronym Definitions

- **RegD** = Regulation D, Dynamic Regulation
- **RegA** = Regulation A, Traditional Regulation
- **ACE** = Area Control Error
- **ACS** = ACE Correcting Signal (ACE*-1)
- **IQR** = Interquartile Range
- **Neutrality** = Keeping the RegD signal centered around 0 over certain time frame (30 minutes)
- **KEMA Study** = Study performed by KEMA in 2011 to identify the substitution rate between RegA and RegD resources
  - http://www.pjm.com/~/media/committees-groups/committees/oc/20150701-rpi/20150701-kema-study-report.ashx
- **Energy Imbalance** = A simulation of the MWh of resources following the RegD signal, this helps to identify when energy limited resources would be either fully charged or discharged
- **Imbalance Bias** = An amount of MW that is fed to the RegA signal that RegD borrowed in order to maintain energy balance (if neutrality feedback is enabled and RegA has capability to do so)

Analysis Timeline

Phase 1 (Signal Design) – Work Completed

- Analyze current signals
- Identify maximized utilization of available resources
- Improve signal design

Phase 2 (Modeled Response and Simulations) – Current Work

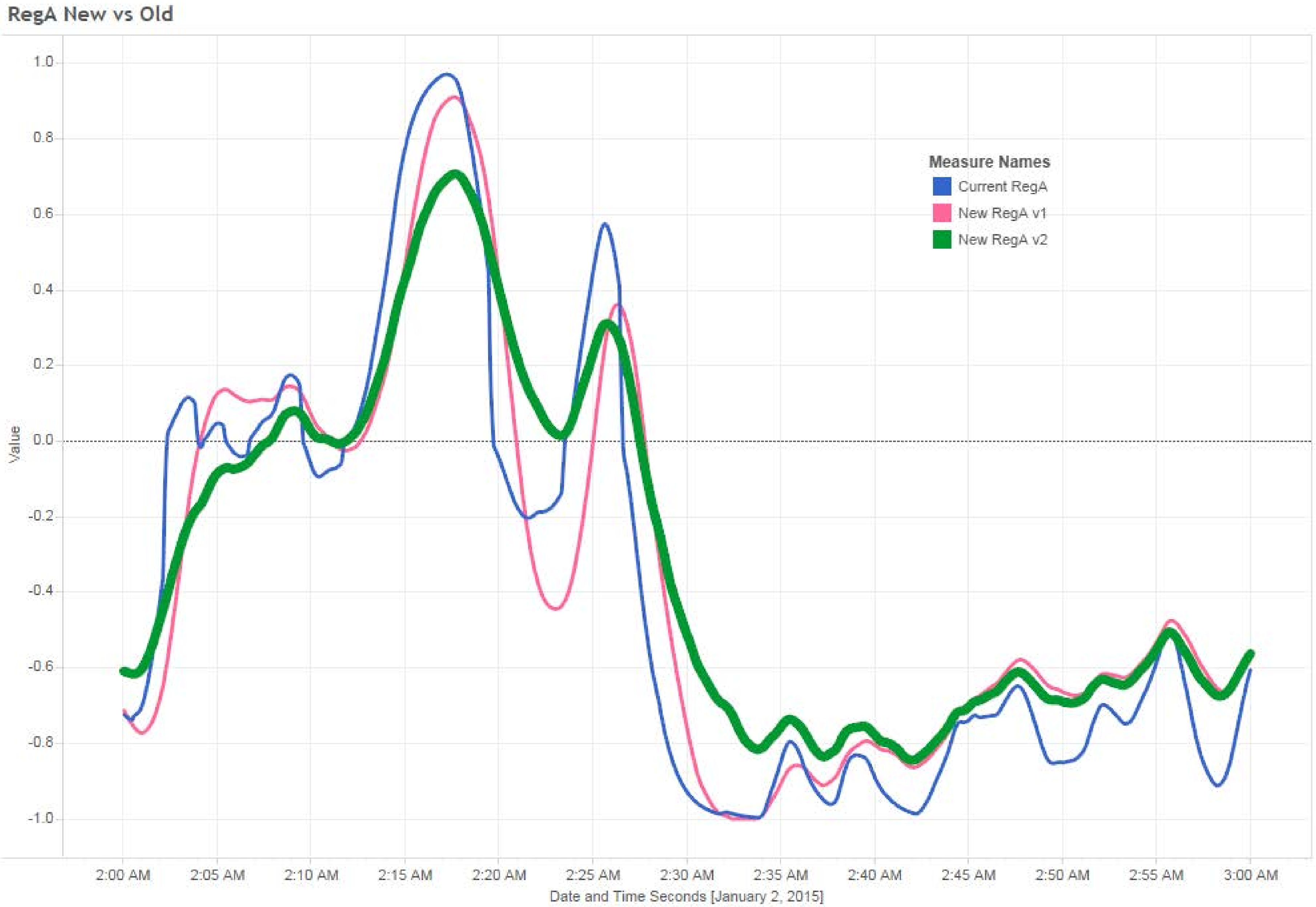
- Finalize signal tuning
- Simulate resource response to new signals (finalize resource models)
- Compare advantages of different signals (metric used for isoquants)

Phase 3 (Resources Substitution) – Future Work

- Define rate of substitution between signal types (this is what the KEMA study was used for in the past)
- Move new signals into PJM's AGC (Development and Test first)

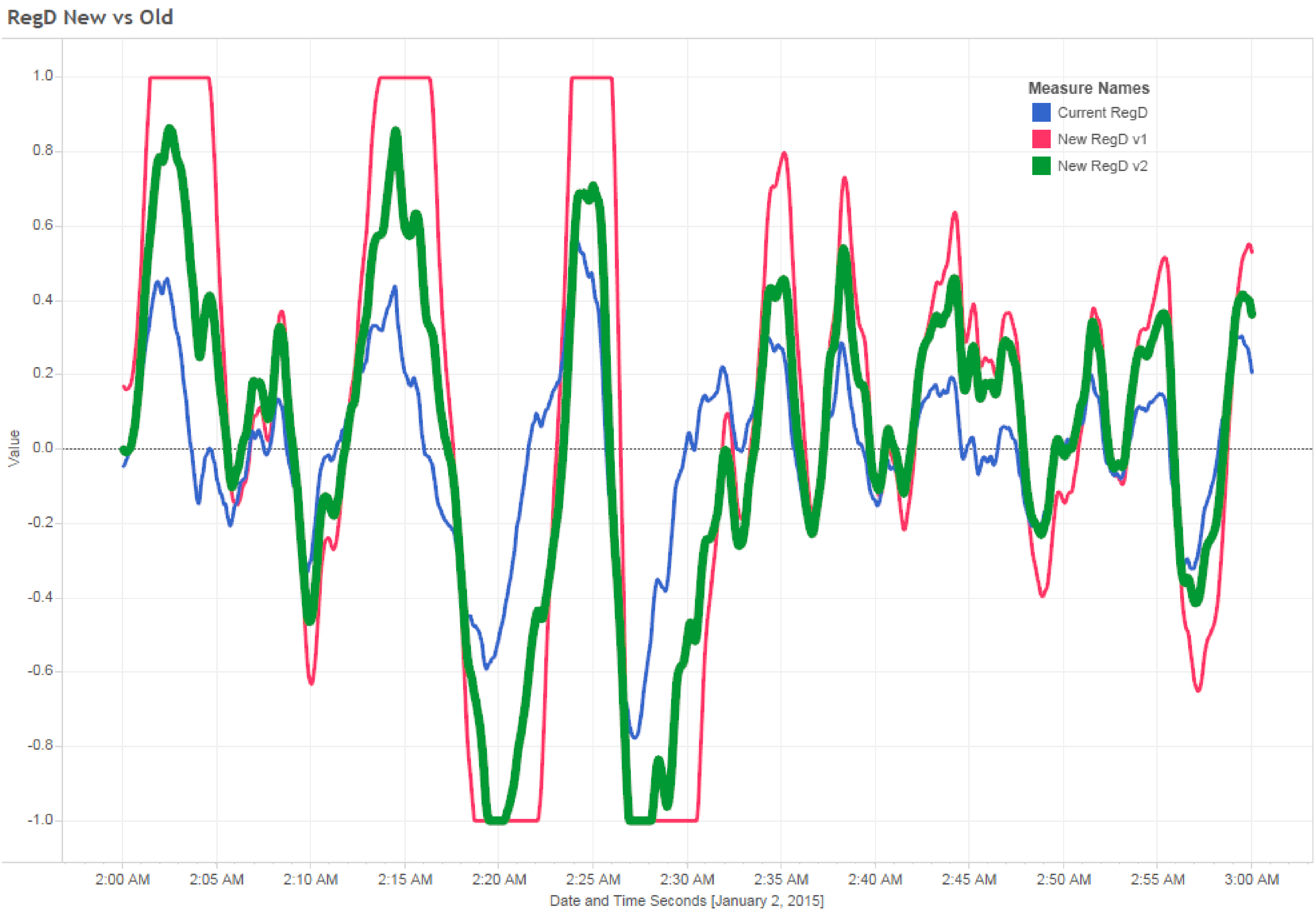
During further regulation signal stability analysis PJM recognized that additional tuning was required in the new signals

- Last revision updated controller to a Proportional-Integral (PI) controller
  - After building this style controller, more analysis was required to tune the integral term of the controller
  - PJM reduced the integral term of the controller to improve signal stability and reduce unnecessary movement of regulation signals
- Additional logic added to payback function in order to ensure both signals are working together to maximize ACE control



Regulation A Signal Tuning

- Pink is version 1 of the new controller (RegA)
  - Overshoots during periods of oscillation
- Green is version 2 of the new controller (RegA)
  - Signal is properly calculated to follow ACE deviations
- Blue is signal in production today (RegA)
  - Signal accelerates back to 0



Regulation D Signal Tuning

- Pink is version 1 of the new controller (RegD)
  - Overshoots during periods of oscillation
- Green is version 2 of the new controller (RegD)
  - Improved energy balance
- Blue is signal in production today (RegD)
  - Signal is not fully utilized when needed

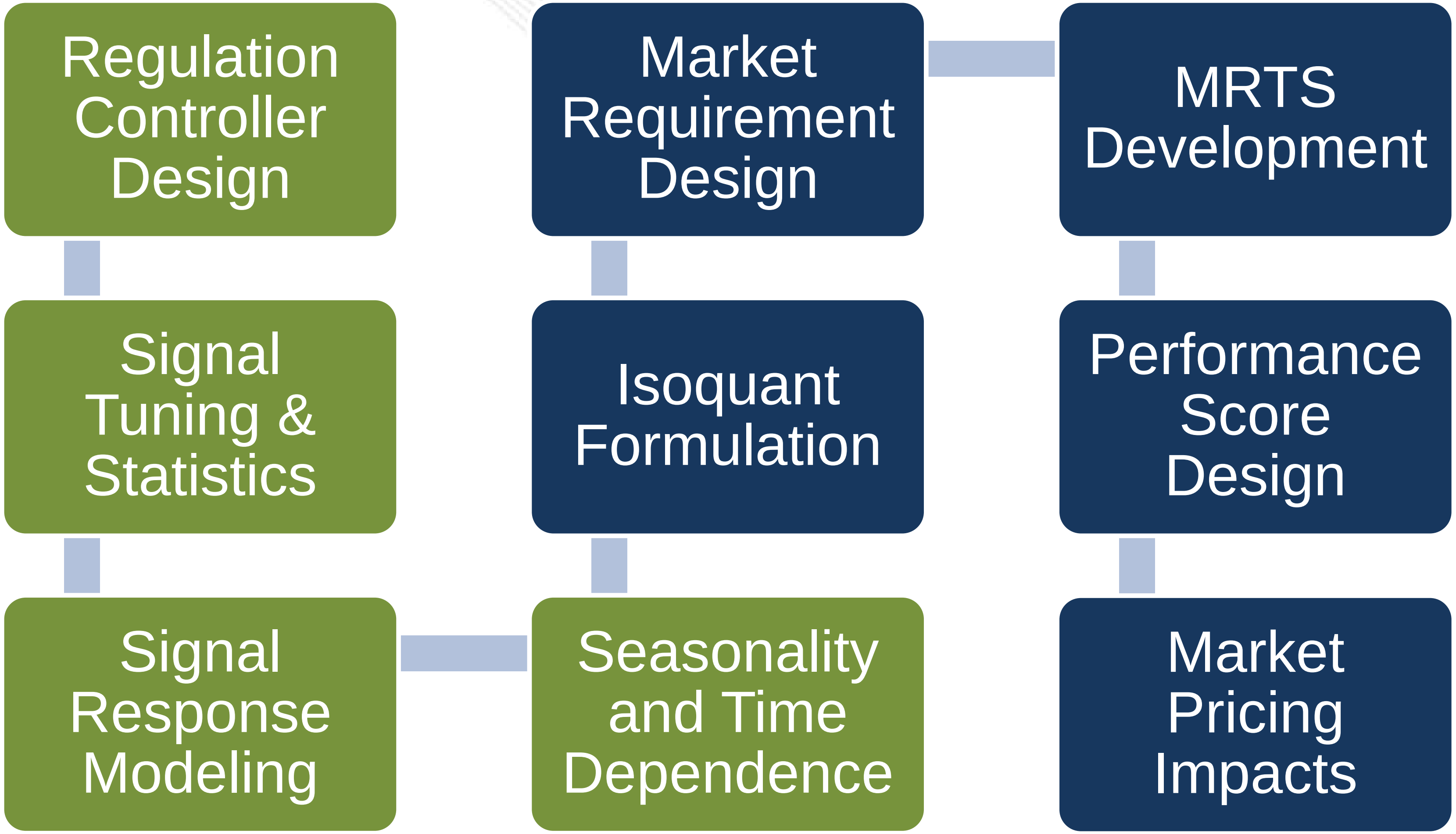
New Sample Signals Posted

- Update to winter week of regulation signals sample
  - January 1 – 7 of 2015
  - The new posted file contains the regulation signals with version 2 of the new controller
- Added 3 more weeks to the regulation signals sample
  - Spring (April 1 – 7 of 2015)
  - Summer (July 1 – 7 of 2015)
  - Fall (October 1 – 7 of 2015)
- File can be found under RMISTF - 7.19.2016 Meeting Materials:
  - http://pjm.com/~/media/committees-groups/task-forces/rmistf/20160719/20160719-regulation-signal-sample-data-4-weeks-new-signals.ashx

- RegD Resource Model
  - Performance is based on historical average performance observed from resources (including signal delay for time it takes resource to receive signal)
  - Energy limited resource response will drop to 0 MW when controller calculates that these resources would be out of charge
  - Currently modeling results with varying duration battery levels (15/30/45/60 minute duration)
- RegA Resource Model
  - Performance is based on historical average performance observed from resources
  - The signal for RegA resources no longer has an acceleration function
  - Signal tuned to better align with resource capabilities

Metric for Isoquants

- Previously we were using a Control Metric defined as follows
  - Control Metric = Average(Median(ABS(ACE)), Average(ABS(ACE)), IQR(ABS(ACE)))
  - Lower Control Metric = Better Control
  - Control Metric = 0 means ACE has no error, perfectly controlled
- Control Metric was difficult to quantify for a threshold requirement and did not fully capture the impact of losing energy limited resources in times of extended duration
- PJM is now looking at using a combination of average (ACE) and L_{10} in order to define a limit to the required control
  - L_{10} is defined by NERC in BAL-001 as an operating limit for average of ACE
  - A presentation will follow with more detail on this evaluation method (analysis still in progress)


Regulation Controller Design
Market Requirement Design
MRTS Development
Signal Tuning & Statistics
Isoquant Formulation
Performance Score Design
Signal Response Modeling
Seasonality and Time Dependence
Market Pricing Impacts