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)

Signal Re-Tune

During regulation signal stability analysis, PJM discovered additional tuning was required for the new signals

- Controller frontend changed to a Proportional-Integral (PI) controller
- RegA and RegD signals receive information about each other to ensure the signals are working together
- Conditional neutrality utilized in order to optimize both resource types for system control
- All parameters of the controller run through regression analysis to ensure that all variables are working together to improve reliability
- Control Metric created to capture the improvement of ACE control
  - 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

Analysis Timeline

Phase 1 (Signal Design) – Work Completed

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

Phase 2 (Modeled Response and Simulations) – Current Work

- Simulate resource response to new signals
- Compare advantages of different signals

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)

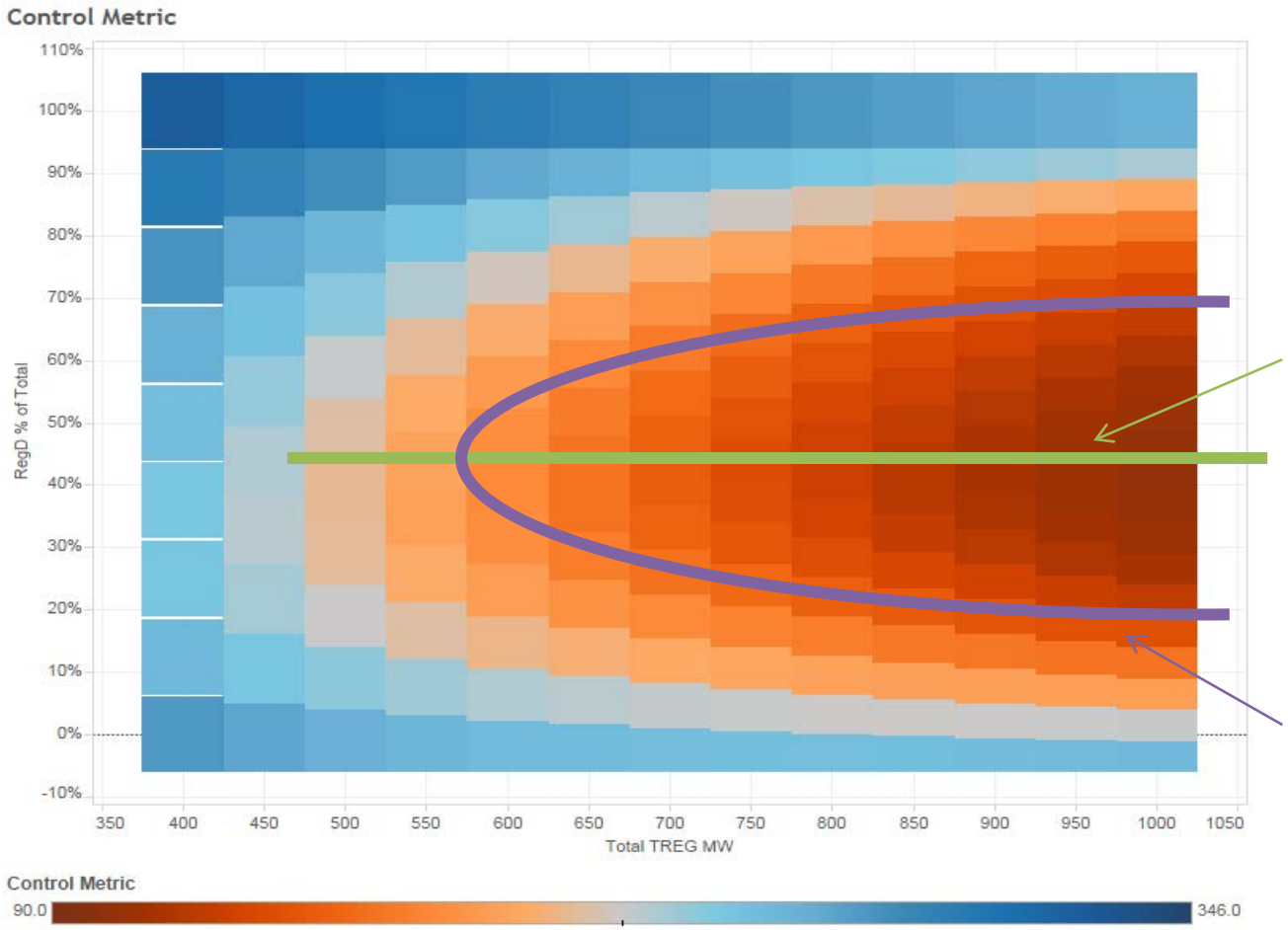
Resource Assumptions for Studies

- RegD Resource Assumptions
  - 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 (storage duration limit = 30 minutes)
  - Controller simulates the possibility of a small amount (10%) of non energy limited resources following the RegD signal
- RegA Resource Assumptions
  - 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

Additional Assumptions for Studies

- Controller uses conditional neutrality which utilizes both resource types available to maximize control of ACE
  - When RegA resources have additional room, energy neutrality is maintained for RegD
  - If RegA resources are fully utilized, RegD will not be controlled to 30 minute energy neutrality
- Study Data Details
  - Data captured and simulated at a 2 second level of detail
  - 4 weeks worth of data (1 week from each season)
  - A week worth of data helped to capture the various operational characteristics of ACE during simulation

Explanation of Curves



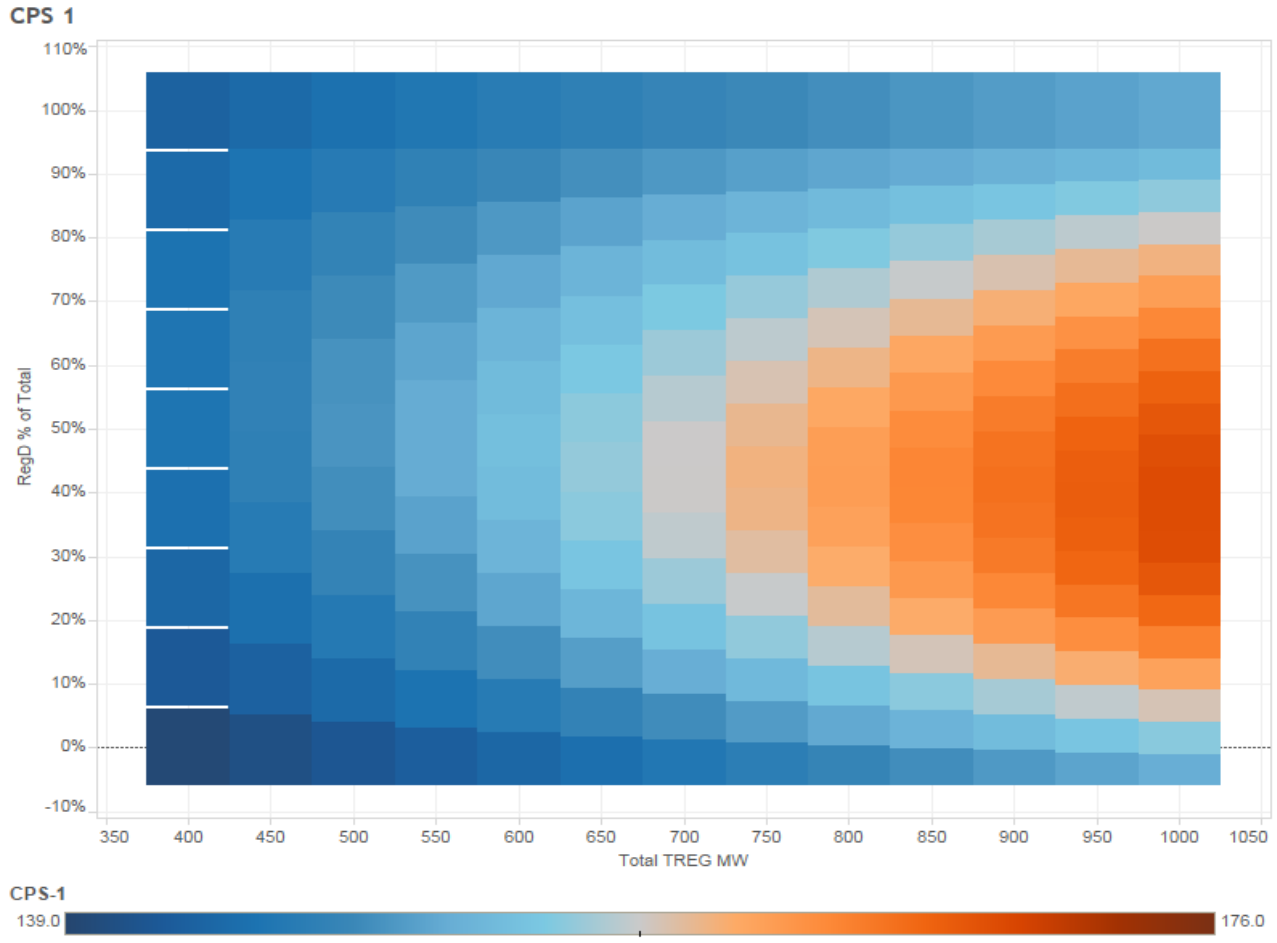
For maximized control, % mix of RegD constant as TReg increases

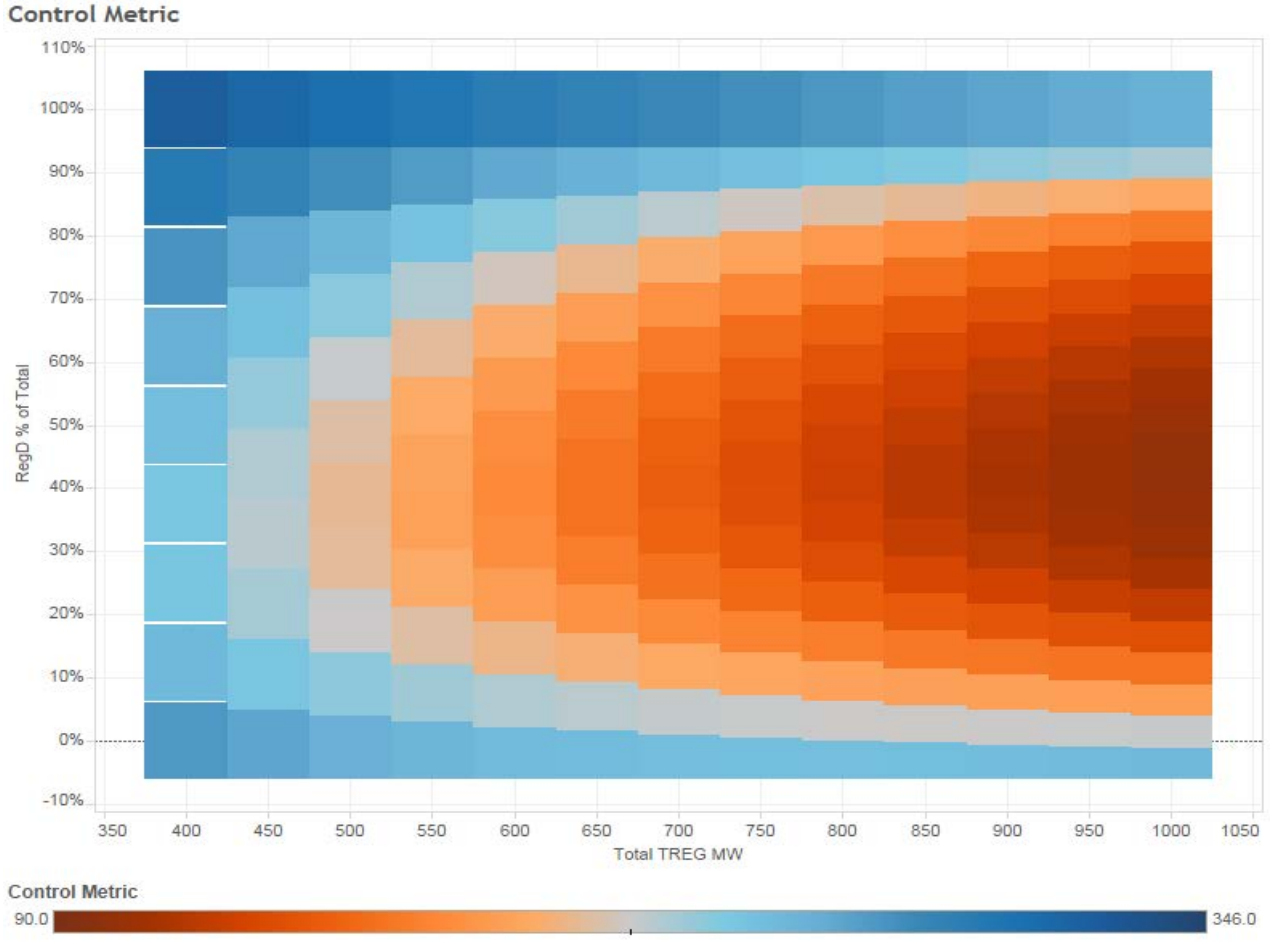
% Mix of RegD for an equivalent level of control

New Controller Design Conditional Neutrality (1 Week of Data, Winter 2015)

43% of Total Reg as RegD maximizes control for 700 Raw MW

Red = Better Control (for all graphs)

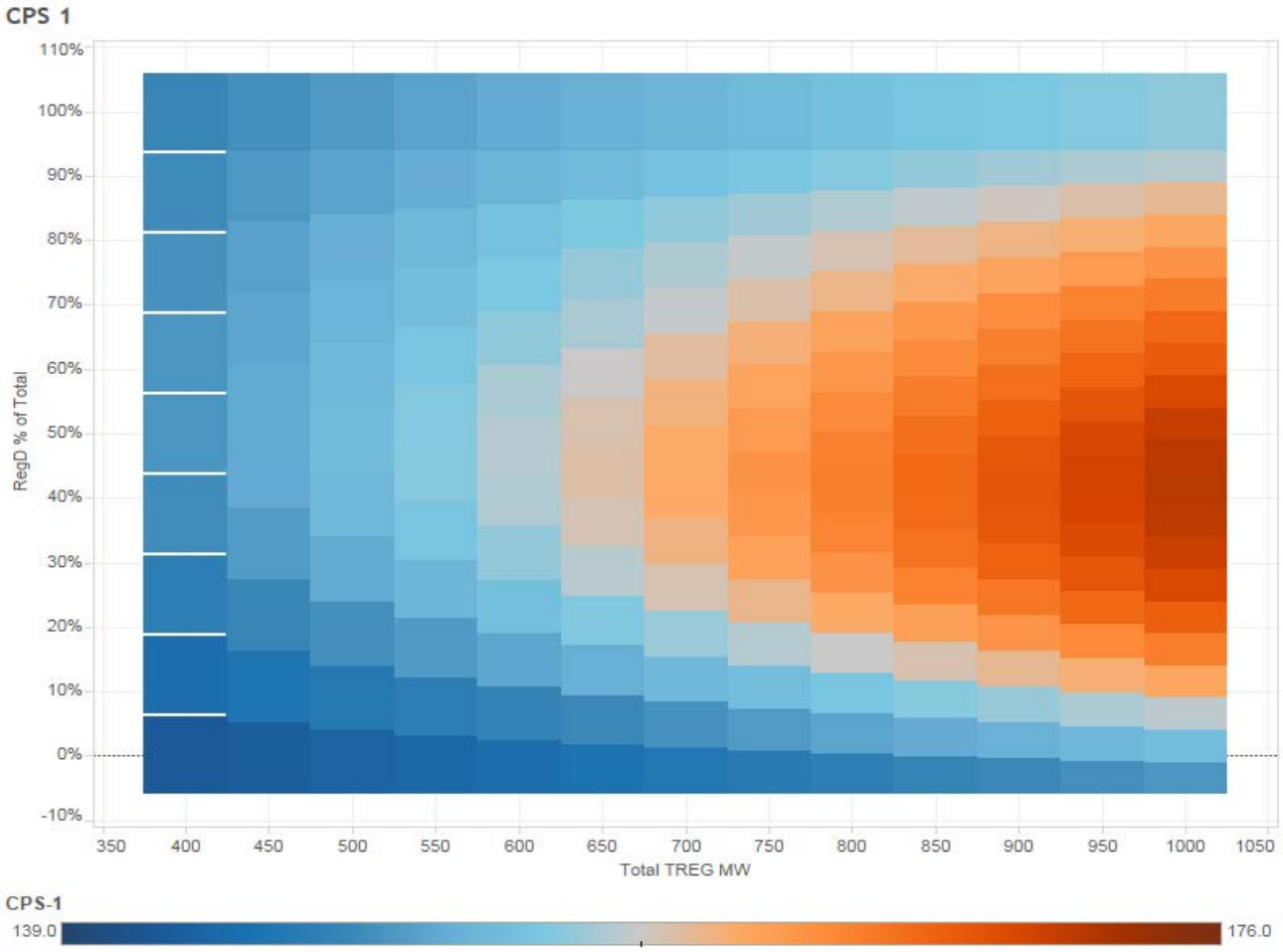


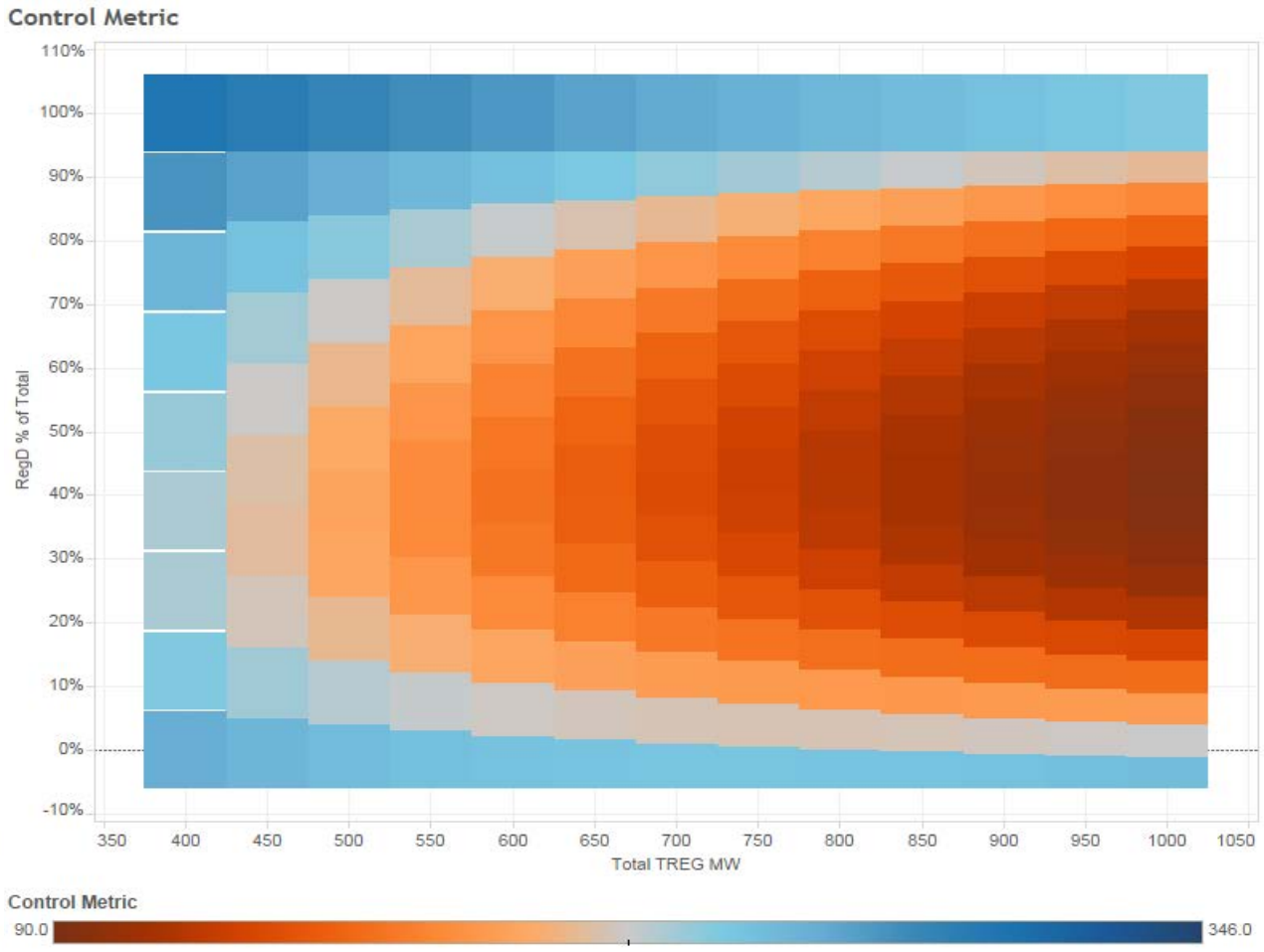


New Controller Design Conditional Neutrality (1 Week of Data, Spring 2015)

43% of Total Reg as RegD maximizes control for 700 Raw MW

Red = Better Control (for all graphs)

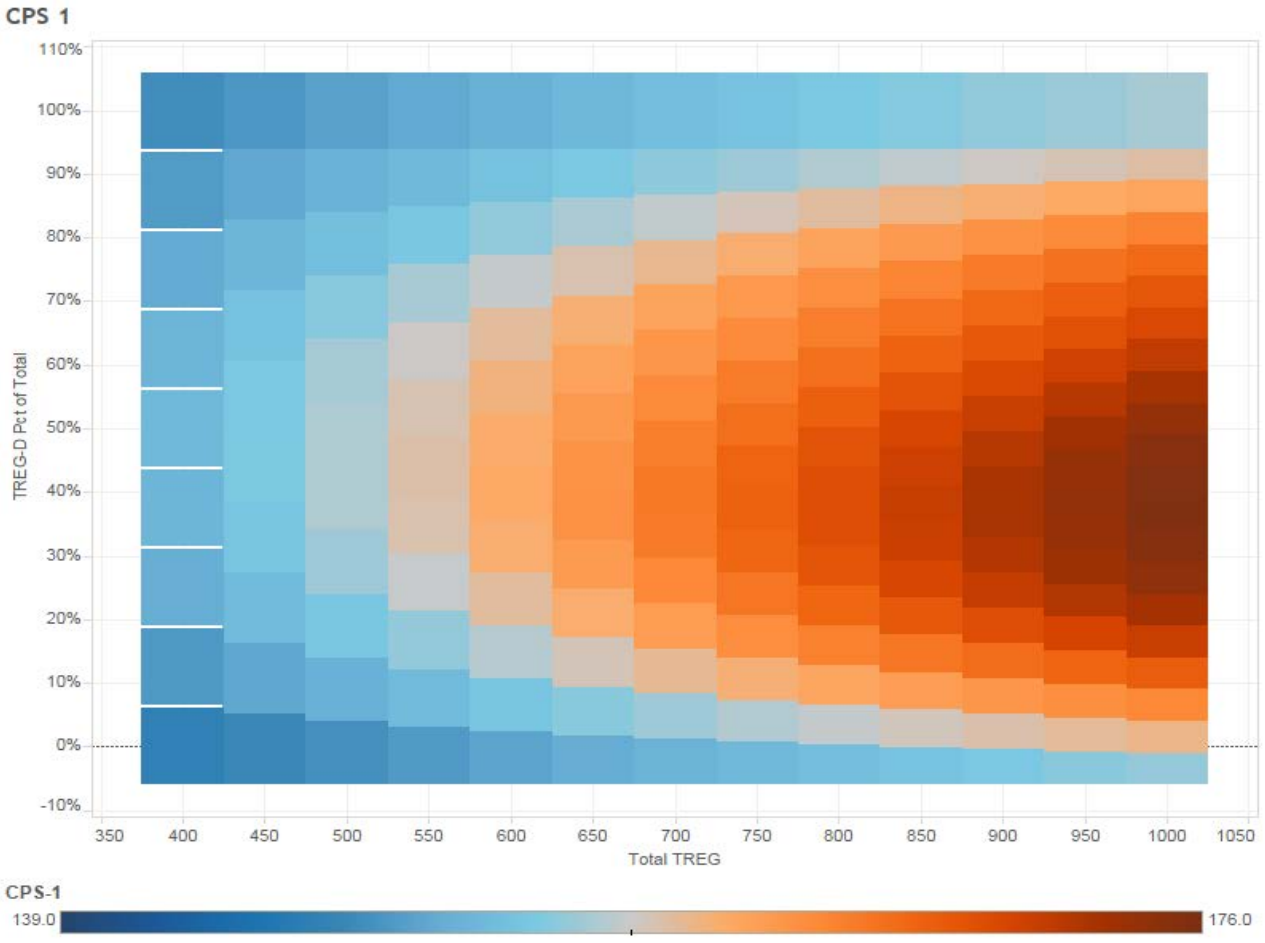


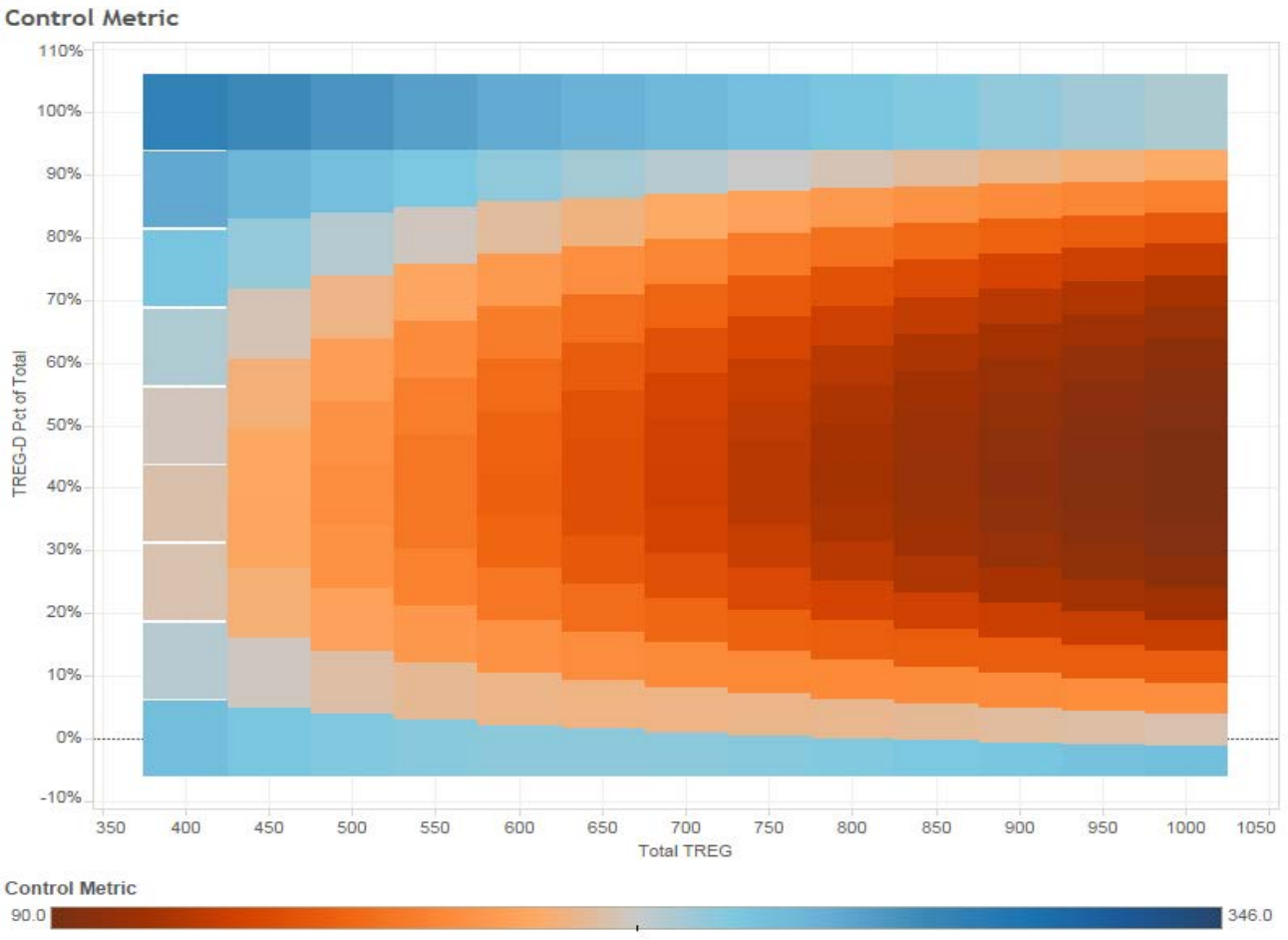


New Controller Design Conditional Neutrality (1 Week of Data, Summer 2015)

43% of Total Reg as RegD maximizes control for 700 Raw MW

Red = Better Control (for all graphs)

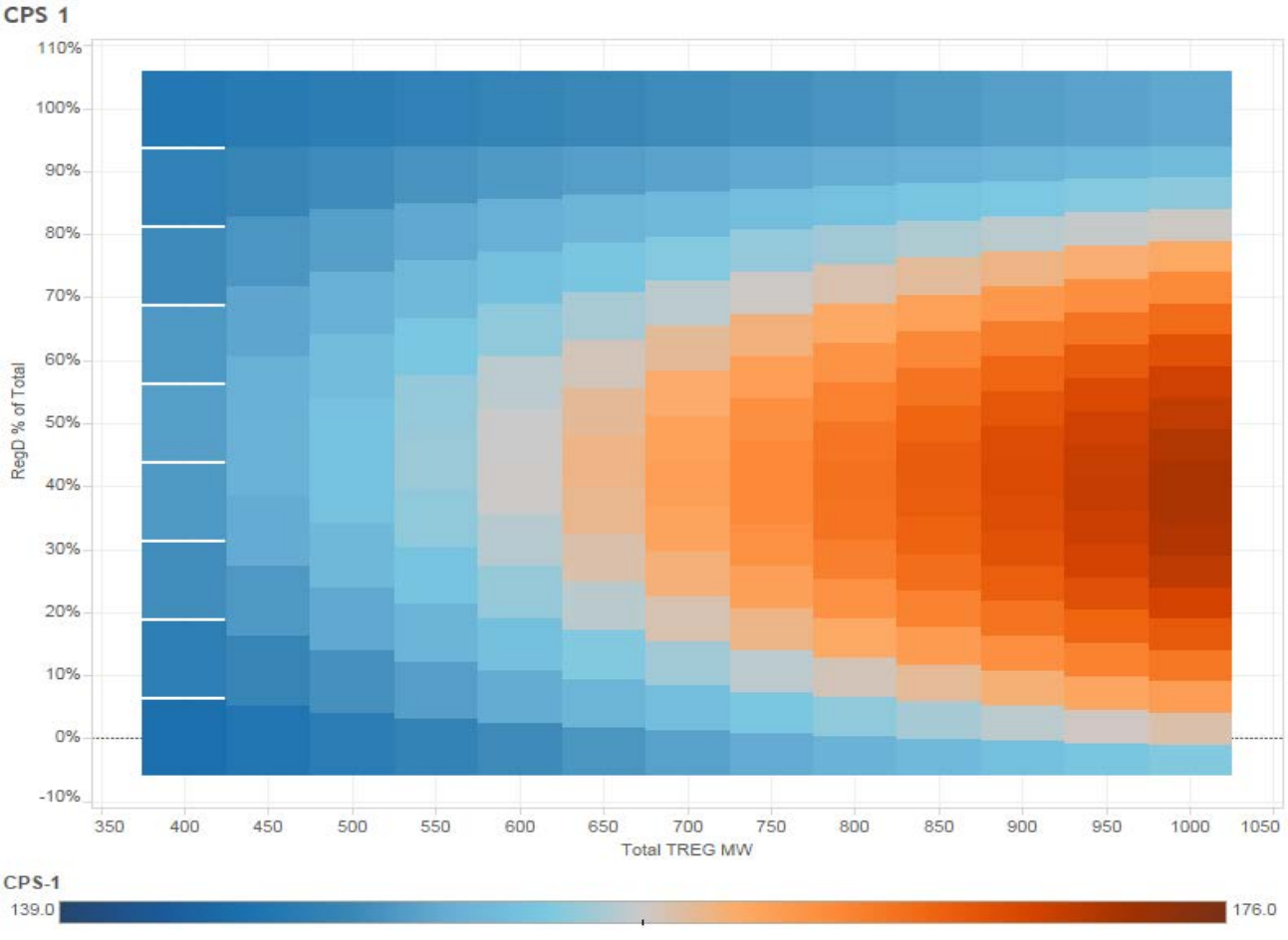


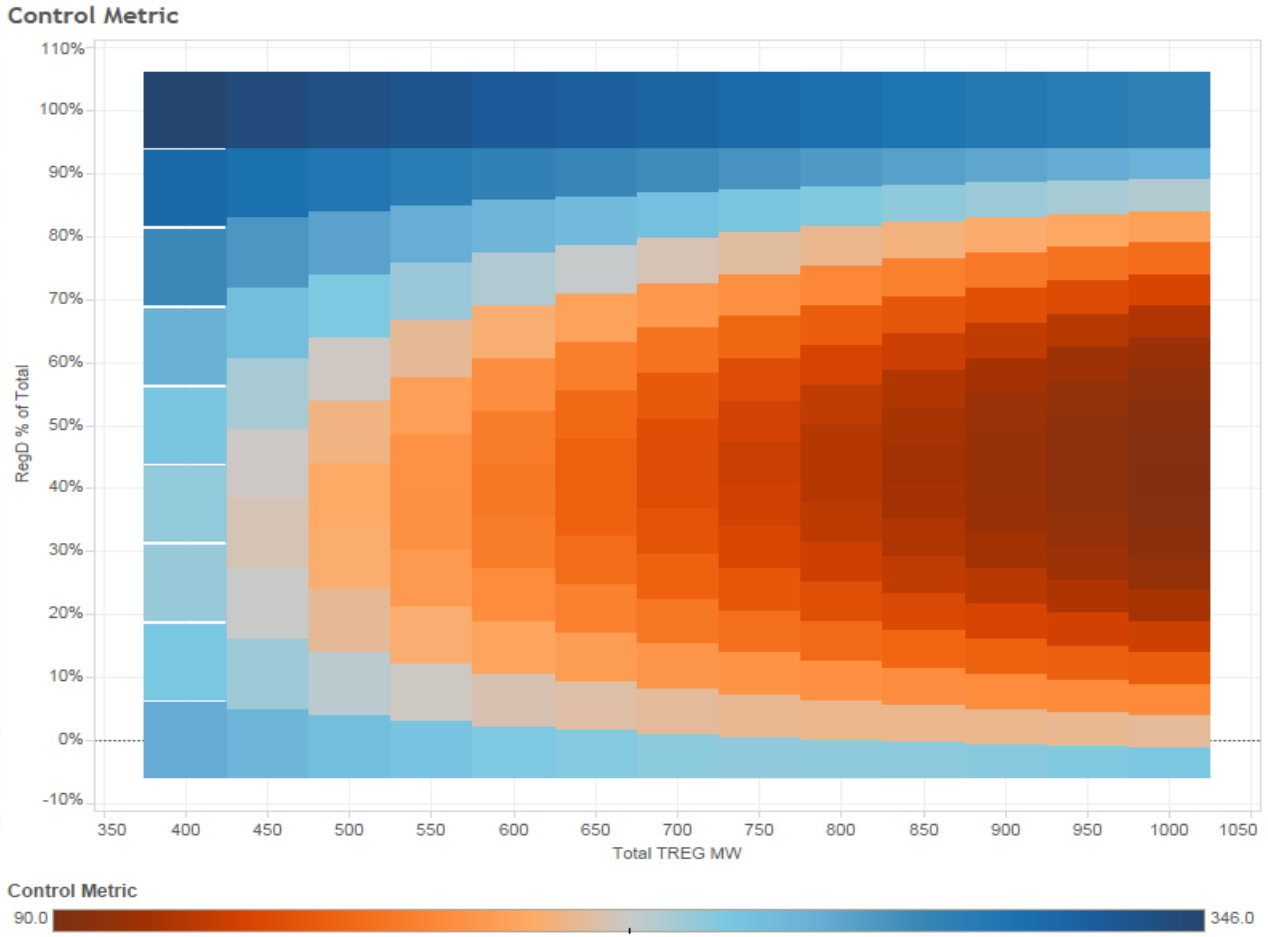


New Controller Design Conditional Neutrality (1 Week of Data, Fall 2015)

43% of Total Reg as RegD maximizes control for 700 Raw MW

Red = Better Control (for all graphs)





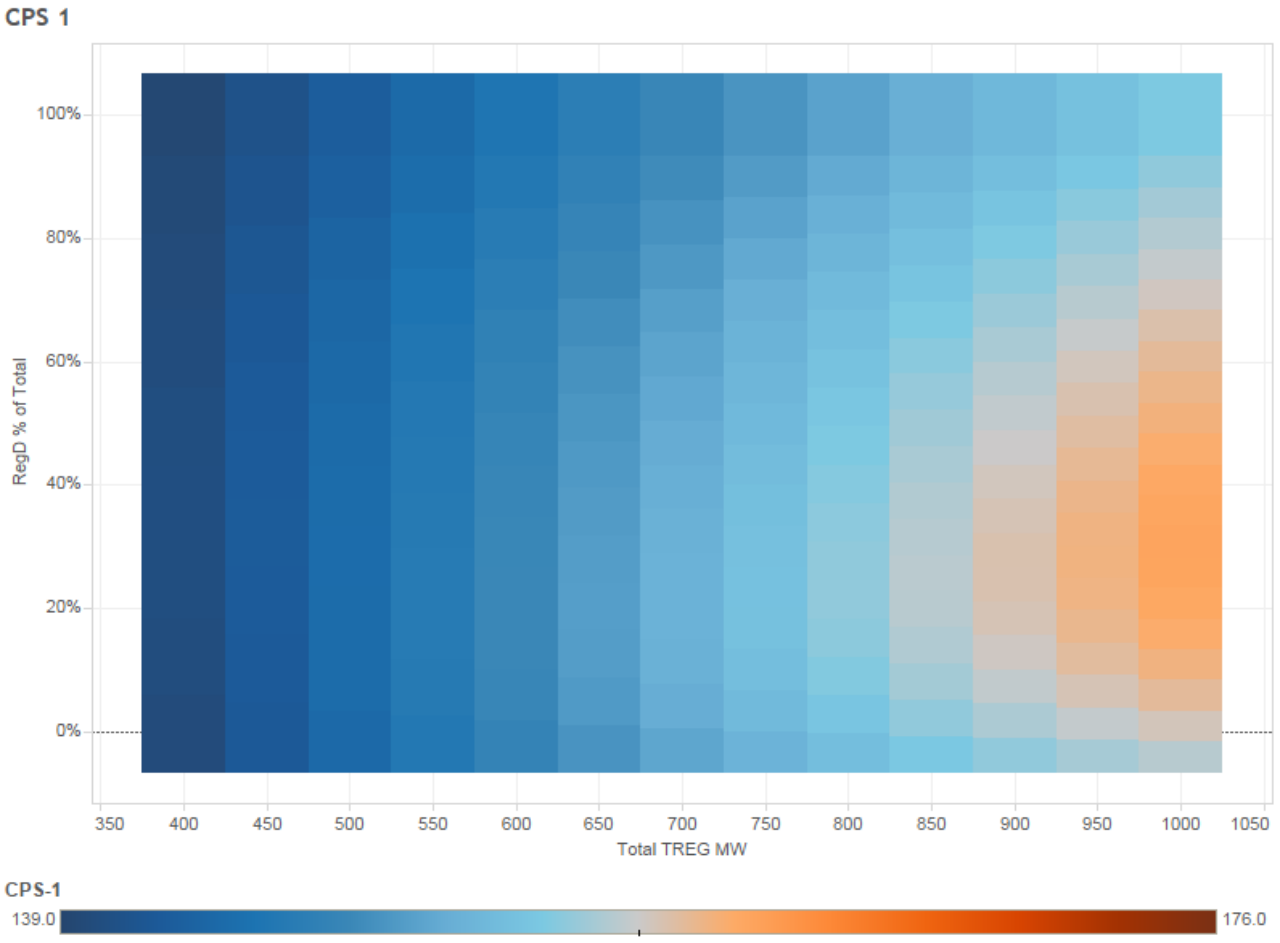
Summary of New Signal Results

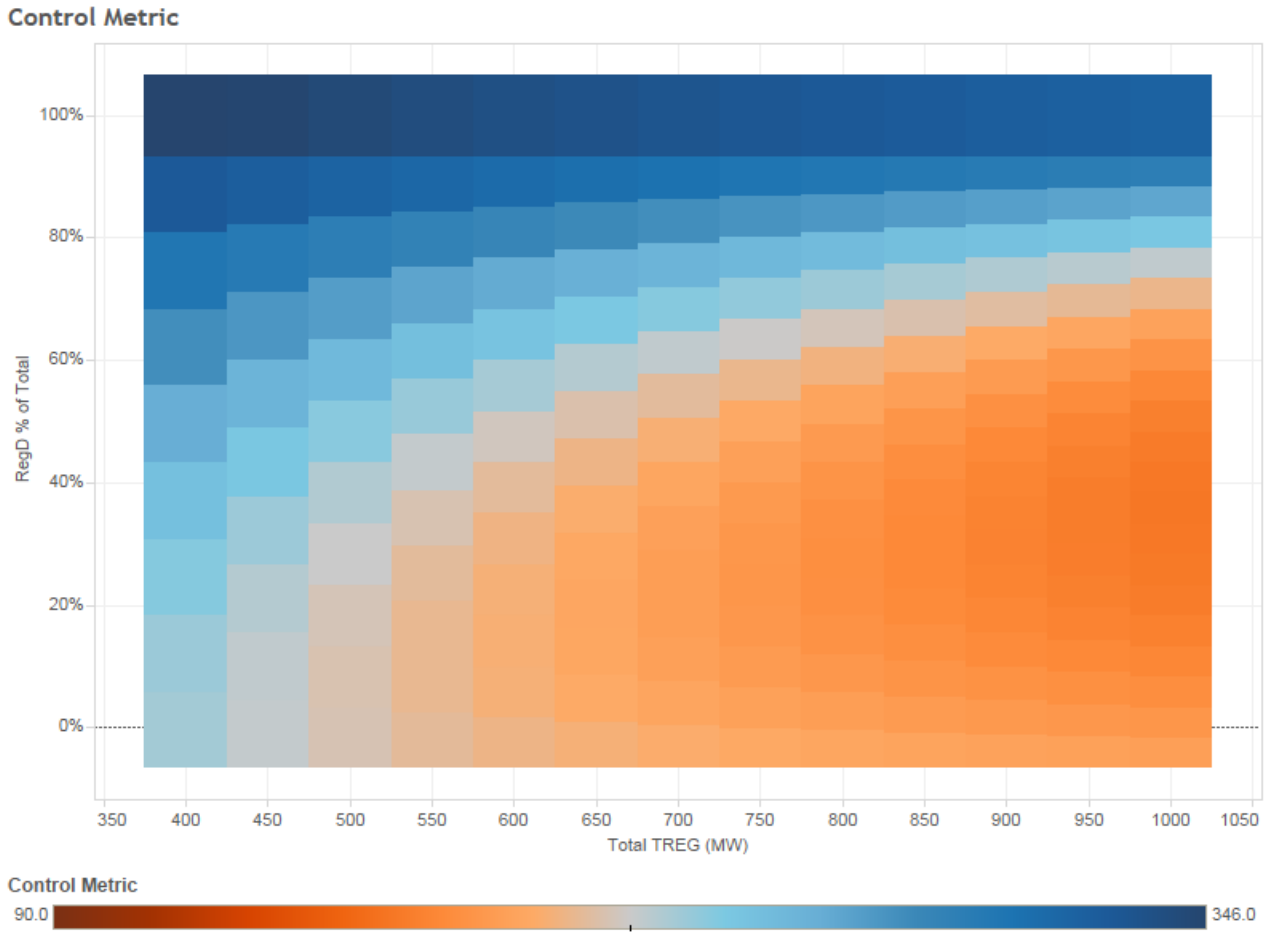
- The mix of RegA and RegD that maximizes control is consistent between various seasons and very close between various total regulation amounts
  - Approximately 43% of RegD @ 700 Raw MW of total regulation
  - This is the value that maximizes control and reliability, the optimal value is determine by the market
- There is a defined benefit to different levels of total regulation MW and changes in resource mix
- Both resource types are required to optimize regulation control
  - RegA – Non energy limited but ramp limited
  - RegD – Non ramp limited but energy limited
- Some variability is observed in the amount of regulation required between seasons
  - i.e. Winter is the most difficult to control requiring more regulation

Current Controller Used in Production Today (1 Week of Data, Spring)

21% of Total Reg as RegD maximizes control for 700 Raw MW

Red = Better Control (for all graphs)





Summary of Current Signal Results

- Reproduction of KEMA study to show mix of resources that maximizes control
- Mix of RegD that maximizes control is at approximately 21% of total regulation amount
- Resources are not fully utilized with current regulation signal design
- Significant improvement in control between the new regulation signals and the regulation signals in production today

What We Will Get from New Signals

- Regulation signals work together to achieve improved system control
- More flexibility in resource procurement
- Improved utilization of resource types
- Defined substitutability between products

What is Next?

- Now that response is modelled and various mixes of products are studied, PJM will determine the substitutability between the two products
- The substitution rate will lead to the development of a mechanism used to clear both products in one resource stack
- The results of these studies will also be used to determine the amount of regulation needed to maintain reliable operations