Mitigating the Operational Impacts of Wind Energy Resources in the BPA Control Area

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Outline

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- Mitigation of Wind Generation Impacts Using a Wide Area Energy Management System (Phase 1)
  - Project Information and Research Team
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  - Stage Gate 3: Analyze Technical and Market Compatibility of the Proposed Integration Schemes with BPA & CAISO Systems
  - Stage Gate 4: Develop Algorithms and Conduct Experiments Using MATLAB Model. Carry Out Cost Benefit Analysis.

I. Expected Impacts of Wind Generation on BPA Load Following and Regulation Requirements

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Expected Impacts of Wind Generation on BPA Load Following and Regulation Requirements

- Research project funded by BPA and conducted by PNNL. Phase 1 completed.
- Research Team
  - PNNL: Yuri Makarov, Shuai Lu
  - BPA: Bart McManus, John Pease, James Murthy
  - CAISO (In a parallel similar project): Clyde Loutan, Phillip De Mello
- Research Papers:
  - Y. Makarov, S. Lu, B. McManus, and J. Pease, “The Future Impact of Wind on BPA Power System Ancillary Services”, Proc. Windpower 2008, Paper #315, Houston, TX, June 1-4, 2008.
  - Y. Makarov, S. Lu, B. McManus, and J. Pease, “The Future Impact of Wind on BPA Power System Load Following and Regulation Requirements”, Proc. 5th International Conference on the European Electricity Market – EEM08, Paper #336, Lisbon, Portugal, May 28-30, 2008.
  - Y. V. Makarov, S. Lu, B. McManus, and J. Pease, “The Future Impact of Wind on BPA Power System Ancillary Services”, 2008 IEEE PES Transmission and Distribution Conference and Exposition, Paper #08TD0325, Chicago, April 21-24 2008.
- Report (submitted to BPA)

Key Elements of the Methodology

- All balancing authorities (BAs = TSOs in Europe) are different, and the impact of wind generation depends on their specific business practices
  - There is no a universal methodology that is suitable for all systems without considering details of BAs' scheduling, load following, and regulation processes
  - Impact of wind can be minimized by adjusting BAs' business practices
  - An adequate BA-oriented methodology could help to find these solutions
- All sources of intermittency including load and wind generation forecast errors, uninstructed deviations of all generators should be reflected in their interaction
- Interdependence between the required balancing power, ramping capability, and ramp duration and balancing energy should be reflected

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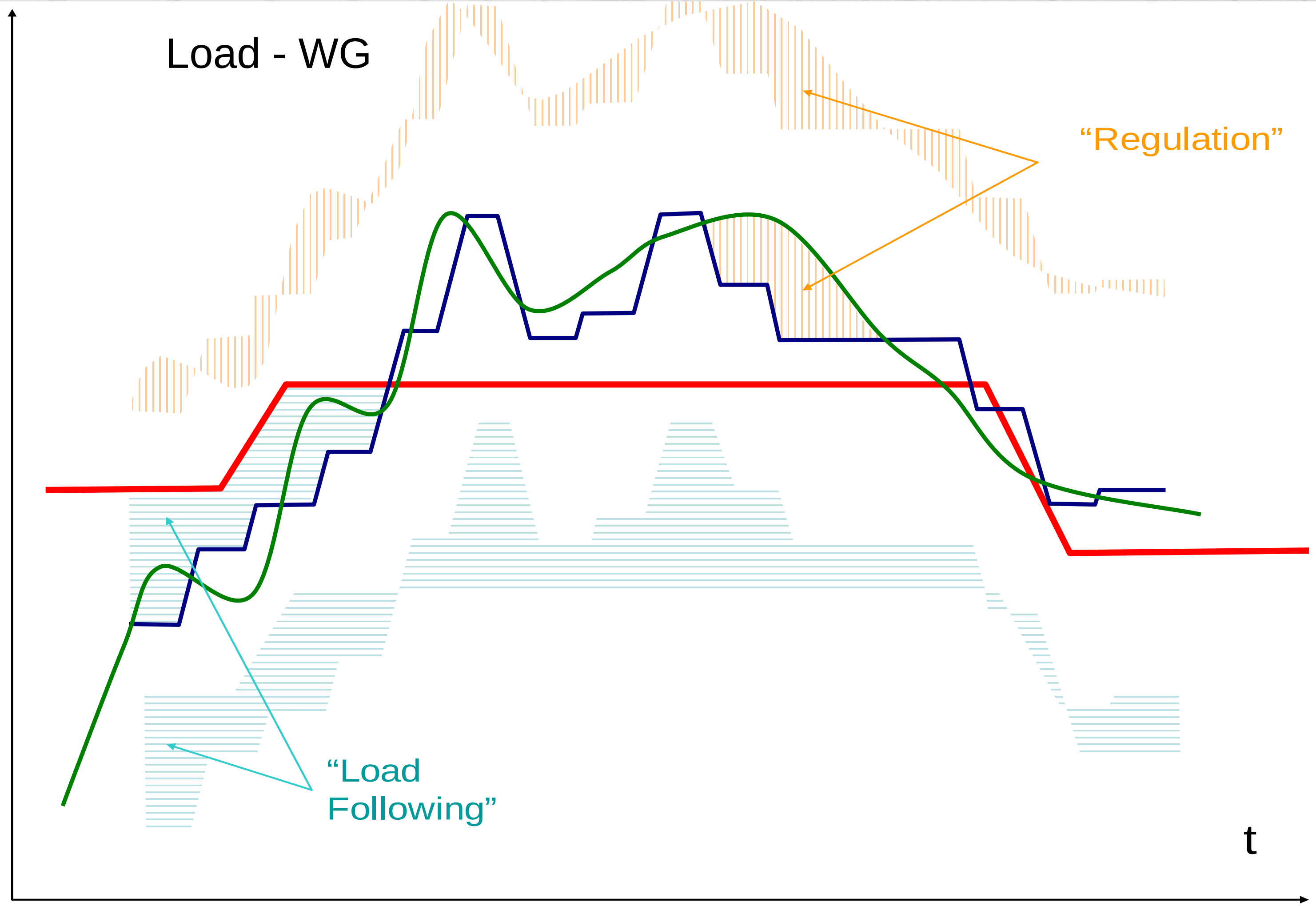
Scheduling, Load Following and Regulation Processes



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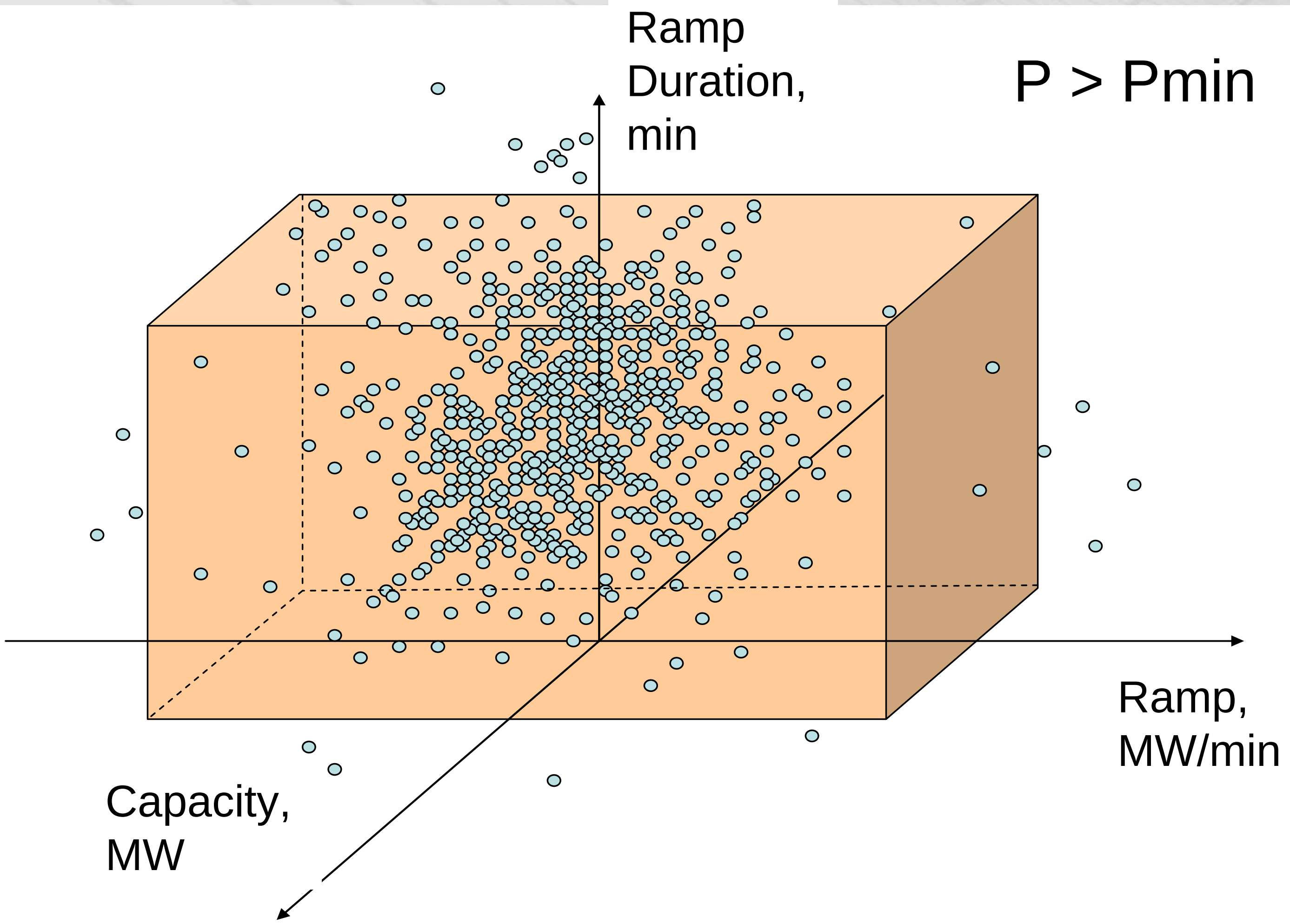
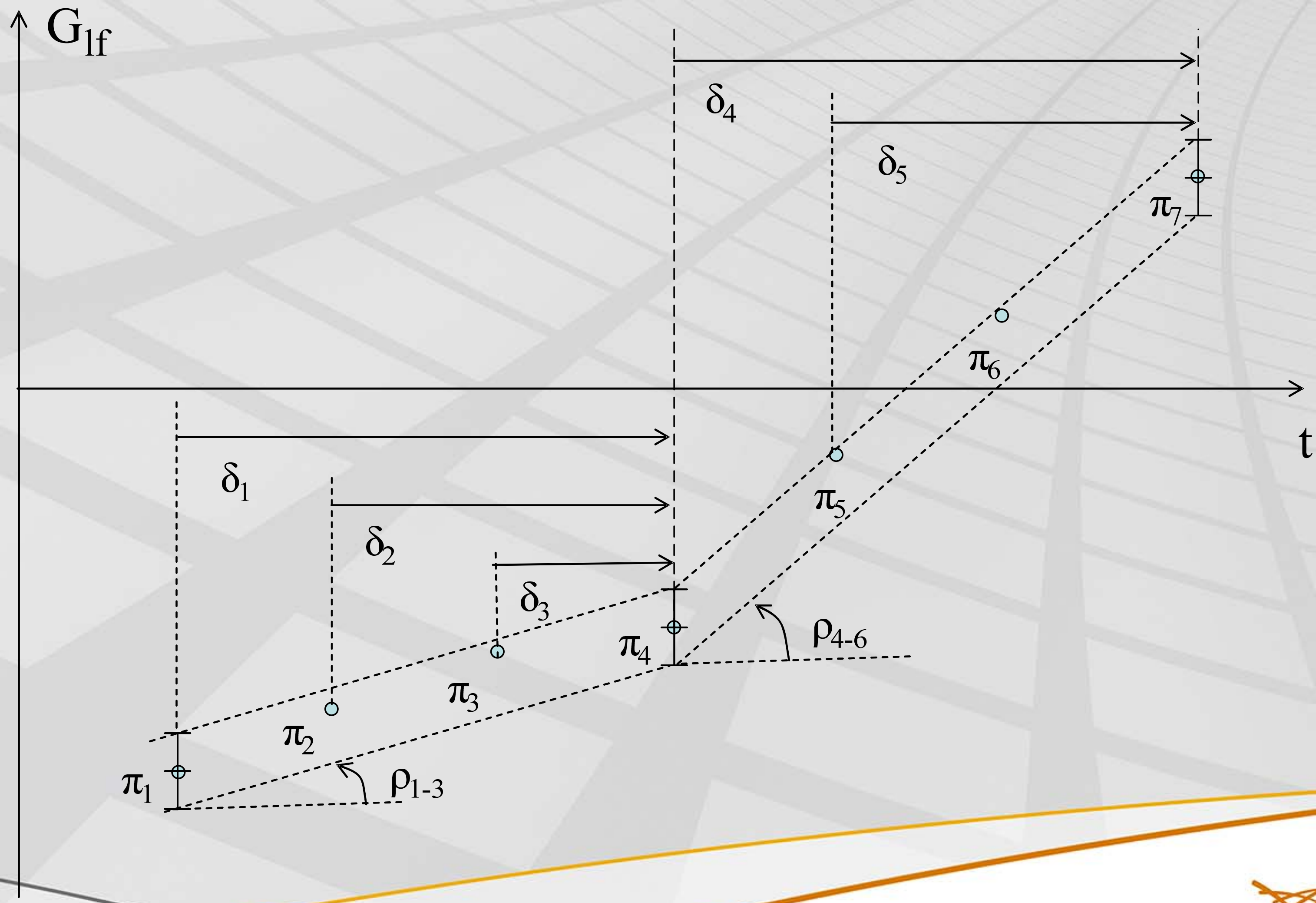
Interdependence Between the Balancing Capacity, Ramping Capability & Ramp Duration



Calculation of Ramps – Swinging Door Algorithm



Generating Data Sets

- Actual load
  - Actual load of year 2006 with 1-min resolution
  - Annual load growth factor is assumed to be 1.5% for future years.
- Hourly load forecast
  - Hourly load forecast data of year 2006 is BPA historical data
  - Annual load growth factor is assumed to be 1.5% for future years.
- Actual wind (the methodology was proposed & implemented by BPA)
  - Wind data of 2006 was generated using a combination of 3Tier Company's model and actual wind farm data.
  - Wind data of future years was expanded from 2006 data, using a capacity coefficient and a delay to count for location difference.
- Hourly wind forecast
  - Generated using a wind forecast formula based on actual wind output in previous hours
- Real-time forecast data (wind and load)
  - Generated using random series with truncated normal distribution with autocorrelation.

Example of generated forecast data

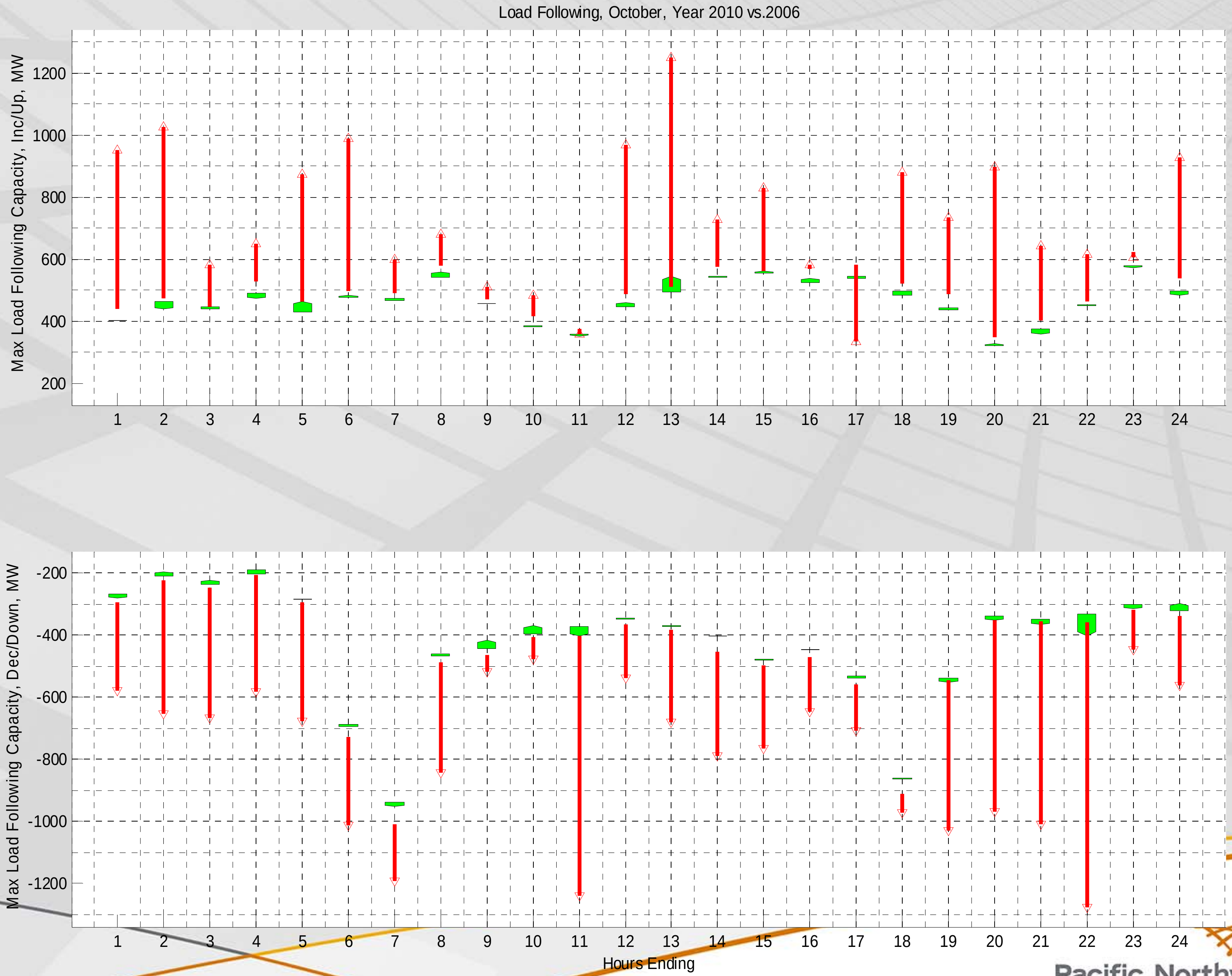
Forecast data example (with forecast error)

Forecast data example (without forecast error)

- Forecast accuracy affects reserve requirements

BPA Study Results (Load Following)

- 5% extreme cases are excluded for load following requirements
- Forecast accuracy affects reserve requirements
- Next slides show results for load following



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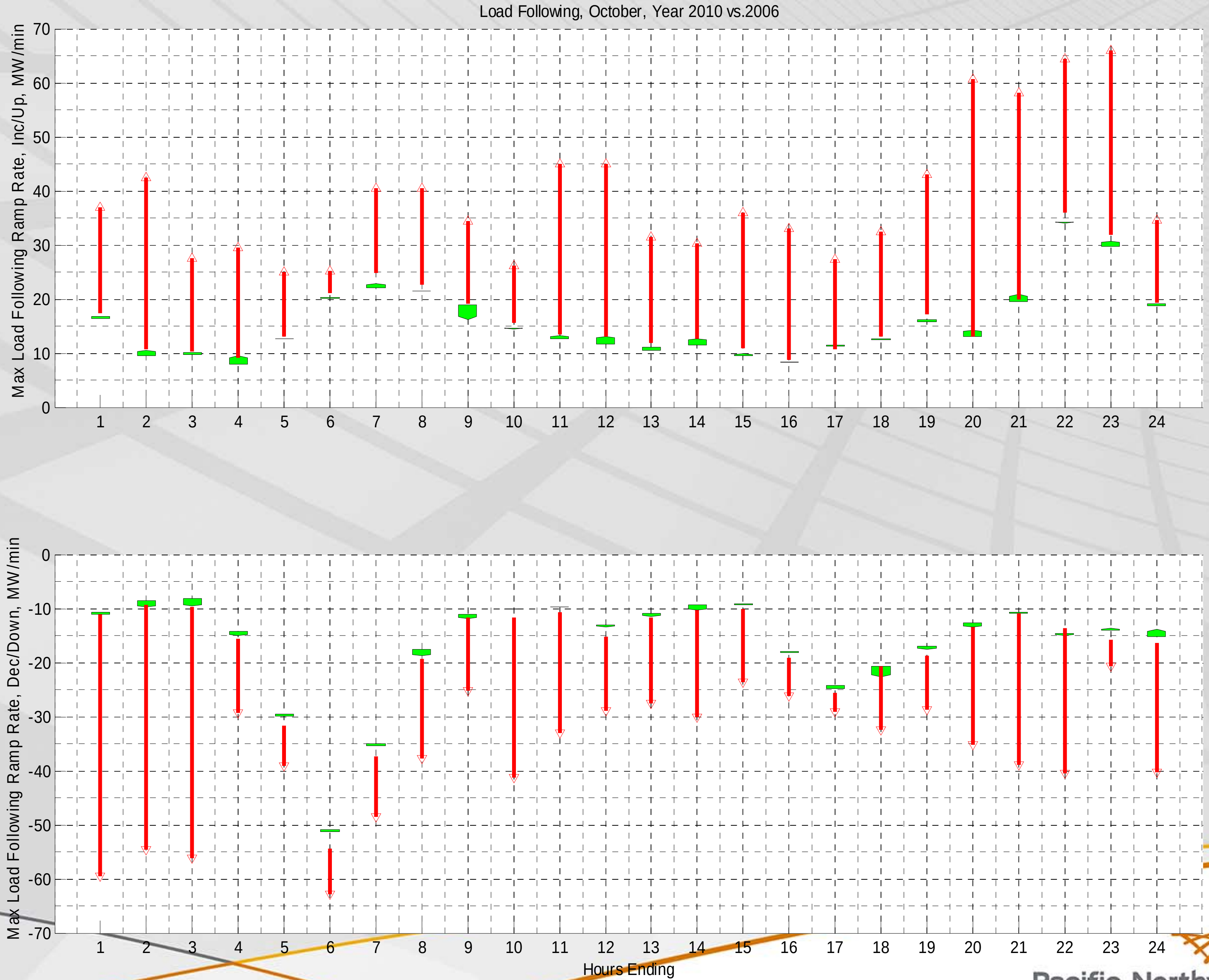

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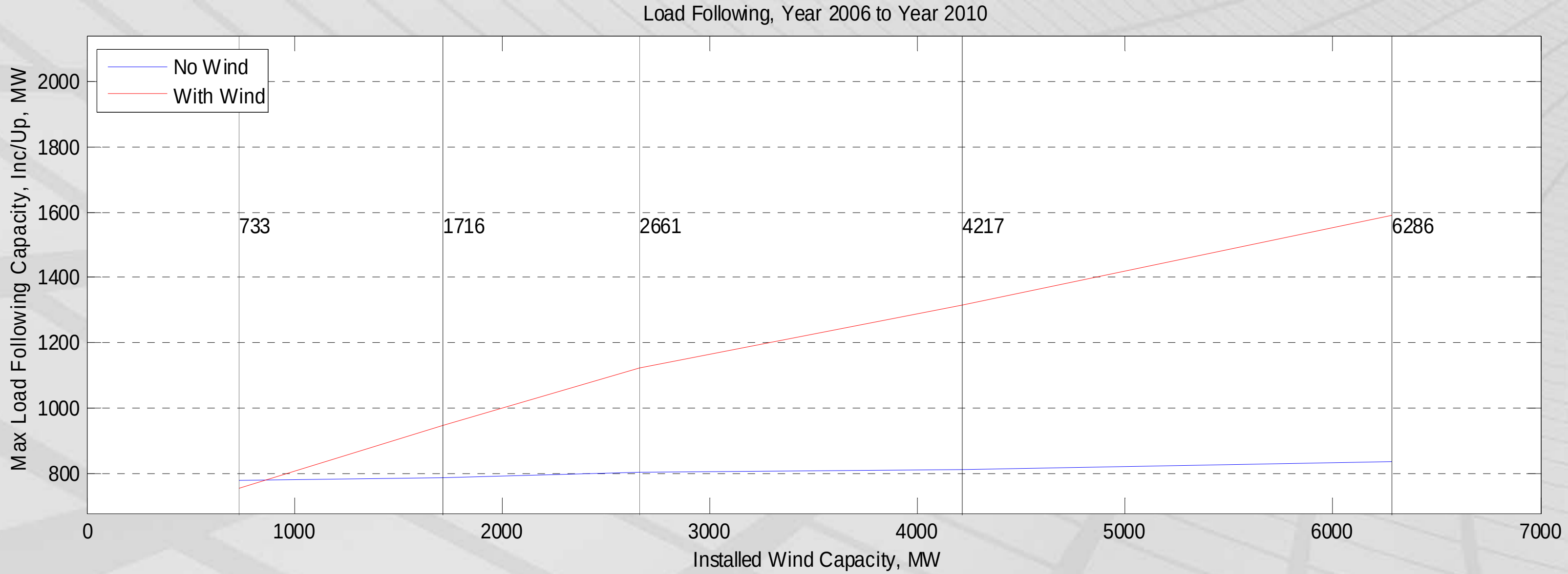

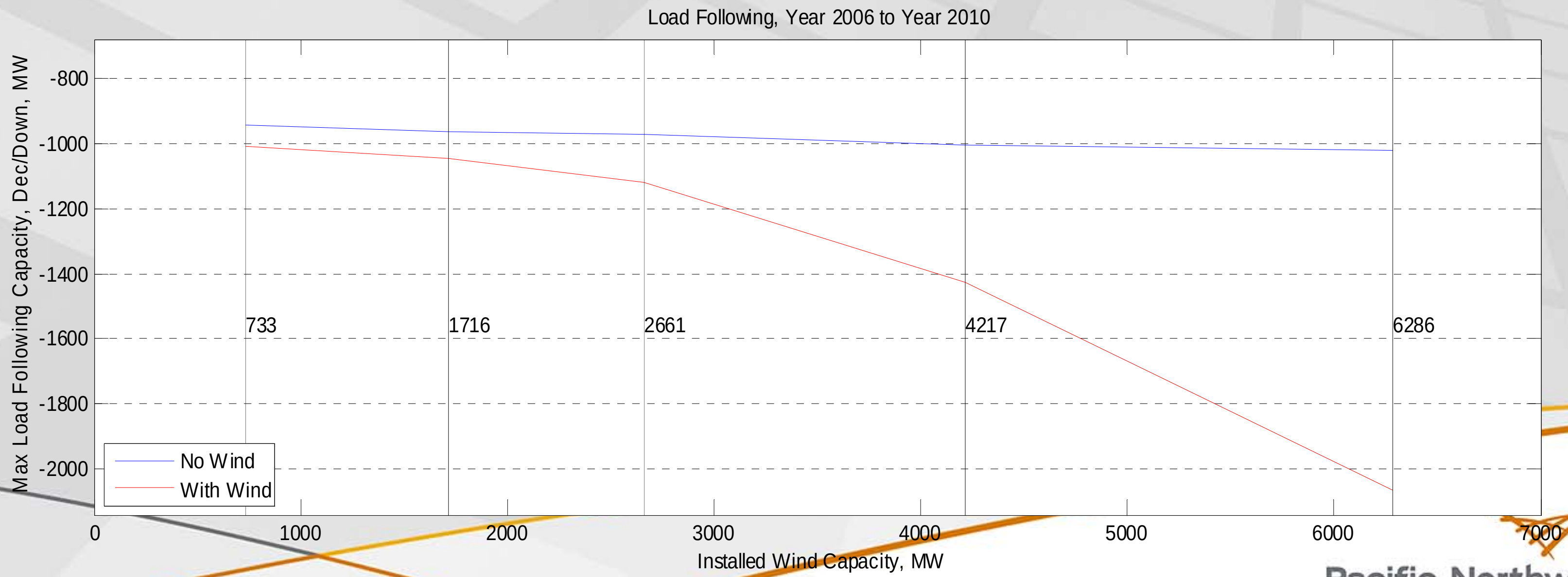

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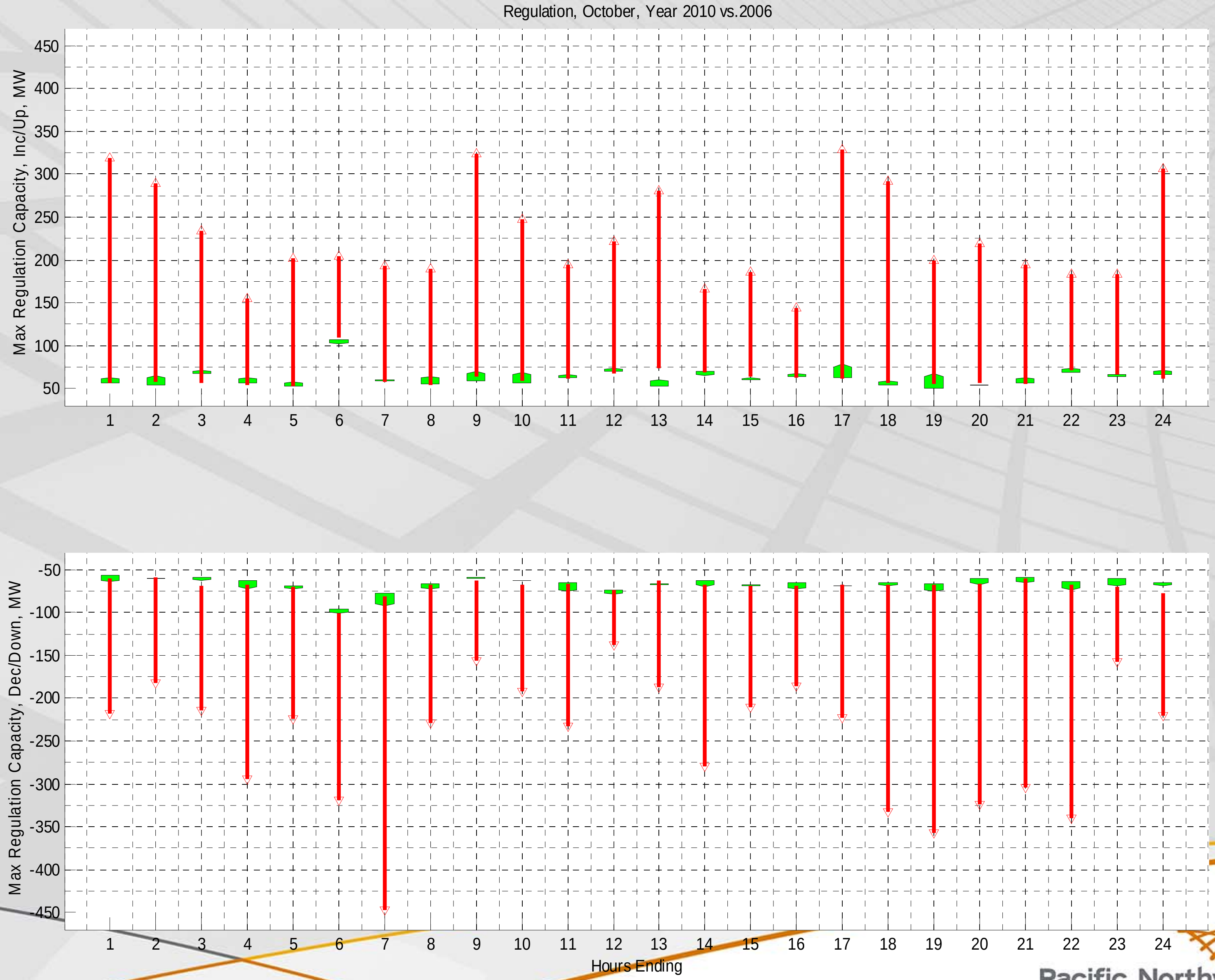
BPA Study Results (Regulation)

- 2.5% extreme cases are excluded from regulation requirements
- Forecast accuracy affects reserve requirements
- Next slides show results for regulation



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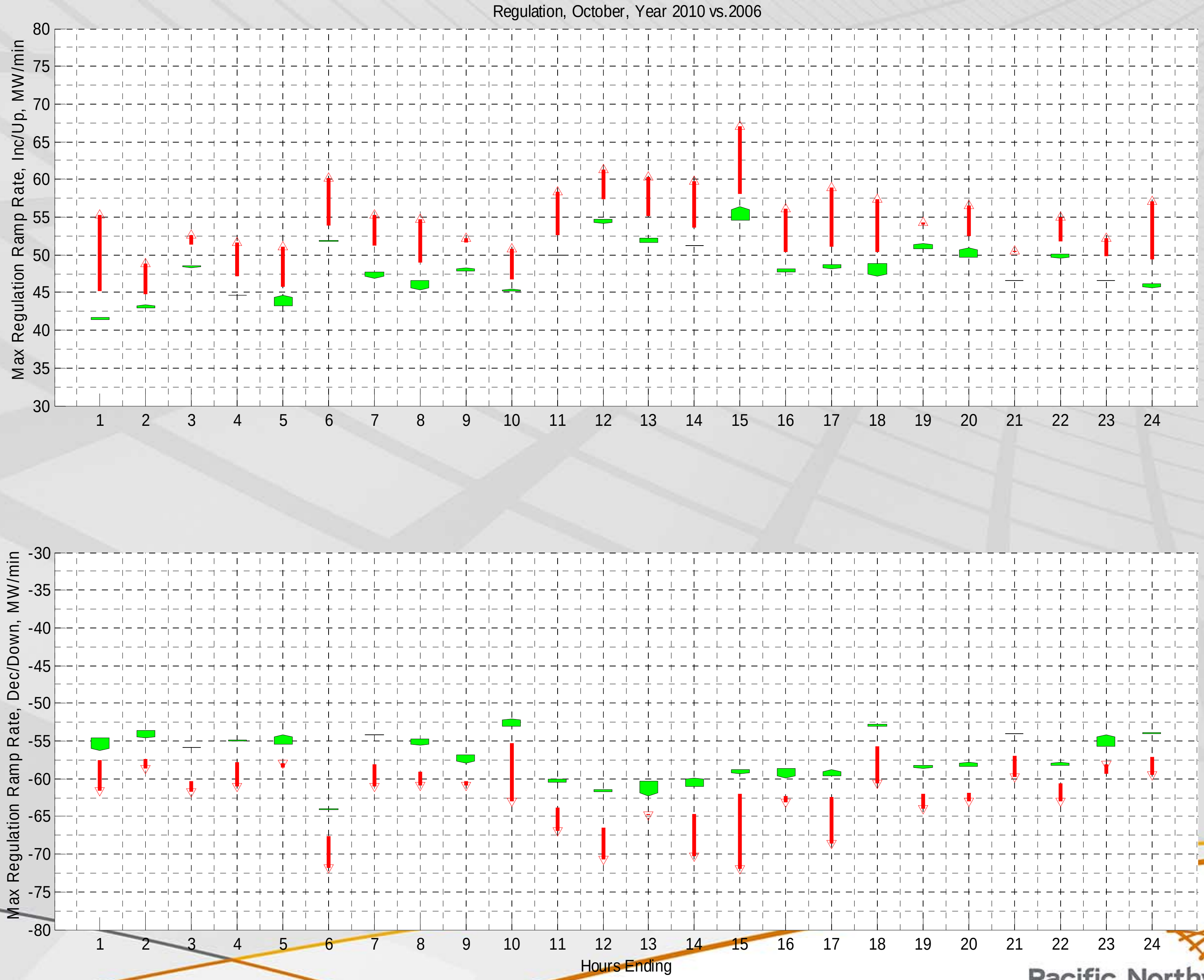

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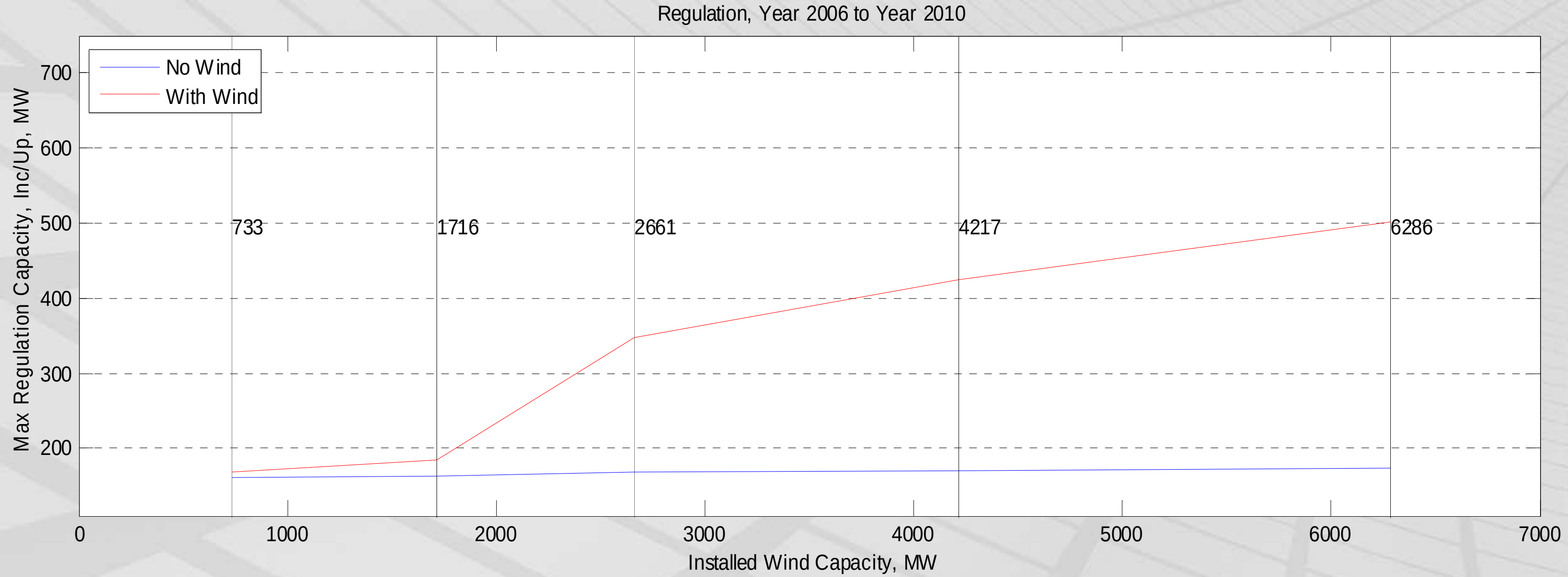

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II. Mitigation of Wind Generation Impacts Using a Wide Area Energy Management System (WAEMS)

Mitigation of Wind Generation Impacts Using a Wide Area Energy Management System

- Research project funded by BPA and conducted by PNNL
- Research Team
  - PNNL: Yuri Makarov, Bo Yang, John DeSteese, Shuai Lu, Carl Miller, Tony Nguyen, Jian Ma, Donald Hammerstrom, Vilayanur Viswanathan
  - Danish Technical University: Preben Nyeng
  - BPA: Bart McManus, John Pease, Juergen Bermejo, James Murthy
  - CAISO (In kind contribution): Dave Hawkins, Clyde Loutan, Sirajul Chowdhury, Tim VanBlaricom
  - Beacon Power Corp. (In kind contribution): Chet Lyons
- Research Papers:
  - B. Yang, Y. Makarov, J. DeSteese, V. Viswanathan, P. Nyeng, B. McManus and J. Pease, "On the Use of Energy Storage Technologies for Regulation Services in Electric Power Systems with Significant Penetration of Wind Energy", 5th International Conference on the European Electricity Market, Paper #328, Lisbon, Portugal, May 28-30, 2008.
  - P. Nyeng, B. Yang, J. Ma, Y. Makarov, J. Pease, D. Hawkins and C. Loutan, "Coordinated multi-objective control of regulating resources in multi-area power systems with large penetration of wind power generation", 7th International Workshop on Large-Scale Integration of Wind Power into Power Systems, Paper #53, Madrid, Spain, May 26-27, 2008.
- Report (submitted to BPA)
  - Y. Makarov, B. Yang, J. DeSteese, S. Lu, C. Miller, P. Nyeng, J. Ma, D. Hammerstorm, V. Viswanathan, "Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administration and California ISO Control Areas", PNNL Project Report, Prepared for the Bonneville Power Administration under Contract BPA 00028087 / PNNL 52946, June 2008.

Stage Gate 1: Evaluate Different Energy Storage Configurations and Identify Top Technologies That Meet the Needs of This Project

- Approach/Section Criteria.
  - Ability to frequently change power output (or store and deliver energy) over a wide range at least several times over a 10-minute interval, preferably, several times over 1 minute.
  - Ramp rate (the technology should be able to respond to control signals, i.e., automatic generation control (AGC) signals, changing every 4 seconds).
  - Response delay time (the lesser is the better).
  - Duration (the technology should be able to provide rated power for 15 - 60 minutes).
  - Resource potential to be scaled to achieve needed energy and capacity.
  - Lifetime.
  - Maturity of the technology.
  - Industrial use experience for regulation/frequency control.
  - Cost.
  - Energy efficiency and power density.
  - Environmental impacts.
  - Ability to provide other ancillary services.
  - Ease of siting.

Stage Gate 1: Evaluate Different Energy Storage Configurations and Identify Top Technologies That Meet the Needs of This Project

- Initially Selected Technologies:
  - Flywheels
  - Hydro power
  - Na-S and Ni-Cd Batteries
- Rejected Technologies:
  - Another analysis will be needed in 2-5 years due to the progress with techlologies listed below
  - Superconducting magnetic energy storage
  - Compressed air energy storage
  - Demand side management
  - Super capacitors
  - Lead acid batteries
  - Nickel metal hydride batteries
  - Lithium ion batteries
  - Zebra batteries
  - Flow batteries
  - Metal air batteries
  - Plug-in hybrid electric vehicles

Stage Gate 2: Design & Evaluate Different Configurations/ Integration Schemes of the Energy Storage. Identify the Most Promising Configurations & Their Benefits

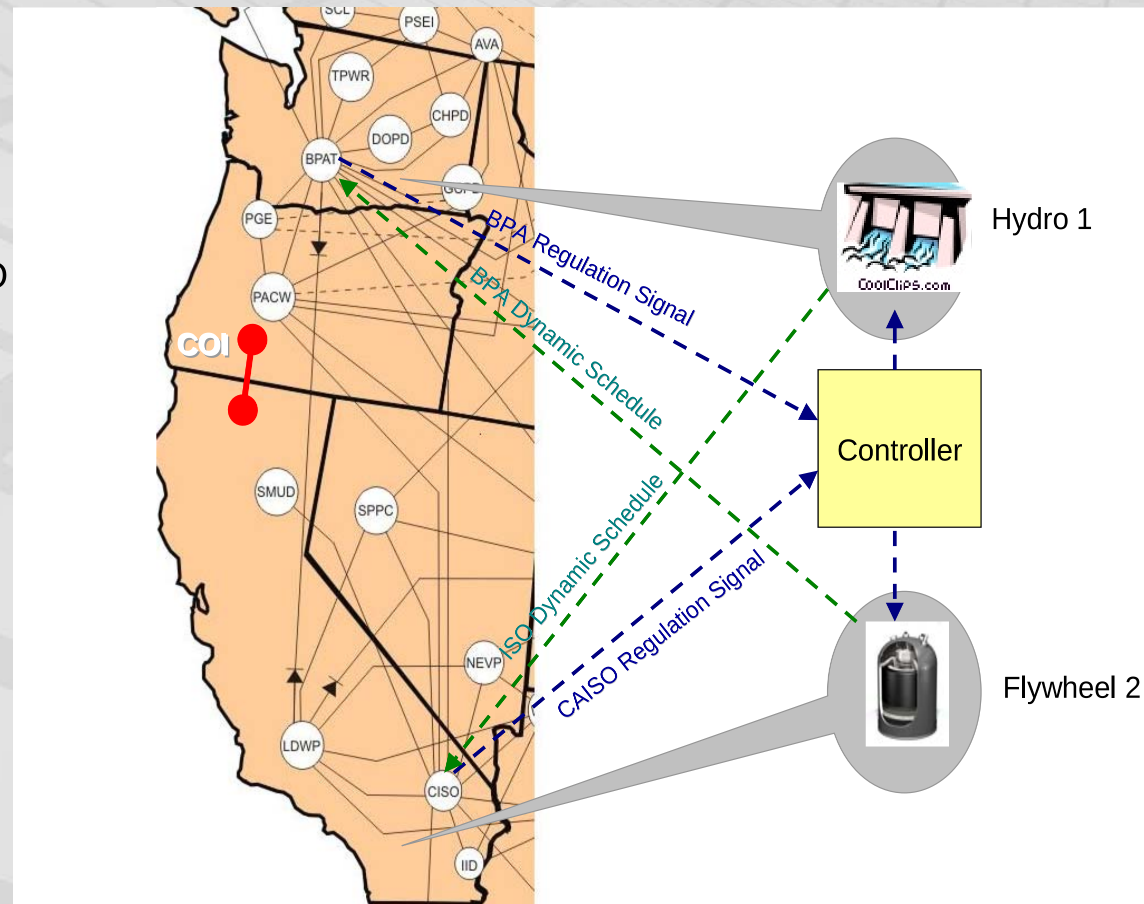
- Requirements:
  - Overall efficiency of the solution (minimum total regulation capacity required).
  - Compatibility with the existing regulation systems and markets (minimum changes).
  - Minimum technical difficulty of implementation.
  - Minimum cost for BPA and California ISO.

Stage Gate 2: Design & Evaluate Different Configurations/ Integration Schemes of the Energy Storage. Identify the Most Promising Configurations & Their Benefits

- Considerations.
- Maximum value of the regulation service is achieved when it addresses multiple intermittent resources distributed over a large geographical area.
- Efficiency of regulation increases if it addresses load intermittency & uninstructed deviations of conventional generators concurrently with the intermittent renewable resources.
- A strategic choice to be made is between the horizontal scheme for balancing intermittent resources (direct integration of regulation service providers with particular renewable projects or groups of projects) and the vertical scheme (indirect integration via the BPA and CAISO EMS or wide area EMS).
- The vertical scheme provides better overall system wide efficiency because it addresses multiple sources of intermittency altogether rather than addressing them one by one.
- The architecture with 2 types of regulation devices, for instance the flywheel and a hydro unit, gives more flexibility and maximizes the value of the wide area EMS compared to the architecture with one ESD.
- Participation of a hydro unit will help to effectively double the flywheel's regulation range and help to continuously maintain the required flywheel's state of charge.
- The flywheel ESD could help to minimize the regulation stress posed on the hydro generation unit and keep the unit within the operational limits.
- The regulation service characteristics and integration requirements should be very similar to the ones that are currently used in service areas.
- Participation of hydro units in the wide area EMS is justified if they are existing units.
- California Oregon Intertie operating transfer capability should be addressed.
- An important feature is that ESDs are employed to provide additional services such as static VAR control, frequency response, and the others. This helps to justify the ESD's cost.

Stage Gate 2: Design & Evaluate Different Configurations/ Integration Schemes of the Energy Storage. Identify the Most Promising Configurations & Their Benefits

- Selected System Configuration:
  - Configuration with two ESDs: flywheel & a hydro
  - Vertical configuration that would integrate the wide area EMS with the BPA and CAISO AGC systems
  - BPA's and CAISO ACE or "conventional regulation unit" signals will be used
  - Dynamic schedules will be used to incorporate the ESD regulation into the corresponding neighboring control area AGC system.
  - Control algorithms will be designed to mimic behavior of a conventional unit on regulation & to coordinate functions of participating ESDs.

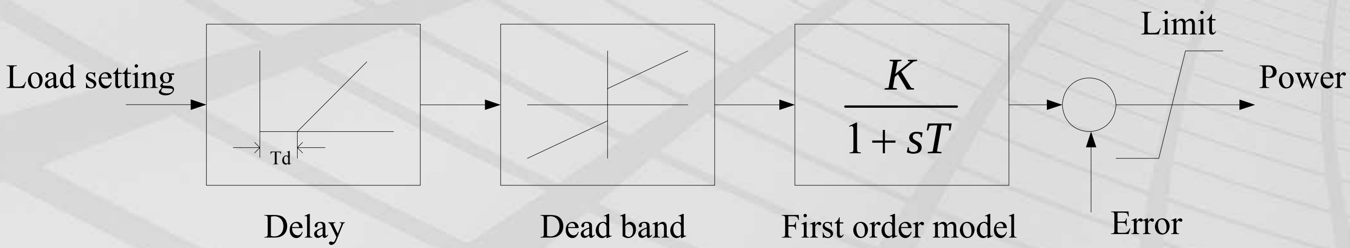


Stage Gate 3: Analyze Technical and Market Compatibility of the Proposed Integration Schemes with BPA and CAISO Systems

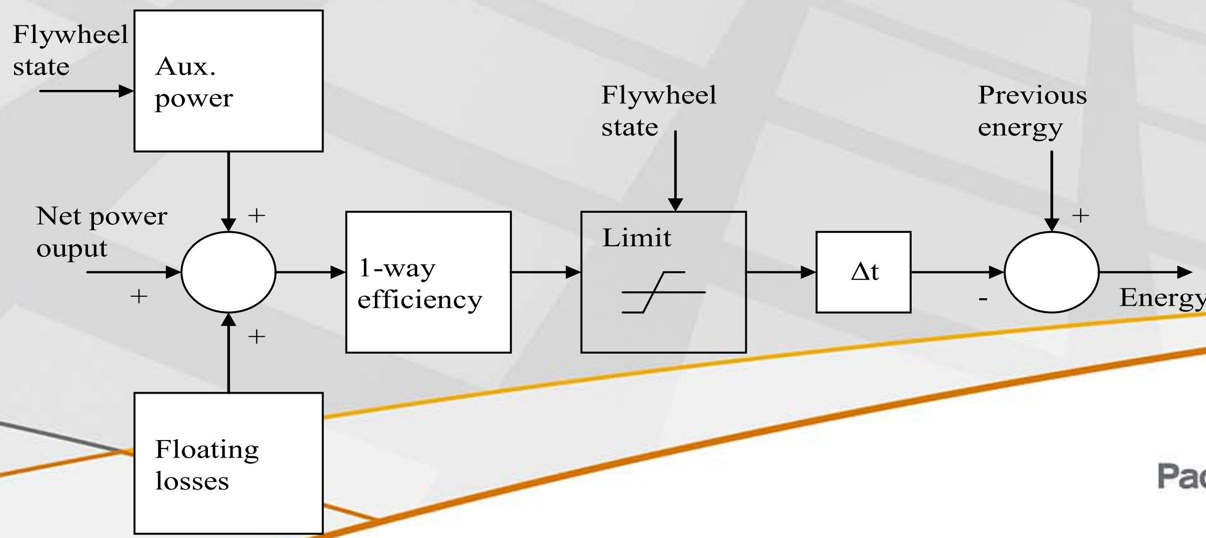
- The work conducted in this stage gate included an in-depth analysis of relevant aspects of the BPA and California ISO systems:
  - Compatibility with ancillary service operating procedures.
  - California ISO's and BPA's AGC systems information and analysis.
  - Compatibility with the AGC systems.
  - Technical requirements for providing ancillary services.
  - Scheduling and load balancing processes in BPA and CAISO systems.
  - Load following and regulation processes.
  - California ISO market processes and timelines.
  - Changes expected under the new California ISO market design (MRTU).
  - BPA and California ISO operating reserve standards.
  - California ISO regulation procurement procedure.
  - Effects of limited ramp rates on ancillary service procurement at CAISO.
  - BPA and California ISO ancillary service rates.
- It has been found that the proposed architecture of the WAEMS is fully compatible with the current BPA and California ISO systems without changes.

Stage Gate 4: Develop Algorithms and Conduct Experiments Using MATLAB Model. Carry Out Cost Benefit Analysis.

- Hydro power plant model

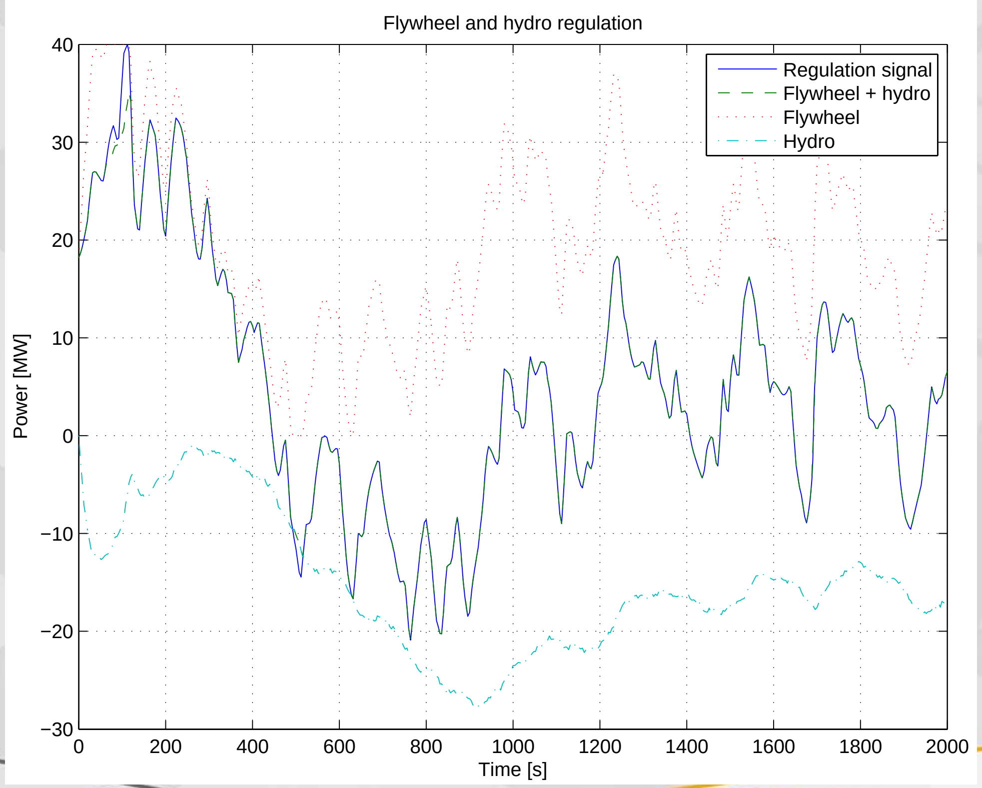


- Flywheel model (provided by Beacon Power)



Stage Gate 4: Develop Algorithms and Conduct Experiments Using MATLAB Model. Carry Out Cost Benefit Analysis.

- Simulation Results:



Comments

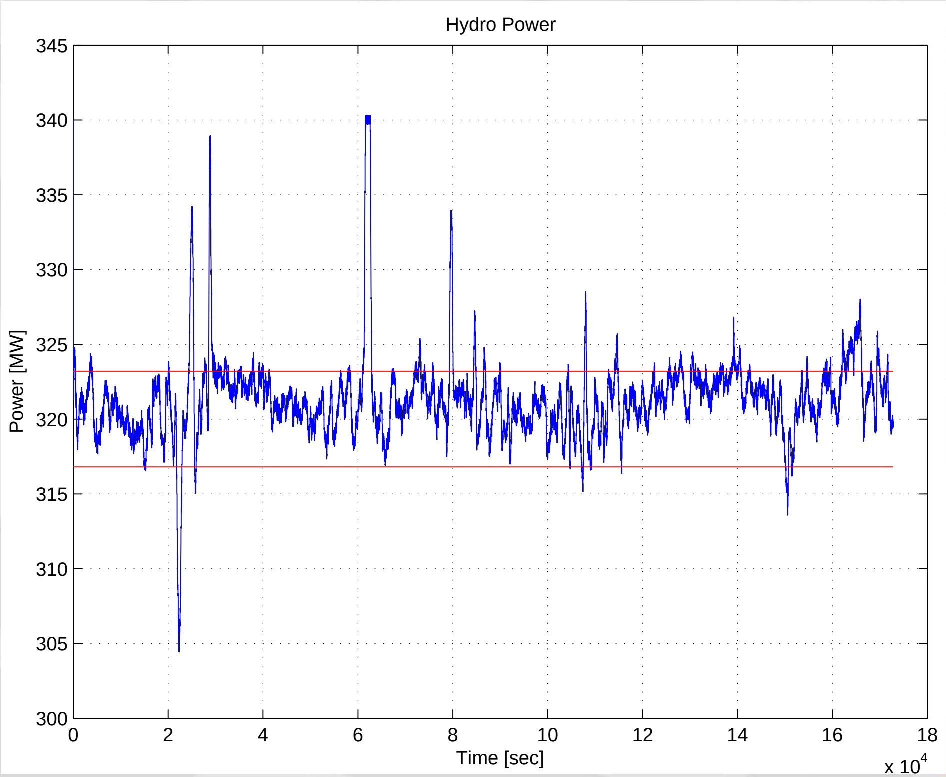
The flywheel-hydro aggregate follows the regulation signal exactly.

The flywheel provides regulation up service. The hydro power plant provides regulation down service.

The flywheel takes most of the regulation task in terms of variability of regulation. Less stress is posed on the hydro unit.

Stage Gate 4: Develop Algorithms and Conduct Experiments Using MATLAB Model. Carry Out Cost Benefit Analysis.

- Simulation Results:



Comments

It is seen that the flywheel helps to keep the hydro plant output close to the desired ±1% range most of the time.

Stage Gate 4: Develop Algorithms and Conduct Experiments Using MATLAB Model. Carry Out Cost Benefit Analysis.

- Cost Benefit Analysis (The battery options are less cost effective because of the cycling requirements that affect battery life time):

Storage System	BPA Financed	California ISO Utility Financed	California ISO Private Financed
Flywheel			
Capital Cost ($M)	30	30	30
Annual Benefit ($M)	3.83	15.88	15.88
Annual Cost ($M)	3.46	5.97	7.86
Benefit/Cost	1.11	2.66	2.02
NPV ($M)	+5.5	+84.4	+68.3
Pumped Hydro			
Capital Cost ($M)	20	20	20
Annual Benefit ($M)	3.83	15.88	15.88
Annual Cost ($M)	2.99	4.49	5.75
Benefit/Cost	1.28	3.54	2.76
NPV ($M)	+12.5	+97	+86.2
Lead Acid Battery			
Capital Cost ($M)	226	226	226
Annual Benefit ($M)	3.83	15.88	15.88
Annual Cost ($M)	38.90	56.39	-
Benefit/Cost	0.1	0.28	-
NPV ($M)	-520	-340	-
Sodium Sulfur Battery			
Capital Cost ($M)	56	56	56
Annual Benefit ($M)	3.83	15.88	15.88
Annual Cost ($M)	9.82	14.24	17.77
Benefit/Cost	0.39	1.12	0.89
NPV ($M)	-110	+14	-16

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Thank you!

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