



B O N N E V I L L E P O W E R A D M I N I S T R A T I O N

# Large Wind Integration Impacts on Operations / System Reliability

By : Steve Enyeart, BPA

With contributions from:

Bart McManus, BPA

James Murphy, BPA

Dmitry Kosterev

5/15/07



# Wind Integration Overview

- Summary of NW Wind Integration Action Plan
- List impacts of wind additions on BPA Operations
- Define Control Area terms as used for wind generation
- Discuss Wind Variability Impacts on Control Area operation
- Describe Wind Ramp Issue, Reliability topic
- Improved AGC Response Algorithm
- Introduce the Ramp Control concept
- Wrap-up and Next Steps

Work Shop Meeting June 21 at Rates Hearing Room on Wind Ramp



## NW Wind Integration Action Plan Summary

- NW added ~900 MW of wind in 2007
- Total Wind in the NW may be 4800 MW by end of 2009
- Power Council target of 6000 MW is achievable, but...
  - Impacts Operating Reserves and Balance of Hour Capacities
  - Impacts Columbia River Hydro System Operation
  - BPA Transmission System Expansion required after 2008
  - Severe wind ramps may impact Reliability of Control Areas



## NWIAP Summary Continued

- Recommends Continuing for 2 Years as the “Northwest Wind Integration Forum” to Address:
  - Wind Integration Costs and Cost Shifts from Load to Wind Generation
  - Peaking Capacity Value of Wind, to Address Future Resource needs for the NW
  - Development of a NW Wind Model and dataset for Region assessment of Wind resources Impacts / Location
  - The Value of a Regional Wind Forecasting System
  - ACE Diversity Interchange and other Control Area sharing ideas to increase flexibility for Wind Integration
  - Transmission System Expansion and Identify a means to fund needed transmission system additions to promote Wind Development

(Complete summary available at: [www.nwcouncil.org](http://www.nwcouncil.org))



## Wind Impacts to BPA Control Area (BA)

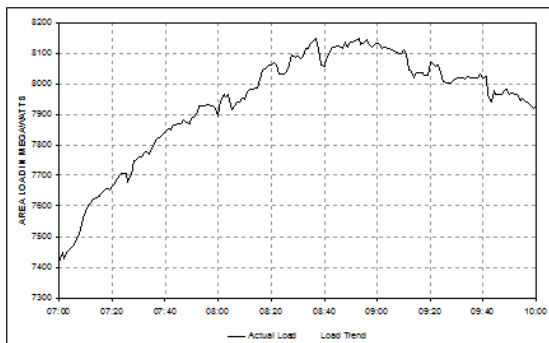
- BPA integrated 650 MW in 2007, total ~1450 MW in the BPA Control area (15% of 9000 MW Peak BPA Load)
- By end of 2009 BPA Control Area total may be 3500 MW
- Issues that need to be addressed:
  - Intra-hour increases in total Balancing\* requirements
  - Impact of severe wind ramps on Balancing Capacity
  - Impacts to Hydro Operations / Optimization
  - Cost/Cost Shift of add'l Balancing Capacity
  - Need for Voltage Support, Dynamic VAR

\* Balancing = within 1 Minute Regulation (AGC response) + Load Following for balance of hour schedule – see next slide

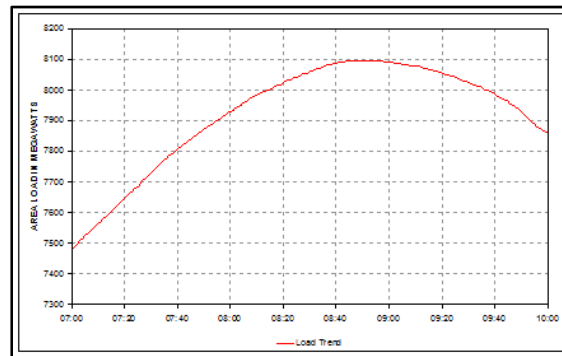


## Within Hour Balancing – Definitions

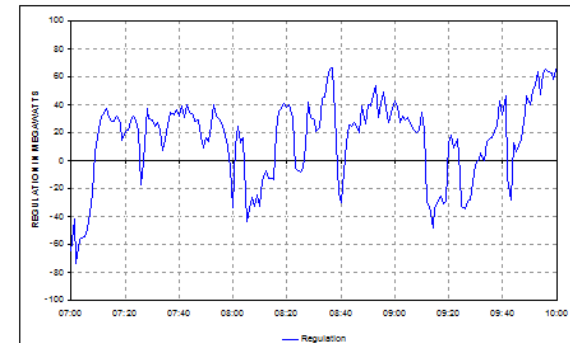
- Regulation is the moment-to-moment difference between actual generation or load signal (AGC).
- Load Following is defined as the change in the general trend over a specific time interval – usually within hour.



=



+

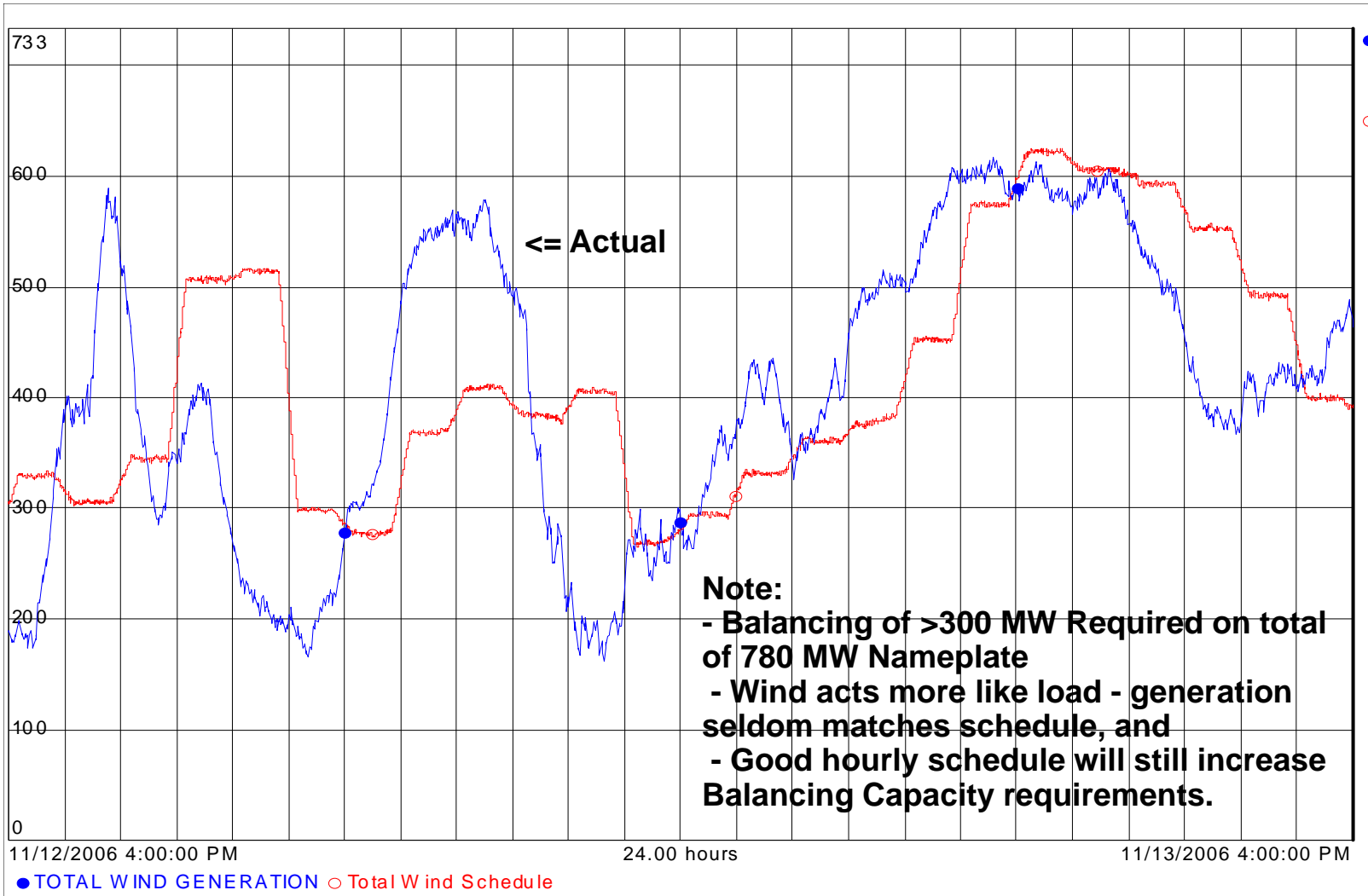


Balancing is the with-in hour adjustments for variances of Load / Generation from Schedules :

Load (or Generation) Deviation = Load Following + Regulation



# Windy Day 11-12-06 Schedule Vs. Actual





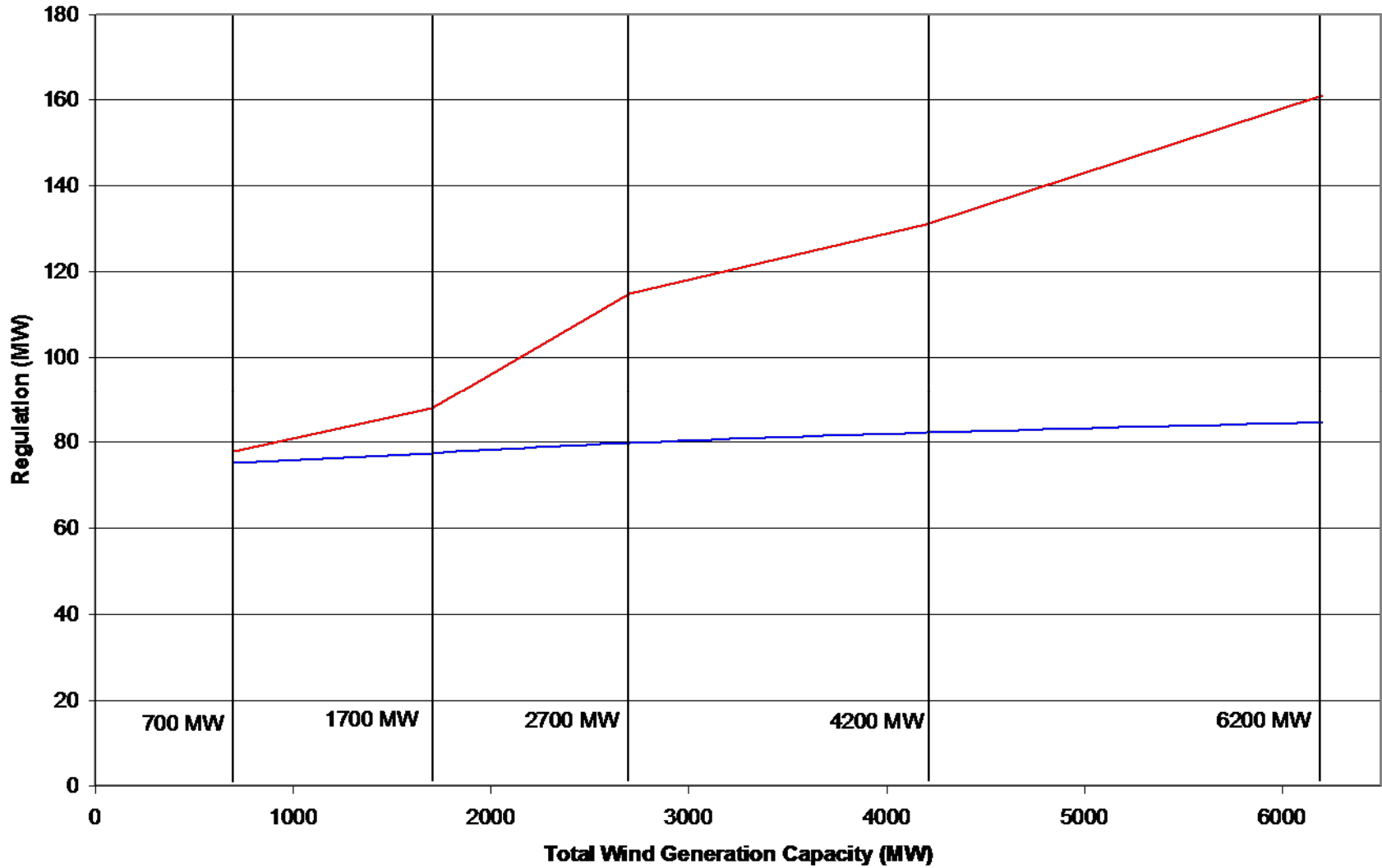
## Estimating Impact on Within-Hour Balancing

- BPA has conducted studies to estimate the increase in Balancing Capacity required for Wind generation connecting to the BPA BA.
- The next 3 slides quantify the increase in Balancing Capacity required for up to 6200 MW.\*
- Note the slope increases as wind variability starts to dominate first regulation, then total balancing above 5000 MW. 5000 MW is average load in study.
- Cumulative Frequency Distribution method used to calculate increase in Balancing Capacity, assuming 97.5% of Regulation and 95% Balance of Hour events are covered.
- Extreme Wind Ramps are not included (2.5%)

\*Analysis includes using locations of proposed wind sites in BPA queue to provide simulation of locational diversity.

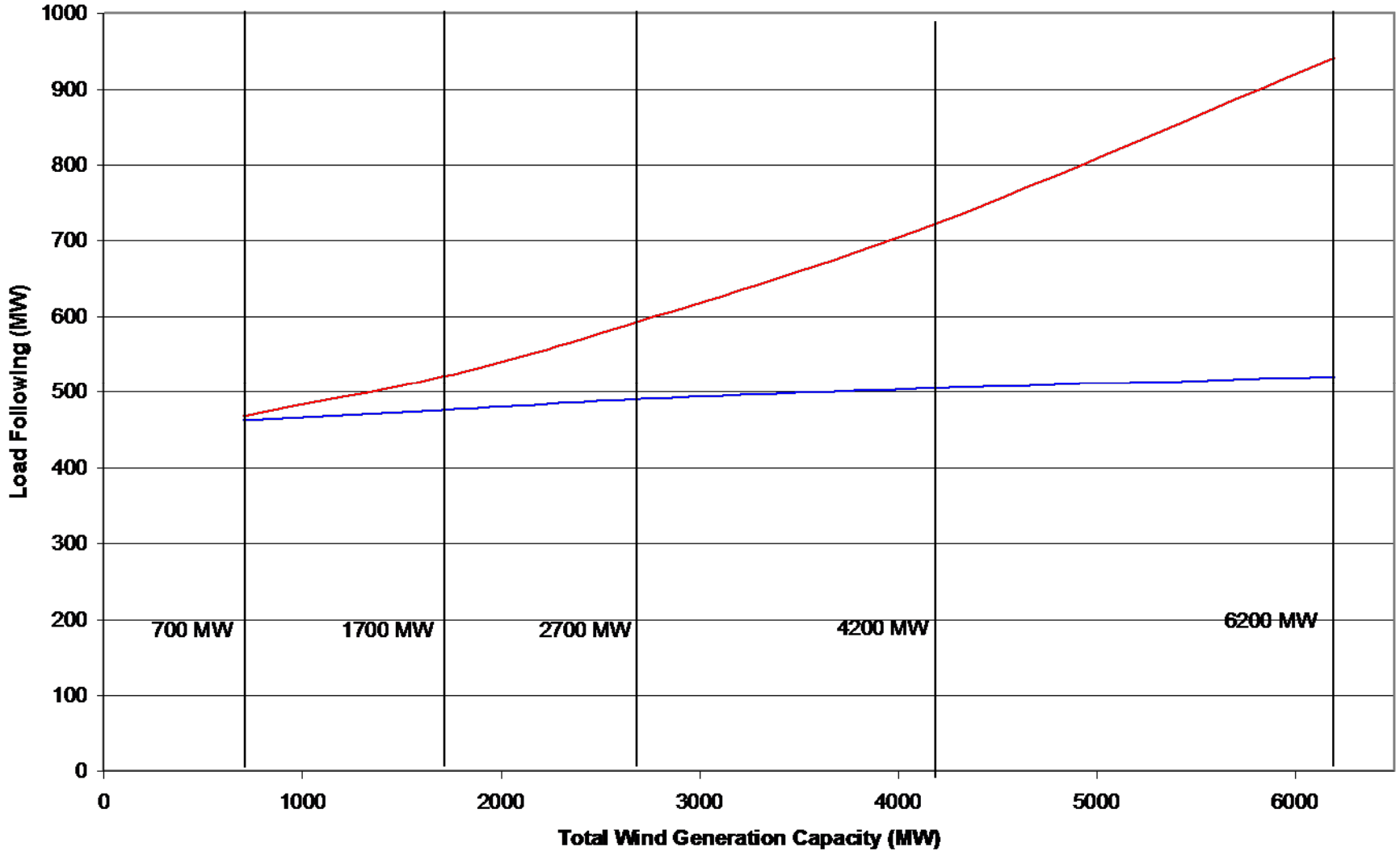


### Regulation



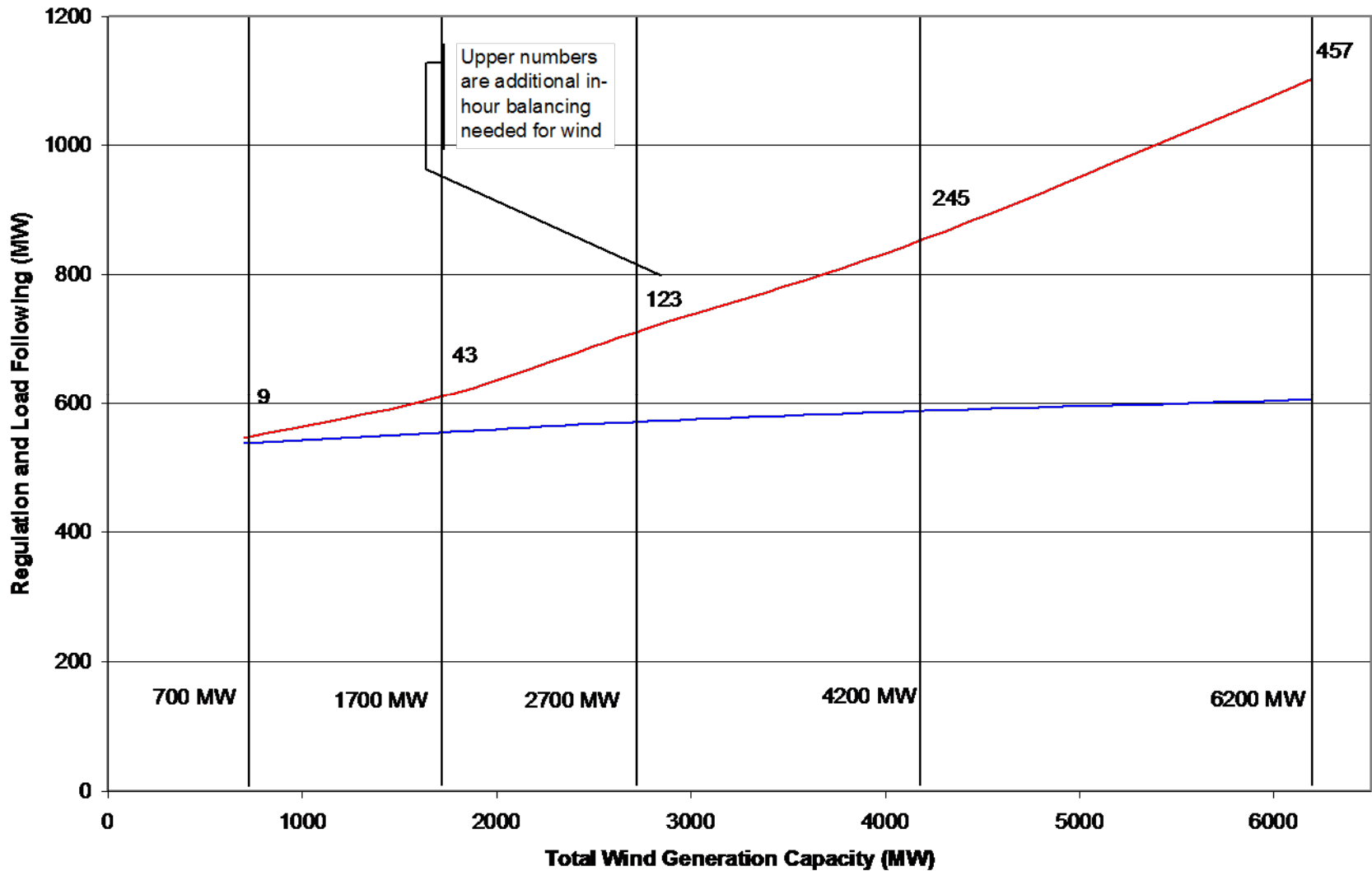


### Load Following





### Regulation and Load Following



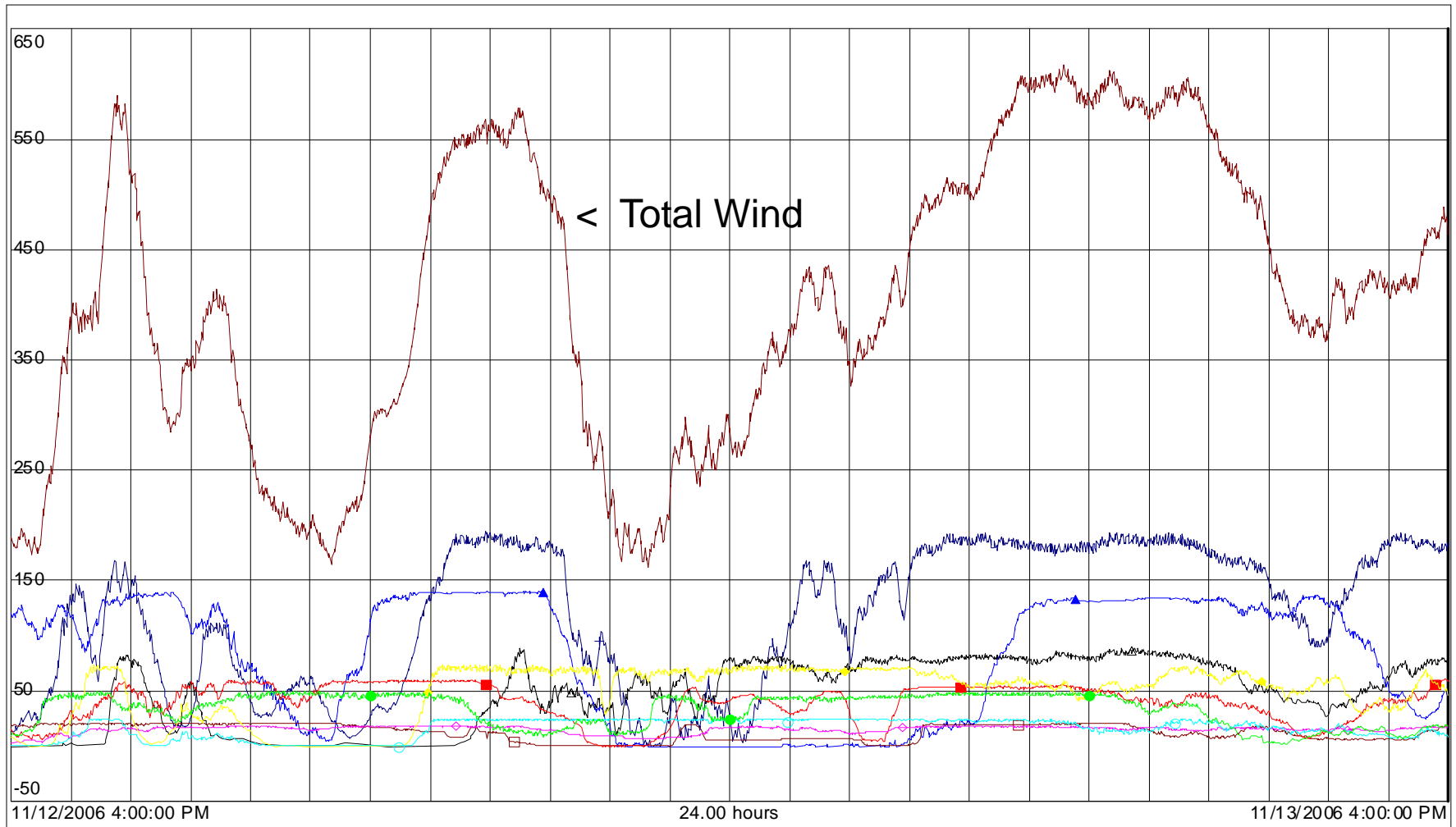


## Wind Ramps

- Wind Ramps are large *unscheduled* changes in the output of a wind farm or the aggregate of all wind farms in a Control Area.
- As seen above Wind increases the Control Area Balancing Capacity Requirements.
- Extreme Wind Ramps could add greatly to the Operating Reserve Requirements, and costs.
- Concern also for Reliability Impacts (CPS2 Violations).
- The next slide shows several large wind ramps, from a 2006 event. Note total swing of over 400 MW and within hour >300 MW.



# Example: 11-12-06 – 730 MW in BPA Control Area





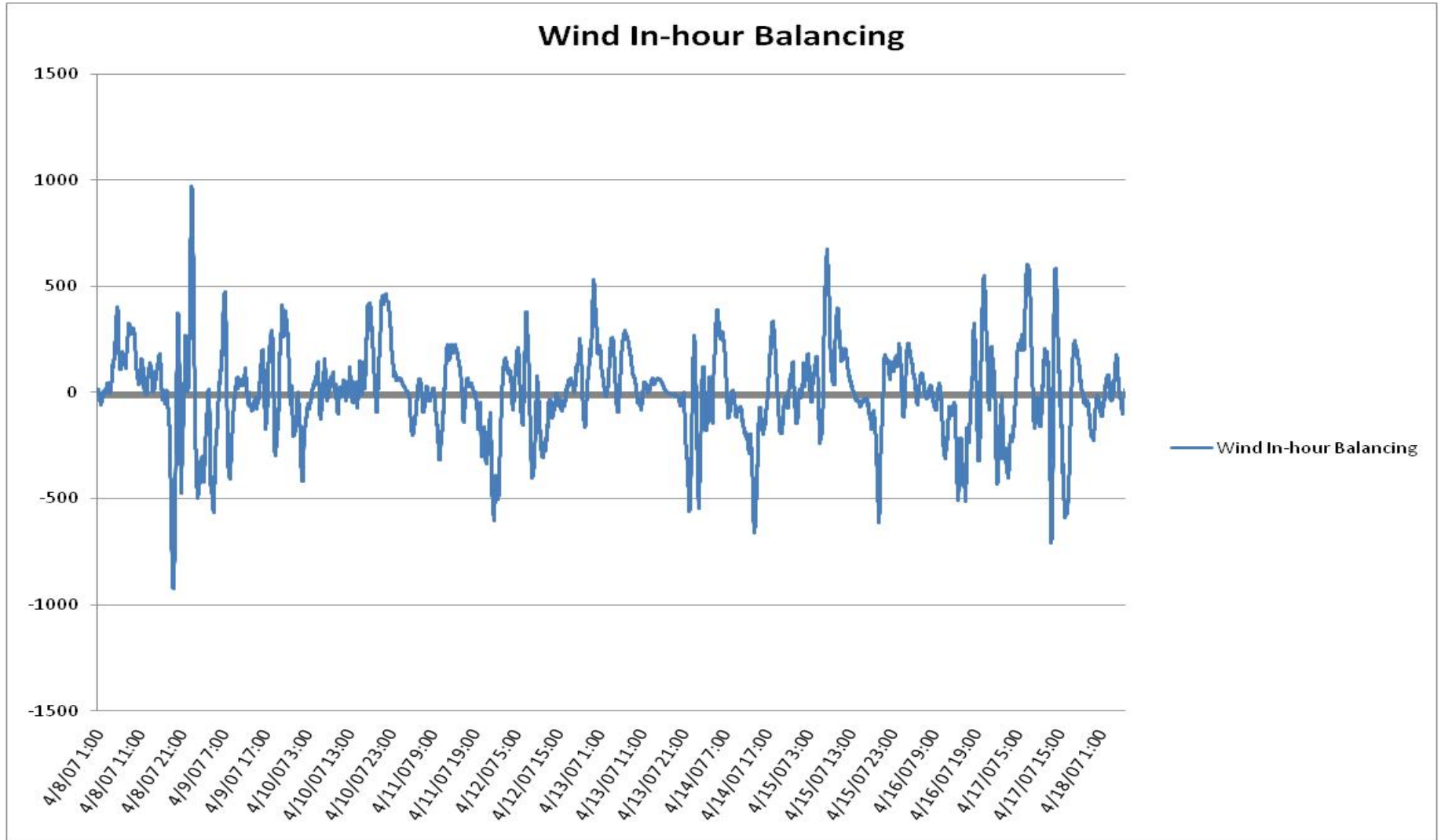
## Preliminary Analysis of Wind Balancing Impacts

- The next slide shows the balancing required for 2007 data (733 MW) expanded to 2700 MW. Note the peak Balancing required.
- The two slides after that show the problems with scheduled vs actual (even with hourly adjustments) and the problem a large wind ramp can have on the AGC reserves required.
- The 4th slide shows the impact on total Balancing Capacity.
- The “Tails” represent the small percentage of time that wind ramps would exceed ~ 300MW.



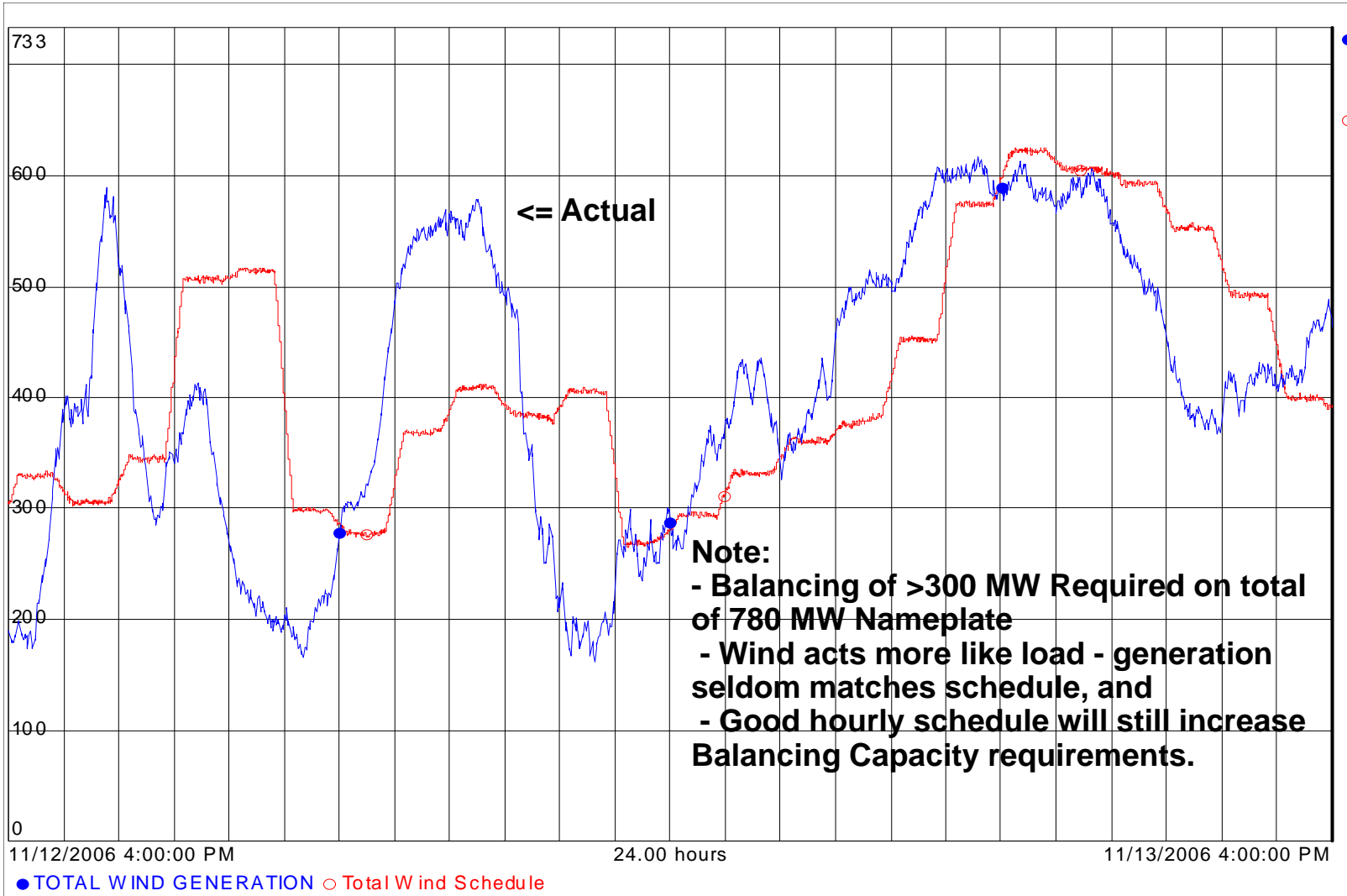
B O N N E V I L L E P O W E R A D M I N I S T R A T I O N

# 2700 MW Simulated Balancing Capacity Requirements



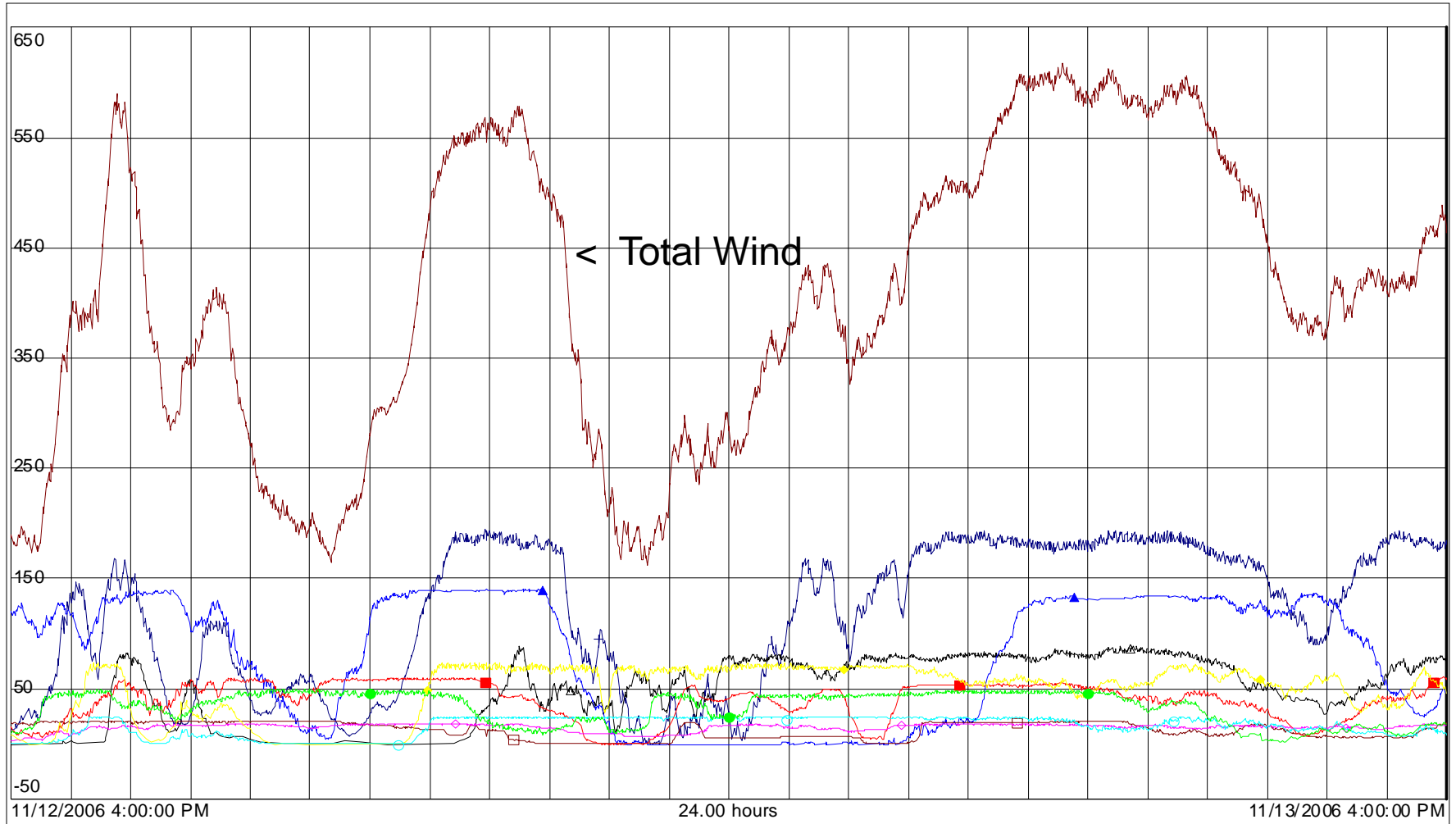


# Windy Day 11-12-06 Schedule Vs. Actual



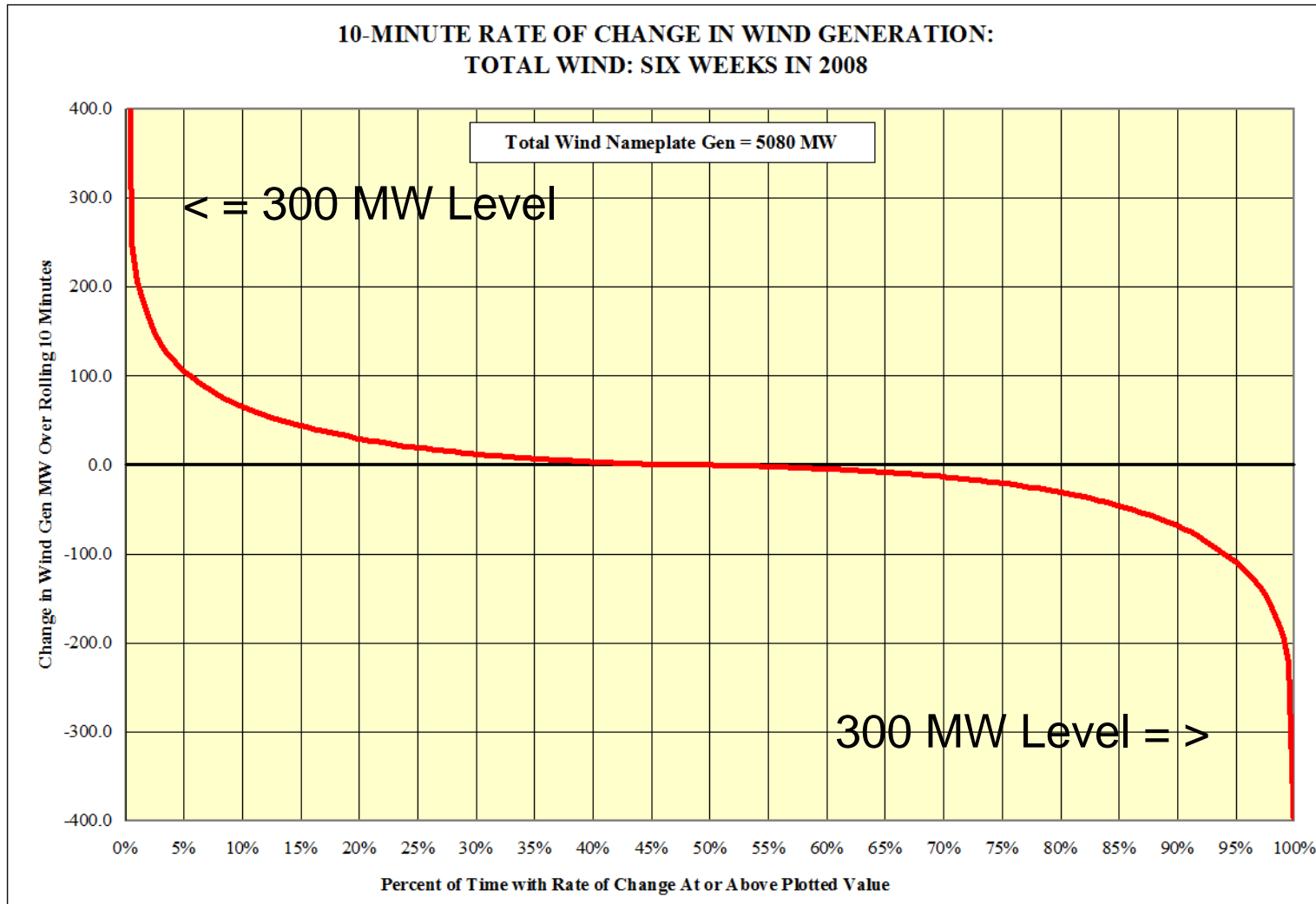


# Wind Ramp Example: 11-12-06 – 730 MW





# Distribution of Wind Ramps – Impact on Balancing Capacity





## 3 Tier Klondike Area Study

- Report focused on ramping events for 18 geographically diverse wind sites (3770 MW total, per locations provided by BPA).
- Simulated each wind farm and their combined output.
- Considered effects at both 10 minute and 60 minute time frames.
- Combined output shows a considerable drop in the number of ramping events larger than 10% of nameplate capacity compared to individual wind farms.
- BPA comment: Simulation compared favorably to BPA SCADA based analysis.



## 3-Tier Study Conclusions

- Larger wind farms show fewer ramps  $> 10\%$  nameplate due to spatial smoothing in all directions.
- Confirms that 10 minute ramp magnitude and frequency far less than for hourly changes.
- Positive ramps tend to be greater than negative ramps, less so for hourly changes.
- Spatial smoothing more significant on the 10 minute time scale.
- Overall – Smoothing effect reduced the magnitude of ramps for combined regional output due to geographic diversity of the wind farm locations, even for the concentrated area around Klondike.



## Further Analysis of Operating Impacts

- Severe Wind Ramps will either require additional Balancing Capacity or Ramp limits to limit the amount of Generation set aside for Wind.
- BPA proposes to expand study of wind impact on Balancing Capacity scaled up to 6000 MW:
  - Study underway with PNNL to establish Balancing requirements and extreme wind ramps using a different modeling technique.
  - Will update using newer data being collected on existing Wind Farms & include Add new wind farms as data becomes available.
  - Use NW Region Wind Data (Mesoscale data) to look at impact of diversity.
- Perform Cost analysis of wind ramp events.
  - Analysis underway with Power Services to price cost at different wind generation levels.
  - Need to include cost of severe wind ramps separately.



## Improved AGC Response

- BPA Proposal: Modify AGC Algorithm (Feed – Forward AGC)

Present AGC = Load – Scheduled Generation (includes Wind schedules)

New AGC = Load – Scheduled Generation – Forecasted Wind Generation\*

- 5 minute schedules for 60 minutes for aggregate Wind Farm output can be used to anticipate AGC requirements rather than react to error signal alone.

\* Forecasted wind farm schedules requires detailed data from each wind farm.



## Feed-Forward AGC Advantage

- Goal is to dampen AGC response, which will reduce wear and tear.
- Multiple within-hour schedules will be used in AGC Algorithm to anticipate wind ramps and changes in direction (peaks, valleys).
- And reduce amount of generation set-aside for AGC.
- Lowering cost for Wind Balancing
- Provides mechanism to initiate Wind Ramp Limits control if Balancing reserves below minimum capability (next 10 – 30 minutes).



## Wind AGC Pilot Project (R&D)

- The proposal is to do a pilot project with possibly 4 wind farms (remote from each other). The Pilot Project would:
  1. Use existing data from each wind farm (up to one year, if available) to initialize 3-Tier effort.
  3. Require wind farm operators to provide data. Data points would be MW average, wind speed average, direction, and number of units in string on line.
  4. Have 3-Tier provide forecasted schedules for each wind farm
  3. Have BPA develop the Feed-Forward AGC algorithm and test (off-line and compare with existing AGC response).

The Pilot project would involve periodic review with wind farm operators as the project progresses.



## Wind Farm Data Requirements

- It was decided to combine data from each string in the wind farm (4 - 7 WTG's per string), to reduce data computing requirement and limit data transfer requirements. Required Data:
  - MW output and Wind speed average values for each 30 seconds
  - Wind direction and units online in string, snapshot every 30 seconds
  - Provide data every 30 seconds to 3-Tier using Internet FTP format (SSH secure)
  - 3-Tier to provide forecast schedules for each wind farm to BPA every 5 minutes.



# Timelines

- October 3, 2007 – Kick-off Meeting with Public
- October 15, 2007 – Sign-up Wind farms to participate in Pilot Project, provide NDA
- November 1, 2007 – Existing Wind Farm data sent to 3-Tier
- May 1, 2008 – Review 3-Tier forecasting Algorithm
- June 1, 2008 – Establish links with each wind farm
- October 1, 2008 – Establish data link 3-Tier to BPA, begin testing Feed-forward AGC Algorithm



## Next steps

- Data Collection from existing Wind Farms and study extrapolation to 3000M and 6000MW
- Work with Northwest Wind Integration Forum on Meso-scale data for study extrapolation to 3000M and 6000MW
- Perform Cost analysis of wind ramp events
- Evaluate improved AGC response using forecasted wind generation
- Discuss need for data collection from Wind Farms for a forecasting service
- Discuss data requirements – MW, MVar, Wind Speed, Direction and Collection method



# Wind Integration Rate

- The Northwest Wind Integration Action Plan (March 2007), sponsored by BPA and the Northwest Power and Conservation Council, defined a regional approach to integrating large amounts of intermittent renewable resources.
  - The Action Plan concluded that wind energy, by virtue of its natural variability and uncertainty, increases the demand for system flexibility and contributes relatively little peaking capacity to the PNW's energy system.
  - The Action Plan also noted that utilities' existing rates may be insufficient to achieve appropriate cost recovery and allocation.
- BPA will have integrated about 1400 MW of wind generation into the BPA control area by the end of 2007 (approximately 15 percent of the BPA peak load of 9000 MW).
  - BPA is expecting to integrate another 1000 MW of wind by the end of 2008 for a total of about 2400 MW of wind generation in the BPA control area.



# Wind Integration Rate Development

- BPA is developing a rate proposal to recover within-hour balancing costs associated with integrating wind generation into the BPA Control Area.
  - Costs to be recovered from parties causing those costs.
  - Rate to be effective for a one-year period, FY 2009
- Within-hour balancing for wind resources: Generation Capacity reserved for wind's within-hour variability and uncertainty.
  - The amount of generation capacity needed for within-hour balancing to meet NERC/WECC balancing standards increases with the interconnection of additional wind resources.
- Rate workshops have been held since early September, attended by industry experts, wind generators, and BPA power customers



# Wind Integration: Costs

- Embedded cost for Big 10 Federal Hydro projects
  - O&M, Depreciation, Net Interest, Fish & Wildlife limitations
- Additional costs for AGC operating generation units
  - Increased Machine O&M, Decreased Unit Efficiency, Increased Cycling
- Energy Shift - From heavy load hours to light load hours
- Impact to River System Scheduling Efficiency
  - Due to additional reserve capacity and uncertainty in wind forecast



# Wind Integration Rate Design

- Option 1: Allocate costs and charge rate based on installed wind capacity
- Option 2: Allocate costs and charge rate based on wind energy generated
- Option 3: Base charge on variability of wind to provide a price signal
- Formula rate (could apply to any of above options)
  - Revise rate quarterly as total installed wind capacity and associated balancing costs change
  - Costs are non-linear function of installed capacity (i.e., costs increase faster than installed capacity)

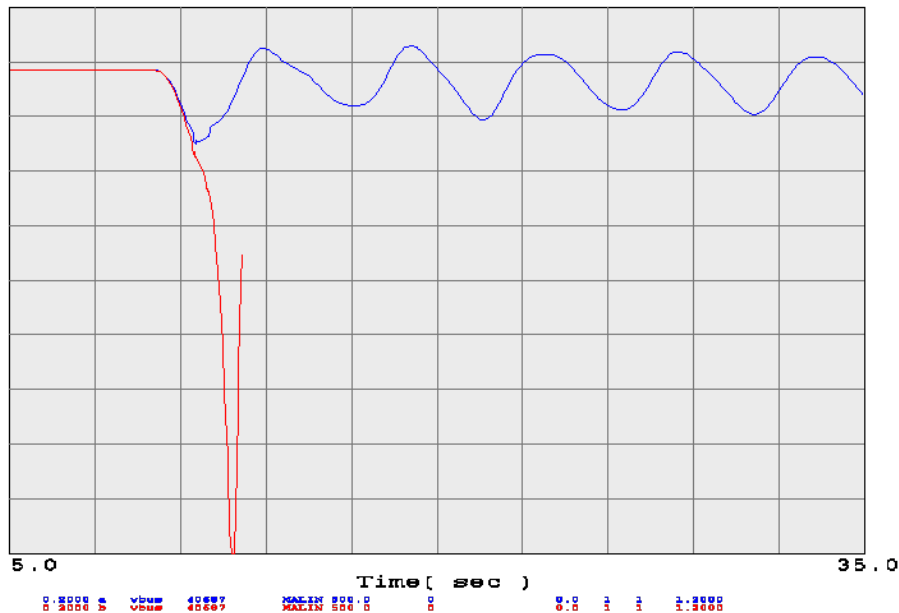


## Wind Farm Dynamic Voltage Performance

- Integration of large amount of wind generation with no dynamic control capabilities will reduce ATC of the control area
- New wind generation technologies are capable of providing dynamic performance comparable to that of conventional generators
- Next slide demonstrates effect of 2700 MW of wind on grid without Dynamic VAr support (assumes fully loaded system, 2PV case)



# Dynamic Simulations - Malin 500-kV bus voltage



Baseline

2700 MW of  
Wind with No  
Voltage Control  
replaced 2700 MW of  
hydro + thermal

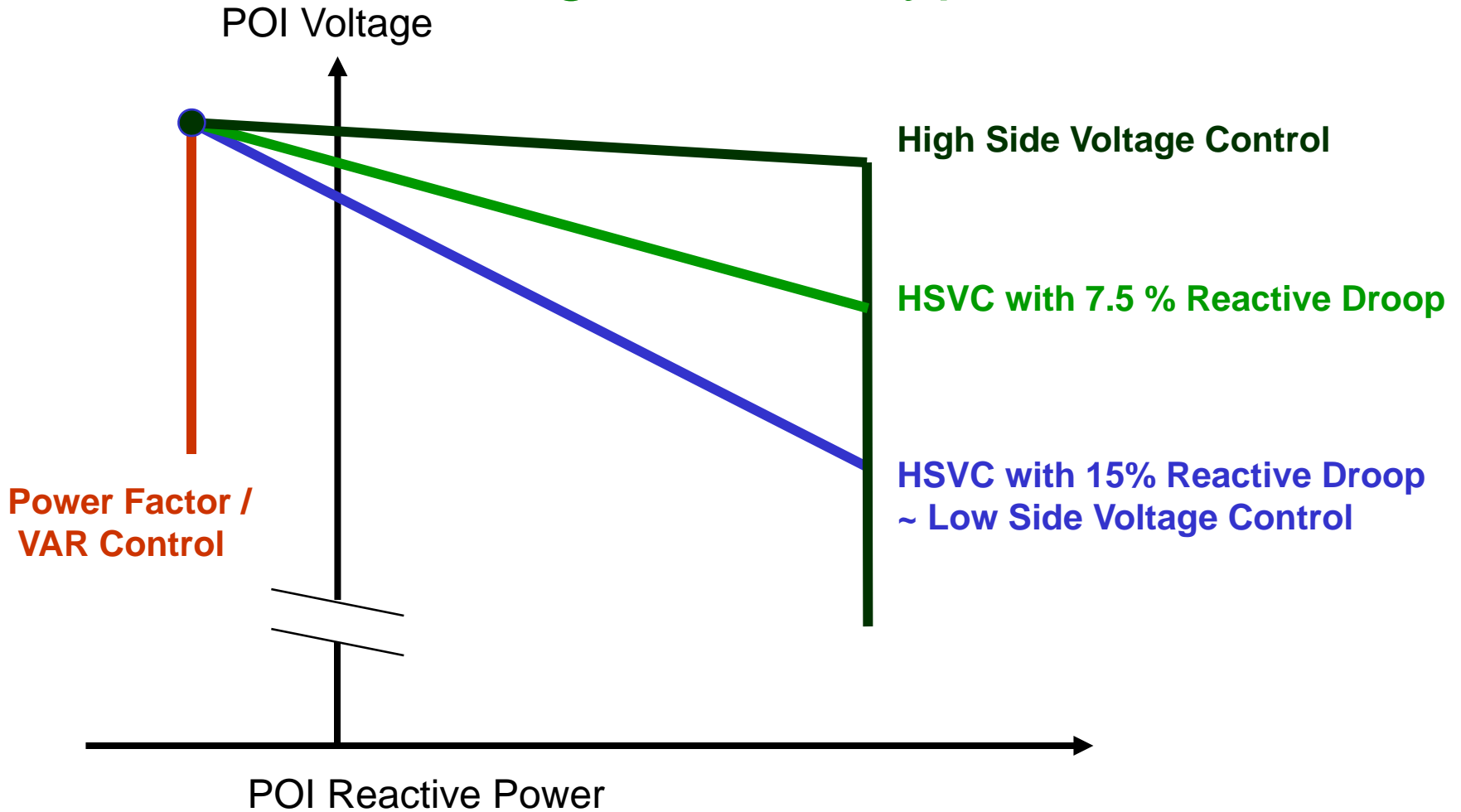


## Wind Farm Dynamic Performance

- For large wind generation not to degrade grid performance:
  - Controllable Dynamic VAr devices must be installed (either WTG or DVar devices) similar to Hydro/Thermal
  - Collector system losses need to be included in total VAr requirements
  - *Voltage* control mode must be used (PF mode will not support system needs)
  - Type of voltage control is now in question



# Voltage control types





## Wind Farm Voltage controller requirements

- Voltage control of wind farms required to provide primary voltage support for system events
- High side voltage control overly sensitive
- Qdroop of 7.5 Typically works best
- Qdroop of up to 15% only in extreme case of System voltage change (mid-line subgrid)
- Next slides 1-Line schematic of controller and Dynamic controlled devices



## Other Wind Farm Performance Requirements

- Voltage ride-through
- Under/over Voltage and Frequency capability
- Voltage stability control – primary and secondary
- Dynamic performance required:
  - Transient Stability
  - Oscillation damping