Transmission To Capture Geographic Diversity of Renewables

Cost Savings Associated with Interconnecting Systems with High Renewables Penetration

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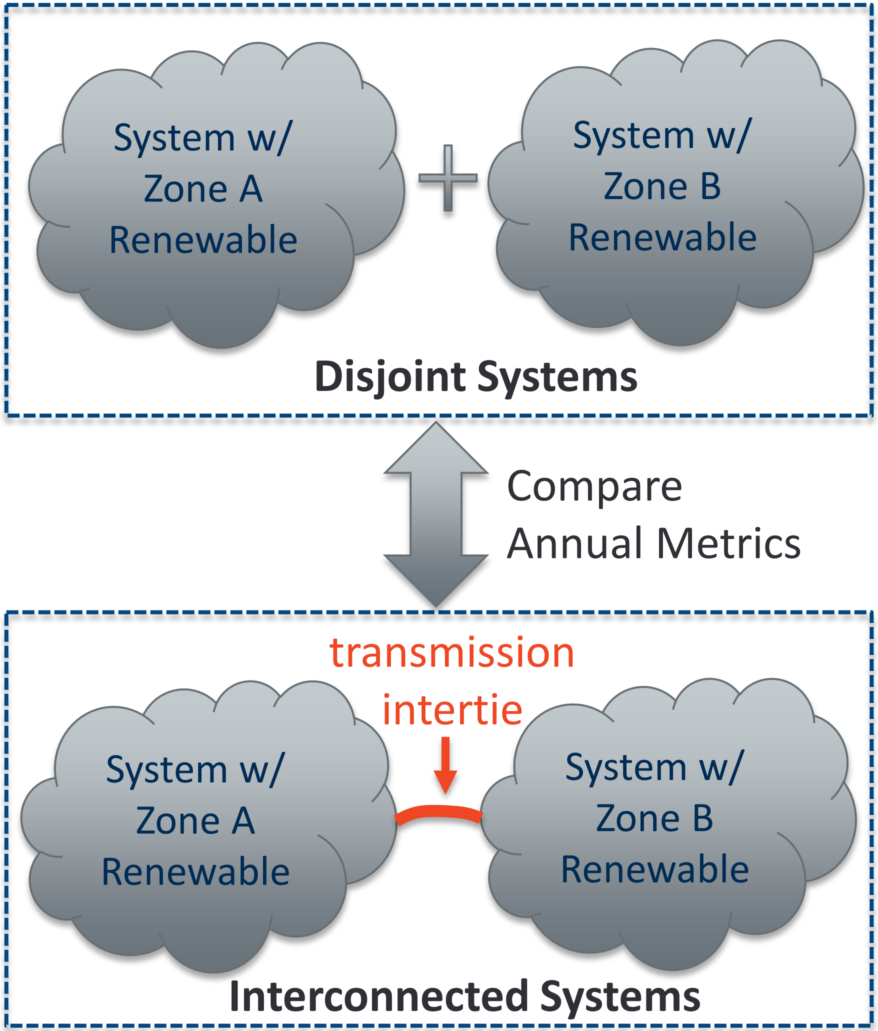
Content

- Example of Capturing Diversity of Renewable Generation Across Regions
- Estimation of Benefits of Interconnecting High Renewables Areas
- Implications for the West

Estimating Benefits Associated with Transmission that Interconnect High Renewable Regions

Goal:
To isolate the benefits ONLY associated with interconnecting diverse renewable resources

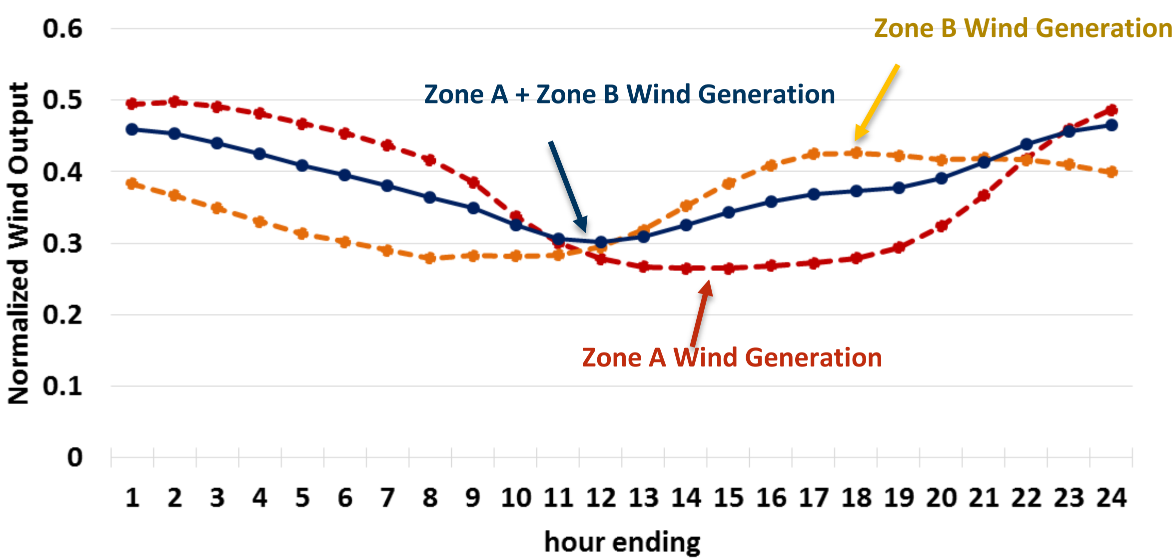


- Create two identical systems, except for the renewable generation profiles.
- Because generation and load are identical, dispatch would be identical except for differences due to renewable generation profiles
- Analyze the systems as “Disjointed” and as “Interconnected

Modeling Intra-Hour Operations of Two Systems

- Constructed a test system representing **two identical systems** (to isolate the effects from other efficiency gains across diverse systems):
  - Approximately **generating capacity of 16,000 MW** with different technologies and diverse fuel mix.
  - **Actual load** data, with 14,000 MW peak
  - **Actual wind generation** data from two windy regions
- Used **Power System Optimizer (PSO)** to simulate unit-commitment and dispatch on a day-ahead (DA), hour-ahead (HA), and real-time (RT) basis, including explicit simulations of spinning, regulation up and down, and intra-day commitment option (ICO) reserves

Average Normalized Wind Output by Hour of Day



Types of Benefits To Be Estimated

- Reduced production costs
  - Lower cost generation from interconnected areas is shared across the regions
- Reduced wind curtailments
  - Generator flexibility shared across the regions reduces the need to curtail wind during times of high wind output and/or low load
- Reduced reserve requirements
  - Reserves needed (based on system contingency requirements) by the interconnected area is less than the sum of those needed by the separate systems
  - Reduced net load volatility reduces regulation needs
  - Reduced net load forecast error reduces Intra-Day-Commitment needs
- Increased Reliability
  - Additional generator flexibility and reduced net-load volatility reduces incidents of load shedding and contingency reserve calls.

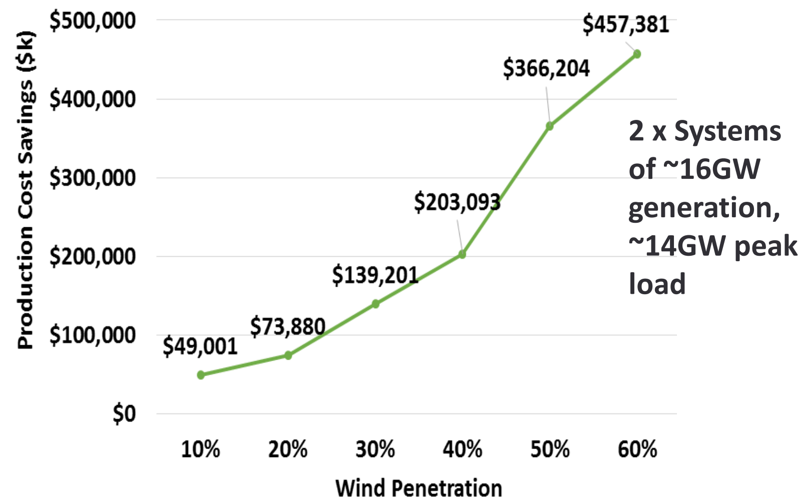
Production Cost Savings ONLY Due to Renewables Production Diversity

The production cost savings are substantial by interconnecting the systems:

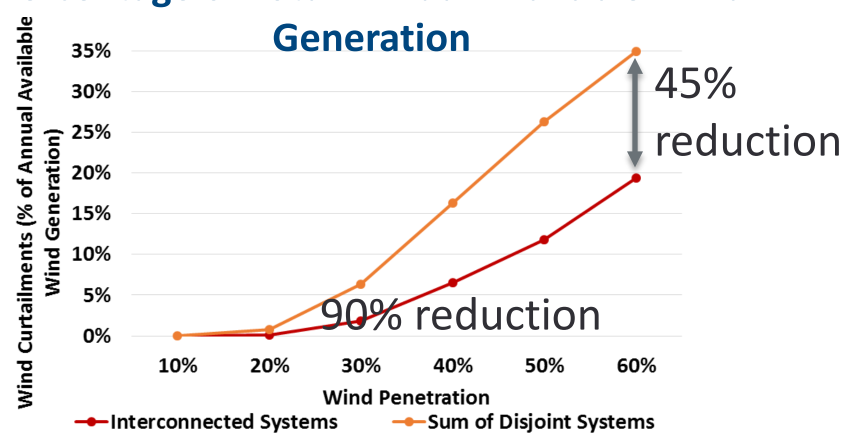
- Interconnection resulted in **$49 to $460 million in annual production cost savings** depending on the level of renewable penetration.
- **Wind curtailments were reduced dramatically, (by 45% to 90%)** with higher percent reductions at lower renewables penetrations

Interconnecting systems with wind can result in substantial production cost and curtailment reduction benefits

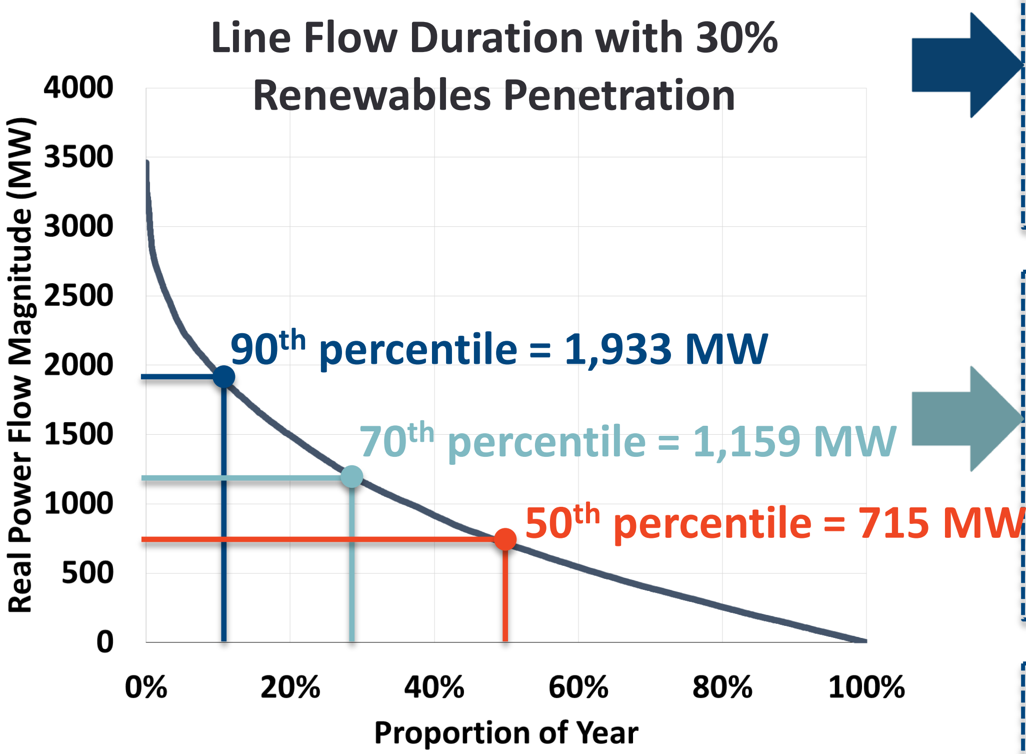
Annual Real-Time Production Cost Savings

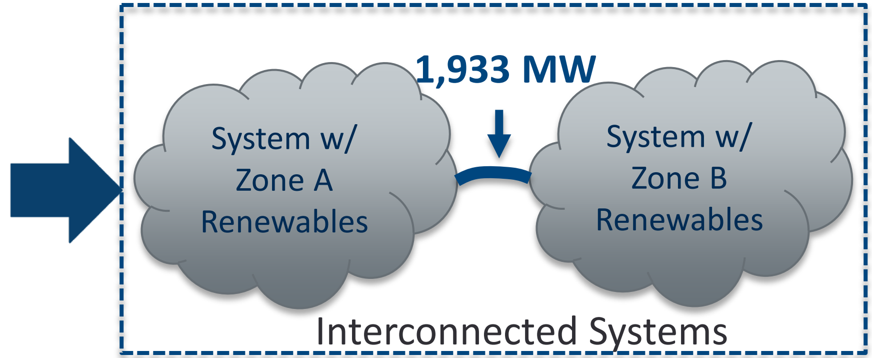


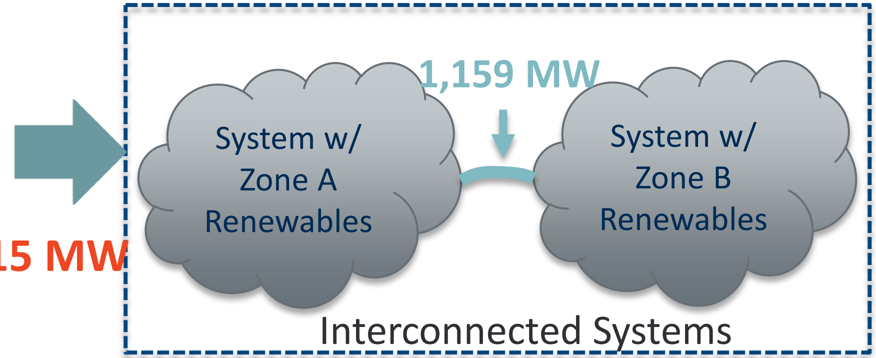
Annual Real-Time Wind Curtailments as a Percentage of Total Annual Available Wind Generation

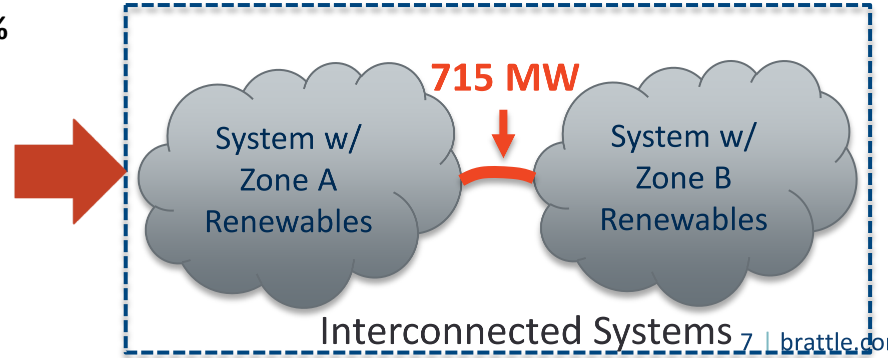


Assessing Size of Interconnection Needed







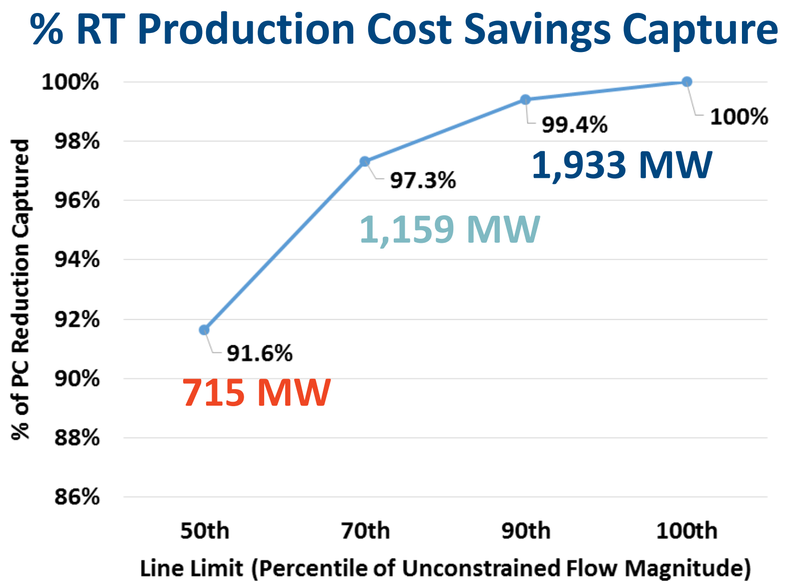


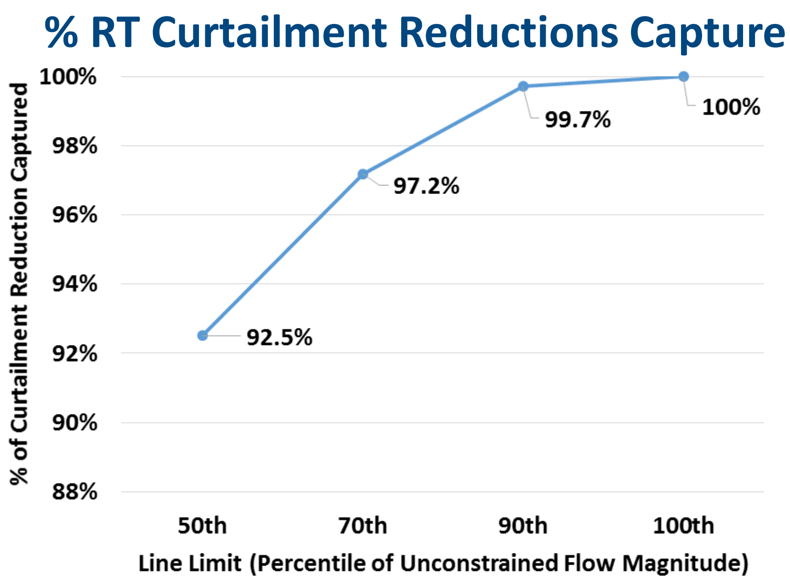
Limited the tie-line capacities based on measured flows over copper-sheet scenario (based on 30% renewable penetration)

Benefits Can be Captured Even with Modestly Small Interconnection Capacity

- The benefits of system interconnection are relatively insensitive to tie-line capacity
- With a tie-line of capacity equal to the 50th percentile of the amount of unconstrained flow, >90% of the production cost savings and wind curtailment benefits are captured.

(The percentage savings captured relative to line size is the same in Real Time and Day-Ahead time frame)

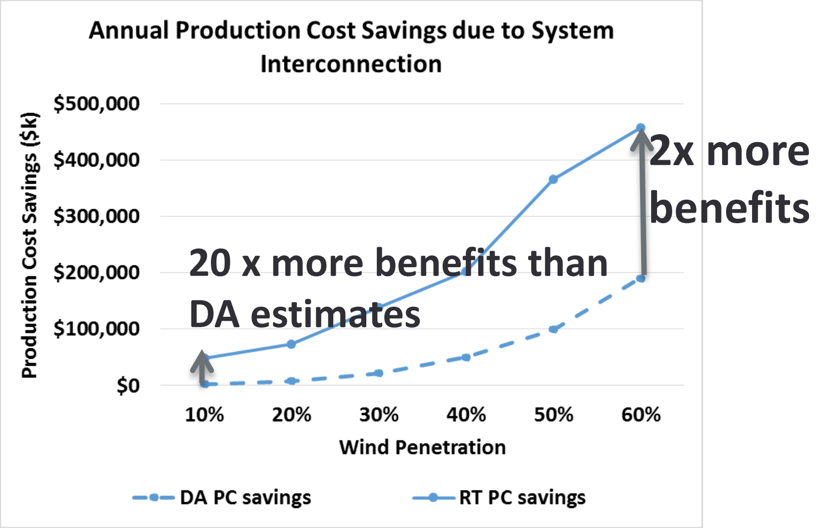


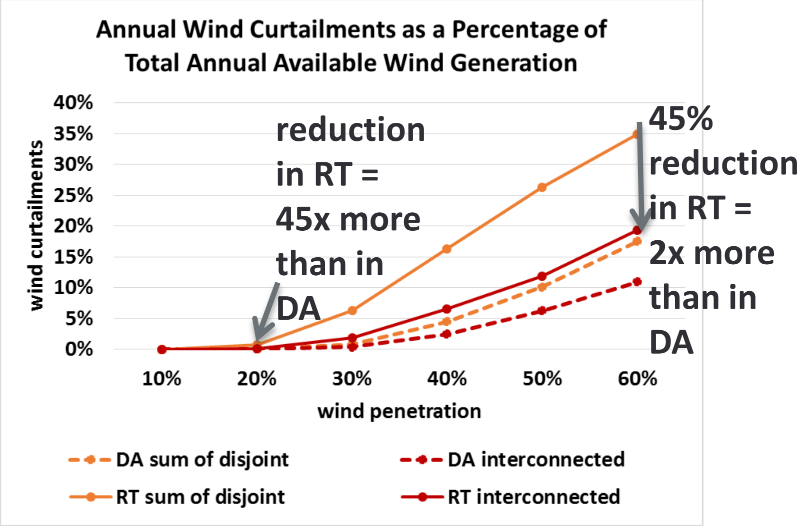


Real-Time Benefits Are Significantly Greater than Day-Ahead Benefits

- We found that the RT production cost savings are between 2 to 20 times those in DA
- In DA, only forecasted output is available, thus the benefits also show up in the day-ahead commitment
- In RT, the variability of renewable output cross-compensate, leaving both less units committed and costly ramping up and down of expensive units
- The actual renewable curtailment reductions that materialize in RT are double those that are expected in DA
- Capturing the RT benefits also capture the high impact, low frequency events.

The benefits of interconnecting regions with diverse renewable generation would be under-estimated using only DA markets.

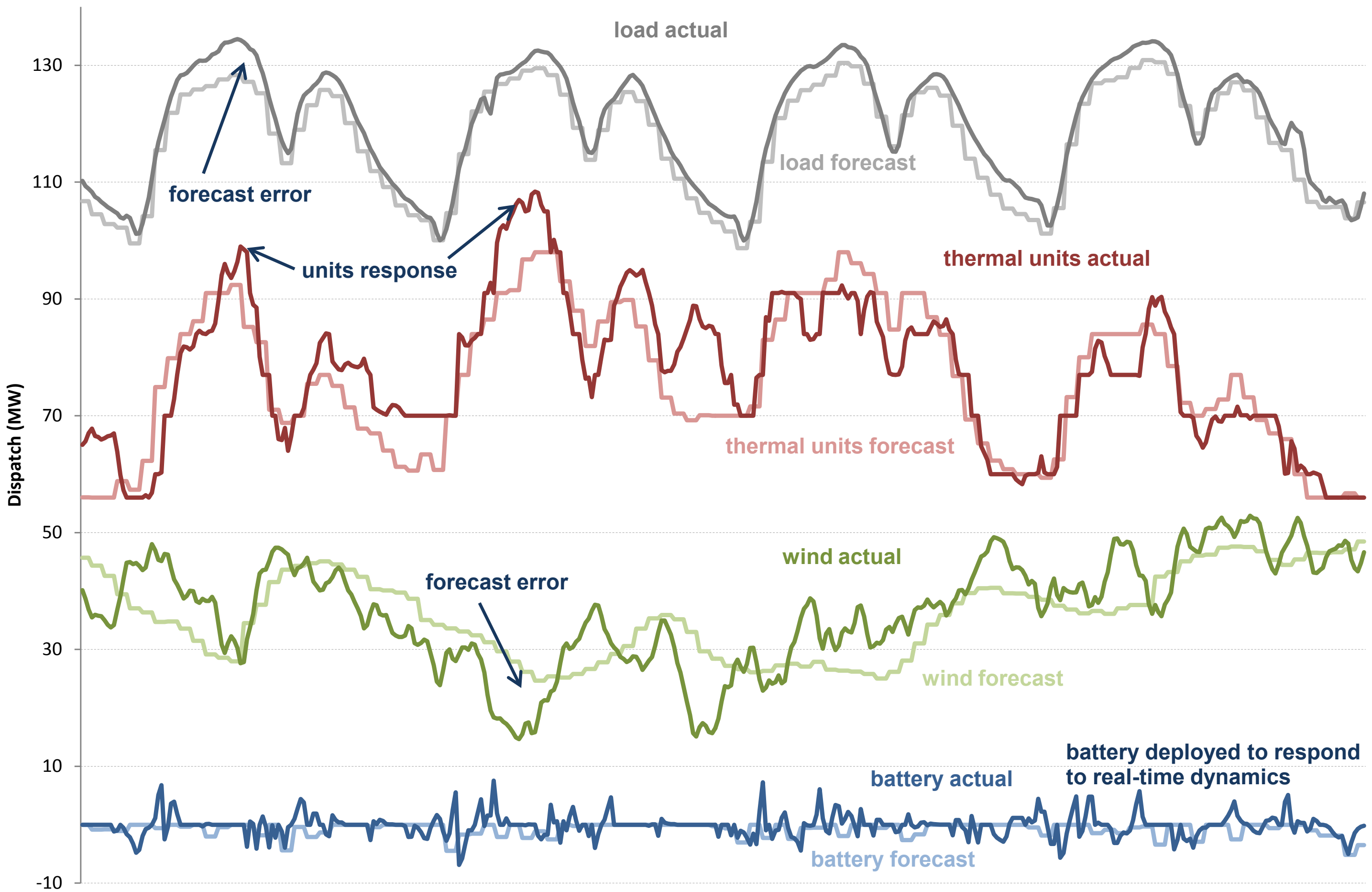




Intra-Hour Simulation Captures Forecast Errors at Different Time Frames

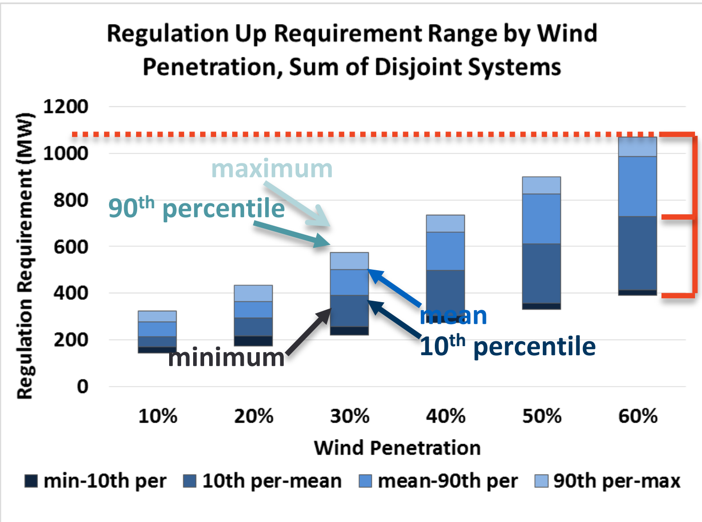
PSO simulates actual operations, not just setting reserves aside. This feature is important to capture the actual effects of generation profile diversity

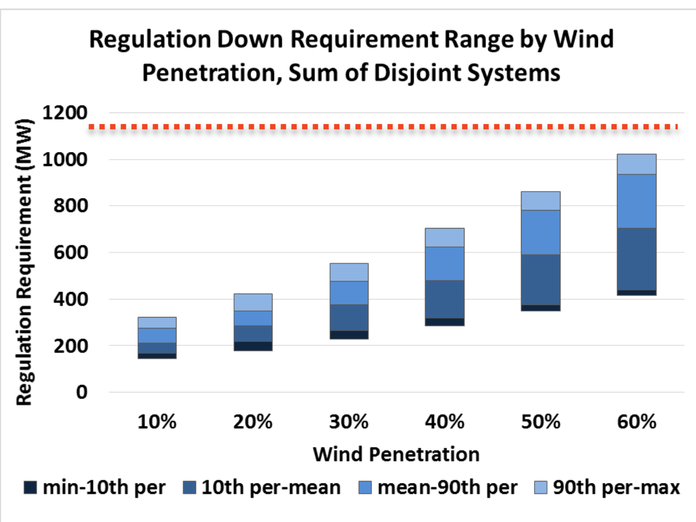
4-Day Summary of a Operations Simulation at 15 Minute Increments



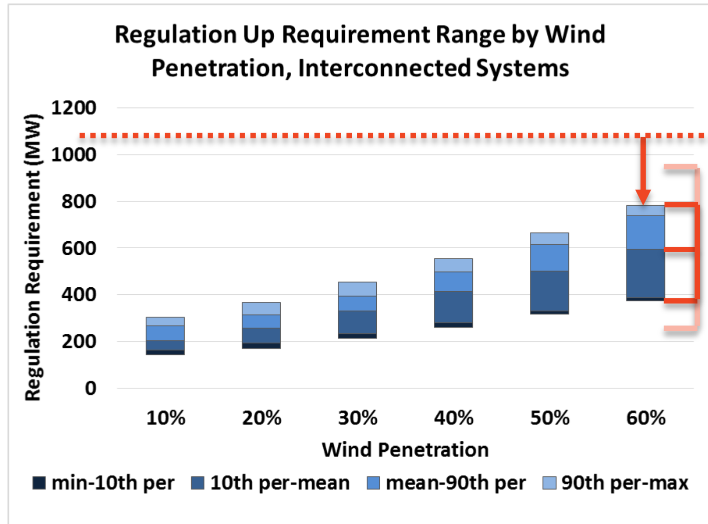
Additional Benefits: Regulation Reserve Requirements Decrease with Interconnected Systems

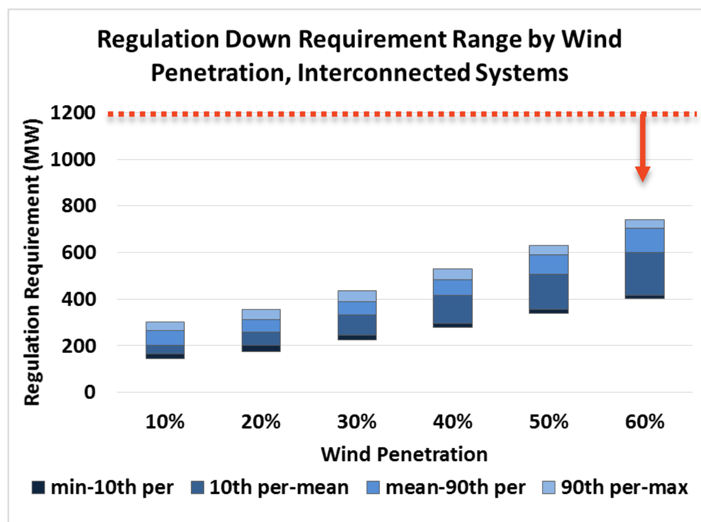
Before Interconnecting





After Interconnecting





- In this example, the reduction is modest at 30% renewable penetration
- But sub-regions with very high renewables, benefits can be significantly higher

Main Takeaways – Implications for the West

- Our analysis finds significant diversification benefits associated with interconnecting systems with high renewable penetration.
  - This is distinct and separate from other transmission benefits, which include:
    1. Traditional Production Cost Savings
    2. Reliability and Resource Adequacy Benefits
    3. Generation Capacity Cost Savings
    4. Market Benefits
    5. Environmental Benefits
    6. Public Policy Benefits
    7. Employment and Economic Stimulus Benefits
    8. Other Project-Specific Benefits
- Size of the transmission interconnecting the regions do not need to be large
- Real-Time benefits considering forecast uncertainties are substantially larger than benefits measured in day-ahead, assuming known load generation levels
  - Traditional tools (e.g. Promod, Gridview) will significantly underestimate these benefits – which are roughly 20 times greater at 30% renewable penetration
- With the upcoming implementation of Energy Imbalance Market, the “joint” market will benefit from resource diversity
- All future proposed transmission in the West should consider such renewable diversification benefits.

Additional Reading

Chang, Pfeifenberger, Newell, Tsuchida, Hagerty, "Recommendations for Enhancing ERCOT's Long-Term Transmission Planning Process," October 2013.

Chang, Pfeifenberger, Hagerty, "The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investments,“ prepared for WIRES, July 2013.

Chang, "Implications of the Increase in Wind Generation for Alberta's Market: Challenges of Renewable Integration," presented at 13th Annual Alberta Power Summit, Calgary, Alberta, November 28, 2012.

Chang, "Challenges of Renewable Integration: Comparison of Experiences," presented at Transmission Executive Forum West 2012, Meeting Public Policy Objectives through Transmission Investment, October 22, 2012.

Pfeifenberger, Chang, Hou "Bridging the Seams: Interregional planning under FERC Order 1000," *Public Utilities Fortnightly*, November 2012.

Pfeifenberger "Transmission Investment Trends and Planning Challenges," *EEI Transmission and Wholesale Markets School*, August 8, 2012

Pfeifenberger and Hou, "Seams Cost Allocation: A Flexible Framework to Support Interregional Transmission Planning,“ April 2012.

Pfeifenberger and Hou, *Transmission's True Value: Adding up the Benefits of Infrastructure Investments*, Public Utilities Fortnightly, February 2012.

Pfeifenberger and Hou, *Employment and Economic Benefits of Transmission Infrastructure Investment in the U.S. and Canada*, on behalf of WIRES, May 2011.

Pfeifenberger, Chang, Hou, Madjarov, *"Job and Economic Benefits of Transmission and Wind Generation Investments in the SPP Region," The Brattle Group, Inc.*, March 2010.

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Note:

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Ms. Judy Chang is an energy economist and policy expert with a background in electrical engineering and over 16 years of experience in advising energy companies and project developers with regulatory and financial issues. Ms. Chang has submitted expert testimonies to the U.S. Federal Energy Regulatory Commission, U.S. state and Canadian provincial regulatory authorities on topics related to transmission access, power market designs and associated contract issues. She also has authored numerous reports and articles detailing the economic issues associated with system planning, including comparing the costs and benefits of transmission. In addition, she assists clients in comprehensive organizational strategic planning, asset valuation, finance, and regulatory policies.

Ms. Chang has presented at a variety of industry conferences and has advised international and multilateral agencies on the valuation of renewable energy investments. She holds a Master's in Public Policy from Harvard Kennedy School, is a member of the Board of Directors of the Massachusetts Clean Energy Center, and the founding Executive Director of New England Women in Energy and the Environment.

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Hannes has extensive experience in the economic analyses of wholesale power markets and transmission systems. His recent experience includes reviews of RTO capacity market and resource adequacy designs, testimony in contract disputes, and the analysis of transmission benefits, cost allocation, and rate design. He has performed market assessments, market design reviews, asset valuations, and cost-benefit studies for investor-owned utilities, independent system operators, transmission companies, regulatory agencies, public power companies, and generators across North America.

Hannes received an M.A. in Economics and Finance from Brandeis University and an M.S. in Power Engineering and Energy Economics from the University of Technology in Vienna, Austria.

About the Brattle Group

The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies worldwide.

We combine in-depth industry experience and rigorous analyses to help clients answer complex economic and financial questions in litigation and regulation, develop strategies for changing markets, and make critical business decisions.

Our services to the electric power industry include:

- Climate Change Policy and Planning
- Cost of Capital
- Demand Forecasting Methodology
- Demand Response and Energy Efficiency
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Environmental Compliance
- Fuel and Power Procurement
- Incentive Regulation
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Appendix A:
PSO Capabilities

PSO Functional Goals

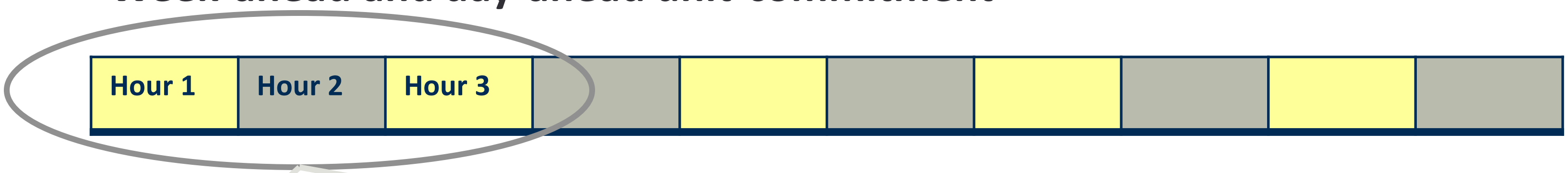
Polaris Systems Optimization has developed Power System Optimizer (“PSO”) to support the simulation of multi-level, nested time intervals that simultaneously optimize energy and ancillary services dispatch, and can simulate uncertainties. The model can:

- Simulate intra-hour operations and constraints (minute-to-minute or multiple seconds)
- Model dispatch decision at different time intervals and the impact of generation and load uncertainties on decision making
- Flexibly model new types of resources (generation, load, transmission, storage, services, …) without predetermined parameters – allows users to set operational assumptions
- Co-optimize across markets (energy and individual types of ancillary service markets)
- Support development of new modeling approaches (transmission switching, stochastic methods, multi-product models, …)

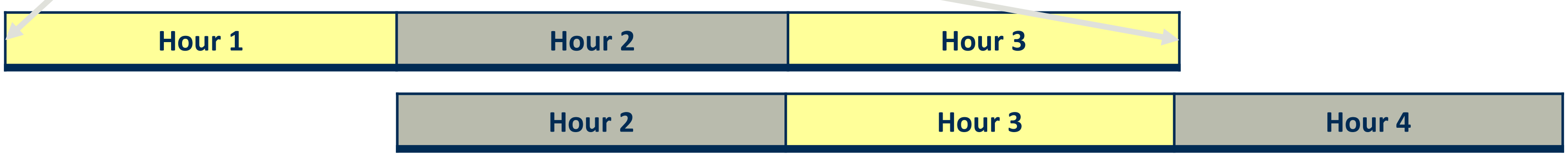
PSO Decision Cycles – Example

PSO evaluates maintenance, commitment, and dispatch decisions on timescales that match real-world decision processes and information flows (year-ahead to minutes)

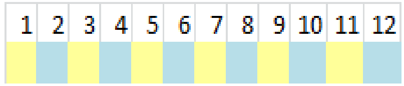
Week-ahead and day-ahead unit-commitment



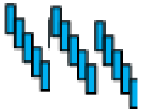
Hour ahead dispatch



5-minute interval actual dispatch



1-minute “Regulation”



Traditional Production Simulation Tools vs. PSO

Traditional Production Simulation Models

Strengths

- Decision support tools for developing trading strategies and operating plans.
- Detailed modeling of operational characteristics of thermal units with transmission system constraints.
- Pre-packaged.

Weaknesses

- Unable to model **different decision timeframes**
  - Real time (e.g., 5-minutes ahead)
  - Hour-ahead
  - Day-ahead
- **Deterministic** decision methodologies do not optimize accounting for forecast uncertainty.
  - Uncertainty captured only in additional simulation mode (Monte Carlo approaches).
- Decisions **not strongly linked between different timeframes** lead to operational and trading issues (e.g., real time issues due to lack of appropriate modeling in intermediate time decisions).
- **Preset interval length** modeling.

Power Systems Optimizer (PSO)

Strengths

- Has all capabilities of traditional simulation models
- Supports **decisions at various overlapping timeframes (year, month, week, day, hours, minutes)**
- Flexible **intra-hour modeling**, can set user-defined time intervals and decisions
- Can **simulate user-defined individual ancillary services** and products
- Can simulate **forecast uncertainties for load and generation**
  - Can use user-specified probabilistic parameters to generate forecast and realization time series
  - Can also directly use historical time series
- Can simulate uncertainties (costs, outages, etc.) and obtain results in **probabilistic distributions** of the variables of interest using a Monte Carlo approach
- Can perform stochastic optimization of commitment and dispatch
- Can **simulate energy storage directly** based on efficiency parameters
- Can view all dispatch decisions graphically

PSO Functionality

- Modeling based on Mixed-Integer Programming
- Decision cycles: user-defined, including the mapping of decisions to cycles (e.g., unit commitment in week-ahead or day-ahead cycle, dispatch in hour-ahead, and actual within the hour)
- Hydro and other energy-limited resources: can simulate specific characteristics (cascading systems; value of water as input; target levels)
- Storage resources: can simulate based on user-specified efficiency, energy storage capability, and ramp rate
- Thermal generation: detailed representation of each unit or groups of units, including combined cycles – all can be user-specified
- Transmission: detailed nodal models, security constraints
- Ancillary Services: user-defined characteristics and products
- Most parameters can be mapped to a time series, or a set of time series (AS requirements, resource capabilities, forecasts, etc…)
- Modeling consistent with market operations software (main PSO developer worked on the PJM, ISO-NE, MISO, and other markets)

PSO Cycle Results to Evaluate System Performance

PSO provides a detailed solution for each cycle

- Unit Commitment, Energy and Ancillary Services Dispatch
- LMPs, shadow prices
- Day-ahead and real-time
- Violations (resource adequacy, A/S, ramping, and others)

Analysis of cycle results to document operational performance

- Ancillary service deployment
- Impact of uncertainty and variability
- Causes of real-time market solution volatility

Cycle results allow root cause analysis of reliability challenges

Type of Violations	Earlier Cycle (DA)		Later Cycle (RT)	
	Energy	AS	Energy	AS
Real-time AS requirement too low			✓	✓
Day-ahead AS commitment deficiency				✓
Day-ahead AS requirement unnecessarily high		✓		
Resource adequacy deficiency	✓	✓	✓	✓
Flexible resource deficiency		✓		✓

Operating PSO on pCloud

To increase speed and allow simultaneous scenario simulations, we have partnered with a cloud-based computing firm.

- pCloud is a custom platform that allows PSO to run in the cloud and leverages the almost unlimited computing capability to perform multiple simulations faster at a reasonable cost
- We are working with the developers of pCloud to improve user interface
- For long-duration simulations, pCloud can partition time-series, run simulations separately, and “stitch” back results
- The ability to have simulation results from hundreds of scenarios enables more in-depth analysis of outlier scenarios