The Brattle Group

How are Markets Adjusting to Large Amounts of Renewable Generation?

Presented at:

8th Annual Carnegie Mellon Conference on the Electricity Industry
DATA-DRIVEN SUSTAINABLE ENERGY SYSTEMS

Kamen Madjarov
Judy Chang

March 14, 2012

Agenda

A. Background: RPS Policies & Wind Development

B. Interconnection Policies & Challenges:

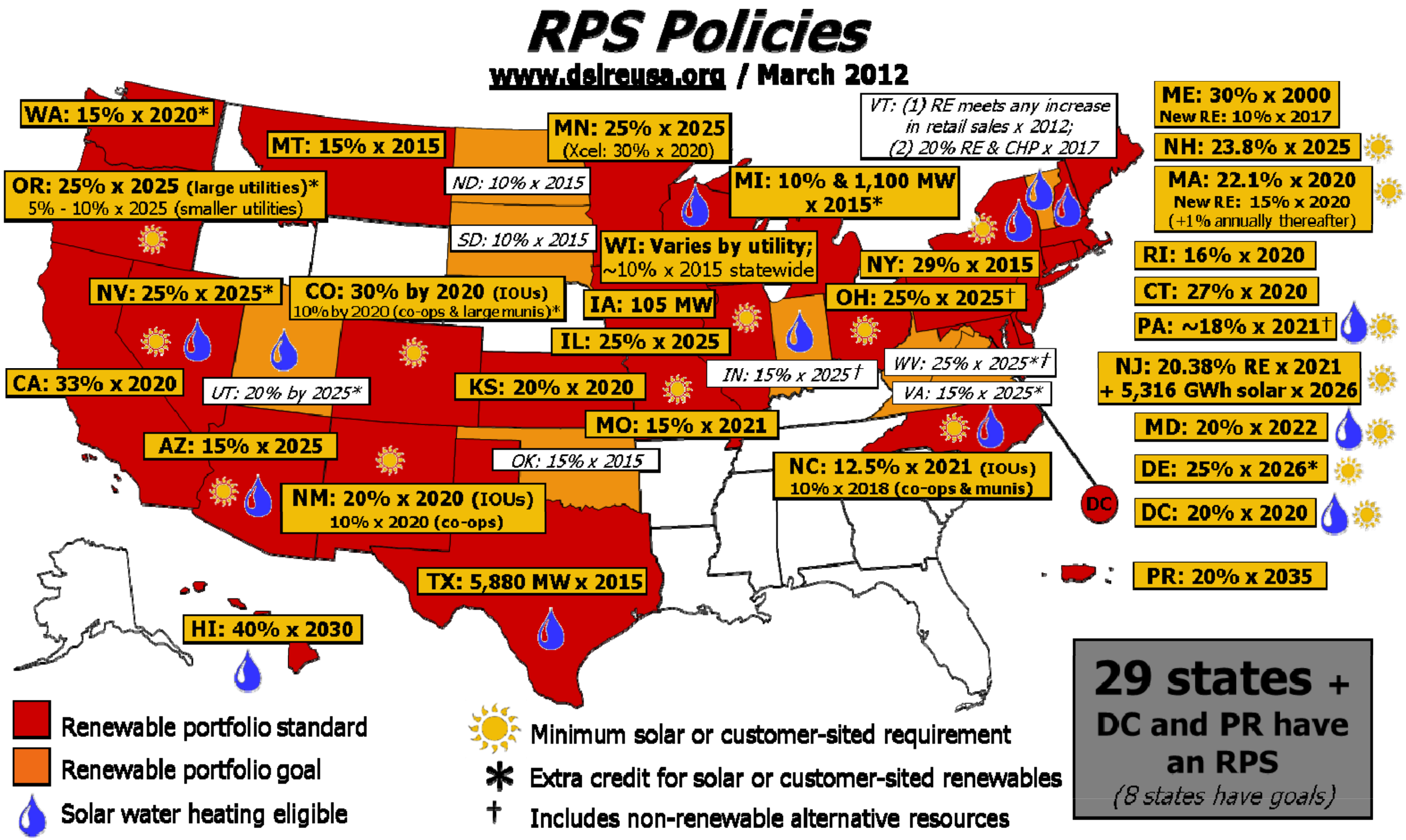
1. RTO Interconnection Policies for Wind
2. Dispatchability & Congestion Management

C. Operational & Grid Balancing Challenges

1. Ancillary Services
2. Impacts on Market Operations
3. Wind Integration Studies

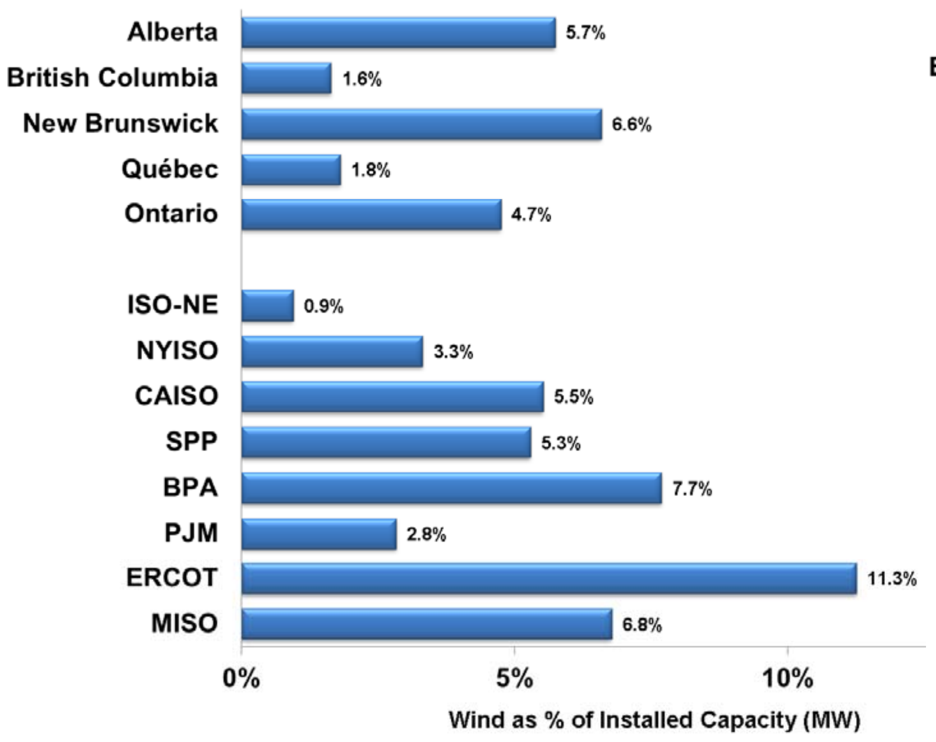
A. Background: Wind Development & Grid Integration

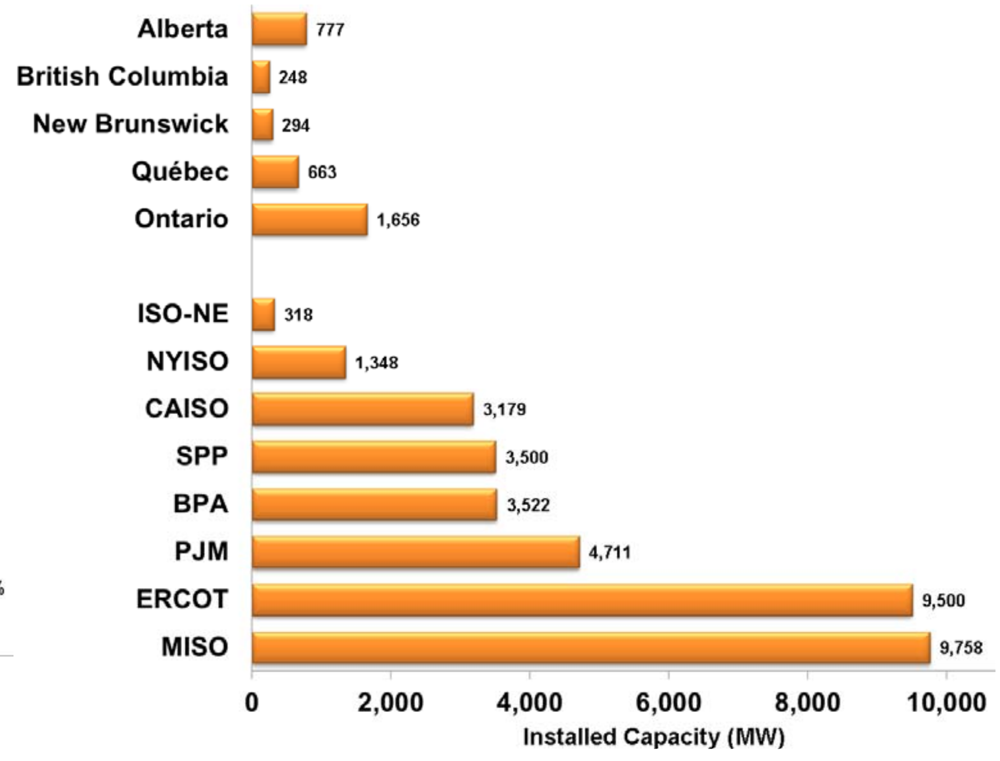
U.S. Renewable Portfolio Standards



A. Background: Wind Development & Grid Integration

Installed Wind Capacity: North America





Source: *The Brattle Group* analysis

B.1 RTO Interconnection Policies for Wind

Wind is subject to the same interconnection charges as conventional generation

- **NYISO, PJM, ERCOT–** 100% of upgrade costs.
- **Midwest ISO –** 100% of upgrade costs <345kV; 90% if equal to or above. Multi-Value Project (MVP) may include portions of network upgrades otherwise allocated to generator.
- **CAISO –** Specific tariff for location-constrained resources where interconnecting generators pay their pro-rata share of the total upgrade cost.
- **SPP** – Varies between 0% to 100% depending on network upgrade voltage and wind location compared to transmission customer.
- **BPA** – "Network open season" at embedded cost (reforms to Interconnection Procedures currently under review).

B.2. Dispatchability & Congestion Management

Legacy treatment of wind as a non-dispatchable resource still prevails in many energy markets. Under this treatment wind:

- Is not dispatched based on economics.
- Is a price-taker.
- May be manually curtailed in real-time to manage congestion (and system events; e.g. minimum generation events) outside the market-based congestion process.

As newer wind turbines are capable of controlling their output according to dispatch instruction, some markets are treating wind as a dispatchable resource in their real-time energy market

- **NYISO**: since 2009 wind **must participate as a dispatchable resource**
- **MISO**: since June 2011 wind **may participate as a dispatchable resource (will become mandatory in 2013)**, but it can change its Forecast Maximum Limit up to which MISO can dispatch the resource
- **PJM:** wind **may offer into the RT market as a dispatchable resource**, but it can change the maximum limit to which it can be dispatched can be changed only once per hour.
- **ERCOT:** wind generators are dispatchable, but unlike conventional generators, they must take action only if being curtailed; failure to generate within the required range may result in a deviation charge.

B.2. Dispatchability & Congestion Management

NYISO: Dispatchable Wind in RT Energy Market

In 2008, NYISO was the first RTO to introduce centralized wind forecasting and to start treating wind as a dispatchable resource:

- This was prompted by a growing transmission congestion problem, especially during high-wind, low-load periods, due to the fact that wind farms are clustered in certain parts of New York State.

Centralized wind forecasts are integrated into NYISO's DA and RT market processes.

- Centralized wind forecasts are developed using meteorological data from wind resources. Data must be submitted for every 15-minute interval (24x7); failure to submit data may result in penalties.

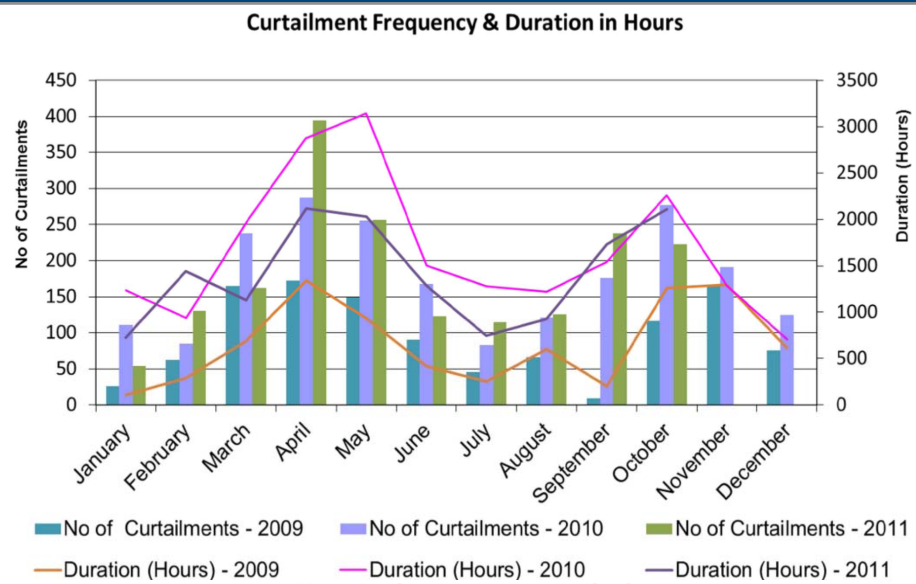
Market rules were changed to treat wind as dispatchable (in the downward direction) resource in the RT market

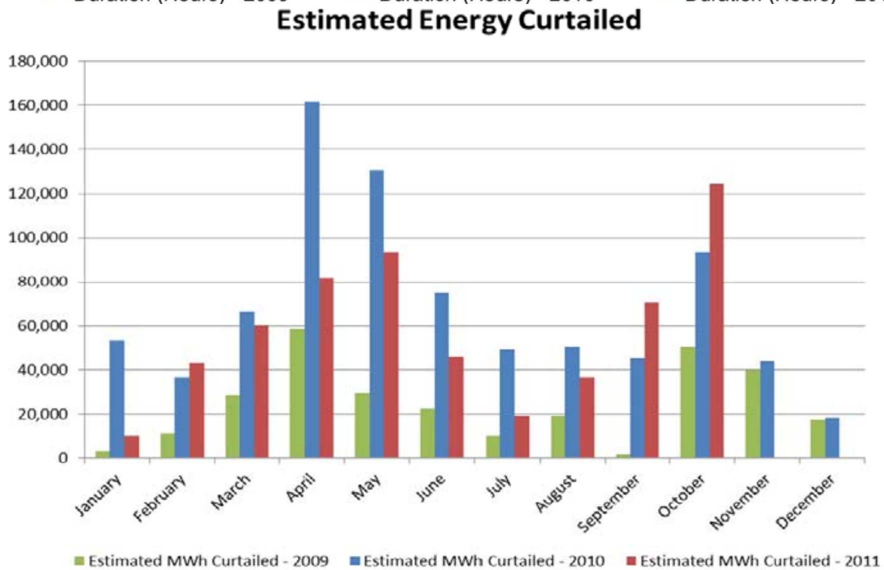
- **Wind generators are required to submit economic energy offers into the RT market** indicating the market price at which they wish to curtail and the corresponding output levels.
- **Participation in RT market as a dispatchable resource is mandatory** for all wind farms, except for the two oldest resources.
- **RTD software <u>may dispatch down</u> wind generators based on their offers to relieve transmission constraints.**

MISO: Dispatchable Intermittent Resource (DIR)

MISO Independent Market Monitor Fall 2011 findings:

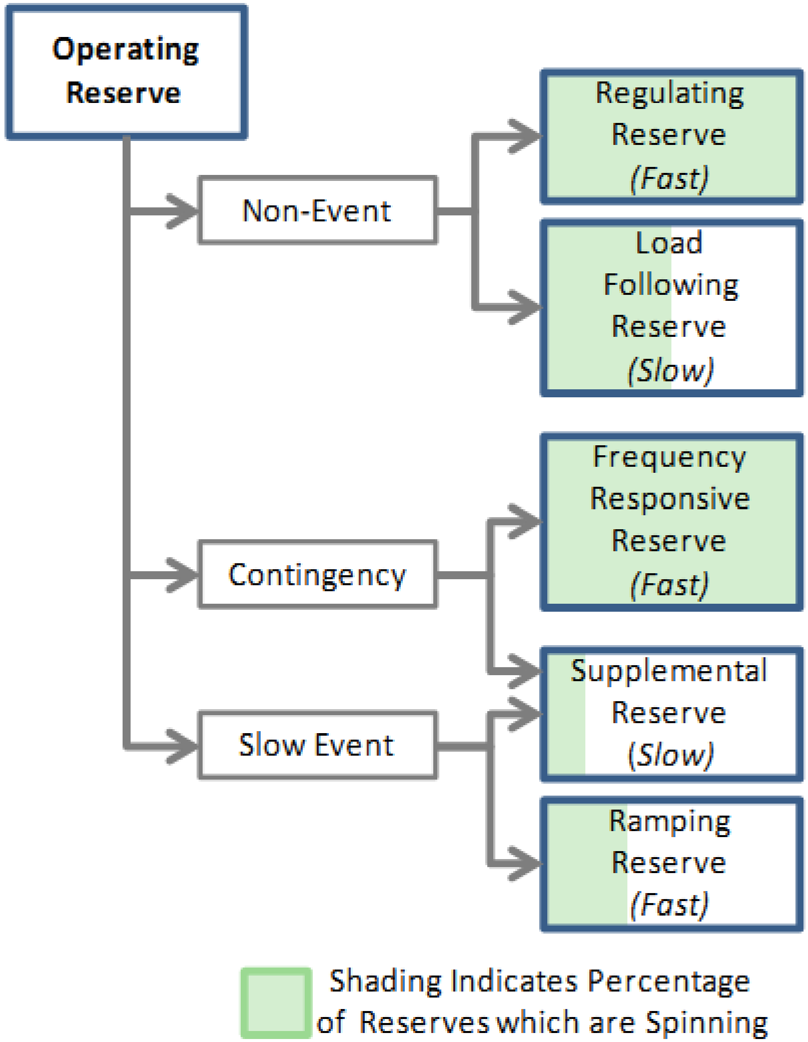
- Congestion manageability in the West improved partially due to higher availability of DIR wind units;
- 16 resources (14 active) totaling over 2 GW were registered as DIR in fall 2011; over 8.6 GW of wind remains non-dispatchable
- An average of 36 MW was economically curtailed per interval—economic DIR curtailments have increased since implemented in June 2011





Sources: Midwest ISO, IMM Quarterly Report: Fall 2011 September-November, Dec. 2011; MISO "September/October 2011 Wind Curtailments and DIR Update," Kris Ruud, RSC, November 29, 2011

C.1. Ancillary Services



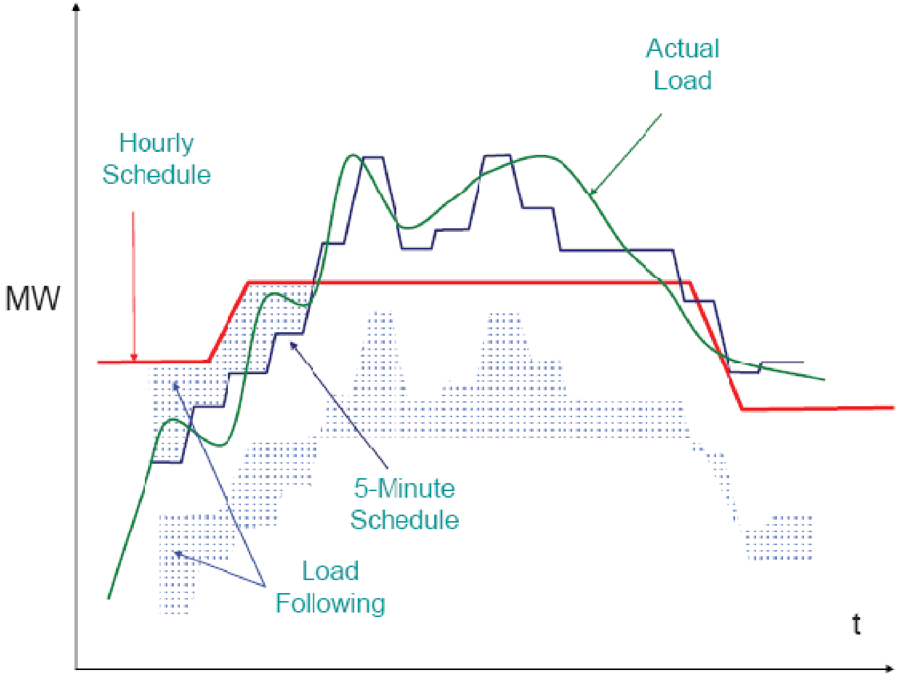
- **Operating Reserve:** Capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages and local area protection—includes spinning and non-spinning reserves.
- **Regulating Reserve**: An amount of reserve responsive to Automatic Generation Control (AGC), which is sufficient to provide normal regulating margin.
- **Frequency response**: The ability of a system or elements of the system to react or respond to a change in system frequency.
- **Frequency Regulation**: The ability of a Balancing Authority to help the Interconnection maintain Scheduled Frequency. This assistance can include both turbine governor response (primary response) *and* AGC.

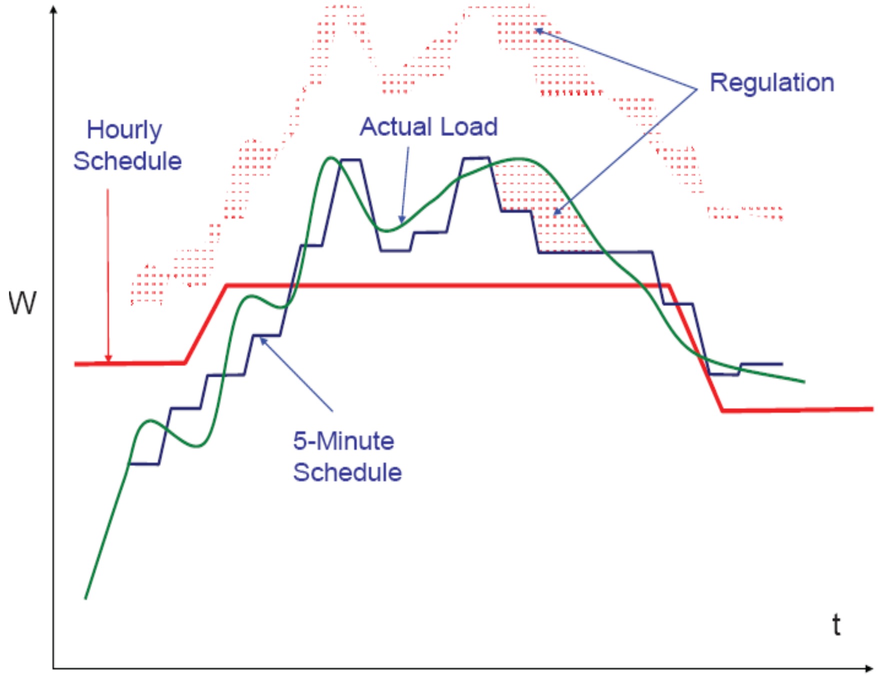
Sources: NERC "Operating Reserves and Wind Power Integration: An International Comparison Preprint," October 2010; NERC "Glossary of Terms Used in NERC Reliability Standards," May 2011; NREL "Eastern Wind Integration and Transmission Study," January 2010

CAISO Regulation and Load Following

The CAISO differentiates the two services by the process of scheduling and the timing of the forecast

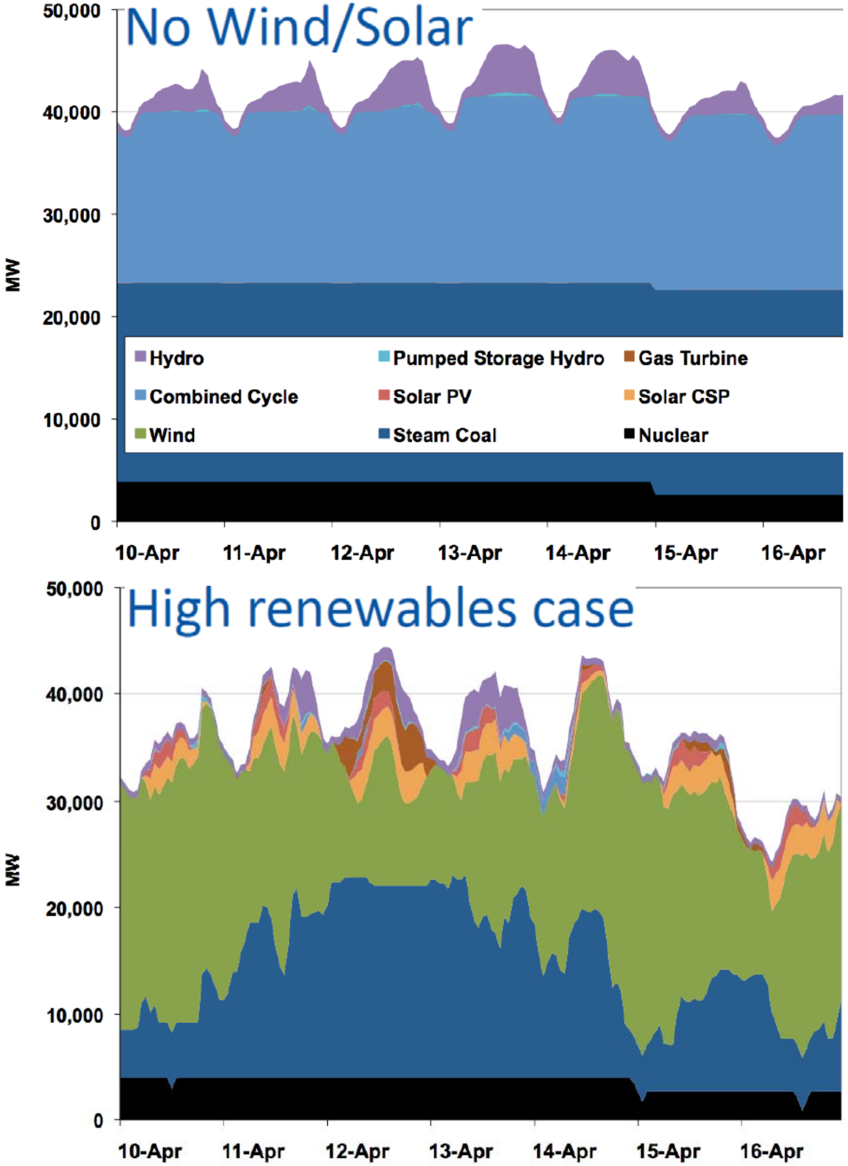
- Load following = difference between the **hourly schedule** (shown as red line) and the **5-minute schedule** (blue line) of generation to meet forecast load: the area shaded light blue.
- Regulation = difference between the **5-minute schedule** (blue line) and the **actual load/wind** (green line): the area shaded red.





Source: CAISO Integration of Renewable Resource, November 2007

C.2. Impacts on Market Operations



Sources: NREL, Stakeholder Webinar May 19, 2011 WWSIS Phase 2

Western Wind and Solar Integration Study (WWSI) Phase 1 (2010):

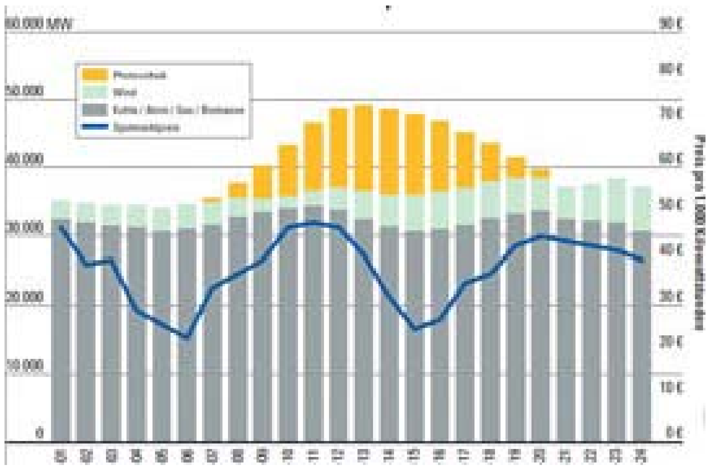
- Analyzed up to 35% of wind & solar penetration in WestConnect (up to 27% in WECC)
- Modeled the year 2017 three times and used historical load and weather patters from 2004-2006
- Provided statistical analysis of variability and examined extreme events (mid-April week was the worst of the 3 years analyzed—graph on the left)

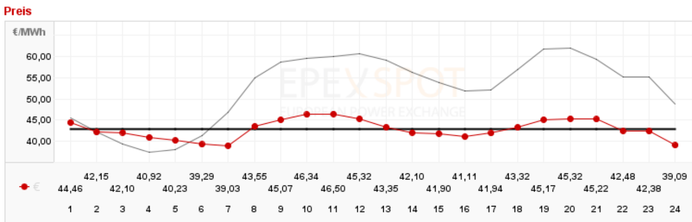
Phase 1 found 30% wind and 5% solar can be accommodated in WestConnect conditional on:

- Significant increase in balancing area cooperation—must coordinate commitment and dispatch over wider regions
- Increased reliance on sub-hourly scheduling and transmission utilization
- Commitment of additional operating reserves as needed
- Integration of forecasts in dispatch and operations
- Increased flexibility from conventional generation (cycling/ramping) and renewable generation (ramping down)

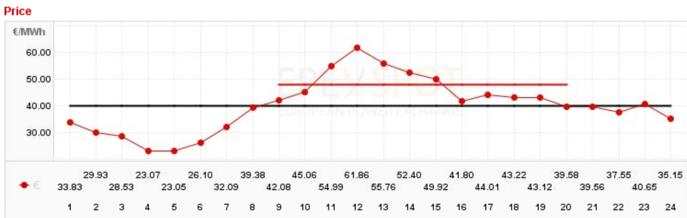
Germany: Peak Prices with High Solar PV Penetration

German Power Market July 16, 2011





German Power Market July 16, 2009



Sources: Solarserver.de; EEX

- Germany has seen significant growth in solar PV capacity
- In February 2012, the German government proposed FIT cuts of up to 29% to contain solar capacity growth
- Price impacts illustrated on 7/16/2011
  - Solar generation (yellow) smoothed the “peakiness” of residual load
  - Resulting hourly prices (red on middle graph) were almost completely flat
  - Compared to a “typical” summer day (7/16/2009 – red line in lower graph)

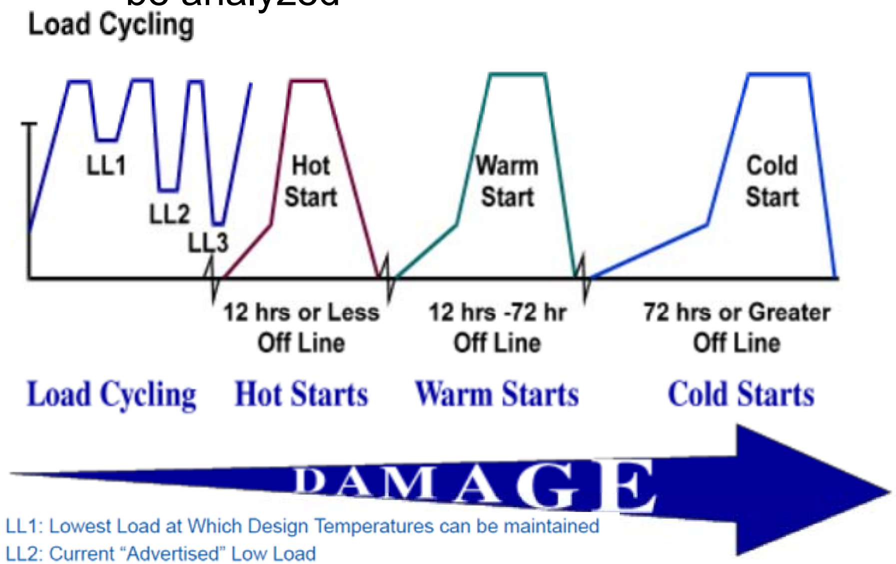
The Brattle Group

C.2. Impacts on Market Operations

Analyzing Cost Impacts & New Market Designs

WWSIS Phase 2 is currently under way:

- Main goal is to examine in greater detail the impacts of renewable generation on thermal units and the availability of mitigation options
- The study will gather improved data on wear and tear costs from increased cycling and ramping of thermal units
- Emission impacts and optimal unit commitment and economic dispatch will be analyzed



- LL1: Lowest Load at Which Design Temperatures can be maintained
- LL2: Current "Advertised" Low Load
- LL3: Lowest Load at Which the Unit can Remain On-Line

The PUC Energy Imbalance Market (EIM) Group is working on formalizing Western balancing areas cooperation:

- Comprised of commissioners from 12 states (AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, WY)—intent on investigating the relevant issues, costs, and benefits of a sub-hourly EIM
- In preparation for a May 2012 meeting, PUC EIM Group is working on 3 areas of analysis:
  - NREL to conduct an intra-hour analysis of the potential social benefits and attribute the potential benefits to individual balancing areas;
  - Xcel Energy and SPP are drafting a market design derived from SPP's current market structure;
  - SPP and CAISO will provide cost estimates for a market operator based on the proposed market design.

Sources*:* NREL, Stakeholder Webinar May 19, 2011 WWSIS Phase 2
PUC EIM Group Presentation February 10, 2012

Overview

Grid operators, regulators, and utilities have commissioned a growing number of wind integration studies and related analyses:

- Their scope generally includes:
  - Estimation of the operational impacts of integrating large levels of wind generation.
  - Examination of the changes to system dispatch order and generation fleet characteristics in a future system with high wind penetration scenarios.
  - Identification of key assumptions about major future transmission upgrades—especially interconnections between neighboring control areas.
- Study-specific methodologies and results differ; however, there is a general consensus that wind integration will require incremental increases in the quantity and the quality of flexible resources needed for reliable grid operation
- Most studies recognize that significant transmission upgrades will be needed; some assume the transmission upgrades in their base case scenarios
- Effects on system operation depend on the penetration and characteristics of the wind generation portfolios.
- System impacts are driven by the uncertainty and variability of wind generation:
  - Due to the uncertainty of day-ahead wind forecasts, extra resources may have to be committed to ensure that adequate generation is available in case actual wind output is less than forecasted.
  - Short-term uncertainty and real-time variability in wind output must also be accommodated with sufficient quantity and quality of flexible generation resources.

Methodologies

Most RTO and other large-scale wind integration studies share a number of similar approaches:

- Address the lack of sufficiently long or granular historical data on renewable generation and forecasts through:
  - Statistical approximations or “naïve” short-term forecast methodologies (e.g., past-period levels are predictors of next-period levels).
  - Simulation of wind generation data for future portfolio locations from granular weather data
- Identify operating reserve needs through statistical analyses of system load, aggregate wind generation, and relevant forecast data.
  - Sub-hourly analyses yield ancillary service impacts for regulation and load following
  - Assessments of hourly and day-ahead net load patterns provide estimates of additional near-real-time and day-ahead reserve needs.

Integration costs are estimated through three primary methods:

- Simulating the incremental operational impact and estimating the associated variable and fixed costs.
- Simulating the full system with and without variable wind resources.
- Using historical resource needs and costs as proxy for future needs, which may involve applying a fixed cost per MW of incremental service need.

Meeting the Renewable Integration Challenge

System operators and policy makers are actively working to address the multiple aspects of integrating renewable generation on the grid:

- RTOs are re-examining interconnection policies
- Wind dispatchability and congestion management has already been formally codified in some markets

Balancing the grid with high levels of renewables will require:

- Increasing balancing area coordination with respect to real-time balancing and intra-hour scheduling
- Exploring the creation of new A/S market products and encouraging new technologies and DR resources
- Further study of cycling impacts on thermal generation

Additional Reading

Hanser, Madjarov, Katzenstein, and Chang, “Riding the Wave: Using Demand Response for Integrating Intermittent Resources,” *Smart Grid: Integrating Renewable, Distributed, & Efficient Energy*, Edited by F. Sioshansi, Elsevier 2012.

Chang, Madjarov, Fox-Penner, Hanser, “Policy Challenges Associated with Renewable Energy Integration”, 2011 MIT Energy Initiative Symposium Proceeding on Managing Large-Scale Penetration of Intermittent Renewables, April, 2011.

Madjarov, “Impacts of Changes in Market Rules and Policies on Wind & Solar Integration,” Infocast Wind & Solar Integration Summit, Phoenix, Arizona, January 25, 2011

Chang, “High Wind and Solar Penetration on the Grid” *NARUC Renewable Energy Retreat*, Riverside, CA, October 7, 2010

Chang and Hanser, “Renewable Integration Model”, *California Long-Term Procurement Plan Workshop, Energy Division of the California Public Utilities Commission (CPUC)*, CPUC Auditorium, San Francisco, August 25, 2010

Hajos, Attila, “Market Impacts of Large Scale Variable Generation,” *IEEE PES Summer General Meeting*, July 29, 2010

PacifiCorp’s 2010 Wind Integration Resource Study and Appendix, September 1, 2010

Chang, Madjarov, Baldick, Alvarez, Hanser, "Renewable Integration Model and Analysis," *Proceedings of the Transmission and Distribution Conference and Exposition, 2010 IEEE Power and Energy Society*, April 2010.

About *The Brattle Group*

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

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

Climate Change Policy and Planning
Cost of Capital
Demand Forecasting and Weather Normalization
Demand Response and Energy Efficiency
Electricity Market Modeling
Energy Asset Valuation
Energy Contract Litigation
Environmental Compliance
Fuel and Power Procurement
Incentive Regulation

Rate Design, Cost Allocation, and Rate Structure
Regulatory Strategy and Litigation Support
Renewables
Resource Planning
Retail Access and Restructuring
Risk Management
Market-Based Rates
Market Design and Competitive Analysis
Mergers and Acquisitions
Transmission

Kamen Madjarov (kamen.madjarov@brattle.com)
44 Brattle Street, Cambridge, MA 02138
617-864-7900 (www.brattle.com)