MAINTAINING GRID RELIABILITY WITH INCREASING PENETRATIONS OF WIND AND SOLAR POWER

MAY 13, 2016

FOUR CORNERS WIND RESOURCE CENTER WEBINAR

BRIAN PARSONS

WESTERN GRID GROUP

BROAD MESSAGE

- Reliability concerns are valid as the grid changes
- Business as Usual will not be adequate
- "The Western Interconnection can be made to work well with high wind and solar, and substantial coal displacements, using good established planning and engineering practices, and commercially available technologies" GE/NREL/DOE Western Wind and Solar Integration Studies, phase 3

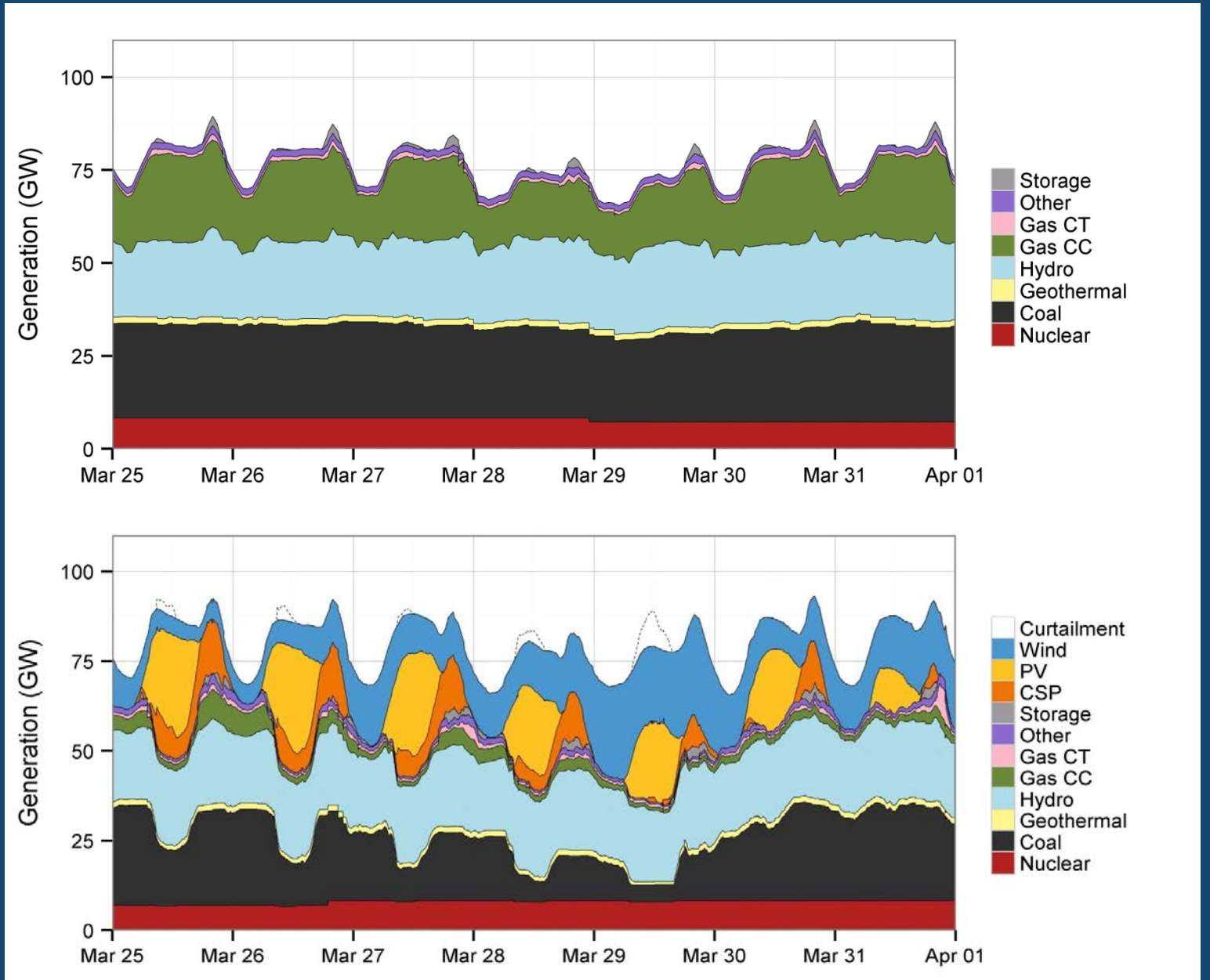
ACTIONS

- Support accurate and thorough operational and disturbance response assessments
- Ensure the full suite of system-wide technology and institutional practice solutions are considered
- Evaluate performance against specific reliability standards

SPRING IS MOST CHALLENGING FOR OPERATIONS

No Renewables

High Mix
16.5% wind and
16.5% solar
energy penetration



ADDRESSING INTEGRATION: SOURCES OF FLEXIBILITY

IMPROVED INSTITUTIONAL FLEXIBILITY

- Shorter intervals for unit commitment and dispatch, Fast markets
- Resource diversity and cooperation over larger geographic areas
- Advanced forecasting techniques
- Better use of existing transmission

A MORE FLEXIBLE GENERATING FLEET

- Modify existing plants to increase flexibility
- New flexible generating plants

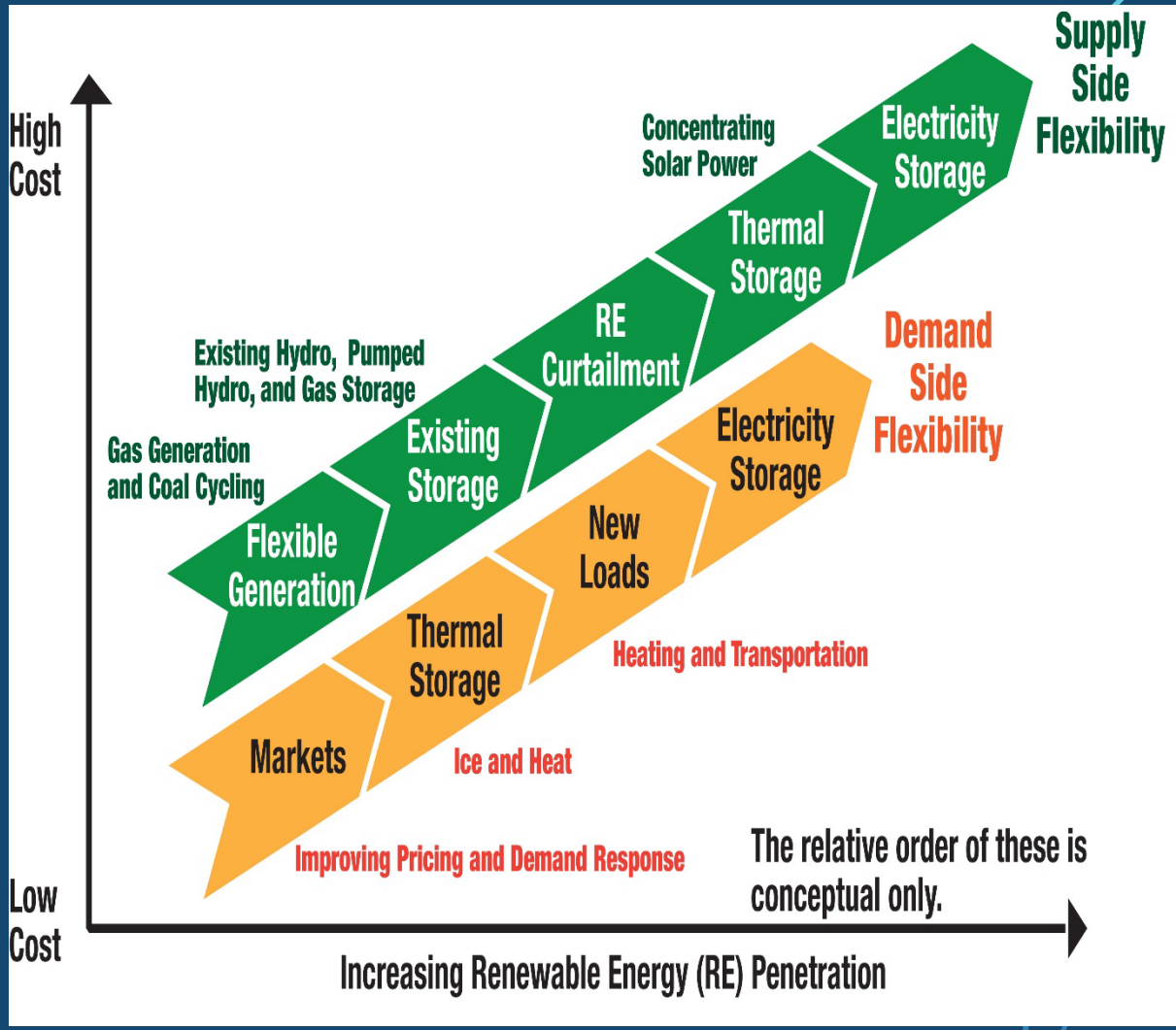
CAPABILITIES OF DEMAND RESPONSE

- Control loads with dispatch and automation
- Loads can act as reserve resources

ADEQUATE TRANSMISSION IS NECESSARY

ENERGY STORAGE OPTIONS

- Better use of existing pumped hydro, expand gas storage, and thermal/ice are early options
- New pumped hydro, batteries, CAES, PHEVs are potential future options



Studies of high percentage RE cleaner electricity futures have *consistent overall messages and frameworks*:

1. High penetrations of wind/solar are compatible with a reliable grid at reasonable cost.
   - Analysis of issues is not simple or quick. Selection of tools, data, and assumptions are critical to ensuring valid and insightful results. Technical review by experts in a transparent fashion is important.
   - Potential impacts are system specific, and need careful evaluation
   - "with good engineering and planning…"
2. Business as Usual is not sufficient to move rapidly toward cleaner grid futures
   - Historic procedures and practices were not designed with VER characteristics in mind
3. Three main areas of Reliability must be considered:
   - Resource adequacy and planning
   - Normal grid operations and load/generation balancing
   - Disturbance and contingency loss response

SMART ENGINEERS AND TECHNOLOGY

October 2, 2015

NEWS RELEASE

Xcel Energy Media Relations
1800 Larimer Suite 900
Denver, CO 80202
(303) 294-2300
www.xcelenergy.com

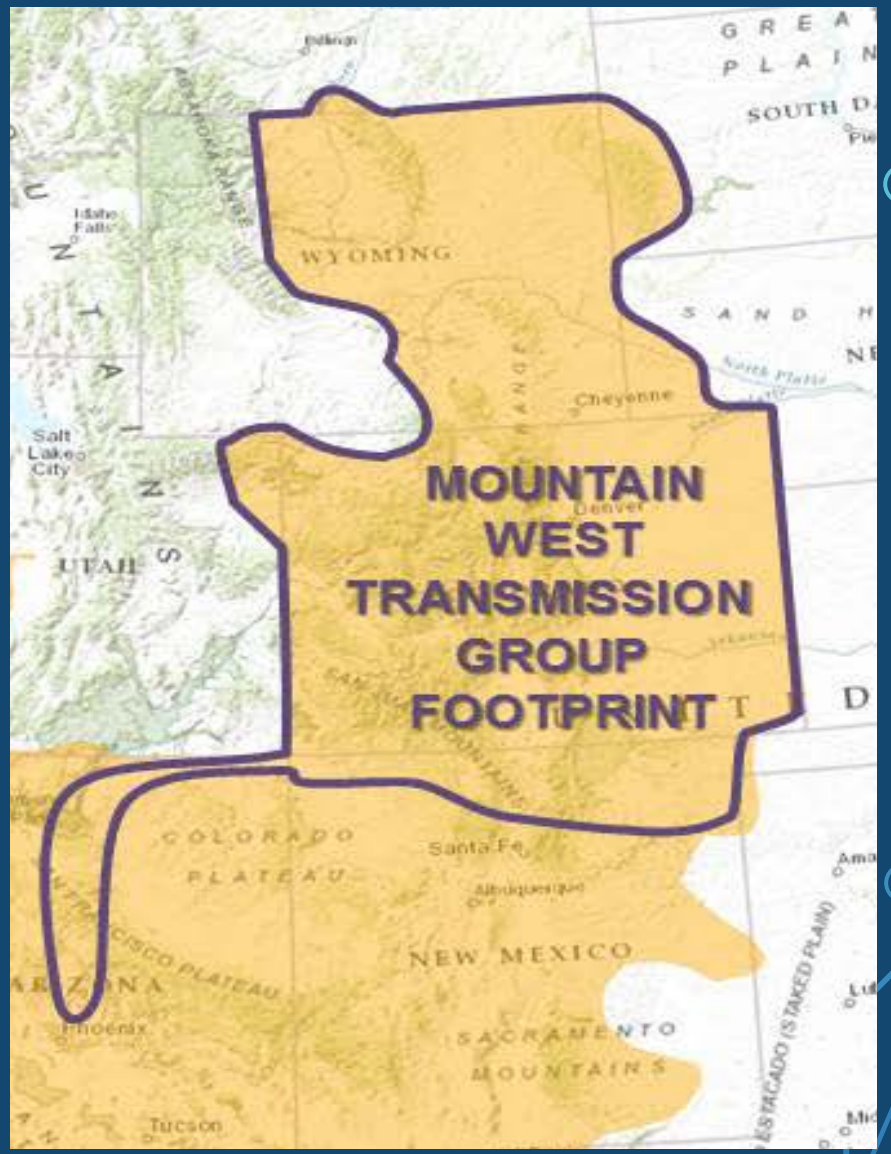
Xcel Energy Sets 24 Hour Wind Generation Record

DENVER – On Oct. 2, 2015, Xcel Energy, the nation's No. 1 provider of wind energy, set a new wind generation record by powering more than half of its entire system with wind power for more than 24 hours.

"For the first time, wind generation supplied more than half of our customers' energy for an entire day, reaching a daily average of 54 percent," said Drake Bartlett, senior trading analyst in Xcel Energy's Commercial Operations area. "Most notably, wind energy served more than 50 percent of our customers' load every hour that Friday, except during the last hour of the day when it served about 49 percent of the load."

A LOOK TO YOUR EAST…..

- Xcel Colorado BA has 25% annual power from renewable resources, and wind has provided greater than 2/3 of demand for an hour last November
- Re-negotiated wind PPA's to use wind power as a regulation resource when curtailed during low-load periods when conventionals are parked at min gen
- Mountain West Transmission group is working to form a single tariff area
- Joint Dispatch Agreement within Xcel BA with Platte River Power Authority and Black Hills to take effect this summer
- Refit Cabin Creek pumped hydro facility for regulation service and ramping to accommodate renewables
- Increased front-range gas storage to address deliverability issues when the wind forecast is over-optimistic
- Advanced wind forecasting development and operator use project with NCAR and NREL



What is "Reliability"?

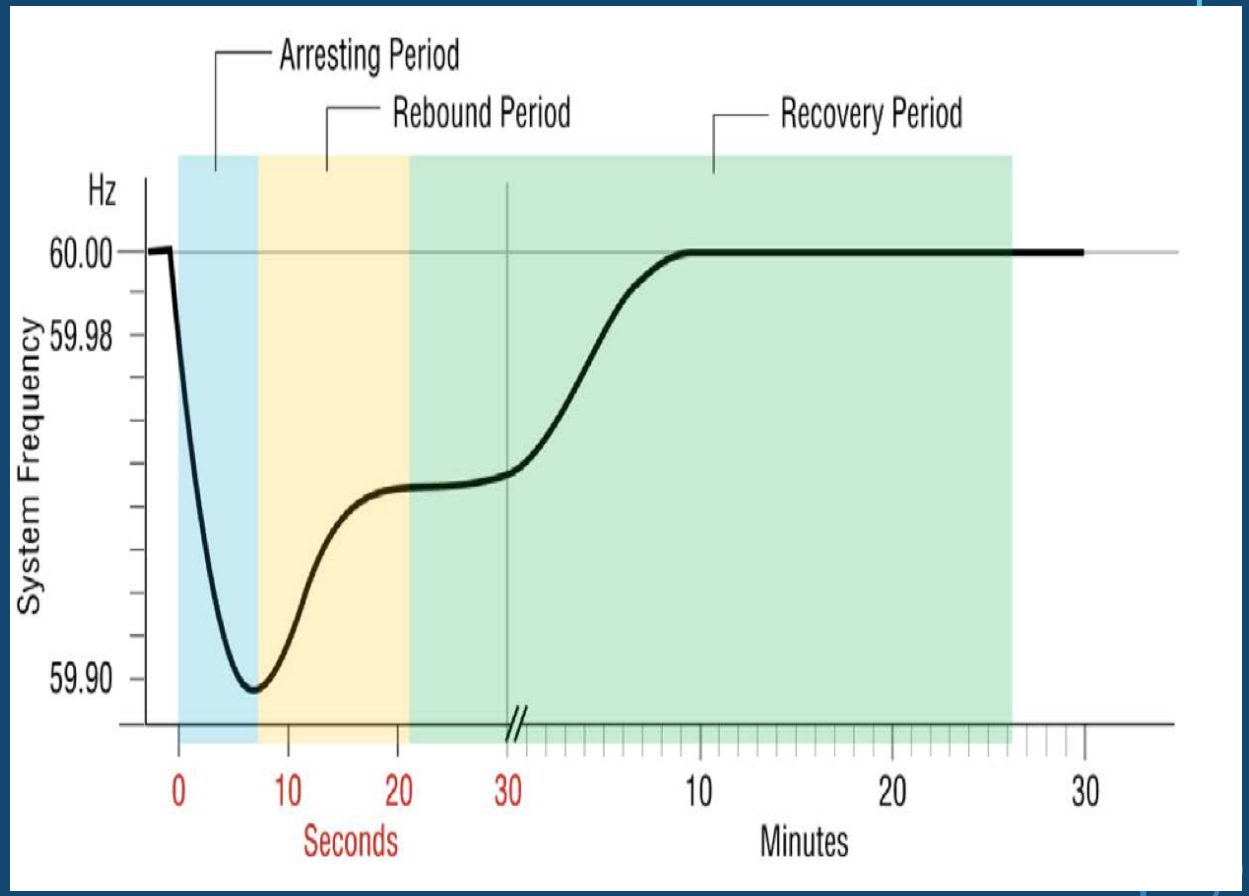
- "Keeping the lights on"
- NERC's definition of "reliability" consists of two fundamental concepts :
  - **Adequacy** is the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components.
  - **Operating reliability (former known as "security')** is the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system component
- Long-term adequacy measured by capacity margin or LOLE
- Operating reserves employed to insure short-term adequacy

Supply exceeds demand, tomorrow and in 2022

System is maintained in state to withstand loss of any element(s); no cascading outages

FREQUENCY RESPONSE

- Primary Frequency Control
  - Inertia – spinning mass of generators and motors
  - Governor response – "droop" is a generator specific set-back from maximum power
- Secondary Frequency Control
  - Spinning reserve, perhaps quick-start non-spin
  - Automatic Generation Control triggered by signal from control room
- NERC: Restore import/export to schedule in 15 minutes, all reserve levels restored in 60-90 minutes, Inter-connect wide Frequency Response Obligation is parsed to BA's but can be acquired from out of BA resources
- Under Frequency Load Shedding
  - Protects equipment from damage
  - Envelop of allowable frequency is dependent on duration of the event
  - WECC – subregional UFLS at 59.5 Hz



J. Eto, LBNL, http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

FREQUENCY RESPONSE FROM INVERTER-BASED GENERATION

Electronics, not Mechanics =>Advanced controls on inverter-based generators can provide the *capabilities*

- ✓ Increased complexity, but may be "better" than synchronous capabilities
- ✓ Commercial options available, not generally requested or required (Wind in ERCOT and Quebec exceptions)
- ✓ Wind inertial option has no energy/opportunity cost
- ✓ Governor droop and AGC ramp-up are essentially pre- curtailment, so use sparingly

Approximately 30% of on-line generation is adequate => Market Design and Economic Optimization Issues?

DISTURBANCE RESPONSE

- Frequency Response
  - ✓ Interconnect-wide issue
  - ✓ Contingency reserves large enough to make up for "n-1"
    WECC event is loss of 2 Palo Verde units (2750 MW)
  - ✓ Worst case for RE – Light spring load, with lots of wind/solar
- Transient Stability
  - ✓ Sub-regional, local issues (*LOCATION MATTERS!*)
  - ✓ WECC examples: Pacific DC Intertie 3100 MW outage, Broadview 500kV (Colstrip) fault and trip, Laramie River 345kV fault and trip
  - ✓ Worst case for RE – High summer load, with heavy path loading

DISTURBANCE RESPONSE CONVENTIONAL SOLUTIONS

Traditional transmission system reinforcements to address stability, voltage, and thermal problems include:

- Transformers
- Shunt capacitors
- Series compensation
- Static VAR compensators (SVC)
- Static Compensators (STATCOM, including D-Var)
- Local transmission lines

DISTURBANCE RESPONSE WITH WIND AND SOLAR WWSIS 3 FINDINGS

- Frequency response degrades, but remaining conventional generators keep nadir > 59.5 Hz
- WECC-wide Frequency Response Obligation (FRO) meets NERC standards (~860 MW/0.1 Hz), but some BA's may need resource sharing (allowable)
- Location is most important for transient stability, not generator type
- High power transfer cases require Remedial Action Schemes, with and without wind/solar
- WECC 80% reduction in Coal commitment acceptable, 90% reduction necessitated addition of 3 synchronous condensers
- Tripping of rooftop PV without fault ride-through can result in system collapse (IEEE 1547 fix underway, CA Rule 21 Smart Inverter Stds.)

DISTURBANCE RESPONSE ADDITIONAL SOLUTIONS

- Frequency responsive controls on synchronous Concentrating Solar Power (and Hydro) plants
- Synchronous condensers
  - ✓ New ($200/MVA)
  - ✓ Conversions of retiring fossil plants ($40/MVA)
  - ✓ Clutch option on new gas generators
- Storage, and Demand Response

KEY RESULTS FROM OPERATIONAL INTEGRATION STUDIES

A library of studies: 25%-33%-40%-50% annual electric from wind and solar

Economic, reliable operations are technically feasible

High value from:

- Regional grid cooperation
- Demand Response as source of reserves
- Incorporating wind and solar forecasts in grid operations
- Dynamic variability reserve to address solar
- Shorter unit-commit and dispatch windows

Reserves practices are not standardized, and overly conservative or outdated procedures are detrimental

KEY RESULTS FROM OPERATIONAL INTEGRATION STUDIES

Transmission

- Limited wires expansion needed for 10-20%, if existing lines are better utilized
- Region-to-Region transmission *expansion is necessary* for higher 20-35% penetrations

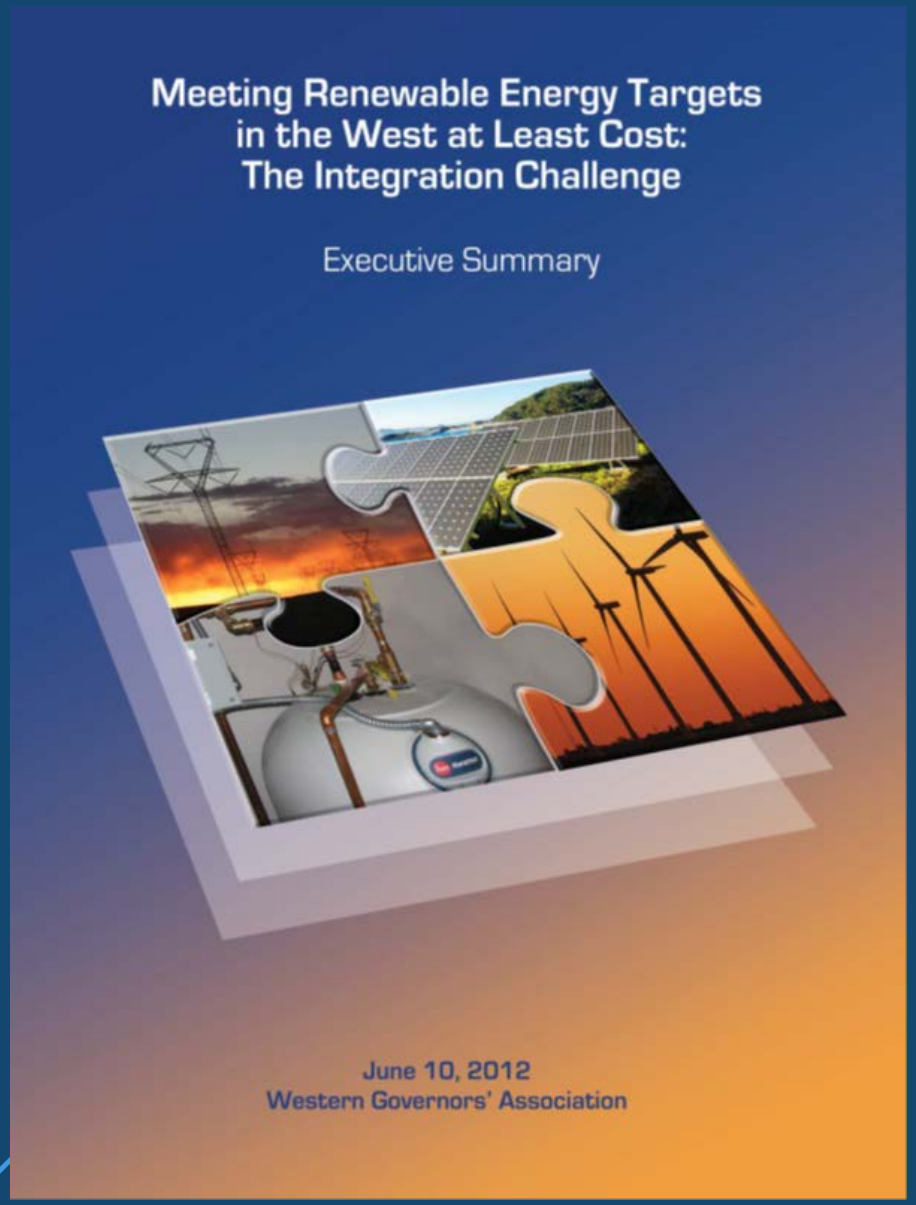
Fossil cycling (ramping and start up)

- may add around $1/MWh of fossil (0.5%-2% of fuel savings)
- minor emissions impacts

Storage valuation is tricky

- better use of existing facilities, CSP, and thermal/ice are near-term, high value
- little near- to mid-term justification for advanced, new technology due to high cost

WGA REPORT: PATHWAY TO A HIGH RENEWABLE GRID FUTURE



- Builds on NREL Western Wind and Solar Integration Study conclusion: ***technically feasible, but requires a departure from BAU Operations***

- Identifies barriers and institutional challenges, and possible regulatory actions

WGA: GROUPINGS OF 9 INTEGRATION ACTIONS

- Expand subhourly dispatch and intra-hour scheduling
- Facilitate dynamic transfers between balancing authorities
- Implement an energy imbalance market (EIM)
- Improve weather, wind and solar forecasting
- Take advantage of geographic diversity of resources
- Improve reserves management
- Retool demand response to complement variable supply
- Access greater flexibility in the dispatch of existing generating plants
- Focus on flexibility for new generating plants

RECENT PUBLICATIONS

NREL/DOE Western Wind and Solar Integration Study, 3+

Deep dive on “weak grid” issues for NE WECC, extreme situational analysis of disturbance response

California Low Carbon Grid Study

50% carbon reduction operational study, shows how key regional cooperation is to CA goals, and changes needed to minimize RE curtailment

IEEE Power and Energy Magazine, Nov/Dec

Focus on Wind and Solar Plan Integration on the Transmission System

KEY ORGANIZATIONS

The Utility Variable-generation Integration Group

- Mission is to *accelerate the development and application of good engineering and operational practices supporting the appropriate integration and reliable operation of variable generation on the electric power system*. Best utility peer-to-peer forum. Get the right people from your utility and grid operator to participate!

IEA Task 25, *Design and Operation of Power Systems with Large Amounts of Wind Power*

- International Technical Collaboration to provide information to facilitate the highest economically feasible wind energy penetration within electricity power systems worldwide

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  GE/NREL/DOE Western Wind and Solar Integration Studies, phase 3

Let's Get Busy!

ACTIONS

- Support accurate and thorough operational and disturbance response assessments
- Ensure the full suite of system-wide technology and institutional practice solutions are considered
- Evaluate performance against specific reliability standards

FURTHER QUESTIONS??

Brian Parsons

Western Grid Group

brian@westerngrid.net

(720) 360-6412

ADDITIONAL RESOURCES

Large Scale Solar Association, "Integrating Higher Levels of Variable Energy Resources in California", June 15, 2015

- Report by GE examines CA duck curve issues including those arising from import and self scheduling practices, including economic and reliability implications. Suggests mitigation options, including extracting more flexibility from the existing system, and alternative sources of ancillary services

Advanced Energy Economy Institute, "Integrating Renewable Energy into the Electricity Grid, Case studies showing how system operators are maintaining reliability", June 2015

- Report by The Brattle Group summarizes actions taken in ERCOT and by PSCo to accommodate larger penetrations of VER, including market design, transmission construction, advanced forecasting, advanced operations with existing resources, and improved RE technology and use of advanced grid services from inverter based generation and demand response.
- AEEI also has several reports critiquing NERC's initial CPP reliability review, and other reports on RE technology, and other CPP issues

NREL, "Review and Status of Wind Integration and Transmission in the United States: Key Issues and Lessons Learned", March 2015

- In support of the updated DOE Wind vision, this report summarizes the lessons learned from some of the most relevant and comprehensive wind integration studies conducted during the past several years, lessons from operating practices, especially as related to reserves, efficient operating practices, and wind power forecasting. It also describes the main industry organizations involved in wind integration and transmission, and discusses transmission expansion related to wind energy.

The Analysis Group, "Electric System Reliability and EPA's Clean Power Plan" – series , "Tools and Practices", Feb 2015, "The Case of PJM", March 2015, "The Case of MISO", June 2015

- These reports push back against pessimistic reliability claims by looking at how existing standard industry reliability practices can accommodate CPP related changes, similar to past emissions regulation adaptations. Factors demonstrating that grid operators are well positioned to adapt to changes are discussed. PJM analysis of regional solutions, and an increased role for EE and RE are noteworthy.

Taking Advantage of Western Interstate Energy Board work on Renewable Integration

- Variable Energy Resources (VER) Integration Dashboard is aimed at regulatory/energy office technical education

- 2 main products:
  - ✓ Variable Energy Resources checklist – taxonomy of questions to raise in response to common issues *http://wiebver.org/ver-checklist/*
  - ✓ Western Interconnection Regional Advisory Body (WIRAB) 5 webinars on VER Integration topics, Nov-Dec 2014 *http://westernenergyboard.org/wirab/webinars/*

WIRAB WEBINAR SERIES

#1 Utility Operations - VER Reliability and Integration

Basic utility operations: balancing, unit commitment and dispatch, reserves, and forecasting

#2 Ramping Issues and Solutions

Duck curve, flexibility, markets

#3 Frequency Response

Interconnect wide disturbance response: inertia, governor response, under frequency load shedding, advanced inverter control

#4 Transient Stability

Rotor angle and power swing stability, reactive power, synchronous condensers and other mitigation

#5 Distributed Generation

PV concerns, Germany, IEEE 1547, CA Smart Inverter Working Group

The North American Electric Reliability Corporation (NERC) is a not-for-profit, international regulatory authority whose mission is to ***assure the reliability*** of the bulk power system in North America.

- develops and enforces Reliability Standards;
- annually assesses seasonal and long-term reliability;
- monitors the bulk power system through system awareness;
- educates, trains, and certifies industry personnel;
- subject to oversight by the Federal Energy Regulatory Commission and governmental authorities in Canada.

1. Make the best use of what you have got
    - Use the physical capabilities that already exist in the system
        - Conventional Generators: flexibility from gas, hydro
        - Transmission: not contract/ownership limited
    - Institutional constraints may limit access to capabilities
    - Enhance existing capabilities when cost effective
        - Minimum downturn, ramp rates, on/off cycling times
        - Opportunities with gas, coal, pumped and conventional hydro
        - Coal to Synchronous condenser conversions
2. Broader geographic footprints and Shorter time frames are very valuable (Milligan Sumo Wrestler Grid analogy – Big and Fast)
    - Markets, bigger BA's, and other grid cooperation measures for geographic diversity (load, Renewable resources), reserve pooling, forecast error reduction
    - Shorter commitment and dispatch intervals reduce forecast errors, minimize reserve needs
    - Communication and coordination needs may require reform and investments
3. Recognize non-traditional capabilities and sources of services
    - Demand management, VER/inverter based Renewables, Storage, Distributed resources
    - Enhanced capabilities of new gas plants: modular, fast ramp, fast cycling, staged simple cycle/combined cycle, clutch for synchronous condenser operations
    - Inverter based VER can provide
        - primary response (inertia and fast governor response)
        - Voltage and VAR regulation and support
        - Frequency and voltage excursion ride-thru
        - Secondary response and regulation services