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Office of Energy Efficiency & Renewable Energy

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Innovation for Our Energy Future

Wind Integration Impacts: Results of Detailed Simulation Studies and Operational Practice in the US

York, Nebraska
May 13, 2008

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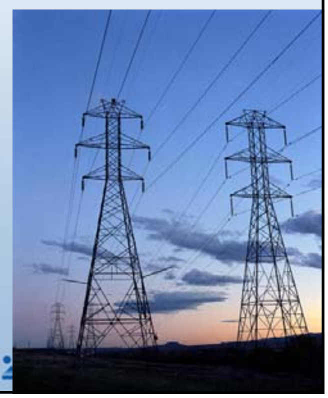

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Presentation Outline

- Issues and time frames of importance
- What are wind's impacts, how are they measured?
- How are wind impacts calculated?
- Emerging best practices
- Stakeholder best practices
- Recent high-penetration studies
- Insights and remaining issues
- New Integration Studies are just beginning

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Problem Introduction

- Reliable power system operation requires balance between load and generation *within acceptable statistical limits*
- Output of wind plants cannot be controlled and scheduled with high degree of accuracy
- Wind plants becoming large enough to have measurable impact on system operating cost
- System operators concerned that ***additional*** variability introduced by wind plants will increase system operating cost

Wind Energy has Costs and Benefits

- Benefits include
  - Reduced fuel consumption from other generating resources
    - Fuel cost reduction
    - Reduces demand for conventional fuels, reducing price (gas, coal) at high wind penetrations
    - Emissions reduction
    - Carbon reduction
  - Costs
    - Capital cost: turbines, interconnection, etc.
    - Increase in power system reserves to cover additional fluctuation in the required conventional generation – ***usual focus of integration studies***

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Wind Myths

- Energy generation from a wind power plant can stop and start suddenly
- For each wind power plant, a conventional generator must be kept standing by in case the wind does not blow
- Wind energy is always more costly than other forms of electricity generation
- These myths have been refuted by
  - Extensive analysis
  - Operating practice of wind plants around the world

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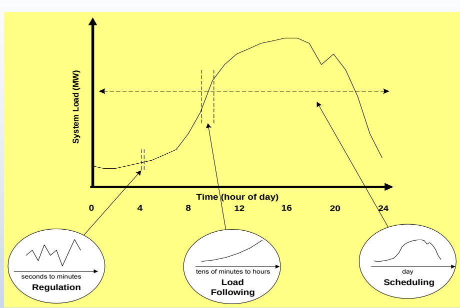
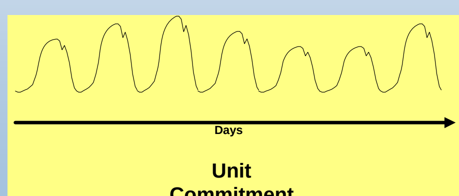
Time Frames of Wind Impact





- Typical U.S. terminology
  - Regulation -- seconds to a few minutes -- similar to variations in customer demand
  - Load-following -- tens of minutes to a few hours -- demand follows predictable patterns, wind less so
  - Scheduling and commitment of generating units -- hours to several days -- wind forecasting capability?
  - Capacity value (planning): based on reliability metric (ELCC=effective load carrying capability)

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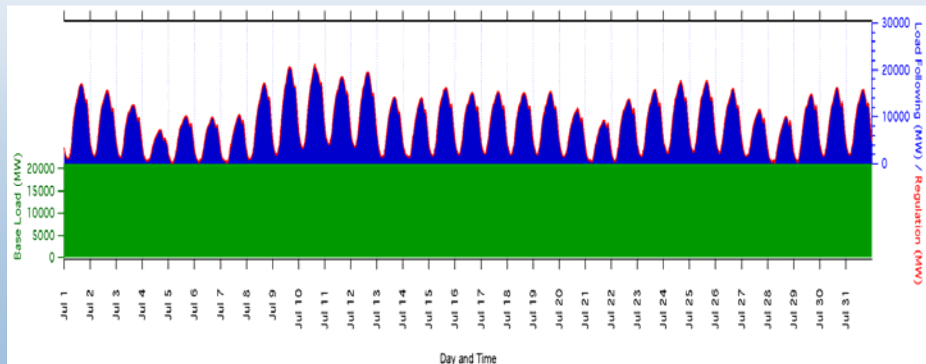
Decomposition of Control Area Loads

- Control area load & generation can be decomposed into three parts:
  - Base Load
  - Load Following
  - Regulation



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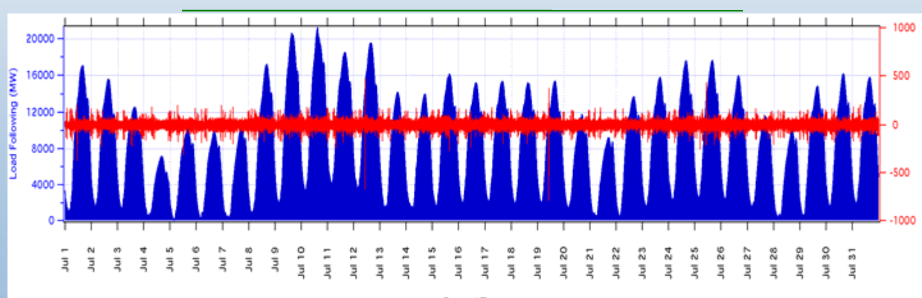
Regulation & Load Following

	REGULATION	LOAD FOLLOWING
Patterns	*Random, uncorrelated*	*Largely correlated*
Generator control	*Requires AGC*	*Manual*
Maximum swing (MW)	*Small*	*10 – 20 times more*
Ramp rate (MW/minute)	*5 – 10 times more*	*Slow*
Sign changes	*20 – 50 times more*	*Few*



Impact of Variable Power Sources

- Power system is designed to handle tremendous variability in loads
- Wind adds to that variability
- System operator must balance loads=resources (within statistical tolerance)
- Key implication: ***It is not necessary or desirable to match wind's movements on a 1-1 basis***

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Typical Objective of Integration Studies

- Determine the physical impact of wind on system operation across important time frames
  - Regulation (a capacity service; AGC)
  - Load following (ramp and energy components)
  - Unit commitment (scheduling)
  - Planning/capacity credit (same as capacity value)
- Use appropriate prices/costs to assess ancillary service cost impact of wind based on the measured physical impacts
- Not all studies focus on all time frames

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Comparison of Cost-Based U.S. Operational Impact Studies

Date	Study	Wind Capacity Penetration (%)	Regulation Cost ($/MWh)	Load Following Cost ($/MWh)	Unit Commitment Cost ($/MWh)	Gas Supply Cost ($/MWh)	Tot Oper. Cost Impact ($/MWh)
May '03	Xcel-UWIG	3.5	0	0.41	1.44	na	1.85
Sep '04	Xcel-MNDOC	15	0.23	na	4.37	na	4.60
June '06	CA RPS	4	0.45*	trace	na	na	0.45
Feb '07	GE/Pier/CAIAP	20	0-0.69	trace	na***	na	0-0.69***
June '03	We Energies	4	1.12	0.09	0.69	na	1.90
June '03	We Energies	29	1.02	0.15	1.75	na	2.92
2005	PacifiCorp	20	0	1.6	3.0	na	4.60
April '06	Xcel-PSCo	10	0.20	na	2.26	1.26	3.72
April '06	Xcel-PSCo	15	0.20	na	3.32	1.45	4.97
Dec '06	MN 20%	31**					4.41**
Jul '07	APS	14.8	0.37	2.65	1.06	na	4.08

* 3-year average; total is non-market cost

** highest integration cost of 3 years; 30.7% capacity penetration corresponding to 25% energy penetration; 24.7% capacity penetration at 20% energy penetration

*** found $4.37/MWh reduction in UC cost when wind forecasting is used in UC decision

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Wind Capacity Value in the US

Region/Utility	Method	Note
CA/CEC	ELCC	Rank bid evaluations for RPS (mid 20s); 3-year near-match capacity factor for peak period
PJM	Peak Period	Jun-Aug HE 3 p.m. -7 p.m., capacity factor using 3-year rolling average (20%, fold in actual data when available)
Minnesota 20% Study	ELCC	Found significant variation in ELCC: 4%, 15%, 25% and variation based on year
ERCOT	10%	May change to capacity factor, 4 p.m. -6 p.m., Jul (2.8%)
MN/DOC/Xcel	ELCC	Sequential Monte Carlo (26-34%)
GE/NYSERDA	ELCC	Offshore/onshore (40%/10%)
CO PUC/Xcel	ELCC	12.5% of rated capacity based on 10-year ELCC study.
RMATS	Rule of thumb	20% all sites in RMATS
PacifiCorp	ELCC	Sequential Monte Carlo (20%). Z-method 2006
MAPP	Peak Period	Monthly 4-hour window, median
PGE		33% (method not stated)
Idaho Power	Peak Period	4 p.m. -8 p.m. capacity factor during July (5%)
PSE and Avista	Peak Period	PSE will revisit the issue (lesser of 20% or 2/3 Jan C.F.)
SPP	Peak Period	Top 10% loads/month; 85th percentile

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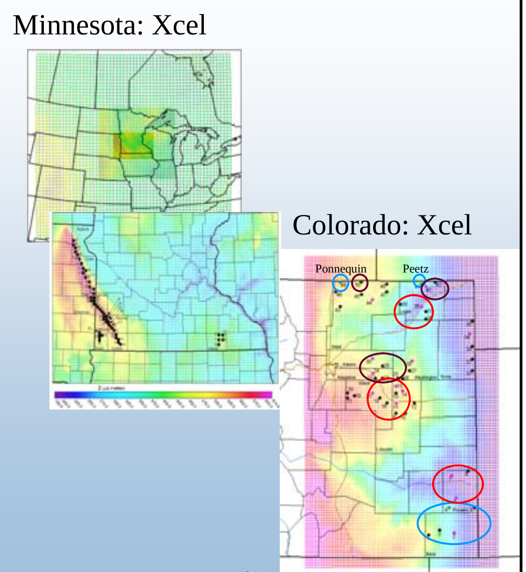
Where Does Wind Data Come From?

- Meso-scale meteorological modeling that can "re-create" the weather at any space and time
- Maximum wind power at a single point ~ 30 MW to capture geographic smoothing
- Model is run for the period of study and must match load time period
- Wind plant output simulation and fit to actual production of existing plants



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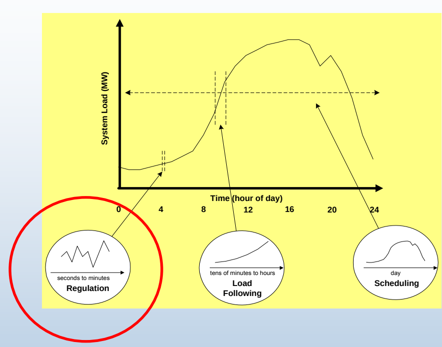
Actual Wind Data Challenges: California RPS Integration Study

- CAISO Power Information (PI) system
- Error removal
- Data storage error results from PI system data compression
- The standard deviation of data storage error is 160 MW or ± 0.6% of the average annual load.
- Old wind turbine technology does not represent the future

How Are Wind's Impacts Calculated?

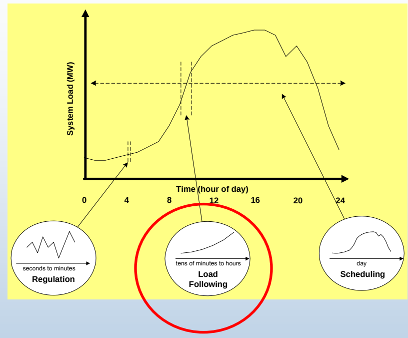
How is Regulation Impact Calculated?

- Based on actual high-frequency (fast) system load data and wind data
- If wind data not available, use NREL high-resolution wind production data characteristics
- Impact of the wind variability is then compared to the load variability
- Regulation cost impact of wind is based on physical impact and appropriate cost of regulation (market or internal)



–Realistic calculation of wind ***plant*** output (linear scaling from single anemometer is incorrect)

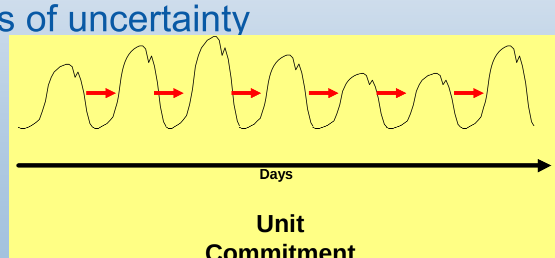
How is Load Following Impact Calculated?



- Based on actual system load data
- …and wind data from *same* time period
  - Meteorological simulation to capture ***realistic*** wind profile, typically 10-minute periods and multiple simulated/actual measurement towers
  - Realistic calculation of wind ***plant*** output (linear scaling from single anemometer is incorrect)
- Wind variability added to *existing system variability* → Implies no one-one backup for wind

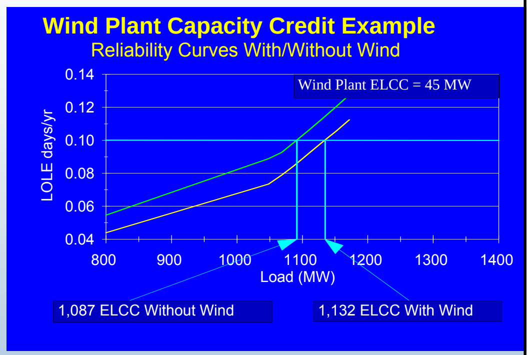
How is Unit Commitment Impact Calculated?

- Requires a realistic system simulation for at least one year (more is better)
- Compare system costs with and without wind
- Use load and wind forecasts in the simulation
- Separate the impacts of variability from the impacts of uncertainty



How is Capacity Value Calculated?

- Uses similar data set as unit commitment modeling
  - Generation capacities, forced outage data
  - Hourly time-synchronized wind profile(s)
  - Several years' of data preferred
- Reliability model used to assess ELCC
- Wind capacity value is the increased load that wind can support at the same annual reliability as the no-wind case



Emerging Study Best-Practices

- Start by quantifying physical impacts
  - Detailed weather simulation or actual wind power data
  - Ensure wind and load data from same time period
- Divide the physical and cost impacts by time scale and perform detailed system simulation and statistical analysis
  - Regulation
  - Load following and imbalance
  - Scheduling and unit commitment
  - Capacity value
- Utilize wind forecasting best practice and combine wind forecast errors with load forecast errors
- Examine actual costs independent of tariff design structure

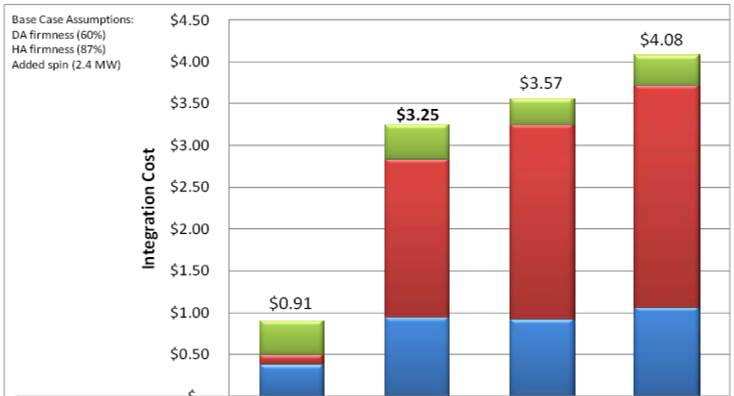
Stakeholder Review
Best Practices

- Technical review committee (TRC)
  - Bring in at beginning of study
  - Discuss assumptions, processes, methods, data
- Periodic TRC meetings with advance material for review
- Examples in Minnesota, Colorado, California, New Mexico, and interest by other states

Recent and High-Penetration Cases

- Arizona Public Service: up to 10% wind energy penetration
- Minnesota PUC: 15-25% wind energy penetration
- California Intermittency Analysis Project (GE)
- Northwest Wind Integration Action Plan and Forum

Arizona Public Service Study
Acker et. al Sep 2007



Wind Energy Penetration	1%	4%	7%	10%
Within-hour Regulating	$0.40	$0.41	$0.31	$0.37
Hour-ahead Uncertainty	$0.11	$1.88	$2.32	$2.65
Day-ahead Uncertainty	$0.39	$0.95	$0.93	$1.06

Figure ES 4 – Sensitivity of integration cost to percent penetration of wind energy, under base case assumptions.

APS Wind Integration Cost Impact Study

Table ES 3 – Matrix of wind integration scenarios considered with the associated integration costs listed in $/MWh.

Integration Cost Summary ($/MWh)

Wind Scenarios		Geographic Diversity		
Energy Penetration	Penetration by Capacity	High	Med	Low
1%	1.5%		0.91	
4%	5.9%	2.60	**3.25**	3.30
7%	10.4%		3.57	
10%	14.8%		4.08	

Gray Shading = Cases run **Bold** = Base Case

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Minnesota 20% Wind Study

- Principle consultant: EnerNex Corp.; MISO modeling
- Objective: Calculate ancillary service cost and capacity value of 20% wind penetration (by energy)
- Study analyzed 15, 20, 25% case
- Wind Capacity approximately 6,000 MW on system peak of 20,984 MW (25% case)
- Connection with the MISO market

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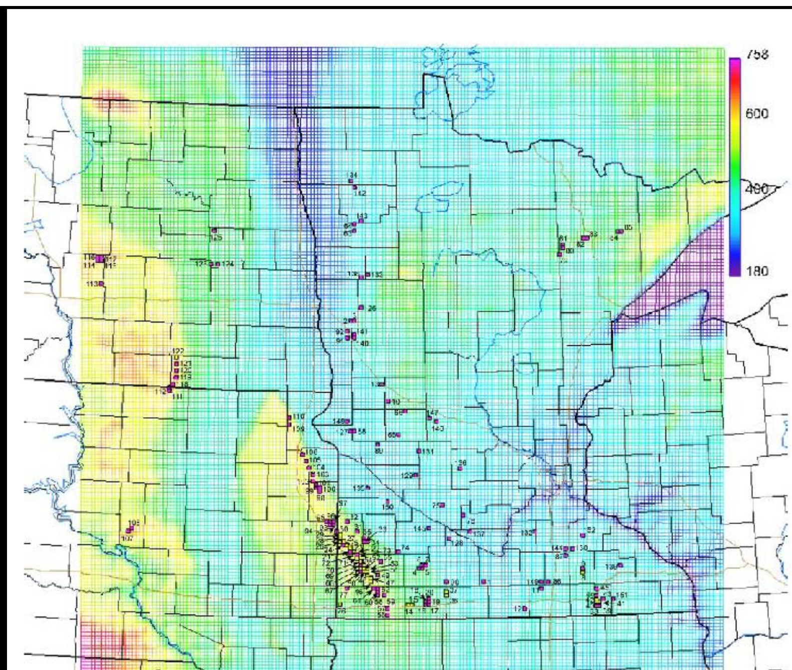
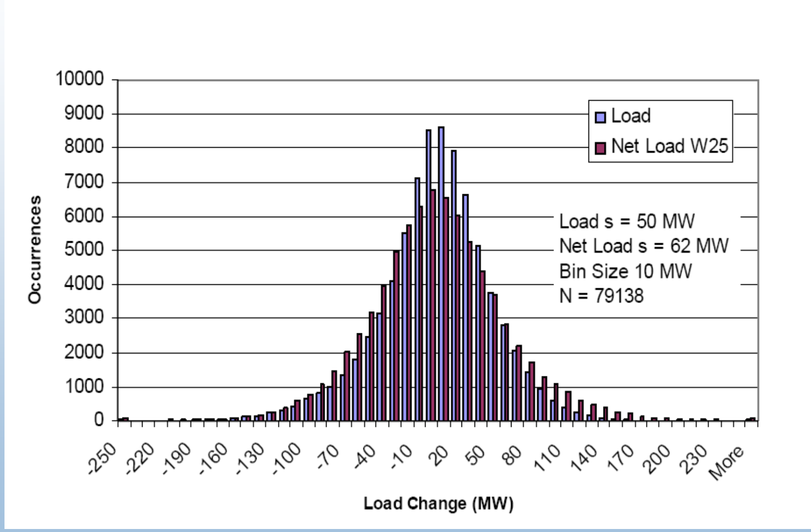


Figure 1: Location of "proxy towers" (model data extraction points) on inner grid.

5-Minute Load/Net Load Changes: 25% Wind Case



Additional operating reserves are required, but are depend on wind output and forecasts

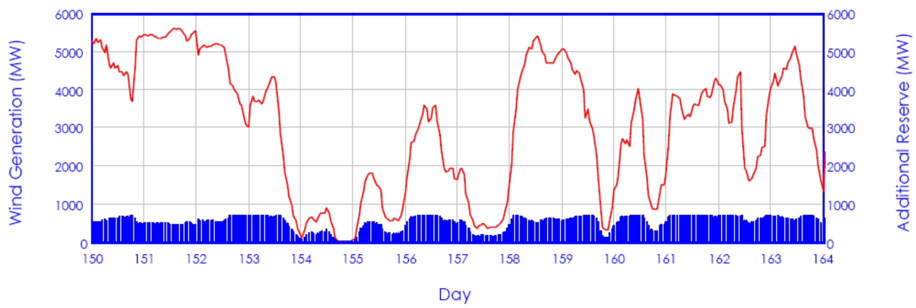
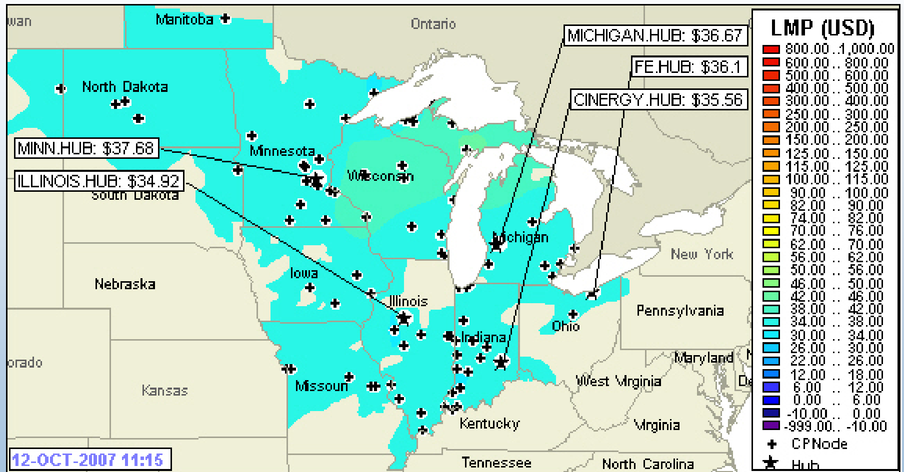
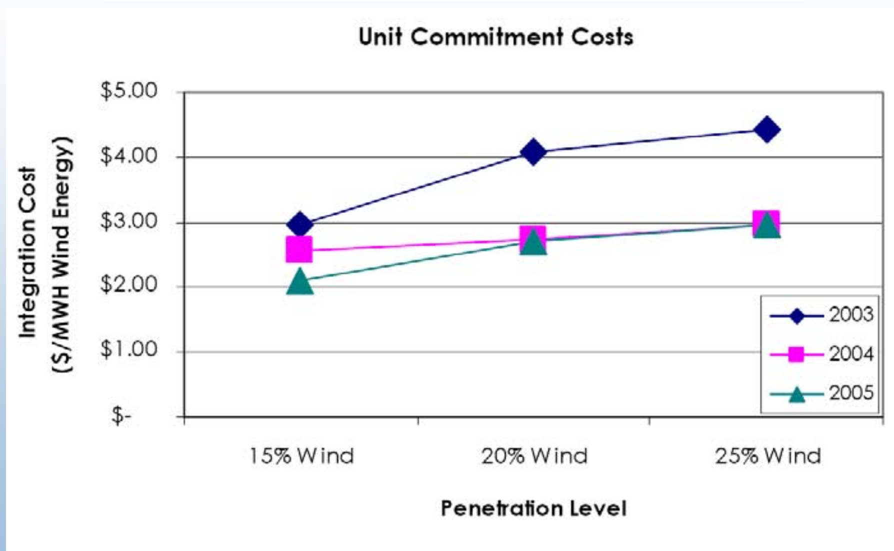


Figure 30: Illustration of time varying "operating reserve margin" developed from statistical analysis of hourly wind generation variations.

Minnesota Market Interaction with MISO

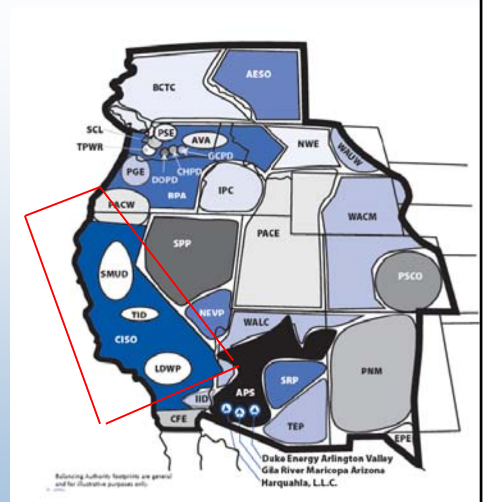


Large Wind Penetrations in Large Markets Can be Managed



California Intermittency Analysis Project

- Consultant: GE Energy
- Up to 24% wind (rated capacity to peak)
- Savings
  - WECC nearly $2B
  - CA $760M
- Wind forecast benefit $4.37/MWh
- Regulation cost up to $0.67/MWh
- Unit commitment w/forecast results in sufficient load following capability (and no load following cost)



•http://www.uwig.org/CEC-500-2007-081-APB.pdf

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Four Scenarios - Overview

	2006	2010T	2010X	2020
Peak California Load, MW	58,670	64,336	64,336	80,742
Peak CA ISO Load, MW	48,466	53,147	53,147	66,700
Total Geothermal, MW	2,400	4,100	3,700	5,100
Total Biomass, MW	760	1,200	1,000	2,000
Total Solar, MW	330	1,900	2,600	6,000
Total Wind, MW	2,100	7,500	12,500	12,700
Wind at Tehachapi, MW	760	4,200	5,800	5,800
CA Wind+Solar Capacity Penetration	4%	15%	23%	23%
CA ISO Wind+Solar Capacity Penetration	5%	17%	26%	25%
CA Wind+Solar Energy Penetration	2%	8%	13%	12%
CA ISO Wind+Solar Energy Penetration	2%	9%	15%	14%

Source: CEC/GE

Conclusions

- 2010X Scenario includes 12,500 MW wind and 2,600 MW solar with projected load and generation mix for year 2010
- These renewables can be integrated into the California grid provided appropriate infrastructure, technologies, and policies are in place
  - Investment in transmission, generation and operations infrastructure to support the renewable additions,
  - Appropriate changes in operations practice, policy and market structure,
  - Cooperation among all participants, e.g., CAISO, investor owned utilities, renewable generation developers and owners, non-FERC jurisdictional power suppliers, and regulatory bodies.

Source: CEC/GE

GE imagination at work

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CAISO Renewable Integration Study

- Operational study
  - Examine ramps in detail
  - Determine ramping requirements due to load following and regulation
  - Examine over-generation issues
- Conclusions - 20% RPS is manageable
  - New market design mitigates current challenges
    - Important to integrate improved wind forecasting with dispatch procedures
  - Operational implications significant but manageable

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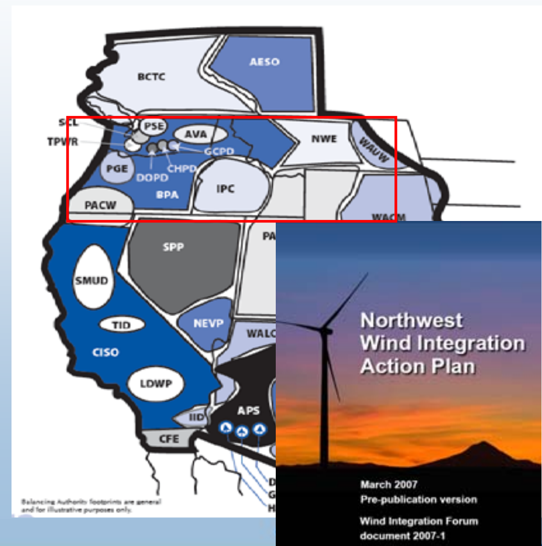
Pacific Northwest Initiated Wind Integration Action Plan

- Intent: Develop a coordinated effort to integrate expected wind
- Large stakeholder effort to examine wind; action items developed
- Wind mesomodel dataset completed
- ACE diversity
- Dynamic load following service
- BPA wind integration rate



Studies in the Northwest

- Studies were not subject to rigorous peer review and may still contain errors
- Avista Utilities: Up to 30% wind penetration (peak)
- Idaho Power: Up to about 30% wind penetration (peak)
  - Settlement proposed, but not finalized ($6.50/MWh)
- BPA: analytical work in progress; integration cost is consistent with others
- Northwest Wind Integration Action Plan: http://www.nwcouncil.org/energy/Wind/Default.asp

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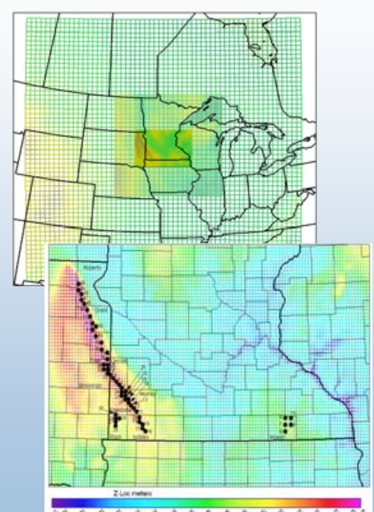
Other Recent Studies

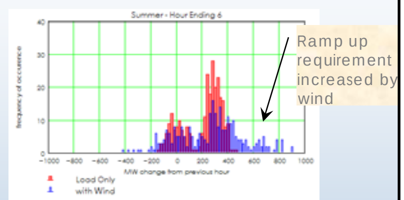
Minnesota Dept. of Commerce/ Enernex Study Framework

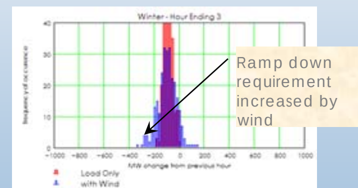
- 2010 scenario of 1500 MW of wind in 10 GW peak load system (< 700 MW wind currently)
- WindLogics:10-minute power profiles from atmospheric modeling to capture geographic diversity
- Wind forecasting incorporated
- Extensive historic utility load and generator data available
- Monopoly market structure, no operating practice modification or change in conventional generation expansion plan



Minnesota Dept. of Commerce/ Enernex Study Results

- Incremental regulation due to wind 3σ = 8 MW
- Incremental intra-hour load following burden increased 1-2 MW/min. (negligible cost)
- Hourly to daily wind variation and forecasting error impacts are largest costs
- Monthly total integration cost: \$2-\$11/MWh, with an average of \$4.50/MWh
- Capacity Credit (ELCC) of 26%





Completed September 2004 *www.commerce.state.mn.us*
(Industry Info and Services / Energy Utilities / Energy Policy / Wind Integration Study)

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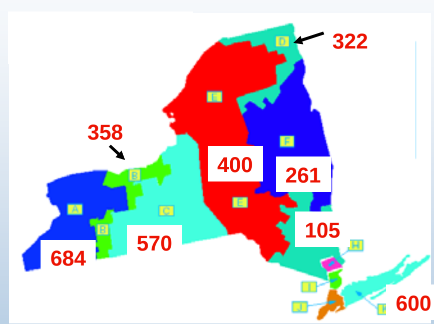
New York ISO and NYSERDA/ GE Energy Study

- 2008 scenario of 3300 MW of wind in 33-GW peak load system (< 200 MW wind currently)
- AWS Truewind: wind power profiles from atmospheric modeling to capture statewide diversity



- Competitive market structure:
  - for ancillary services
  - allows determination of generator and consumer payment impacts
- Transmission examined: no delivery issues
- Post-fault grid stability improved with modern turbines

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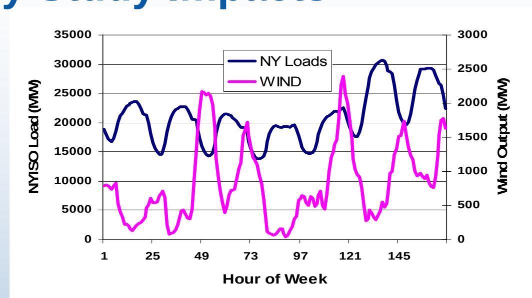
New York ISO and NYSERDA/ GE Energy Study Impacts

- Incremental regulation of 36 MW due to wind
- No additional spinning reserve needed
- Incremental intra-hour load following burden increased 1-2 MW/ 5 min.
- Hourly ramp increased from 858 MW to 910 MW

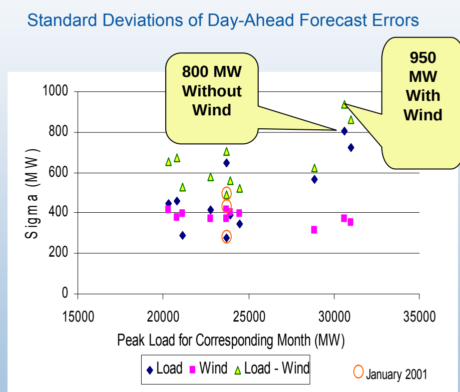


- All increased needs can be met by existing NY resources and market processes
- Capacity credit (UCAP) of 10% average onshore and 36% offshore
- Significant system cost savings of $335- $455 million on assumed 2008 natural gas prices of $6.50-$6.80 /MMBTU.

New York ISO and NYSERDA/ GE Energy Study

Forecasting and Price Impacts

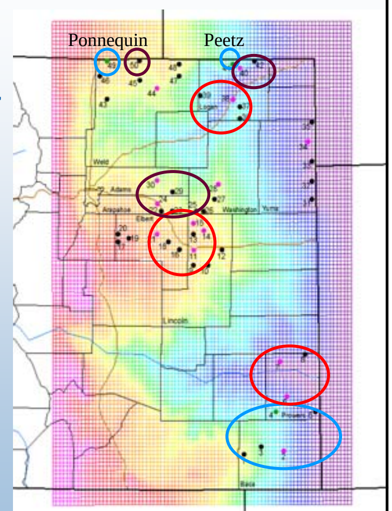
- Day-ahead unit-commitment forecast error σ increased from 700-800 MW to 859-950 MW
- Total system variable cost savings increases from $335 million to $430 million when state of the art forecasting is considered in unit commitment ($10.70/MWh of wind)
- Perfect forecasting increases savings an additional $25 million



http://www.nyserda.org/publications/wind_integration_report.pdf

Xcel Colorado/Enernex Study

- 10%, 15%, and 20%* penetration (wind nameplate to peak load) examined for ~7 GW peak load
- Gas storage & nominations
  - Gas imbalance
  - Extra gas burn for reserves
- Gas price sensitivity
- Transmission constraints
- O&M increase for increased start/stops
- Real-time market access



* 20% case is currently underway

Xcel Colorado/Enernex Study

Penetration Level	10%	15%
Hourly Analysis	$2.26/MWh	$3.32/MWh
Regulation	$0.20/MWh	$0.20/MWh
Gas Supply (1)	$1.26/MWh	$1.45/MWh
Total	**$3.72/MWh**	**$4.97/MWh**

(1) Costs includes the benefits of additional gas storage

Additional work is underway to analyze a 20% penetration case.

- **Without use of 300 MW pumped hydro unit, costs at 10% would be $1.30/MWh higher**

CA RPS Integration Cost Multi-Year Analysis (NREL, ORNL, CAISO, CWEC)

- Perform integration cost and capacity value calculation for 2002 – 2004 for all renewable technologies
- Motivations:
  - Verify applicability of methodologies over additional years
  - Verify consistency of data over several years
  - Examine changes in integration costs over a multi-year period

Final report available at
http://www.energy.ca.gov/2006publications/CEC-500-2006-064/CEC-500-2006-064.PDF

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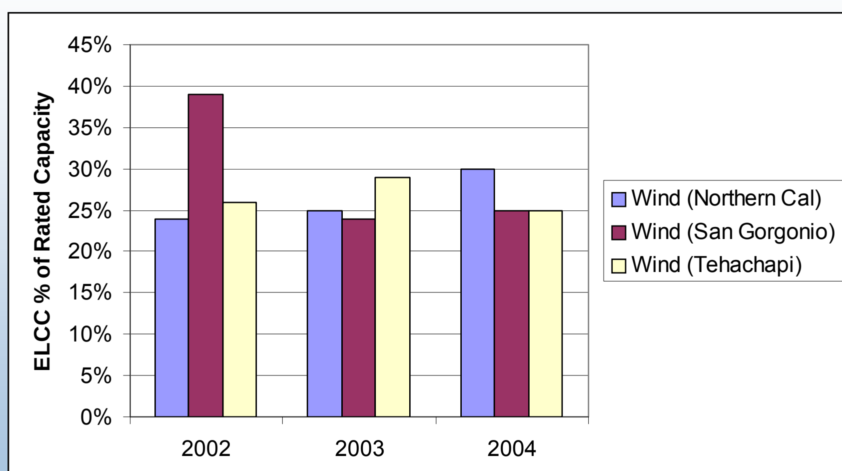
Capacity Value for Wind



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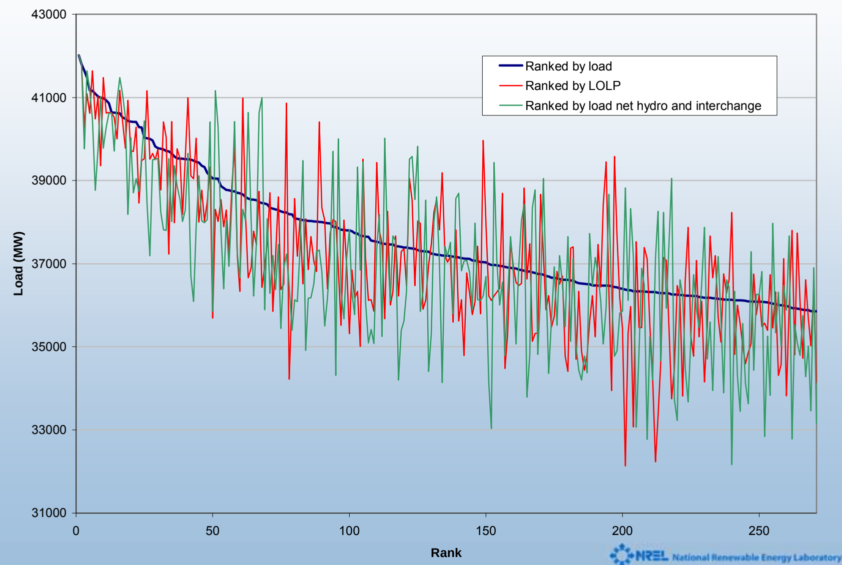
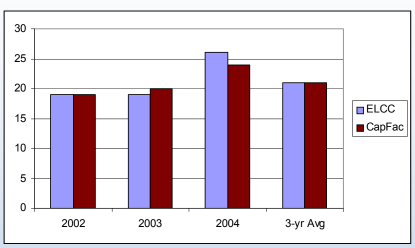
Hydro and Interchange Affect The Risk Profile and ELCC

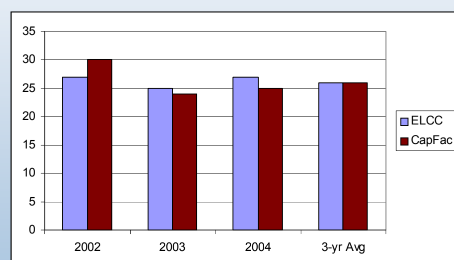


ELCC Without Hydro, Exchange Compared to Capacity Factor Jun-Sep 12p-6p

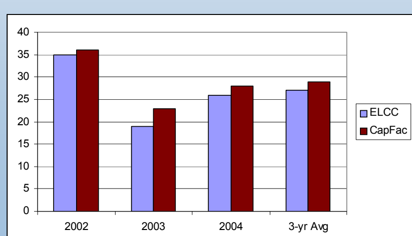
Northern California



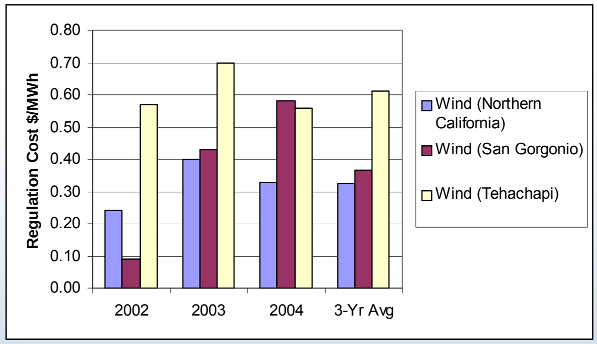
Tehachapi

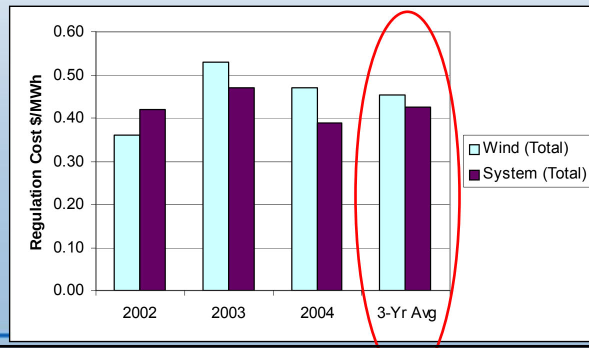


San Gorgonio



Regulation





Factors that Influence Integration Cost Results

- Balancing area size
  - Conventional generation mix
  - Load aggregation benefits
- Wind resource geographic diversity
- Market-based or self-provided ancillary services
- Size of interconnected electricity markets

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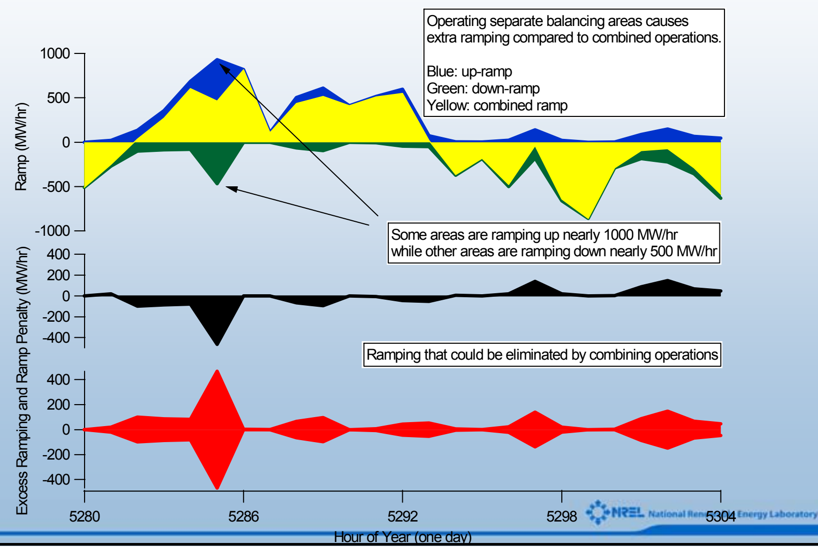
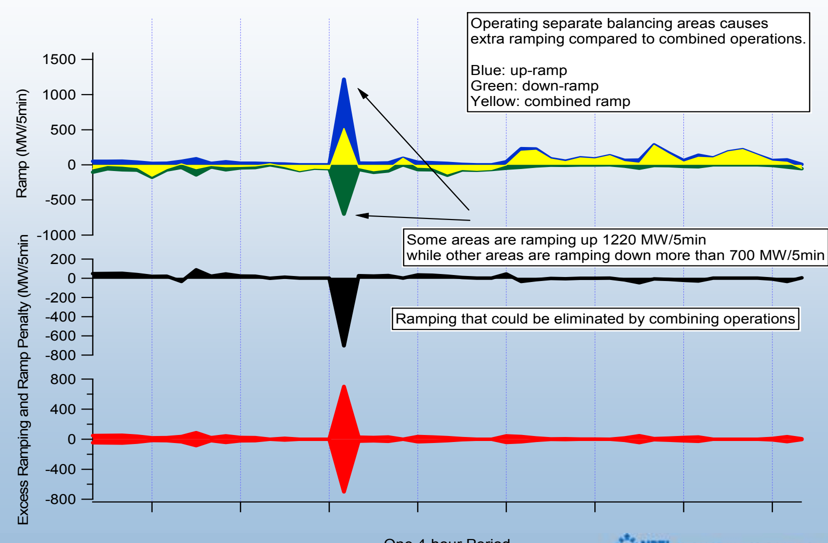
Larger balancing areas can reduce physical ramp requirements

Milligan and Kirby, http://www.nrel.gov/docs/fy07osti/41809.pdf



5-Minute Ramp Savings



Conclusions and Insights

- Additional operational costs are moderate for penetrations at or above portfolio standard levels
- For large, diverse electric balancing areas, existing regulation and load following resources and/or markets are adequate, accompanying costs are low
- Unit commitment and scheduling costs tend to dominate
- State of the art forecasting can reduce costs
  - majority of the value can be obtained with current state-of-the-art forecasting
  - additional incremental returns from increasingly accurate forecasts
- Realistic studies are data intensive and require sophisticated modeling of wind resource and power system operations

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Conclusions and Insights

Data and Modeling Assumptions Matter

- Data from CAISO PI (Power Information) system
  - compression may artificially smooth high-resolution (fast) data
  - Missing data correction algorithm introduced artificial ramps in wind data
- Complex system influences wind capacity value and integration cost
  - Scheduled maintenance of conventional generation
  - Hydro dispatch (needs more systematic work)
  - Interchange schedules, markets

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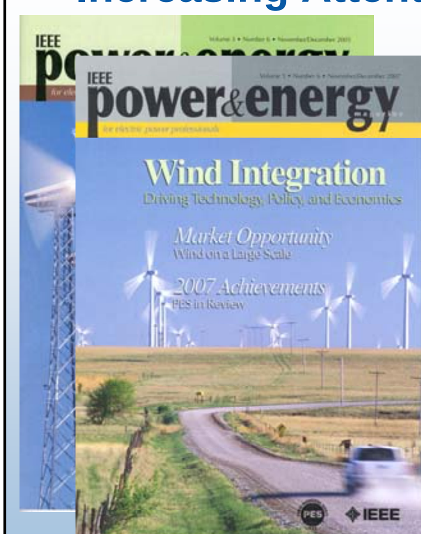
Some Remaining Issues

- Higher wind penetration impacts
- Effect of mitigation strategies
  - Balancing area consolidation and dynamic scheduling (pilot projects underway)
  - Complementary generation acquisition (power system design; quick-response generation) and interruptible/price responsive load
  - Power system operations practices and wind farm control/curtailment
  - Hydro dispatch, pumped hydro, other storage and markets (plug-hybrid electric vehicles, hydrogen)
- Integration of wind forecasting and real time measurements into control room operations (WindLogics/EnerNex/UWIG/Xcel study underway)

Increasing Attention in North America



- IEEE Power Engineering Society Magazine, November/December 2005
- Updated in 2007
- Wind Power Coordinating Committee Wind Super-Session, Summer 2008
- Utility Wind Integration Group (UWIG): Operating Impacts and Integration Studies User Group
- www.uwig.org

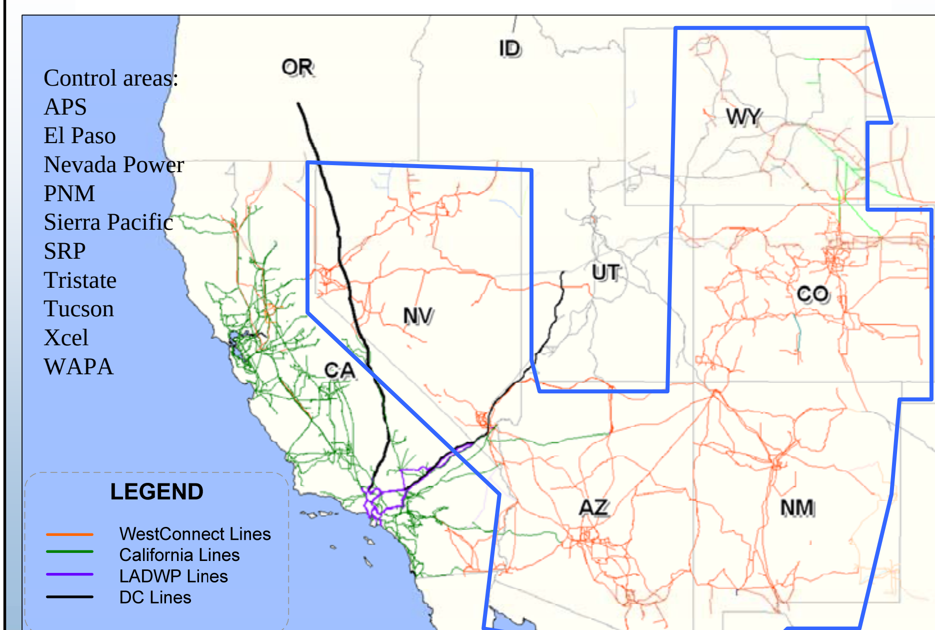
UWIG Utility Wind Integration Group — Accelerating the Integration of Wind Generation into Utility Power Systems

Western Wind and Solar Integration Study - WestConnect

To understand the operating and cost impacts due to the variability and uncertainty of wind and solar power on the grid

- How can utilities manage the incremental variability and uncertainty of wind and solar?
- Do geographically diverse wind/solar resources reduce variability and increase transmission utilization?
- How do local wind/solar resources compare to out-of-state resources in terms of load correlation or cost?
- How can hydro help with wind/solar integration?
- The role and value of wind forecasting
- Can balancing area cooperation help manage the variability?
- How do wind and solar contribute to reliability and capacity value?

Revised Study Footprint



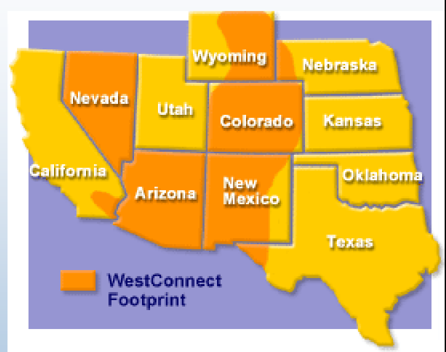
Schedule

Kickoff Stakeholder Meeting	5/23/07
Data Collection	Jun-Dec ’07
Wind/solar mesoscale modeling	Oct ‘07-May ’08
Preliminary Analysis	Feb-Jun ’08
Prelim. results stakeholder mtg	Jul ’08
Production Cost Modeling	Jul ’08-Jan ’09
Interim Technical Results mtg	Dec ’09
Draft report	Feb ’09
Draft results Stakeholder mtg	Mar ’09
Final Report	Apr ‘09

WestConnect

www.westconnect.com

- ACE diversity sharing
  - Underway as pilot
  - Participants report saving
  - Minimal cost – hosted by BCTC
- Under investigation
  - Contingency reserve sharing
  - Ramp sharing



MISO-PJM Wind Integration Study