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National Renewable Energy Laboratory

Innovation for Our Energy Future

Grid Impacts of Wind Power Variability: Recent Assessments from a Variety of Utilities in the United States

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European Wind Energy Conference
Athens, Greece

February 27 – March 2, 2006

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Acknowledgements

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Brett Oakleaf, Xcel Energy

Kenneth Wolf, Minnesota Public Utilities Commission

Matt Schuerger, Energy Systems Consulting Services, LLC

Robert Zavadil, Enernex Corporation

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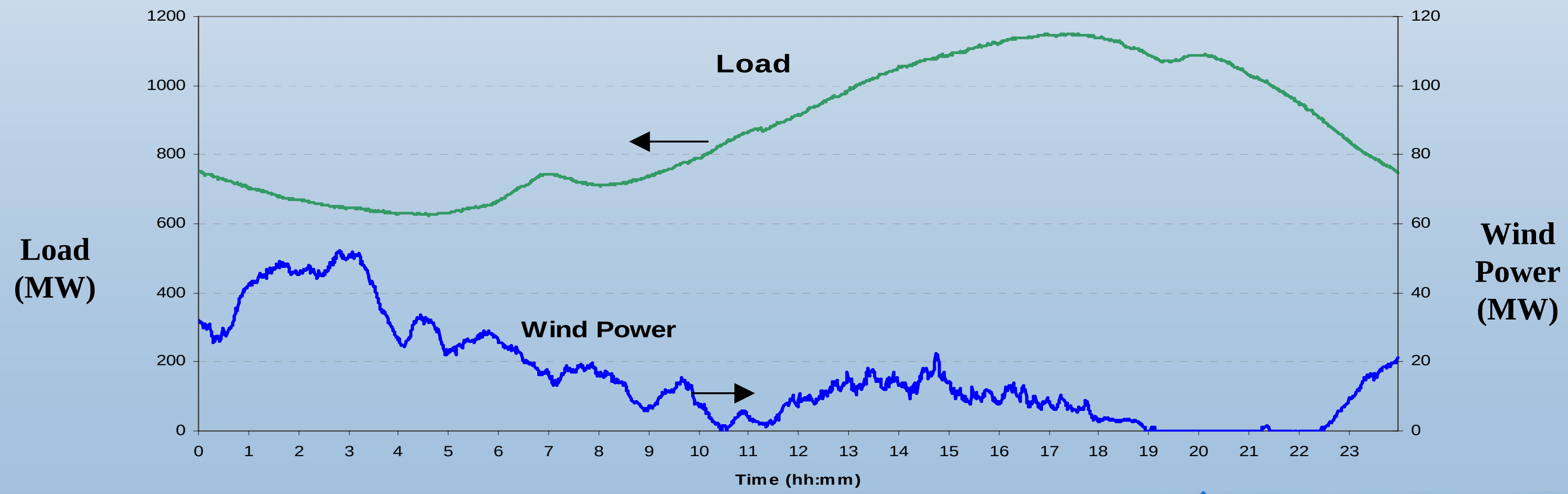
Critical review/input from Nicholas Miller and Richard Piwko of GE Energy, Kevin Porter, Exeter Associates, and Henry Shiu, University of California, Davis

Presentation Outline

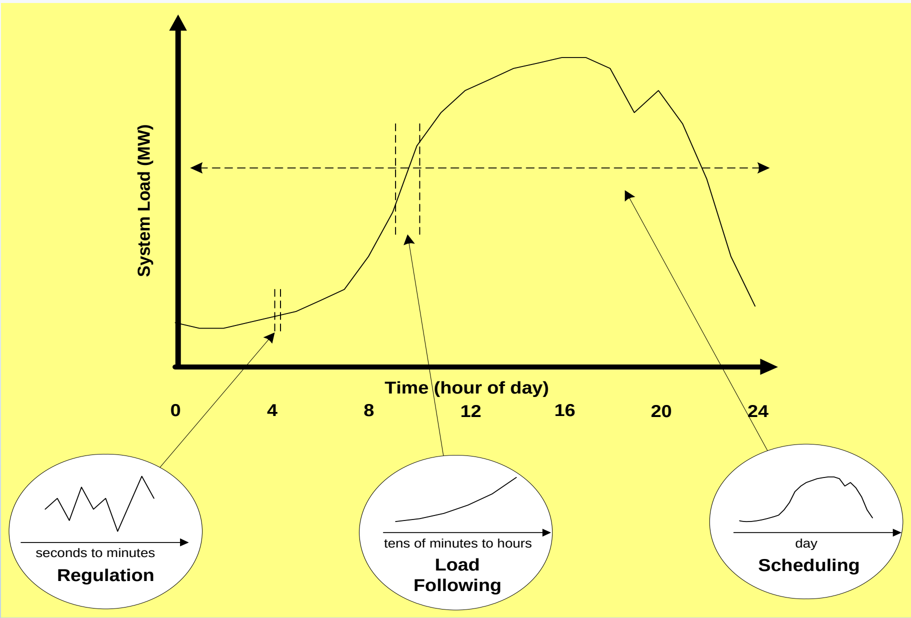
- Issues and time frames of importance
- Methods and approaches
- Four recent studies
  - Minnesota DOC/Xcel North
  - NYSERDA/GE New York State
  - Xcel Colorado
  - California Multiyear RPS Integration Cost Study
- Comparison with previous studies
- Conclusions and remaining issues
- Ongoing/future work

Wind Variability Can Increase Power System Operating Costs

- Committing unneeded generation
- Allocating extra load-following capability
- Allocating additional regulating capacity
- Increased cycling operation
- **These are reflected in *ancillary services* costs**



Wind Variability
Power System Operation Impacts



Typical U.S. terminology

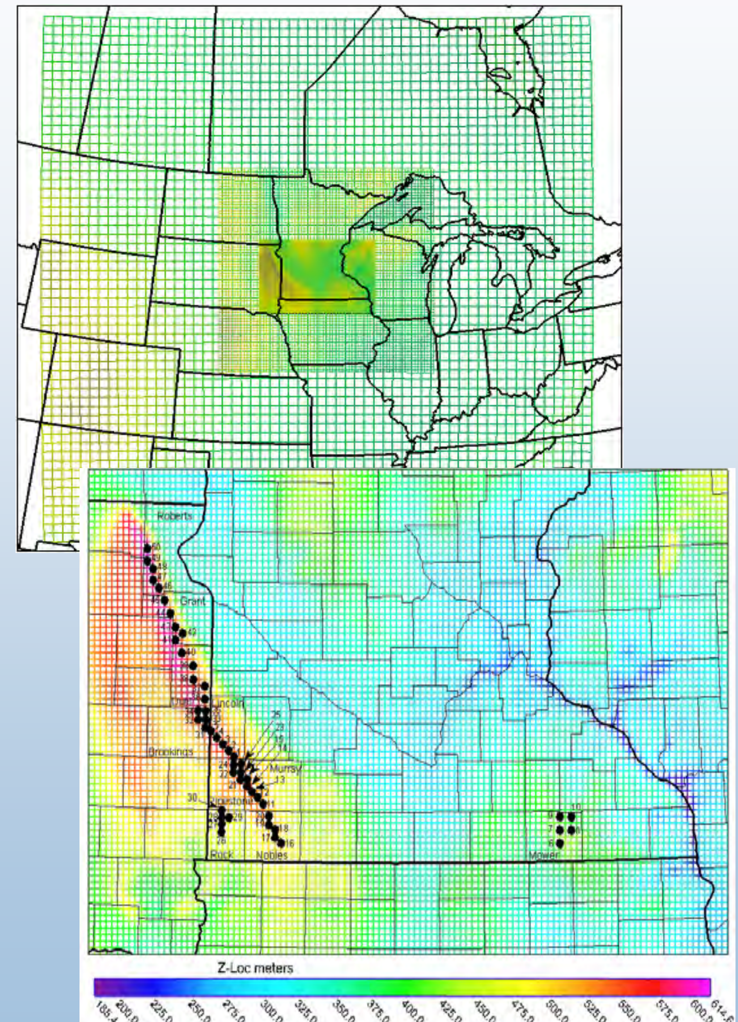
- Regulation -- seconds to a few minutes -- similar to variations in customer demand
- Load-following -- tens of minutes to a few hours -- demand follows predictable patterns, wind less so
- Scheduling and commitment of generating units -- hours to several days -- wind forecasting capability?

Methods
Emerging Best Practices

- Capture system characteristics and response through operational simulations and modeling
- Capture wind deployment scenario geographic diversity through synchronized weather simulation
- Couple with actual historic utility load and load forecasts
- Use actual large wind farm power statistical data for short-term regulation and ramping
- Examine wind variation in combination with load variations
- Utilize wind forecasting best practice and combine wind forecast errors with load forecast errors
- Examine actual costs independent of tariff design structure

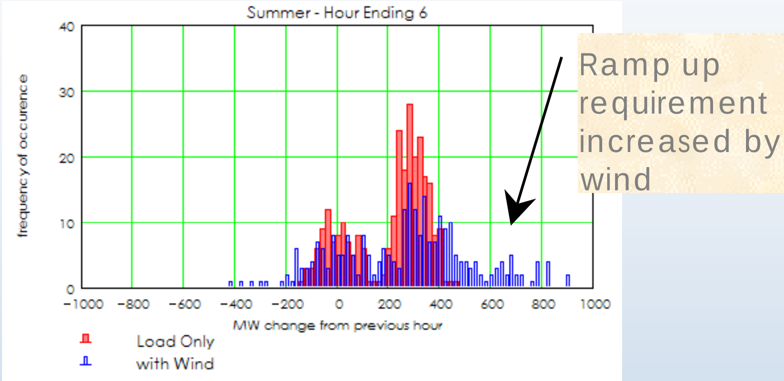
Minnesota Dept. of Commerce/ Enernex Study Framework

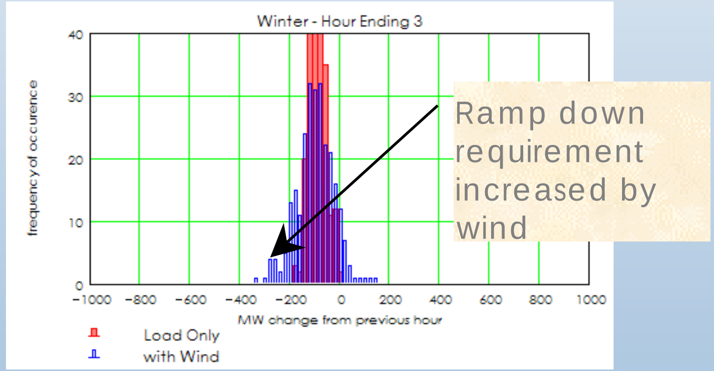
- 2010 scenario of 1500 MW of wind in 10 GW peak load system (< 700 MW wind currently)
- WindLogics:10-minute power profiles from atmospheric modeling to capture geographic diversity
- Wind forecasting incorporated
- Extensive historic utility load and generator data available
- Monopoly market structure, 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%



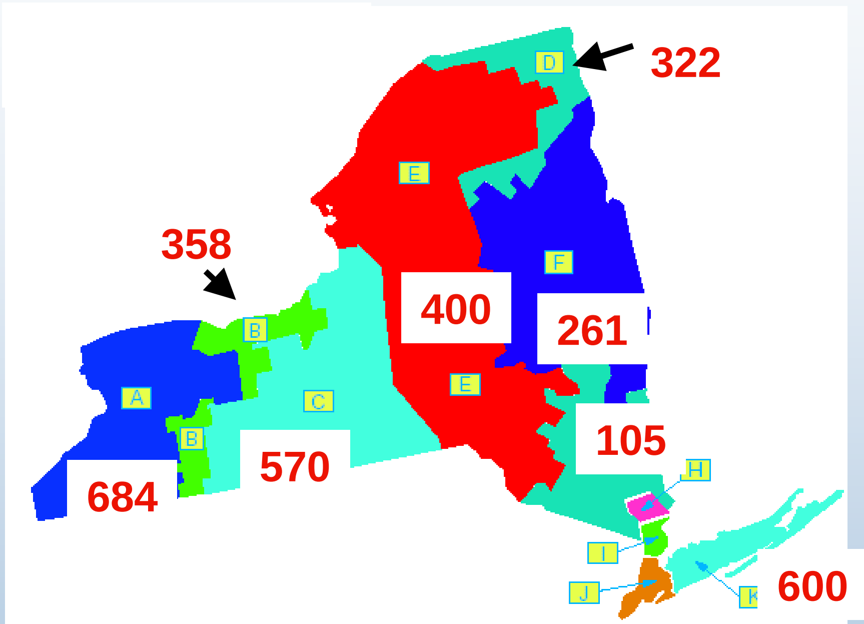


Completed September 2004 *www.commerce.state.mn.us*

(Industry Info and Services / Energy Utilities / Energy Policy / Wind Integration Study)

New York ISO and NYSERDA/ GE Energy Study

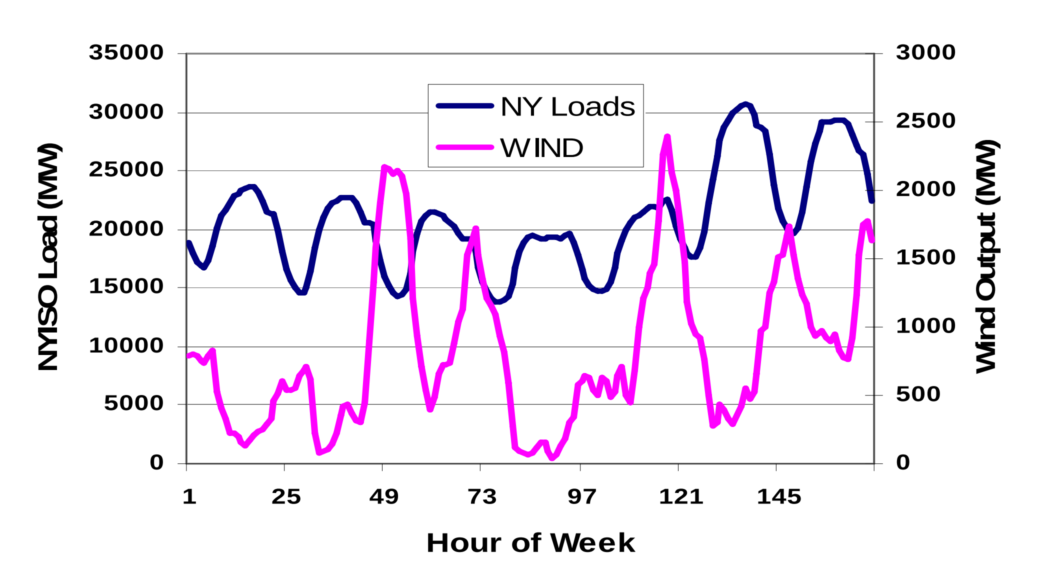
- 2008 scenario of 3300 MW of wind in 33-GW peak load system (< 200 MW wind currently)
- AWS Truewind: wind power profiles from atmospheric modeling to capture statewide diversity



- 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

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



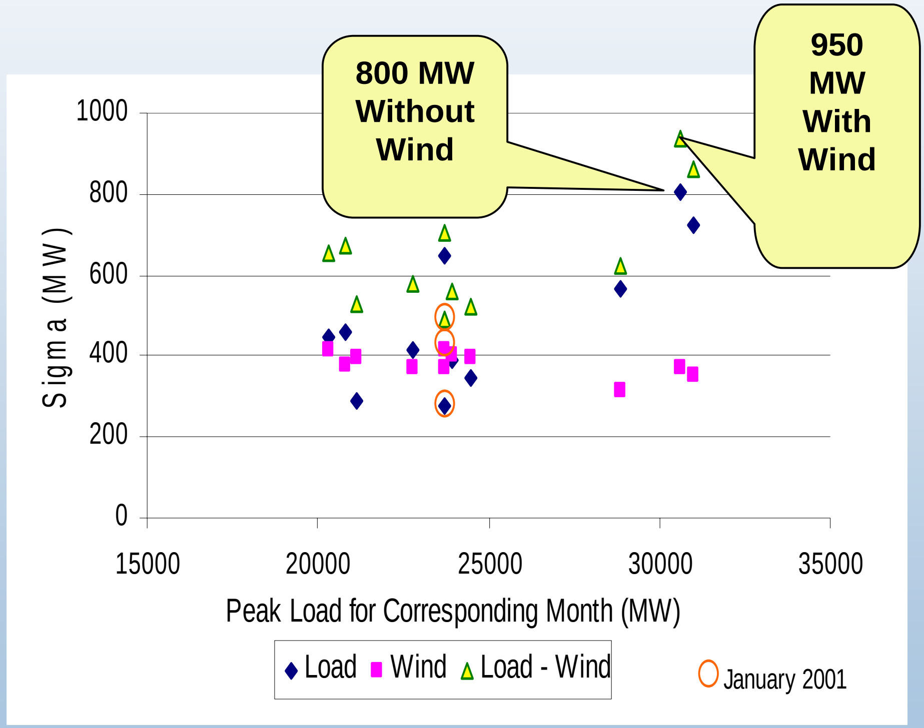
- All increased needs can be met by existing NY resources and market processes
- Capacity credit (UCAP) of 10% average onshore and 36% offshore
- Significant system cost savings of $335- $455 million on assumed 2008 natural gas prices of $6.50-$6.80 /MMBTU.

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

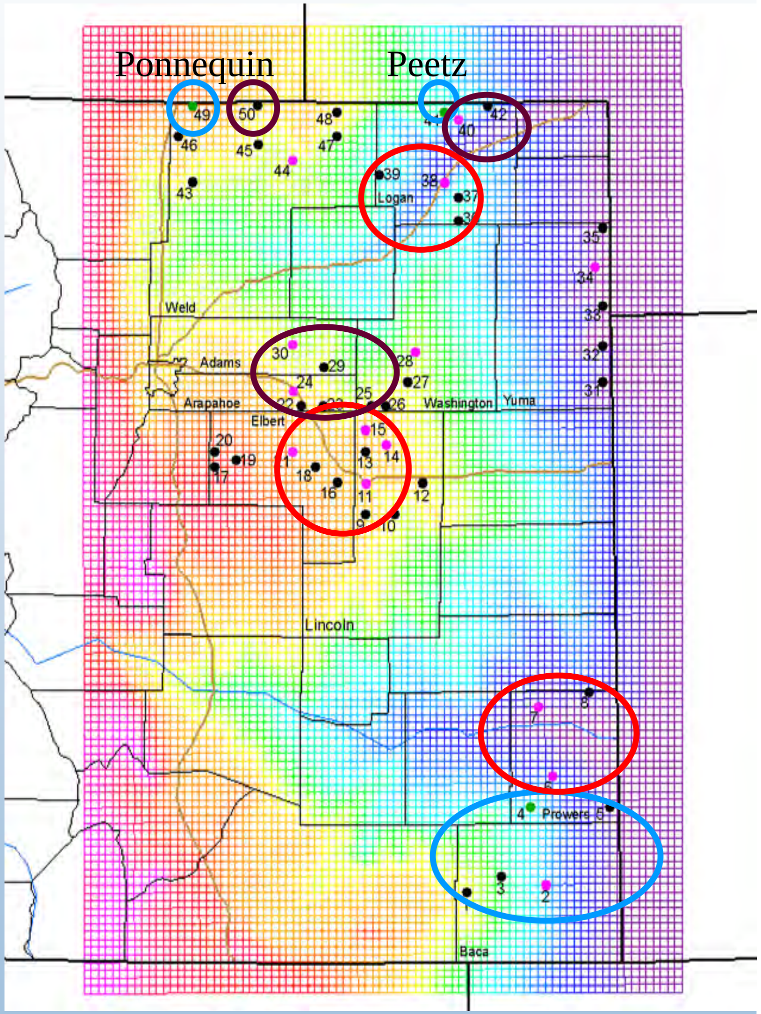
Standard Deviations of Day-Ahead Forecast Errors



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



Xcel Colorado/Enernex Study

Penetration Level	10%	15%	20%[2]
Hourly Analysis	$2.26/MWh	$3.32/MWh	$6.57/MWh
Regulation	$0.20/MWh	$0.20/MWh	$0.20/MWh
Gas Supply (1)	$1.26/MWh	$1.45/MWh	$2.10/MWh
Total	**$3.72/MWh**	**$4.97/MWh**	**$8.87/MWh[2]**

(1) Costs includes the benefits of additional gas storage
(2) Rough results based on scaling wind generation without geographic diversity benefits

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

Preliminary Results – pending final report anticipated in April 2006

Gas Storage Benefits/Results

- Summer/winter arbitrage
  - Cost savings in filling in summer and withdrawing in winter
- Reduction in need for financial hedge (call option)
  - Because the price of the gas in the storage field is known, there is no need to financially hedge the market price of the gas

Wind Penetration	10%	15%	20%
$/ MWH Gas Impact No Storage Benefits	$2.17	$2.52	$3.66
$ / MWH Gas Impact With Storage Benefits	$1.26	$1.45	$2.10

20% results based on scaling wind generation without geographic diversity benefits

CA RPS Integration Cost Project

- Examining impacts of existing installed renewables (wind 4% on a capacity basis)
- Calculated regulation, load following impacts of all renewables
- Capacity value (ELCC) for all renewables
- Regulation cost for wind $0.46/MWh
- Load following: minimal impact
- Wind capacity credit 23%-25% of benchmark gas unit

http://www.energy.ca.gov/reports/reports_500.html

CA RPS Lessons Learned

Data and Modeling Assumptions Matter

- Data from 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
  - Scheduled maintenance of conventional generation
  - Hydro dispatch
  - Interchange schedule
- Multi-year analysis will be released by CEC any day now: regulation impacts similar to 1-year study, capacity value shows some fluctuation year-to-year, load following impact still difficult to detect

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)	Total Operating 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
July ‘04	CA RPS Phase III	4	0.46	na	na	na	na
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	4.6
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
April ‘06	Xcel-PSCo (1)	20	0.20	na	6.57	2.10	8.87 (2)

(1) Preliminary results based on scaling wind generation

Factors that Influence Results

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

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

Some Remaining Issues

- Higher wind penetration impacts
- Effect of mitigation strategies
  - Balancing area consolidation and dynamic scheduling
  - Complementary generation acquisition (power system design) 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

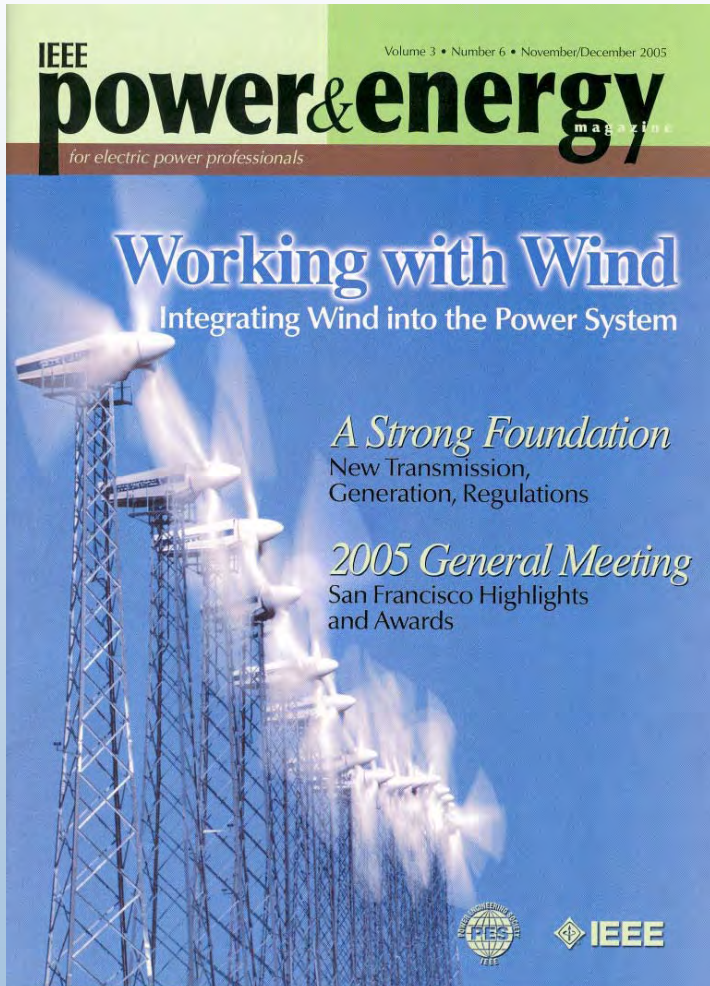
Future/Ongoing Work
(Enernex, WindLogics, Ariva, UWIG team)

- 2006 Minnesota Wind Integration Study
  - Statewide, 20% by *energy* (5 GW wind)
  - New MISO market structure
  - Examine transmission & mitigation strategies
  - Comparison of market operational and reliability rules
  - Completion date 11/06
- Xcel (MN) Renewable Development Fund: Control Room Integration of Wind
  - Define, design, build and demonstrate a complete wind power forecasting system for use by Xcel system operators
  - Optimize the way that wind forecast information is integrated into the control room environment
  - R&D on defensive operating strategies: Value of off-site met towers, high wind warning system, rapid update cycle (RUC) model

More Future/Ongoing Work

- California Energy Commission Intermittency Analysis Project
  - 5 GW of wind by 2010, up to >10 GW by 2020 (~15% by capacity)
  - Will consider whether mitigation measures are necessary at certain times (such as low load, high wind production)
  - Lead contractors: Davis Power Consultants and GE Energy with wind resource simulation by AWS Truewind
  - Completed by end of 2006
- Smaller balancing authority projects
  - Sacramento Municipal Utility District: high penetration, investigate value of pumped hydro
  - Public Service of New Mexico: limited conventional resources, high ramping wind, export and minimum load issues
  - Idaho Power and Grant County projects: integrate with constrained existing hydro

Increasing Attention in North America



- IEEE Power Engineering Society Magazine, November/December 2005
- 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*