Study Of Knowledge Claims Regarding Wind Energy Grid Integration

Presented at the:

World Wind Energy Conference 2010

June 15, 2010

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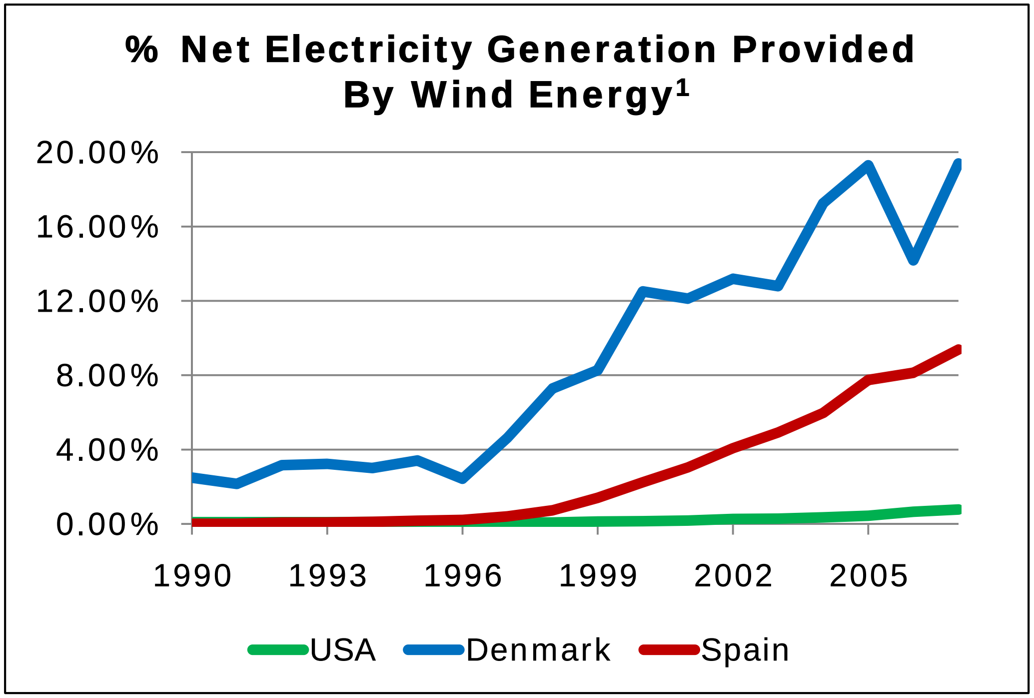
Outline

- Introduction
- Wind Integration Studies
- Comparative Results
- Simple *(mostly qualitative)* Analysis
- Summary and Future Work

Introduction (1)
Growth in Installed Wind Capacity

- Diffusion of wind energy over past 20 years varies by country



% Net Electricity Generation Provided by Wind in 2007[1]	
Country	% GWhr from Wind
Canada	0.4%
USA	0.8%
Denmark	19.4%
Germany	6.6%
Ireland	7.3%
Norway	0.7%
Portugal	9.0%
Spain	9.4%
UK	1.7%

1: Data source: IEA Renewables Information 2008 (SourceOECD Statistics), EIA International Electricity Generation through 2007

Introduction (2)
Wind Energy Growth Projections

- Current Projections for Future Growth Vary Depending on the Source of Information
- Regardless, most project significant levels with respect to overall system capacity and generation

Energy Outlook Reports: Future for Wind Development			
Report	**Year**	**US**	**World**
IEA 2008	2030	5-6%	4-6%
EIA 2009	2030	3%	[redacted]
McKinsey 2009	2030	[redacted]	3-10%
GWEC 2005 / 2008	2020	6% (2005)	4-13% (2008)

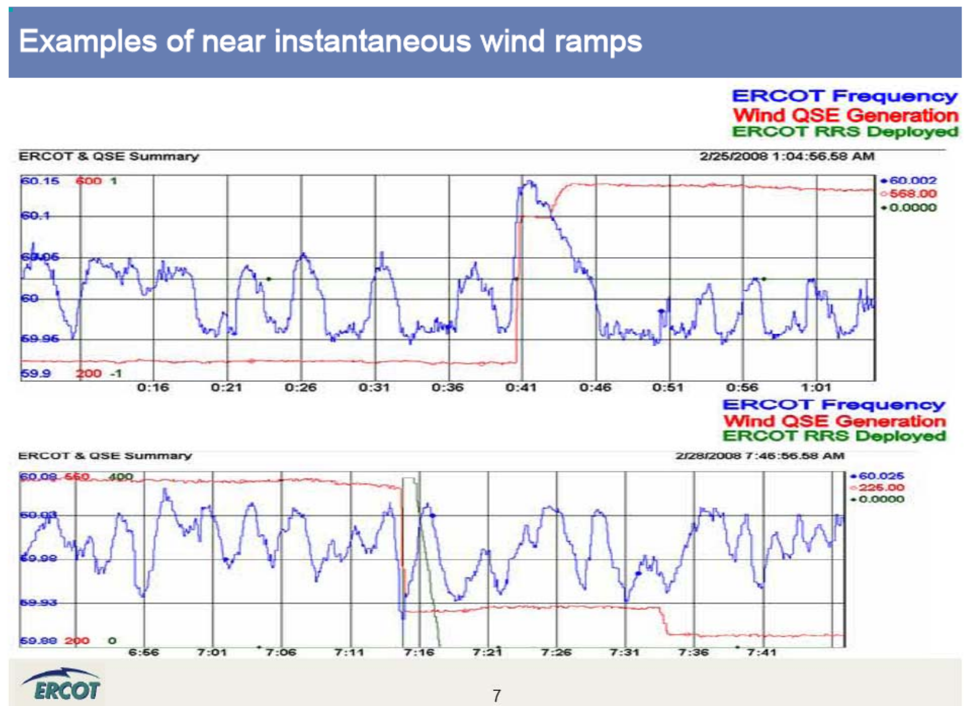
1: Data source: IEA Renewables Information 2008 (SourceOECD Statistics), EIA Energy Outlook 2009, McKinsey Pathway to a Low Carbon Economy Report 2009, GWEC Windforce 12 Greenpeace Report 2005, GWEC Wind Energy Outlook 2008, DOE 20% Wind by 2030 Report

IEA Annual World Energy Outlook (2008)

Introduction (3)
Issues of Wind Integration

- Wind Energy Diffusion Limited by System Reliability and Stability Requirements

- For example: West Texas isolation from rest of in-state and out-of-state grid has caused problems



Introduction (4)
Wind Integration Impacts

- Variability in wind a constant concern for system operators
- Thus, a need arises for systematically characterizing the impacts of wind integration
- Various wind integration studies have been applied to address this issue worldwide

Wind Integration Studies (1)

- 40+ such case-specific studies to date worldwide
  - At least 15 in Europe, another 20 in North America and elsewhere
- Various foci of studies
  - Reliability – fatal flaw analyses
  - Capacity Value – how much of the wind can be considered dependable
  - Integration Impacts – additional reserves and effects on other generation

Wind Integration Studies (2) Factors of Influence

- Various factors affect the integration of wind into the electric system,
- And these vary by case!!!

Factors affecting large-scale wind grid integration			
Wind	Utility	Demand	Market
Resource characteristics (amount and variability)	Generation Asset Mix and Technical Characteristics	Demand profile and make-up	Planning Time-Scales for System Commitment
Number and size of turbines	Reserves and Storage Assets	Demand-side Technology	Interconnection Characteristics Between Balancing Authorities
Turbine Technology	Transmission Technology and Capacity		Information Transparency and Sharing
Geographic Dispersion of Turbines	Distributed Generation in System		System-Level Operating Standards
			Level of regulation

Wind Integration Studies (3) Comparison of Case Profiles

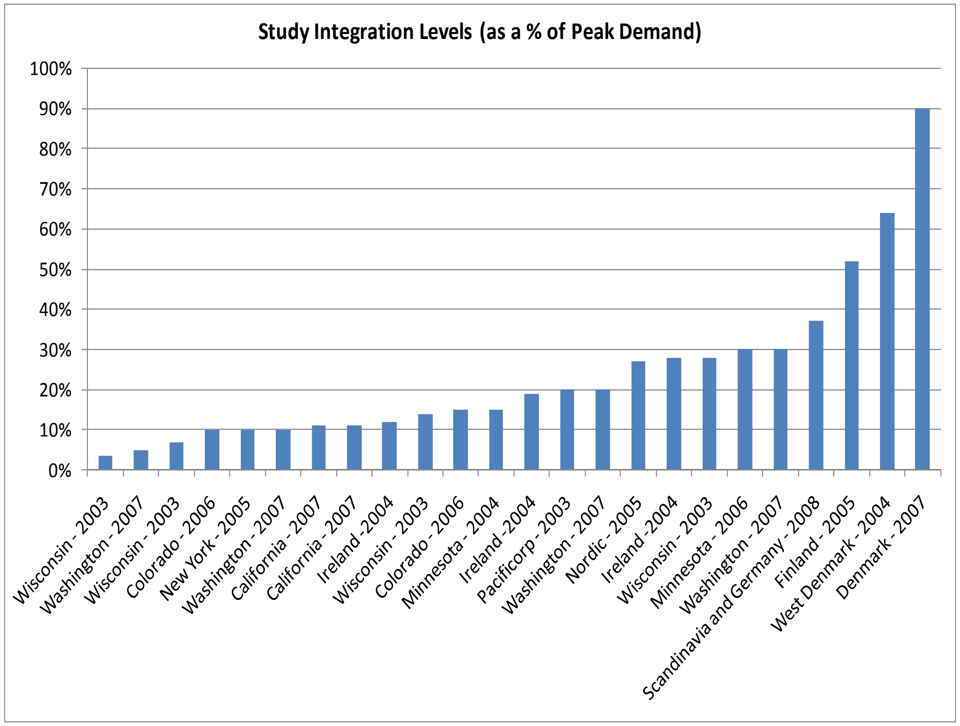
Study	Year	Region	Targeted Year(s)	Peak Load (MW)	Load (TWh)	Wind Capacity (MW)	Wind Levels (% peak load)	Wind Levels (% gross demand)
XCEL Energy and the Minnesota Department of Commerce Wind Integration Study - Final Report	9/28/2004	Minnesota	2010	9933	48.1	1500	15%	12%
2006 Minnesota Wind Integration Study - Final Report Vol I and II	11/30/2006	MISO	2020	20000	85	6000	30%	15%, 20%, 25%
The Effects of Integrating Wind Power on Transmission System Planning, Reliability and Operations	3/4/2005	New York / NYISO	n/a	33000	170	3300	10%	6%
Wind integration Study for Public Service Company of Colorado	5/22/2006	Colorado	2007	7000	36.3	720, 1080, 1400	10%, 15%, 20%	10%
Assessing Wind Integration Costs with Dispatch Models: A Case Study of Pacificorp	5/18/2003	Northwest	n/a	10000	n/a	2000	20%	8%
Intermittency Analysis Project: Final Report	7/1/2007	California / CAISO	2010/2020	62600 / 74300	304	12500 / 12700	19%	11%
Analysis of Wind Generation Impact on ERCOT Ancillary Service Requirements	3/28/2008	Texas / ERCOT	2008/2017	65200	317	5000, 10000, 15000	23%	17%
Final Report: Avista Corporation Wind Integration Study	3/1/2007	Washington (Spokane area)	2001/2002	2100	890	100, 200, 400, 600	5%, 10%, 20%, 30%	n/a

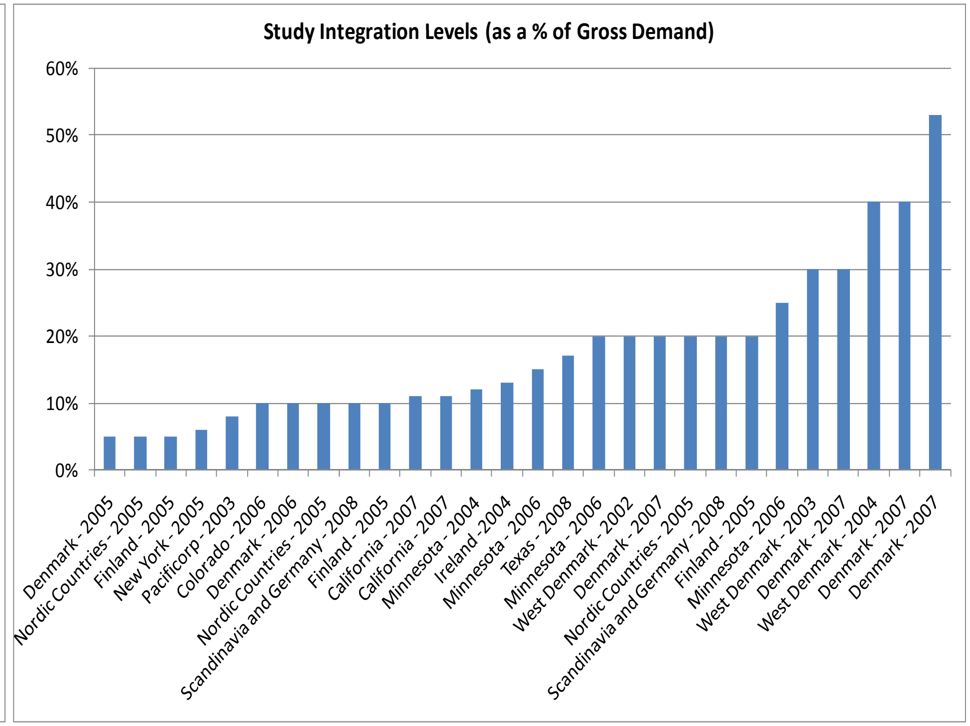
Wind Integration Studies (4) Comparison of Case Profiles

Study	Year	Region	Targeted Year(s)	Peak Load (MW)	Load (TWh)	Wind Capacity (MW)	Wind Levels (% peak load)	Wind Levels (% gross demand)
We Energies System Operations Impacts of Wind Generation Integration Study	7/24/2003	Wisconsin	2012	7045	n/a	250, 500, 1000, 2000	3.5%, 7%, 14%, 28%	n/a
The Effect of Large Scale Wind Power on a Thermal System Operation	2003/2004	West Denmark	2010	3700 / 4130 + 5705 MW heat	1300	2380 (950, 1900, 2710, 3220)	64%	24% (10%, 20%, 30%, 40%)
50% Wind Power in Denmark in 2025 / 50 pct. Wind Power in Denmark and Power Market Integration	7/1/2007	Denmark	2025	7200	2600	6400	90%	53%
The Impact of Large Scale Wind Power Production on the Nordic Electricity System	2004/2005	Nordic Countries	2000-2002	67000	24000	12000	27%	12%
Operational Costs Induced by Fluctuating Wind Power Production in Germany and Scandinavia	8/1/2008	Nordic Countries + Germany	2010	155500	65600	57500	37%	12%
Finland / VTT (part of the Holtinnen study)	2004/2005	Finland	2000-2002	14000	5900	7300	52%	18%
Impact of Wind Power Generation in Ireland on the Operation of Conventional Plant and the Economic Implications	2/1/2004	Ireland	~2010 / ~2020	5000 / 6500	25000	500, 1000, 1500 / 1500, 2500, 3500	54%	5.2%, 10.5%, 15.7% / 11.7%, 19.6%, 27.4%
Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System	8/1/2004	Ireland	2006 / 2010	6900	2455	845 / 1300 , 1950	28%	13%

Wind Integration Studies (5) Wind Levels and Treatment

- Typically testing for a few different scenarios in each study:





- 8 of the 17 studies took measures to ensure geographic diversity

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Wind Integration Studies (6) System Characteristics

- System characteristics: generation
  - Range in control area sizes from small (5 GW) to very large (160 GW) systems
  - Range in amount of peak/non-peak power from 0.13 / 0.21 for small utilities to 88% for hydro rich regions (Washington) or islands (Ireland)
  - Range in amount of hydro power from 0% to 45% of system capacity
  - Range in regulation from vertically-integrated small utilities to large inter-country networks

Wind Integration Studies (7) System Characteristics

- System characteristics: transmission
  - NYISO 2005 / California 2007 performed fatal flaw analysis via power flow modeling for a few extreme scenarios
  - Ireland 2004 / West Denmark 2004 consider transmission expansion plans already under way
  - Germany 2005 / Denmark 2007 explicitly considered expansion needs and estimated costs (100M + Euros at various stages)

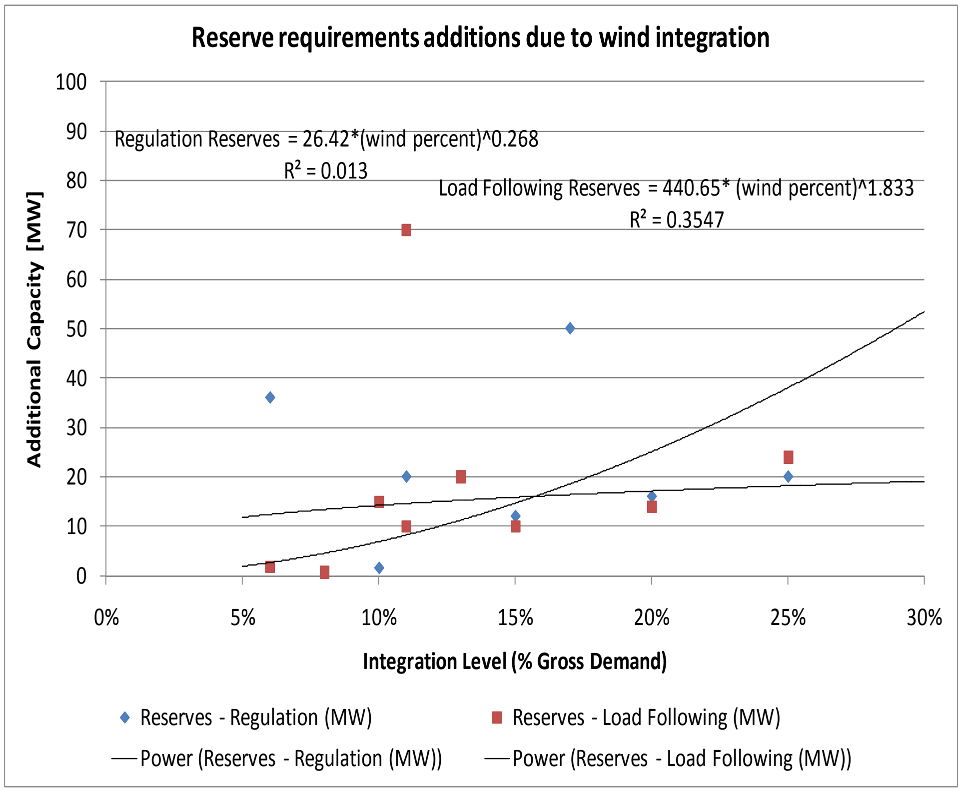
Wind Integration Studies (8) Methods

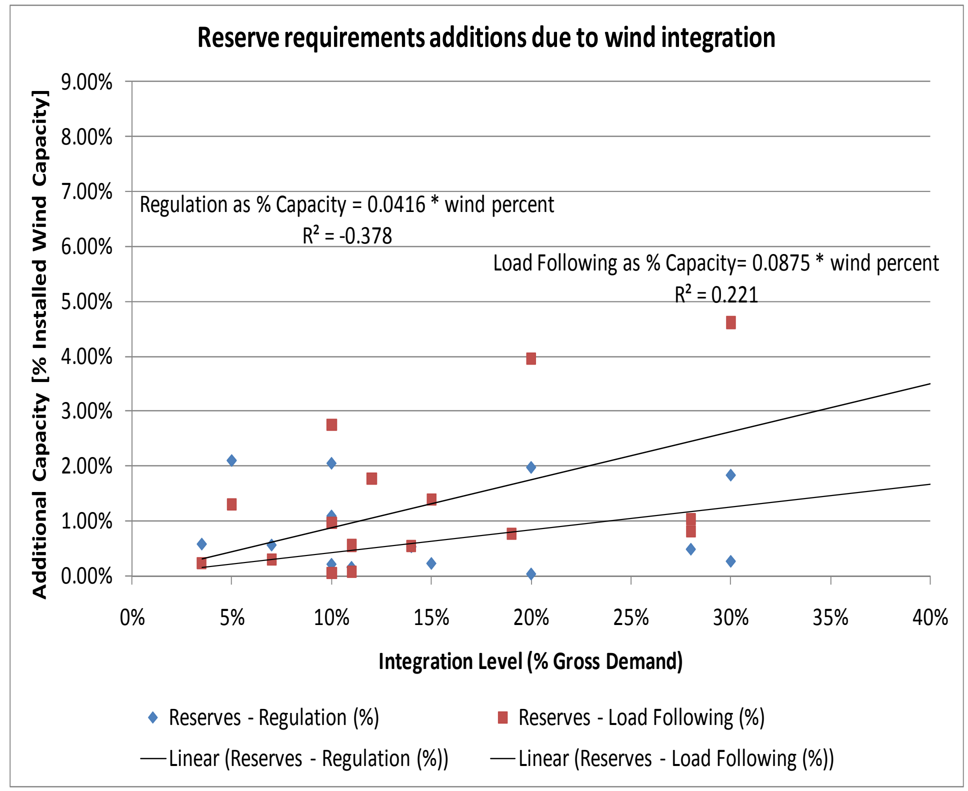
- Depending on study goal, multiple methods have been used

Methods for Power System Analysis		
Time-Scale	**Method**	**Purpose**
Microseconds	Short Circuit Analysis	Short-term stability: System Faults
Seconds to Minutes	Transient Stability Analysis, Statistical Analysis of wind/load variability	Short-term stability: Regulation
Minutes to Intra-hour	Power & Load Flow, Economic Dispatch	Load following and Intra-hour Balancing
Inter-hours	Power & Load Flow, Economic Dispatch	Day-of real-time markets
Days	Unit Commitment	Day-Ahead markets
Months	Hydro / Maintenance Scheduling	Medium-term economic and operational planning
Years	Capacity Expansion (with Transmission)	Long-term economic and operational planning

Comparative Results (1) Reserve Capacity

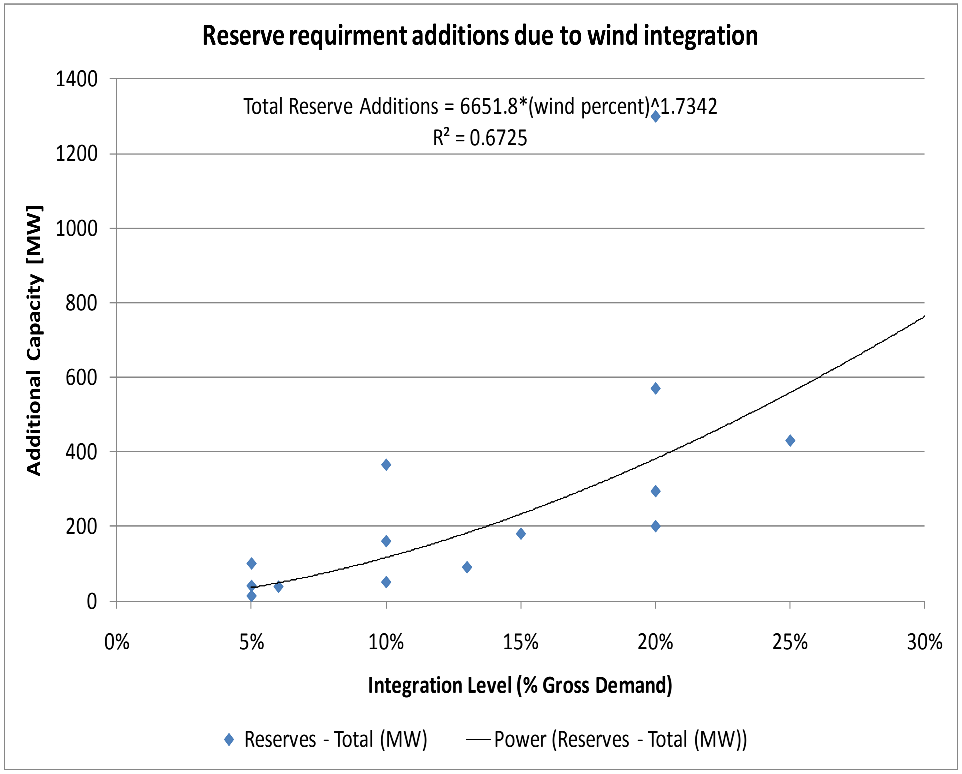
- Regulation and Load-following Reserves – increasing, but with lots of scatter

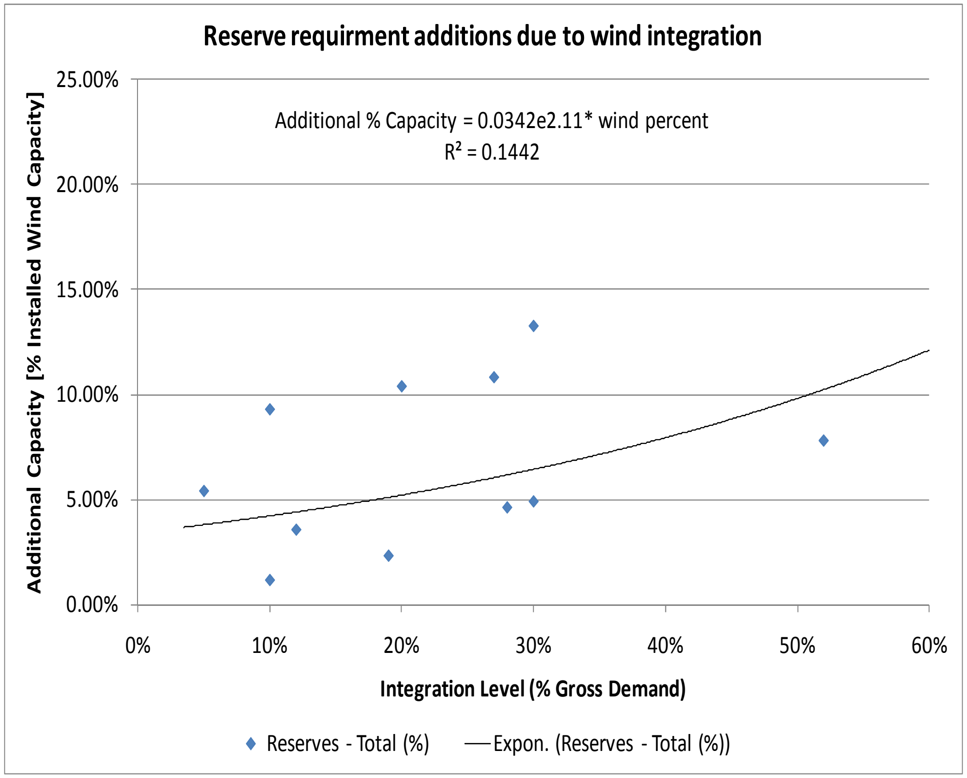




Comparative Results (2) Reserve Capacity

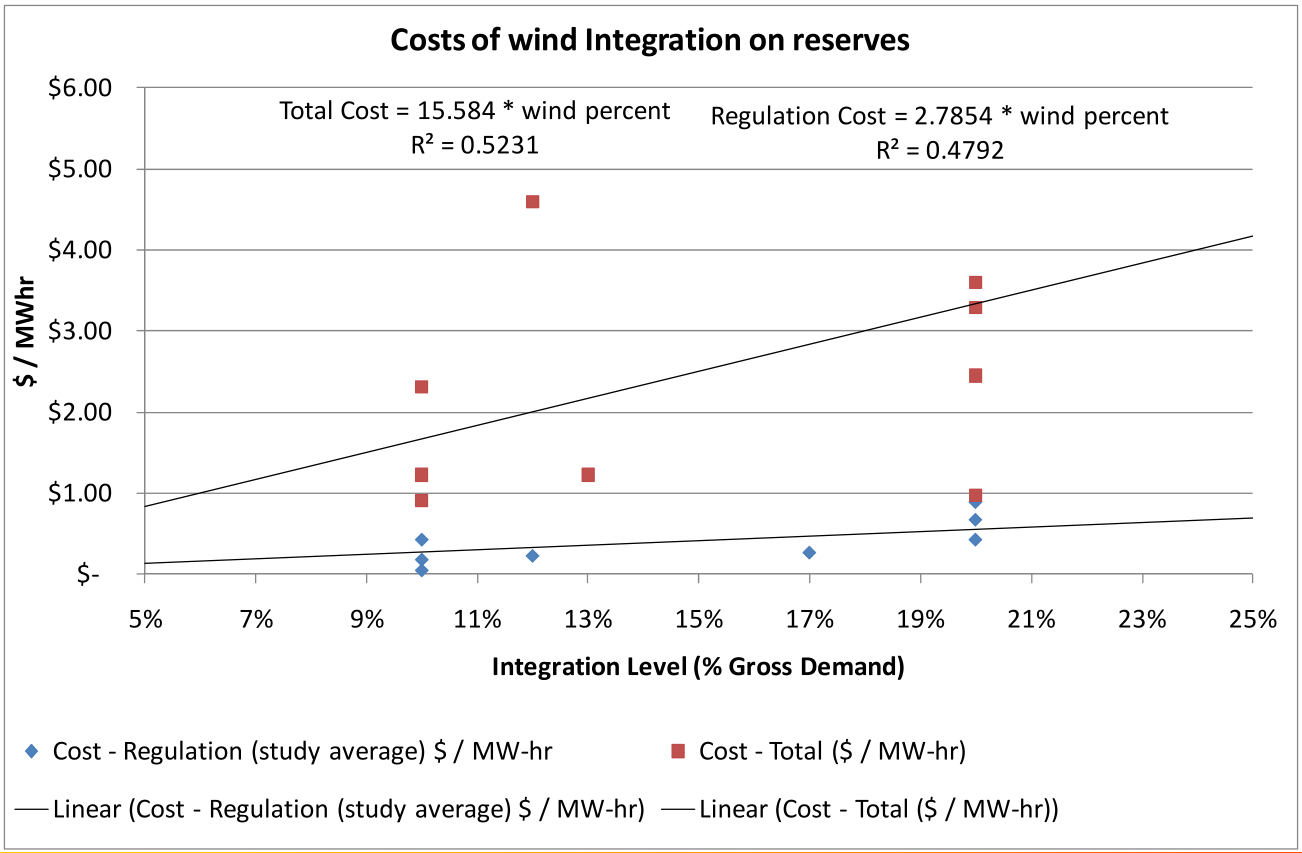
- Total Reserve Requirements (for variability and forecasting error) – increasing both in absolute and normalized





Comparative Results (3)
Reserve Costs

- Reserve costs – increasing cost per MW-hr wind produced (normalized to $ / MW-hr in each case)



Comparative Results (4)
General System Impacts

- Other system impacts
  - Capacity value of wind in system – range of 10 to 27% depending on study
  - Substantial transmission requirements where considered
  - Effects on profitability of other generation units
  - Effects on fuel storage needs (particularly natural gas)
  - Potential increase in exchange across control areas

Analysis (1)

- Methodologies highly variable across studies and case conditions not well detailed and difficult to compare
  - Wind resource, farm planning, forecasting methods differed
  - System characteristics lead to choice of particular methodology
  - Unit commitment and economic dispatch methods similar but can have different time resolution
  - Methods for treating intra-hour reserve requirements varied considerably

Analysis (2)

- Given variety of methods and cases, general conclusions difficult
- Still, with a growing data set of studies, some comparisons possible
  - i.e. influence of region on study conclusions

Wind Integration Total Reserve Costs by wind generation as a percentage of gross demand				
Integration Level	0.10	0.20	0.30	0.40
US	$ 2.31	$ 3.60	[redacted]	[redacted]
Europe	$ 1.07	$ 2.24	$ 5.35	$ 7.00

Wind Integration Total Reserve Costs by wind capacity as a percentage of peak demand				
Integration level	0.10	0.20	0.30	0.40
US	$ 3.47	$ 4.88	$ 5.12	[redacted]
Europe	$ 0.61	$ 0.92	$ 1.84	$ 0.97

Wind Integration Total Reserve Additions (MW) by wind capacity as a percentage of peak demand				
Integration level	0.10	0.20	0.30	0.40
US	20.6	41.6	186.85	[redacted]
Europe	30	30	695	[redacted]

Conclusions

- Studies of wind-electric grid integration vary by treatment of wind expansion, system characteristics, and methods used
- However, an ever increasing number of studies provides some basis for cross-comparison
- It is possible to begin recognizing general trends across studies
- However, this leads to an awareness of just how varied current approaches are: more systematization of techniques across studies is desirable

Future Work

- An additional 20+ studies are available for analysis and can provide a broad set for comparison
- More detailed information on specifics of cases in terms of regulatory structure, generation mix and transmission infrastructure is needed
- General conclusions will be incorporated into current aggregate-based system dynamic models for wind diffusion

Q&A

Thanks for your attention!

References

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