Wind Power Forecasting and Electricity Market Operations

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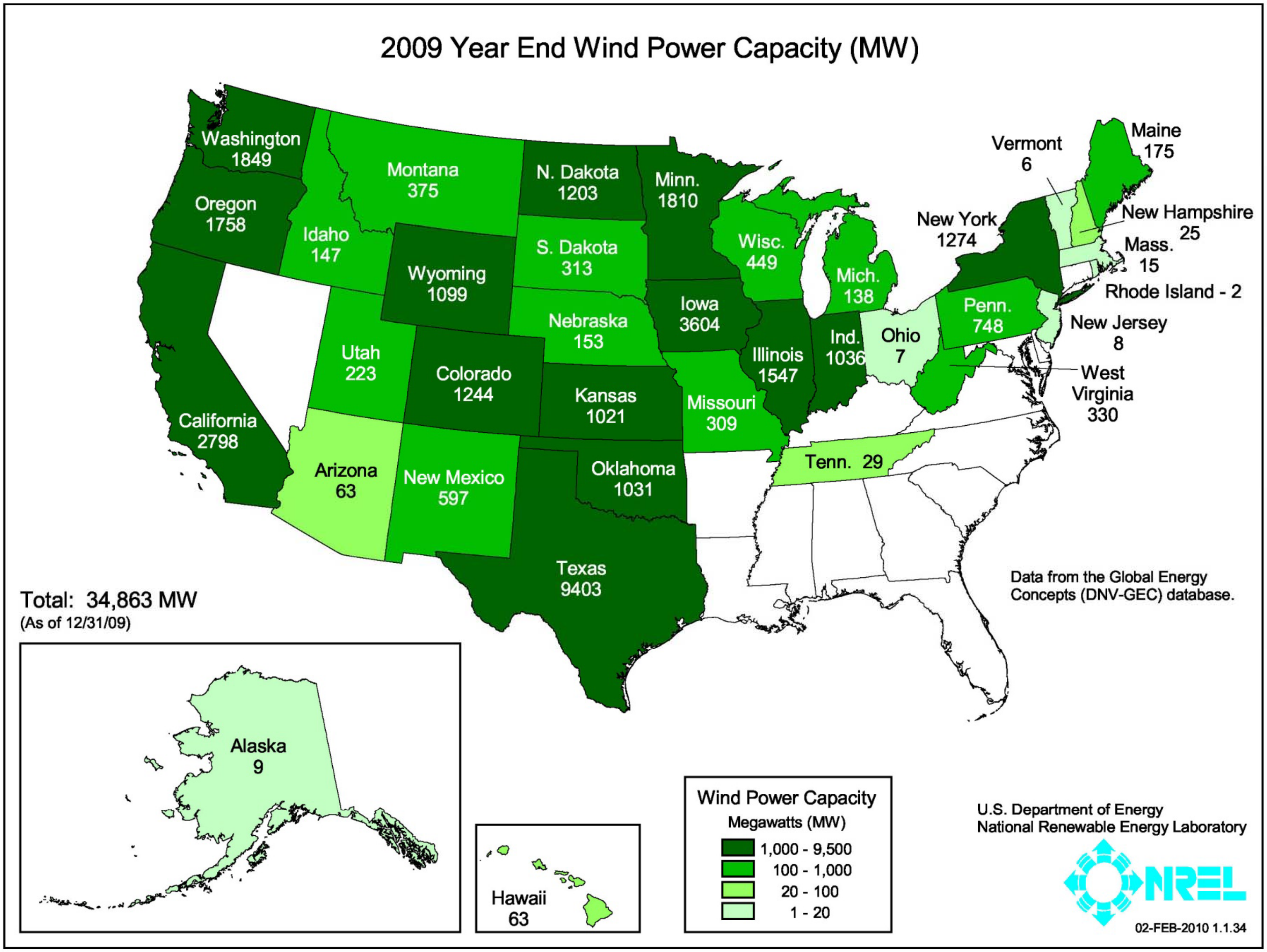
Project website:
http://www.dis.anl.gov/projects/windpowerforecasting.html

IAWind 2010
Ames, IA, April 6, 2010

Outline

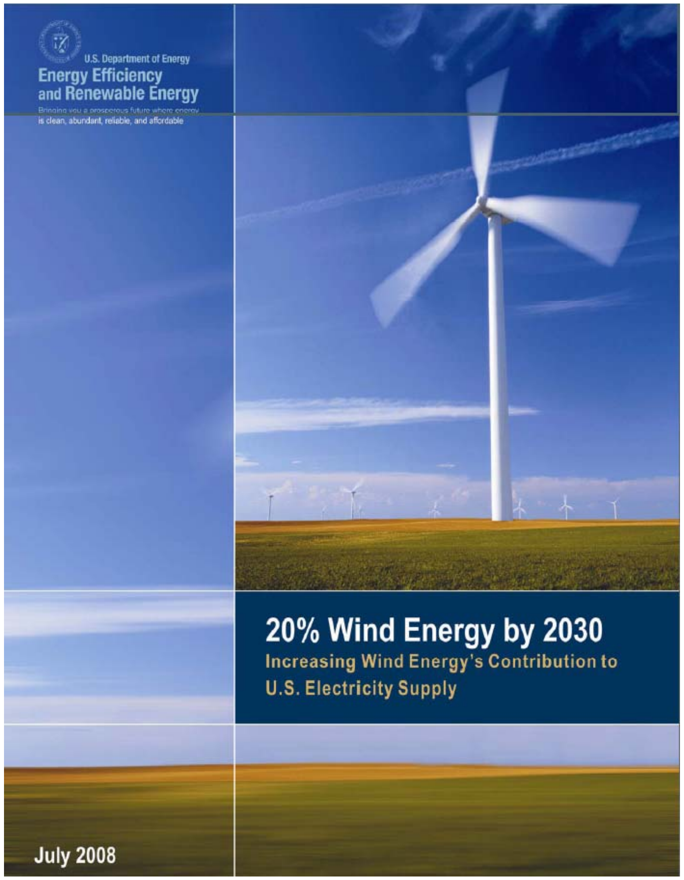
- Background
- Using wind power forecasts in market operations
  - Current status in U.S. markets
  - Handling uncertainties in system operations
  - Wind power bidding under uncertainty
- A stochastic unit commitment model with wind power uncertainty
  - Uncertainty forecasts
  - Brief model description
  - Simple case study results
- Concluding Remarks

Installed Wind Power Capacity in U.S. States



U.S. DOE's 20% Wind Energy by 2030 Report

- Explores "*a modeled energy scenario in which wind provides 20% of U.S. electricity by 2030*"
- Describes *opportunities and challenges* in several areas
  - Turbine Technology
  - Manufacturing, materials, and jobs
  - *Transmission and integration*
  - Siting and environmental effects
  - Markets
- Enhanced *wind forecasting* and better use of forecast in *system operation* is one of the key challenges
  - This is also emphasized by North American Electric Reliability Council in a recent report (NERC, 2009)



Project: "Development and Deployment of Advanced Wind Forecasting Techniques"

Goal: To contribute to efficient large-scale integration of wind power by developing improved wind forecasting methods and better integration of advanced wind power forecasts into system and plant operations.

Collaborators:	Institute for Systems and Computer Engineering of Porto (INESC Porto), Portugal
Industry Partners:	Horizon Wind Energy and Midwest ISO (MISO)
Sponsor:	U.S. Dept. of Energy (Wind and Water Power Program)

The project consists of two main parts:

- Wind power forecasting
  - Review and assess existing methodologies
  - Develop and test new and improved algorithms

- Integration of forecasts into operations (power system and wind power plants)
  - Review and assess current practices
  - Propose and test new and improved approaches, methods and criteria

Wind Power Forecasting: State-of-the Art 2009

- A comprehensive overview of developments in wind power forecasting
  - 200+ pages, 360 references
  - Electronic version available online at Argonne website
  - A brief look at the contents
    - numerical weather prediction models
    - wind power forecast definitions
      - time horizons, reference models, regional forecasts etc.
    - detailed literature overview of WPF models
      - overview of commercial/operational forecasting systems
    - uncertainty in WPF
      - uncertainty representation, estimation methods, techniques for quality evaluation etc.
    - requirements and pre-requisites for WPF models
    - using WPF in power system operation
      - unit commitment with WPF

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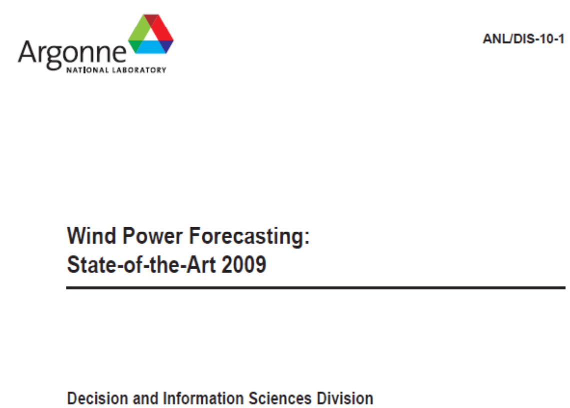

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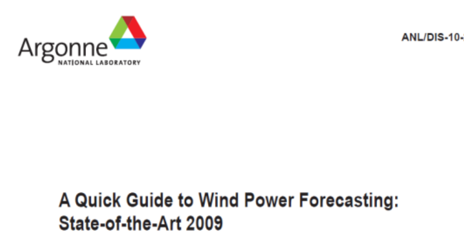
Wind Power Forecasting: State-of-the-Art 2009

Decision and Information Sciences Division



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A Quick Guide to Wind Power Forecasting: State-of-the-Art 2009

- *State of the Art Quick Guide* provided – summary of main findings from the State of the Art overview

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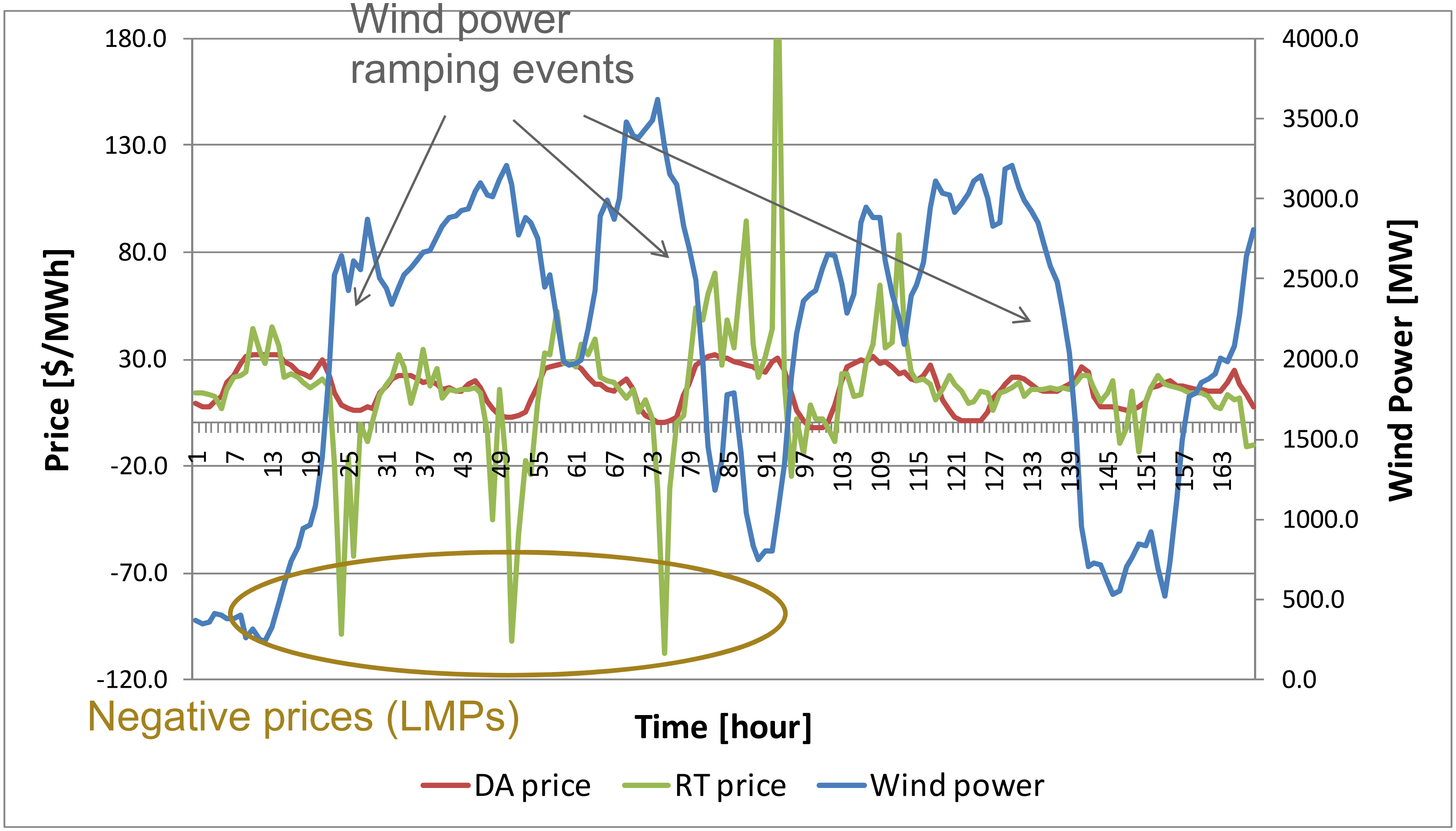
Does Wind Power Influence Market Operations?

Midwest ISO Wind Power and Iowa LMPs, May 11-17, 2009:*



*MEC Interface

Day-Ahead vs. Real-time Prices in Midwest ISO 2009

- Average prices

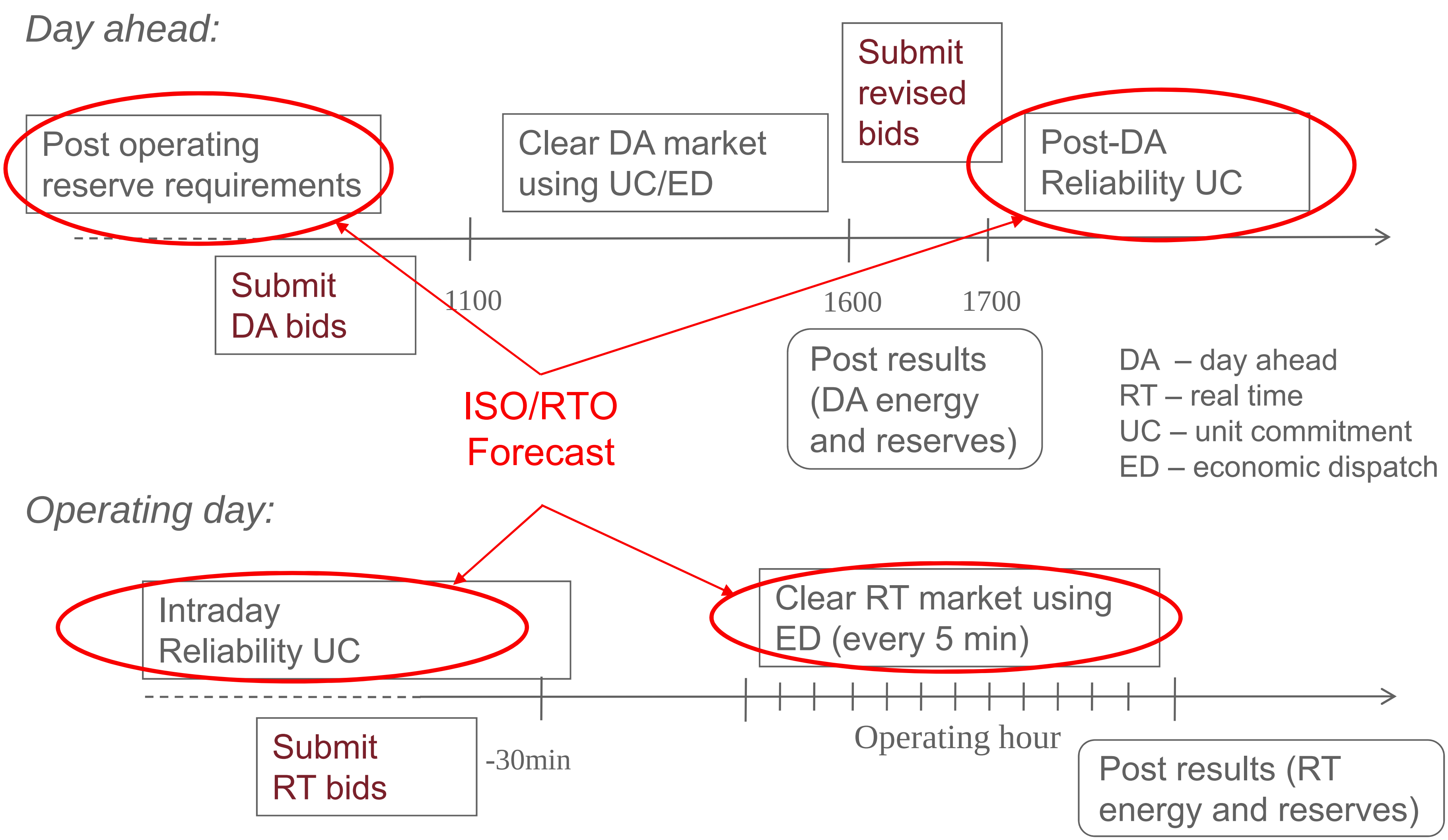
	IA: MEC Interface	IL: Illinois Hub	IN: Cinergy Hub	OH: FE Hub
DA price	24.56	26.05	29.46	30.63
RT price	23.14	24.51	28.98	30.22
DA-RT Difference	**1.42**	**1.54**	**0.48**	**0.41**

- Standard deviation prices

	IA: MEC Interface	IL: Illinois Hub	IN: Cinergy Hub	OH: FE Hub
DA price	12.74	11.29	10.50	10.71
RT price	20.26	19.23	17.40	18.22

Steps in U.S. Electricity Market Operations

(based on Midwest ISO)



Wind Power and Market Operations in selected US Markets

	MISO	NYISO	PJM	ERCOT	CAISO
Wind Cap. [MW]	Ca. 7,600	Ca. 1300	Ca. 2500	Ca. 9000	Ca. 3000
Peak load [MW]	116,030 (7/31-06)	33,939 (8/2-06)	144,644 (8/2-06)	62,339 (8/17-06)	50,270 (7/24-06)
Centralized unit commit.	Yes	Yes	Yes	No	Yes
Congestion management	LMP	LMP	LMP	Zonal	LMP
Co-opt. of energy and reserves	Yes (DA and RT)	Yes (DA and RT)	Yes, but limited	No	Yes (DA and RT)
Dispatch frequency	5 min	5 min	5 min	15 min	5 min
Wind power forecasting	**Since 2008**	**Since 2008**	**Since 2009**	**Since 2008**	**Since 2004**

Wind Power Forecasting at Midwest ISO

- Forecast system introduced in 2008

- Multiple uses of forecast
  - Day-Ahead Reliability Assessment Commitment
  - Intraday Reliability Assessment Commitment
  - Transmission security planning
  - Transmission outage coordination
  - Developing ramp forecasting system

- New market product under consideration: Dispatchable Intermittent
  - Wind power handled more like a traditional generation resource
  - Submits bids (quantity and price) in day-ahead and real-time markets
  - Max quantity bid limit based on forecast
  - More efficient curtailment and better pricing
  - Similar rules already in place in New York ISO

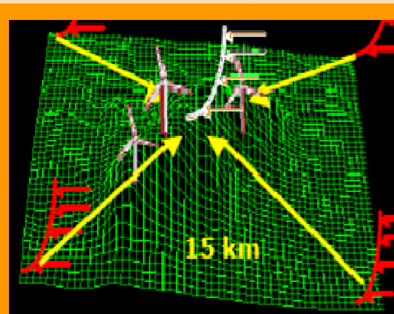
Wind Forecasts are the Result of Combination of Models and Diverse Set of Input Data

NWP Output Data

Weather Data

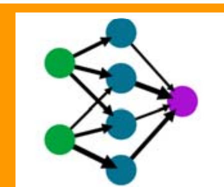
Off-site Met Data

Site Power Gen & Met Data



Physical Models

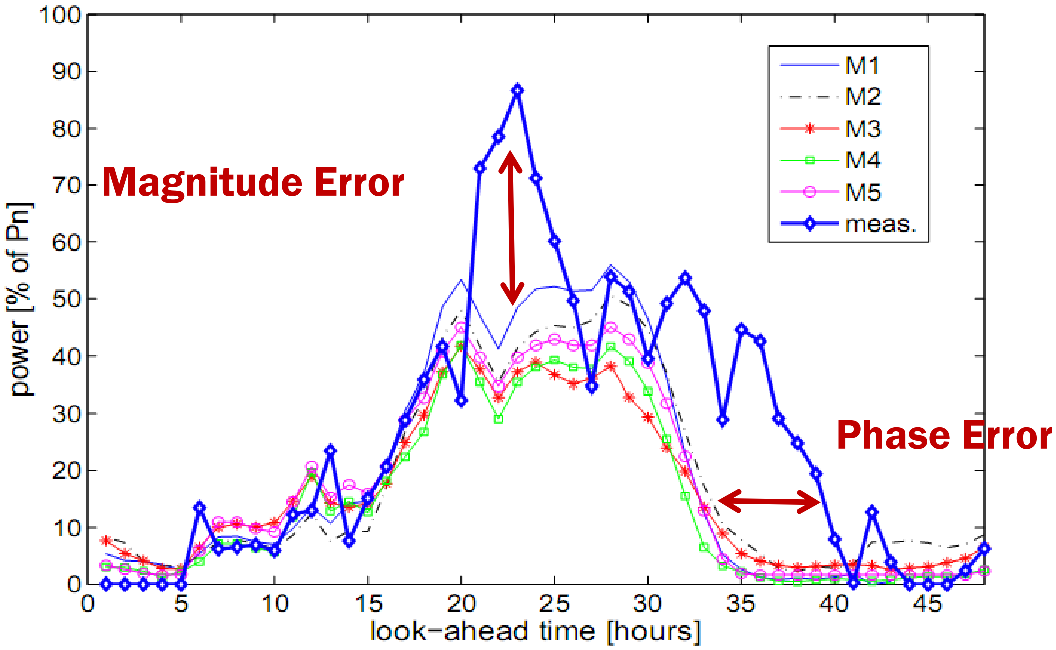
$$X_t = c + \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t.$$



Statistical Models

Forecast Results

Wind Power Forecasts are not Perfect…..



Error sources:

Error in meteorological forecasts

Errors in wind-to-power conversion process

Errors in SCADA information (wind power and met data)

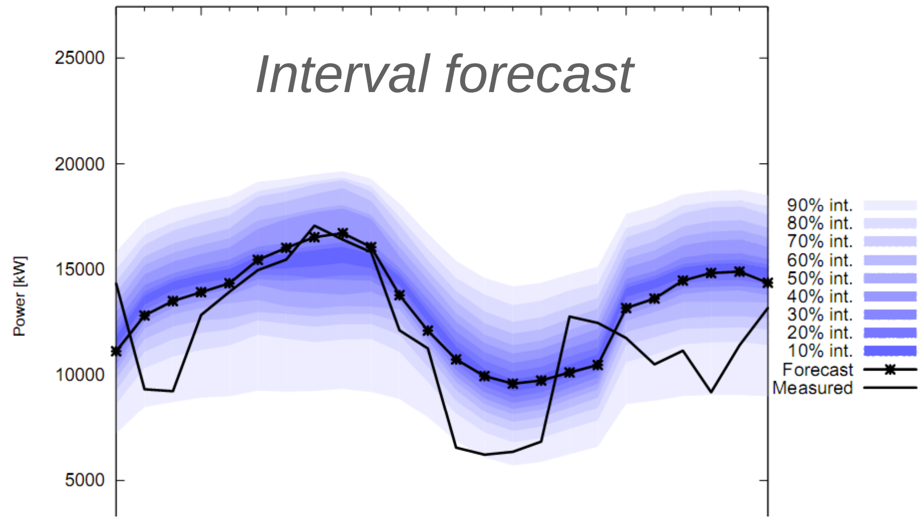
- Error depends on several factors
  - Prediction horizon
  - Time of the year
  - Terrain complexity
  - Spatial smoothing effect
  - Level of predicted power

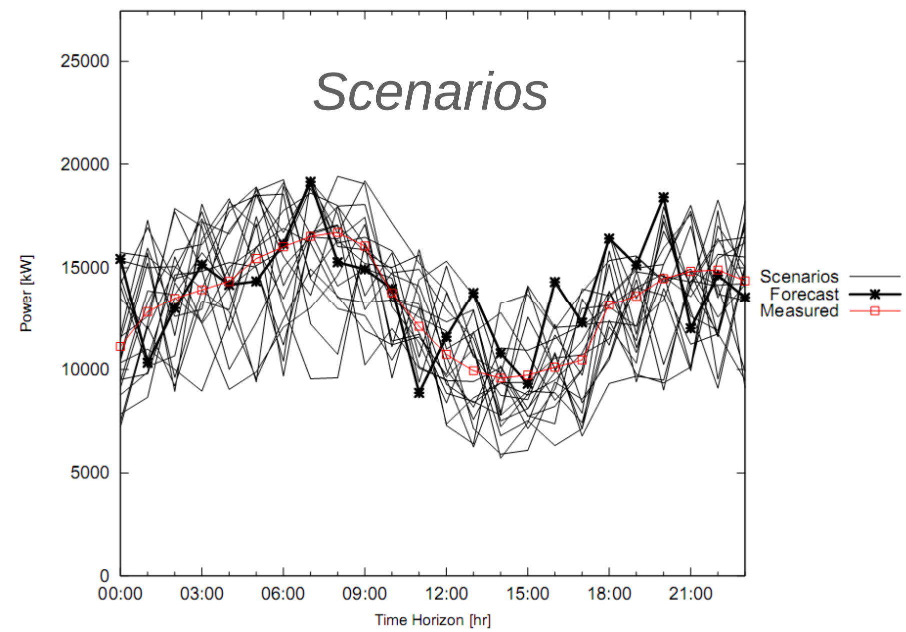
What is the best way to handle these uncertainties?
What is the impact on cost and reliability?

Representing Uncertainty in Wind Power Forecasts

Uncertainty Representation	
Probabilistic	Probability Mass Function
	Probability Density Function
	Quantiles
	Interval Forecasts
Risk Indices	Meteo Risk Index
	Prediction Risk Index
Scenarios of Generation	Scenarios with temporal dependency
	Scenarios with spatial/temporal dependency

Wind Power Forecasting: State-of-the Art 2009





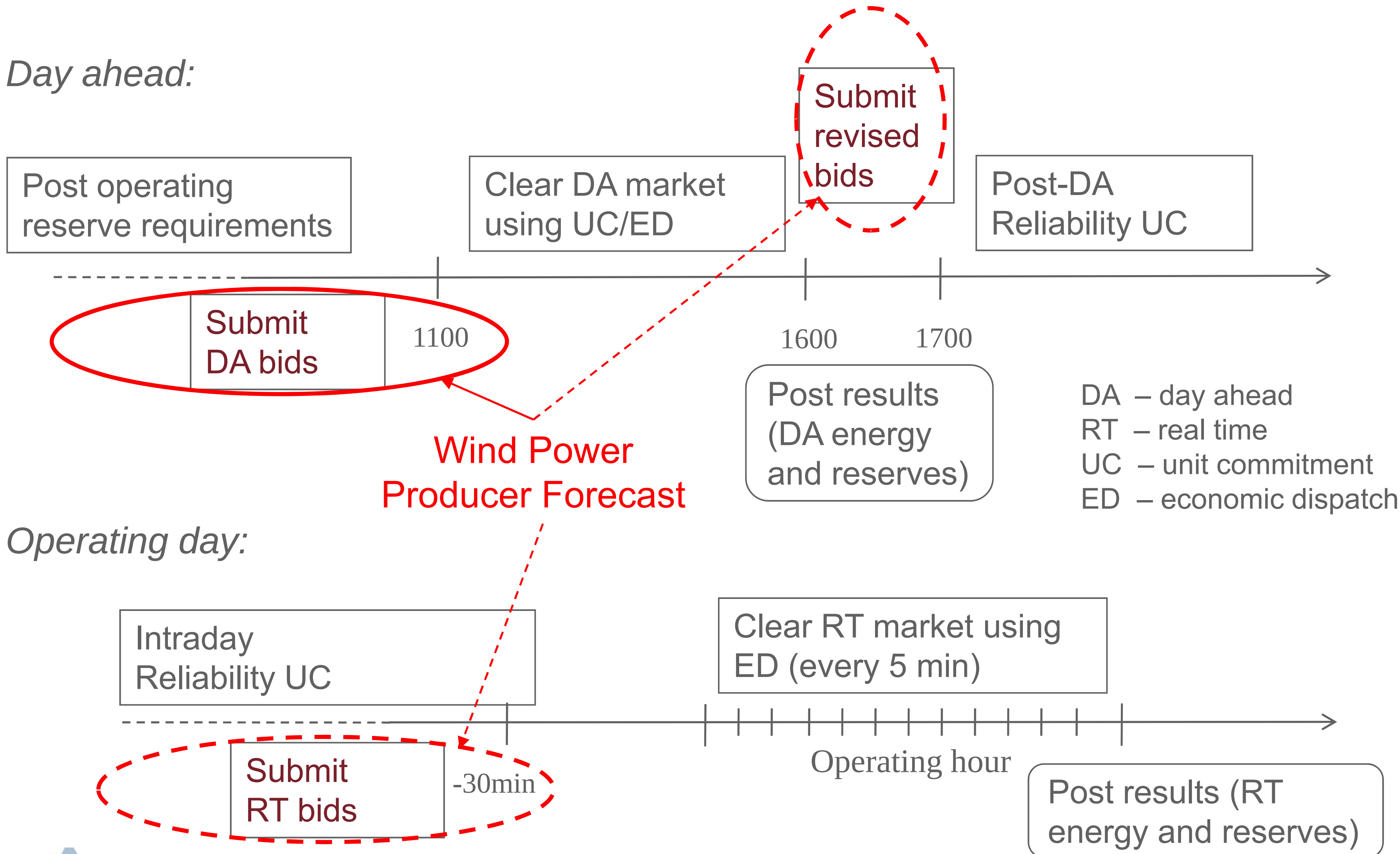
Deterministic vs. Stochastic Approach to Commitment and Reliability

- How to deal with *increased* uncertainty in system operation?
  - How to account for load uncertainty, generator outages, *and wind uncertainty* in the commitment of resources?

- Deterministic unit commitment and reserve requirements
  - Traditional approach used in industry
  - Deterministic optimization problem w/reliability constraints
  - Solution may deviate from economic optimum
  - *Need to revisit current operating reserve requirements*

- Stochastic unit commitment
  - Explicit representation of uncertainty in problem formulation
  - Minimization of *expected costs*
  - May become computationally too intensive
  - *Increasing relevance due to additional uncertainty from wind power*
  - Some references on stochastic UC with wind
    - WILMAR model from Denmark (Risø National Laboratory): http://www.wilmar.risoe.dk/
    - P.A. Ruiz, C.R. Philbrick, and P.W. Sauer, "Wind Power Day-Ahead Uncertainty Management through Stochastic Unit Commitment Policies," *Proc. Power Systems Conf. and Ex.*, March 2009.

Wind Power Forecasting for Wind Power Producers



A Model for Wind Power Bidding in the Day-Ahead Market

Profit, π_h, from bidding into market in hour, *h*:

$$\pi_h = p_h^{DA} \cdot q_h^{DA} + p_h^{RT} \cdot (q_h^{RT} - q_h^{DA}) - pen \cdot dev_h$$

Day-Ahead (DA) | Real-Time (RT) | Deviation Penalty

p – price
q – quantity
pen – penalty
dev – deviation from schedule

Three stochastic variables:

$$q_h^{RT} \quad p_h^{DA} \quad p_h^{RT}$$

What is the optimal strategy?
How much to bid into DA market?

Initial results show that answer depends on:
*- Projections for wind power (**WPF**) and prices*
- Imbalance penalties (market design)
- Producer's risk preferences

Botterud A., Wang J., Bessa R.J., Keko H., Miranda V., "Risk Management and Optimal Bidding for a Wind Power Producer," IEEE Power and Energy Society, General Meeting, Minneapolis, MN, Jul. 2010.

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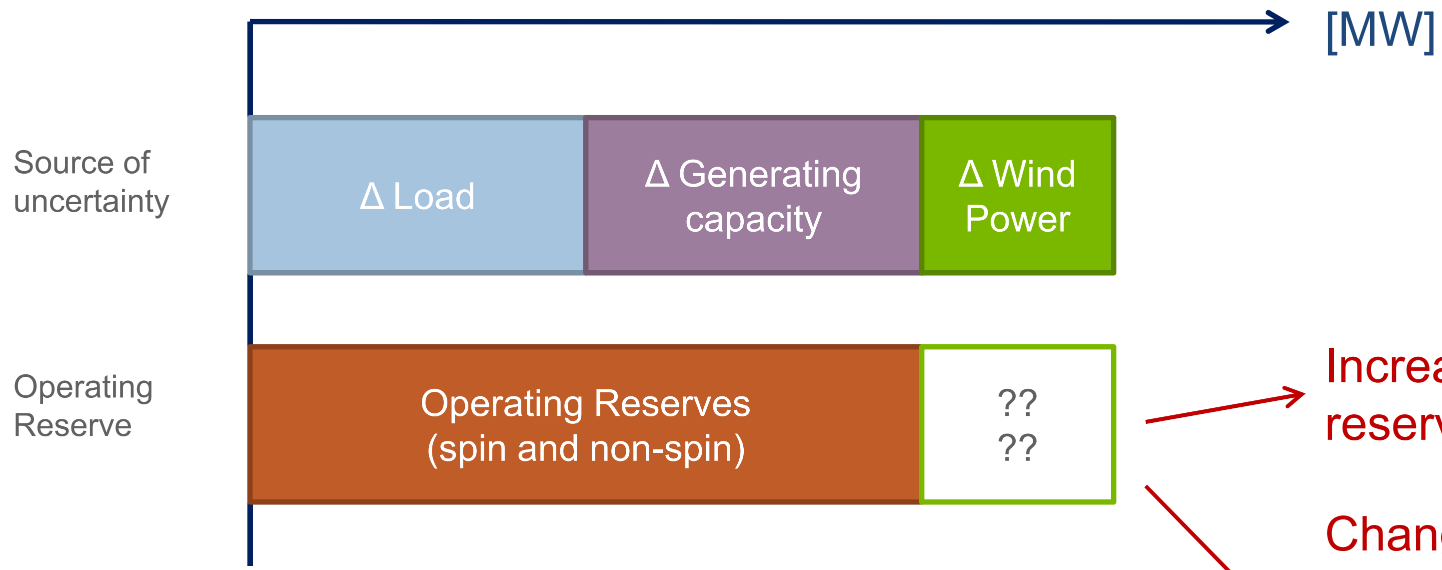
Handling Uncertainties in System/Market Operation



Increase operating reserves?

Change commitment strategy?
- Use conservative forecast
- Stochastic UC

- *What are the impacts on the system?*
  - *Reliability*
  - *System cost*
  - *Economic allocations among market participants*

A Stochastic Unit Commitment (UC) Model w/Wind Power Uncertainty

- Formulation using wind power forecast scenarios (*s*) w/probabilities (*prob*$_s$):

$$Min \sum_{s=1}^{S} prob_s \cdot \{fuelcost_{d,s} + rnscost_{d,s} + enscost_{d,s}\} + startupcost_d$$

Objective function (min daily expected cost)

subject to

$$\sum thermal\ gen_{j,h,s} + \sum windgen_{i,h,s} = load_{h,s} - ens_{h,s} \ , \ \forall \ h, s$$

Energy balance (hourly)

$$\sum available\ reserve_{j,h,s} = reservereq_{h,s} - rns_{h,s} \ , \ \forall \ h, s$$

Reserve balance (hourly)

$$commitment\ constraints_{j,d}$$

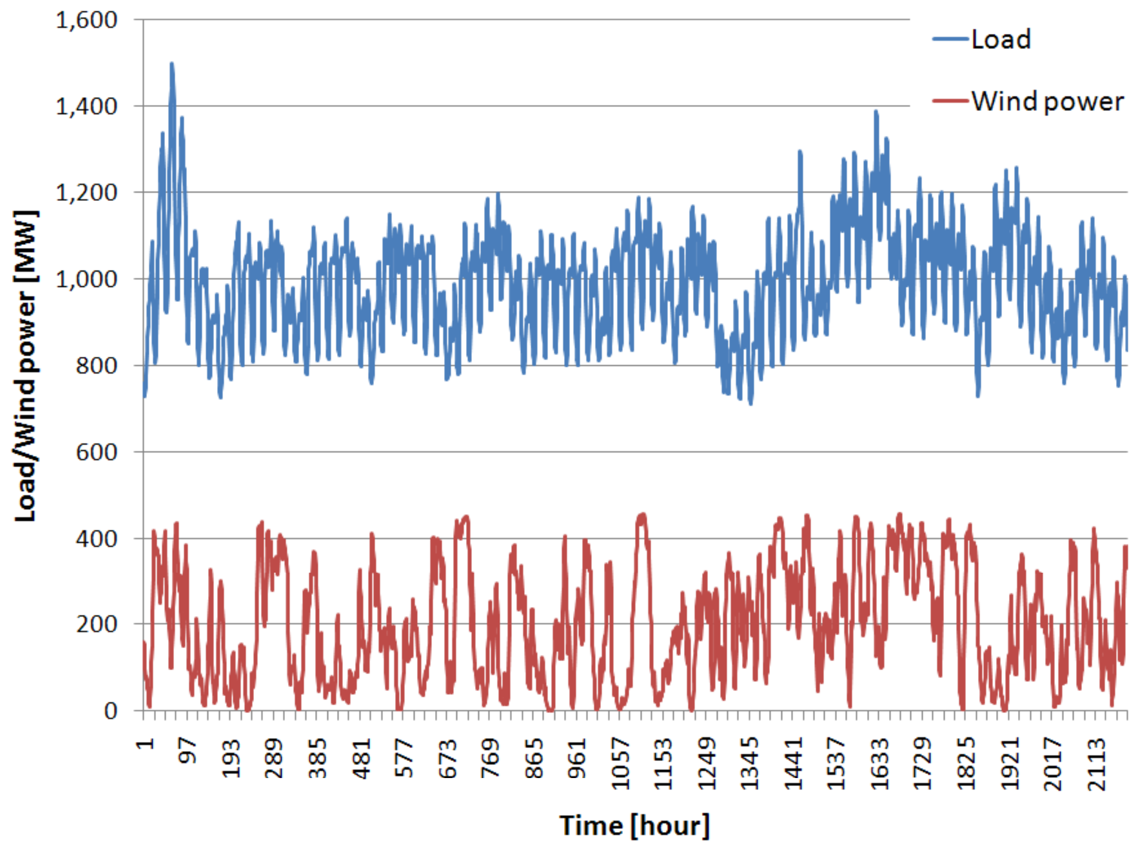
Unit commitment constraints (ramp, min. up/down)

- A two-stage stochastic mixed integer linear programming (MILP) problem
  - First-stage: commitment
  - Second-stage: dispatch

Original description: Wang J., Botterud A., Miranda V., Monteiro C., Sheble G., "Impact of Wind Power Forecasting on Unit Commitment and Dispatch," 8th Int. Workshop on Large-Scale Integration of Wind Power into Power Systems, Bremen, Germany, Oct. 2009.

UC Case Study Assumptions

- 10 thermal units: 1662 MW
  - Base, intermediate peak load
- Wind power: 500 MW
  - 2006 wind series from 15 sites in Illinois (NREL EWITS dataset)
  - 20% of load
- Peak load: 1500 MW
  - 2006 load series from Illinois
- No transmission network
- 91 days simulation period
  - Day-ahead unit commitment w/wind power forecast
  - Real-time dispatch w/realized wind power generation

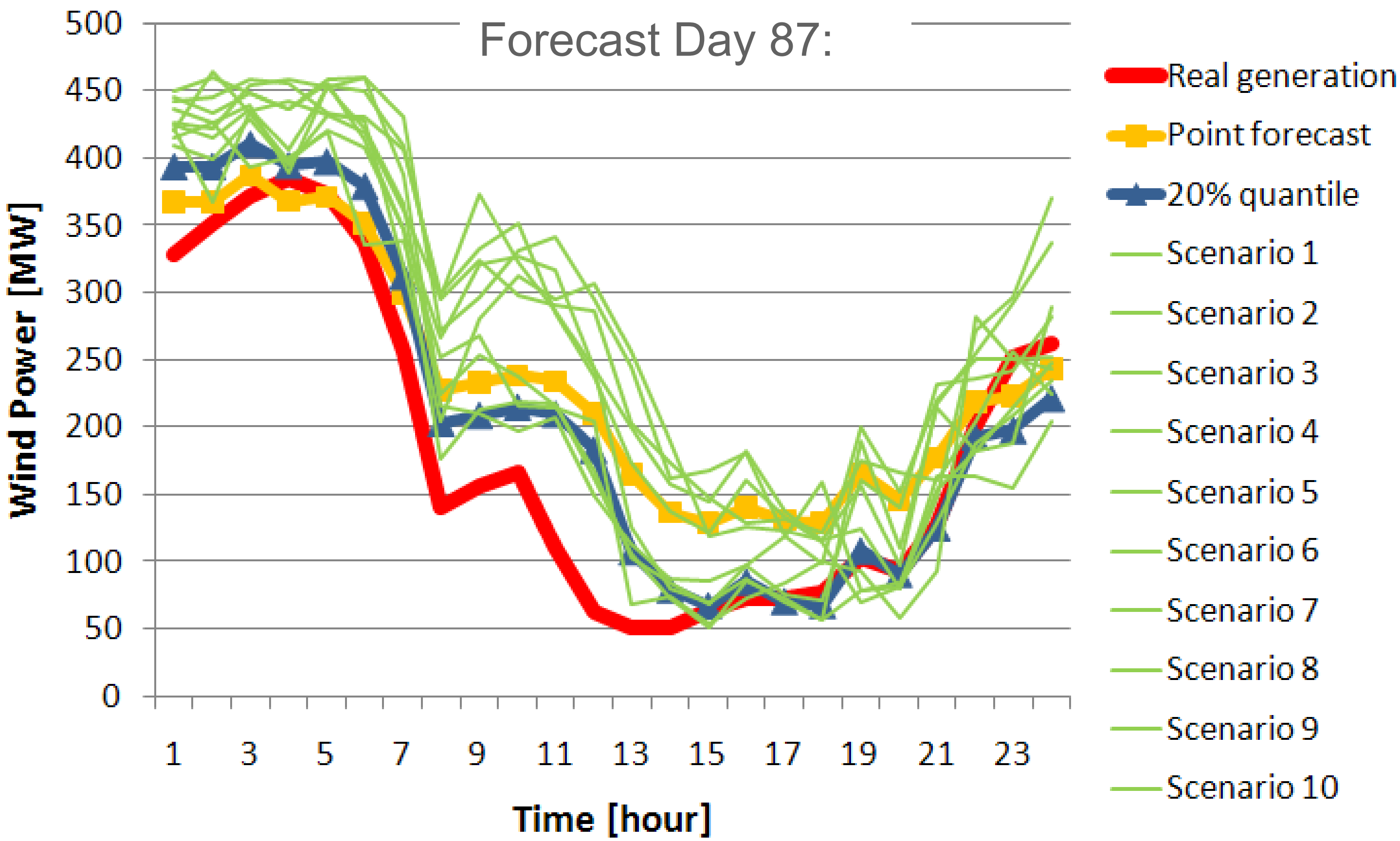


UC Case Study: Simulated Cases

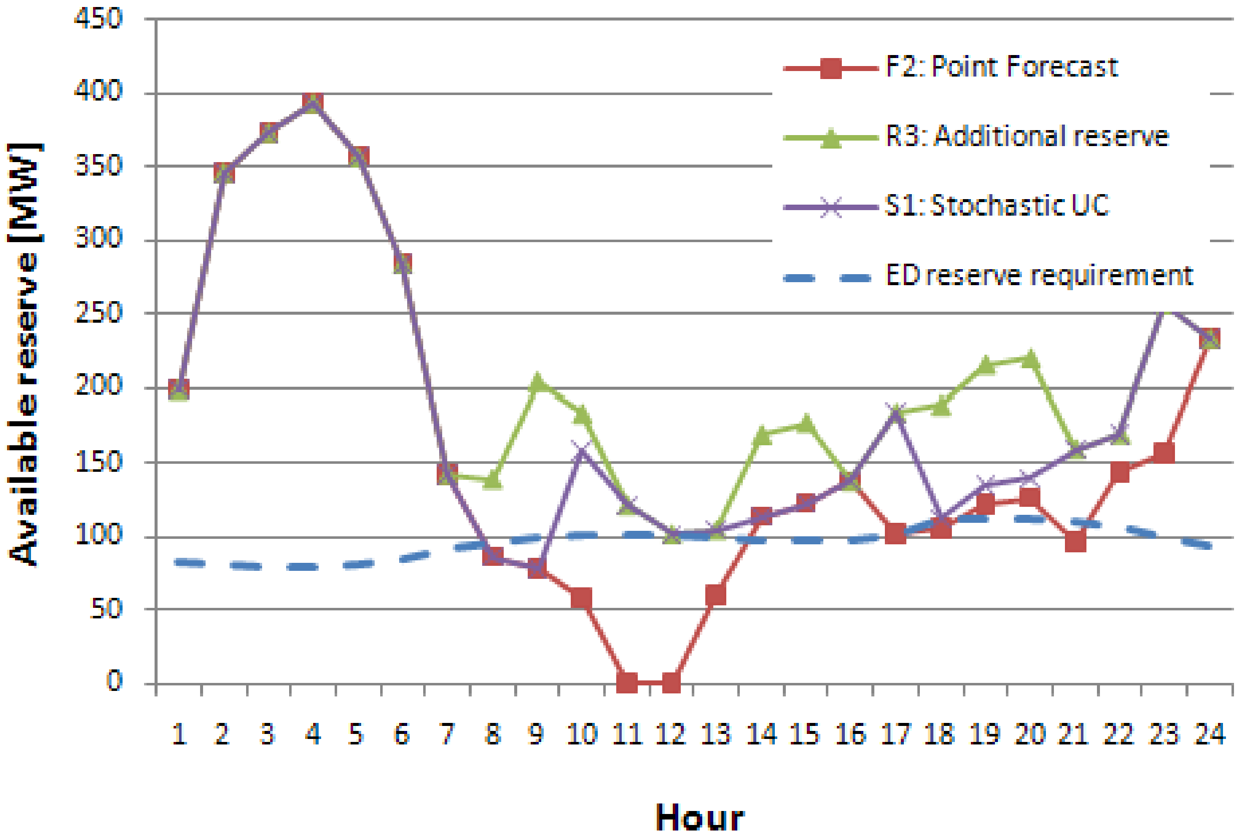
Case	Description	UC	Forecast
Subgroup1 – Different Forecasts			
F1	**Det. UC w/perfect forecast**	**Det.**	**Perfect**
F2	**Det. UC w/point forecast**	**Det.**	**Point**
F3	Det. UC w/no forecast	Det.	No
F4	**Det. UC w/20% quantile forecast**	**Det.**	**Point**
F5	Det. UC w/50% quantile forecast	Det.	Point
Subgroup 2 – Different Reserve Requirements			
R1	Det. UC w/additional reserve (20% of point forecast)	Det.	Point
R2	Det. UC w/additional reserve (point forecast – 10% quantile forecast)	Det.	Point
R3	**Det. UC w/additional reserve (15% of load)**	**Det.**	**Point**
Subgroup 3 –Stochastic UC			
S1	**Stochastic UC w/regular reserve (10% of load)**	**Stoch.**	**Scenarios**
S2	**Stochastic UC w/additional reserve (15% of load)**	**Stoch.**	**Scenarios**

Wind Power Forecast

- Day-ahead point forecast and realized wind generation from NREL EWITS (Illinois)
- Quantiles derived with quantile regression on forecast errors [Nielsen et al. 06]
- Scenarios generated with Monte-Carlo simulation based on quantile distribution (multivariate Gaussian error variable, covariance matrix) [Pinson et al. 09]

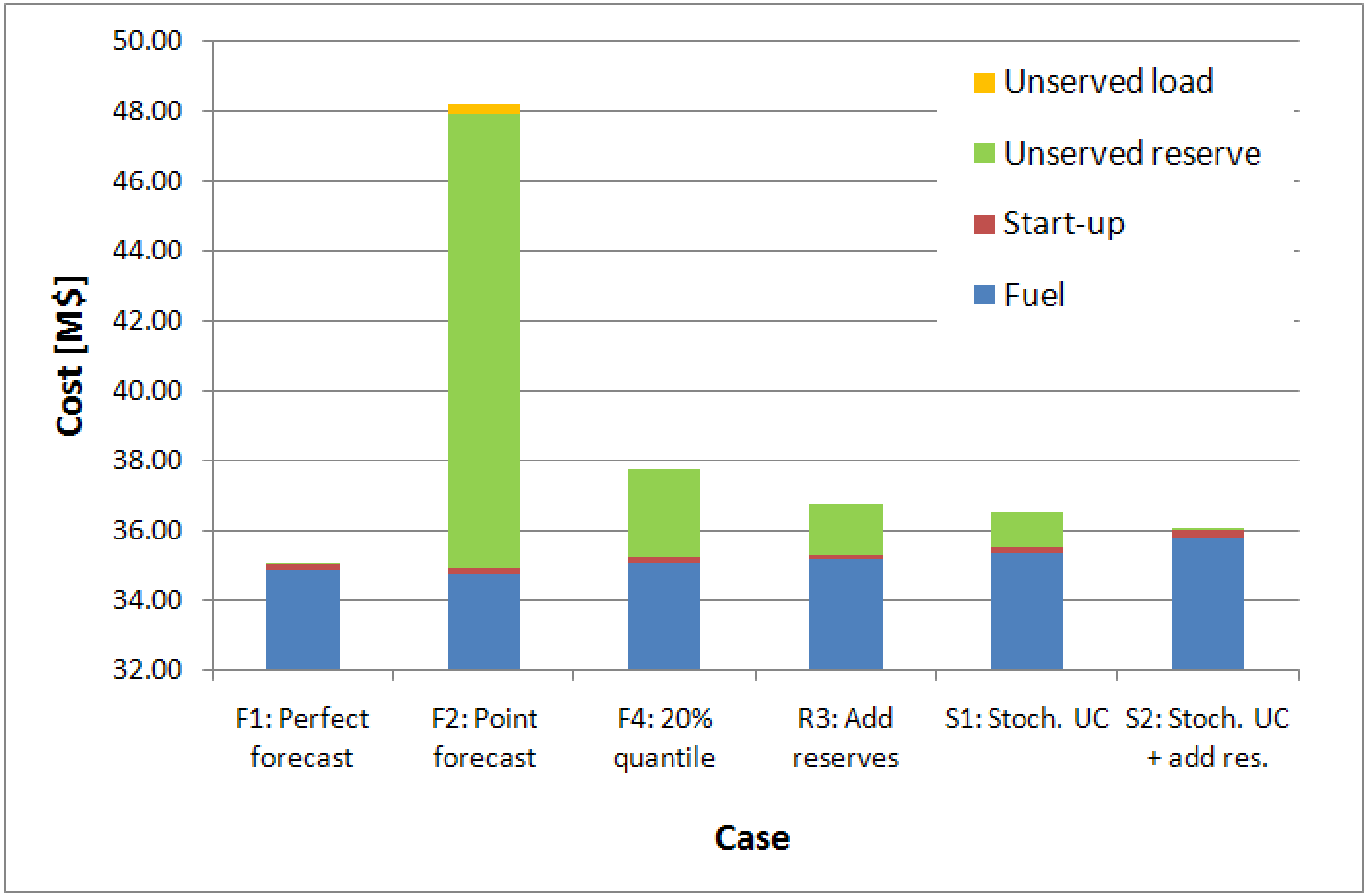


Results: Available Reserves (Day 87)



- *Deterministic point forecast (F2) over-estimates wind power generation. Insufficient commitment of thermal units lead to load curtailment*
- *Deterministic forecast with additional reserve (R3) tend to give too much commitment in some hours resulting in more reserves than needed*
- *Stochastic UC (S1) gives less reserves than R3, but some reserve scarcity in hours 8 and 9*

Comparison of Operating Costs (91 days simulation)



- *The potential value of forecasting illustrated by perfect forecast (D1)*
- *Deterministic UC with point forecast (F2) is too risky*
- *Deterministic UC w/add reserve (R3) and stochastic UC (S1) give similar total cost*
- *Stochastic UC w/add reserve gives lowest total cost*

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Concluding Remarks

- A large-scale wind power expansion requires *new approaches to system operations*
  - Make efficient use of the information in the *wind power forecast*
    - System Operator: Reserve requirements, unit commitment, dispatch
    - Wind power producer: Bidding wind power into electricity market

- Conclusions from UC case study
  - Wind power forecasting is important: *forecast uncertainty*
  - Close relationship between unit commitment strategy and reserve requirements
  - Stochastic unit commitment shows potential
  - Industry must move up the technological ladder: *adaptive, probabilistic methods*

- Future work include:
  - Improved probabilistic wind power forecast; scenario generation
    - Information theoretic learning (entropy), conditional density forecasts
  - UC Model improvements
    - Unit re-commitment between day-ahead and real-time
    - Better representation of reserves, demand-side response
    - More detailed analysis of financial settlement (energy and ancillary services)
    - Case study with real-world power system data (Illinois)
  - Further analysis of wind power bidding problem w/implications for market design

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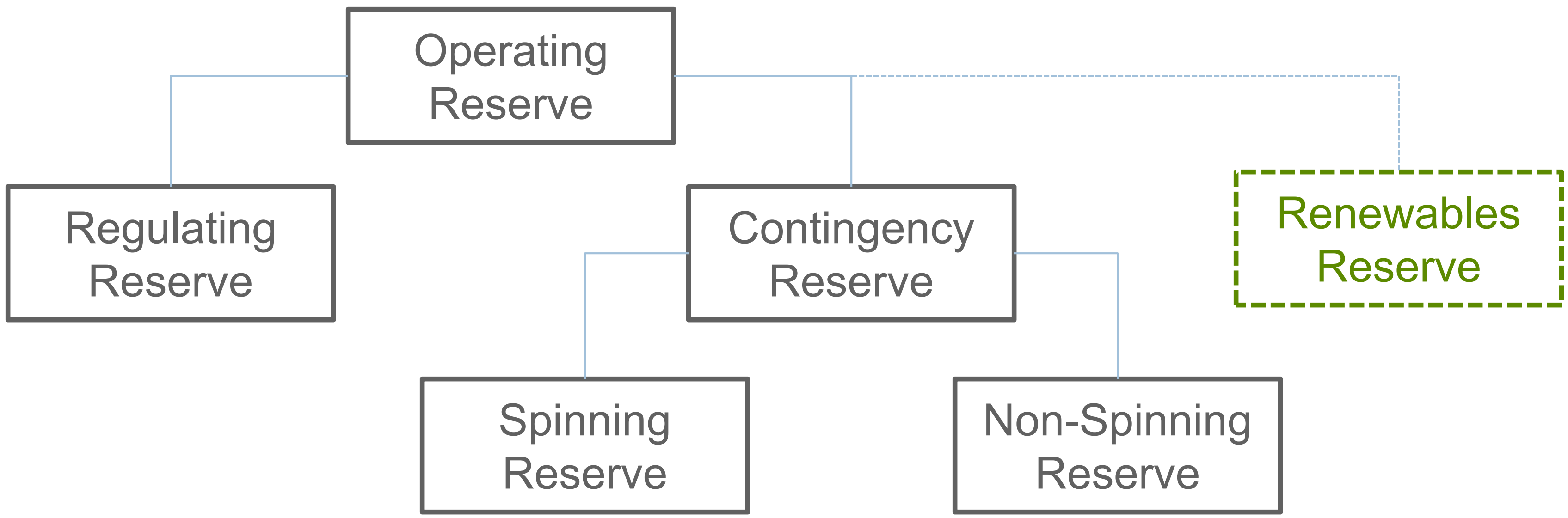
A Need to Revisit Operating Reserves



- New operating reserve products may be needed
  - Different trigger criteria?
  - Slower response time?
  - Longer restoration time?
  - Demand curve for reserves?

- Operating reserve requirements should reflect wind power forecast
  - From fixed to adaptive reserve requirements

Summary of Other Results

Scenario	No. of start-ups	Avg. Avail. Reserve [MW]	Unserved Load [MWh]	Unserved Reserve [MWh]
F1: Perfect forecast	189	177.6	0	0.6
F2: Point forecast	179	171.8	80.6	11836
F4: 20% quantile forecast	216	193.6	0	2259
R3: Add reserve	223	198.8	0	1288
S1: Stochastic UC	255	207.2	0	952
S2: Stochastic UC + res	306	237.0	0	58.8

- Stochastic UC give more available reserves and therefore less unserved reserve
- Stochastic UC give more start-ups, particularly S2
- Load shedding only occurs with deterministic point forecast (F2)