Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois

Zhi Zhou*, Audun Botterud
Computational Engineer
Argonne National Laboratory

galvincenter for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

IEEE PES Power & Energy Society®

Outline

- **Background and Motivation**
- **Market Operation Model**
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- **Test Case**
  - IL Power System
  - System Operation Analysis
- **Conclusions**

Outline

- **Background and Motivation**
- **Market Operation Model**
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- **Test Case**
  - IL Power System
  - System Operation Analysis
- **Conclusions**

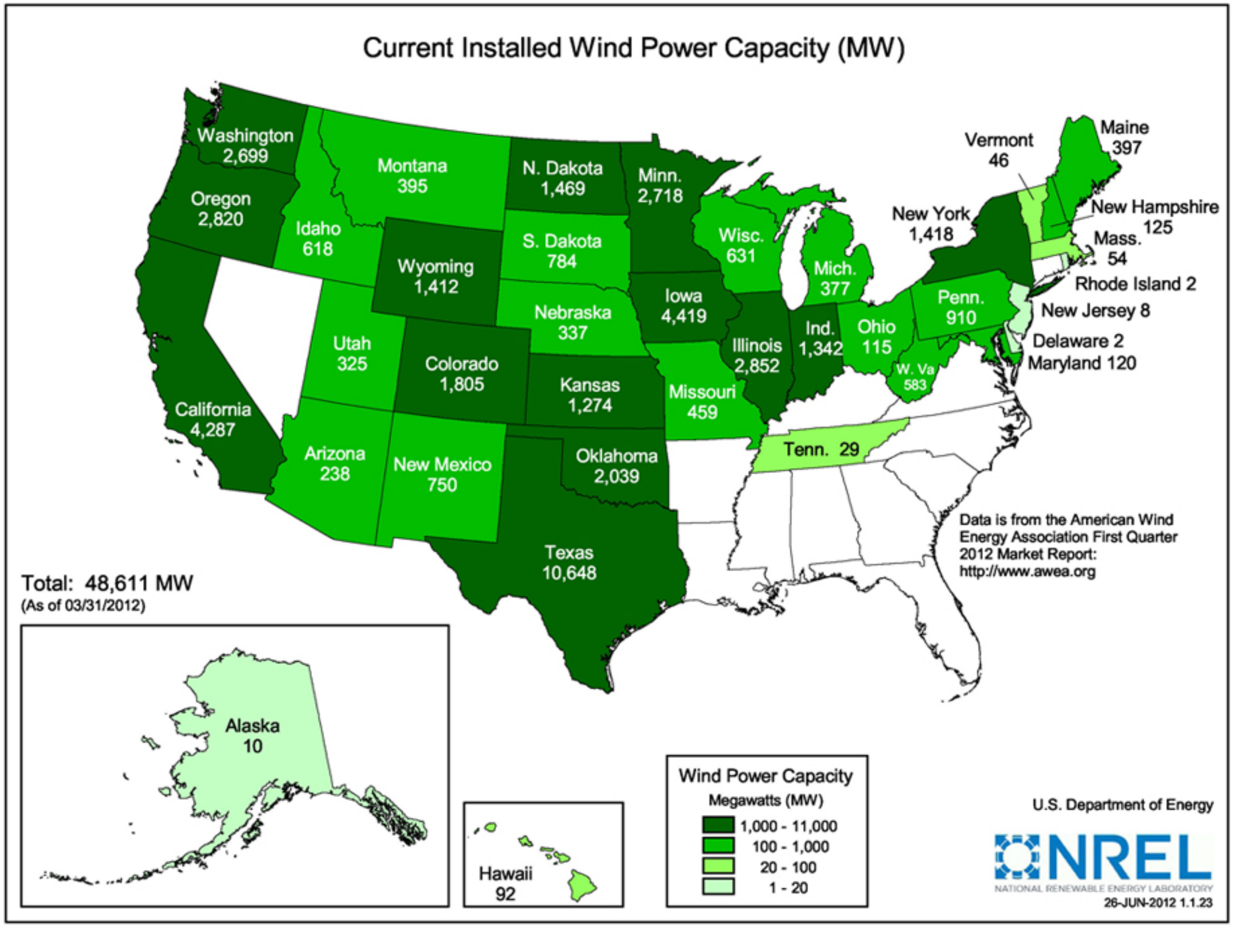
Motivation - Global Installed Wind Power Capacity

Country *(end of 2010)*	MW	%
China	42,287	21.8
USA	40,180	20.7
Germany	27,214	14.0
Spain	20,676	10.6
India	13,065	6.7
Italy	5,797	3.0
France	5,660	2.9
UK	5,204	2.7
Canada	4,009	2.1
Denmark	3,752	1.9
Rest of the world	26,546	13.7

Source: GWEC

Motivation – U.S. Wind Power Capacity

- Wind power has been rapidly integrated into the current power systems



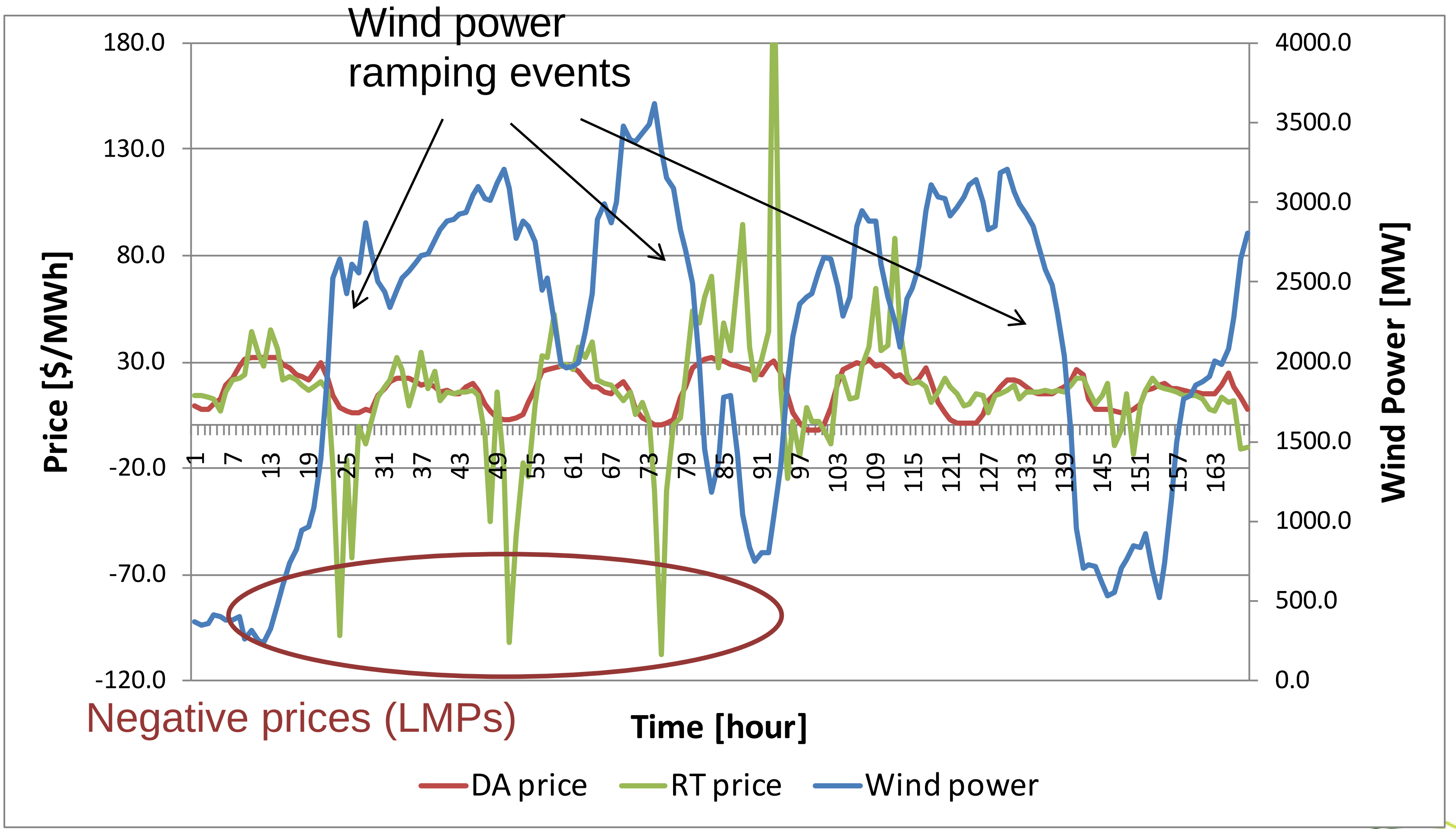
Current Installed Wind Power Capacity (MW)

Total: 48,611 MW
(As of 03/31/2012)

Data is from the American Wind Energy Association First Quarter 2012 Market Report: http://www.awea.org

Motivation - Influence on Electricity Markets Today

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



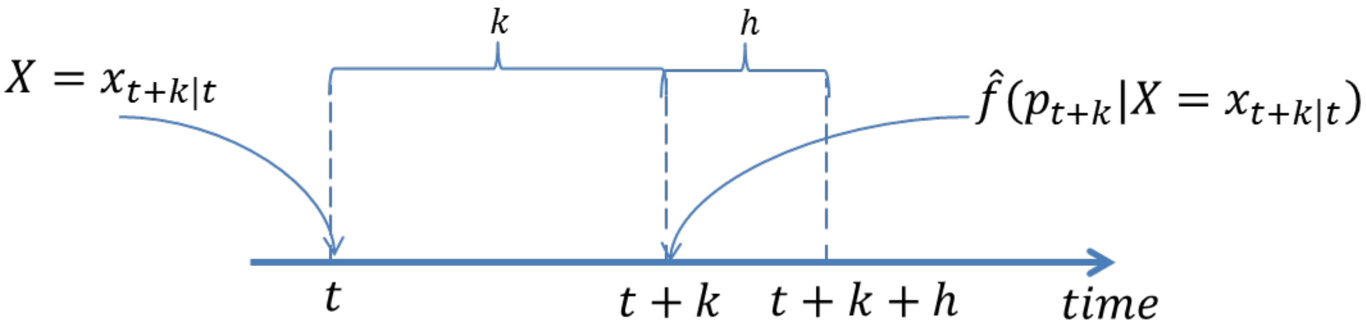
*MEC Interface

Outline

- Background and Motivation
- **Market Operation Model**
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- Test Case
  - IL Power System
  - System Operation Analysis
- Conclusions

Wind Power Probabilistic Forecasting

- Basic problem
  - Given a sequence of independent identically distributed random variables $X_1, X_2, \dots, X_t, \dots$ with common probability density function $f(x)$, how can one estimate $f(x)$?
- Problem description under wind power forecasting



h: forecasting horizon
k: look ahead time step

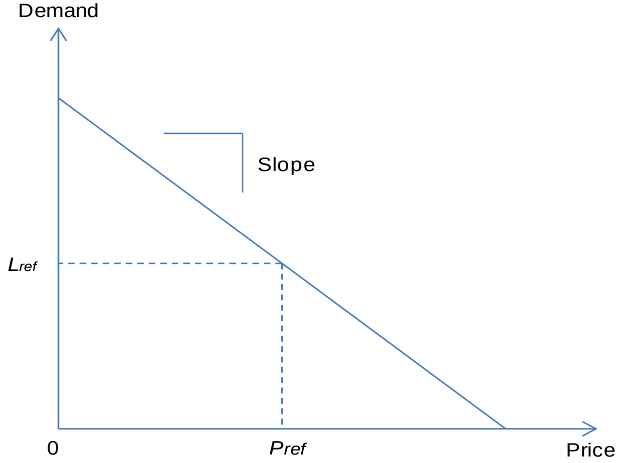
- Formulation based on kernel density estimation

$$\hat{f}(y|X=x) = \frac{1}{N \cdot h_y} \cdot \sum_{i=1}^{N} K_y\left(\frac{y - Y_i}{h_y}\right) \cdot \frac{1}{N} \cdot \sum_{i=1}^{N} K_u\left(\frac{F_X^e(u) - F_X^e(U_i)}{h_u}\right) \cdot K_v\left(\frac{F_X^e(v) - F_X^e(V_i)}{h_v}\right)$$

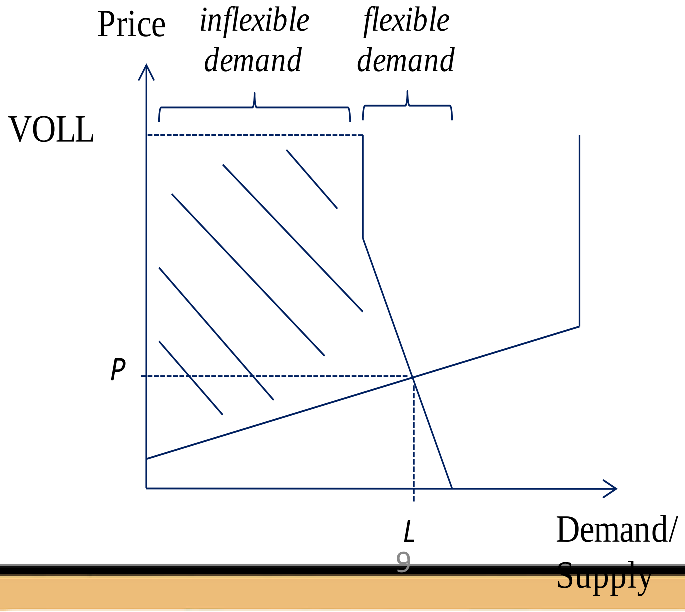
R. Bessa, et. al. "Quantile-copula density forecast for wind power uncertainty modeling," Proceedings IEEE Trondheim PowerTech 2011, Trondheim Norway, 2011.

Demand Dispatch Modeling

- A simplified linear demand dispatch curve

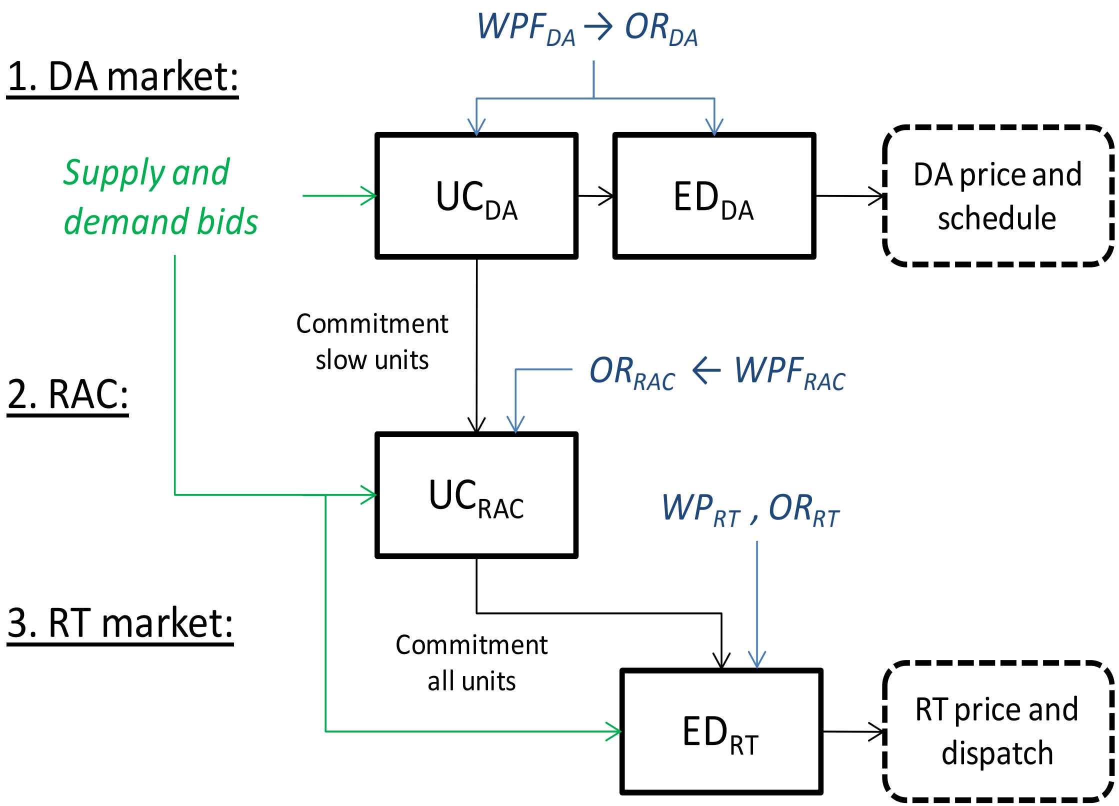


- Market clearing in a market with DD



Market Operation

- Two-settlement market clearing



1. DA market:

$WPF_{DA} \rightarrow OR_{DA}$

Supply and demand bids

UC_{DA}

ED_{DA}

DA price and schedule

Commitment slow units

2. RAC:

$OR_{RAC} \leftarrow WPF_{RAC}$

UC_{RAC}

WP_{RT} , OR_{RT}

3. RT market:

Commitment all units

ED_{RT}

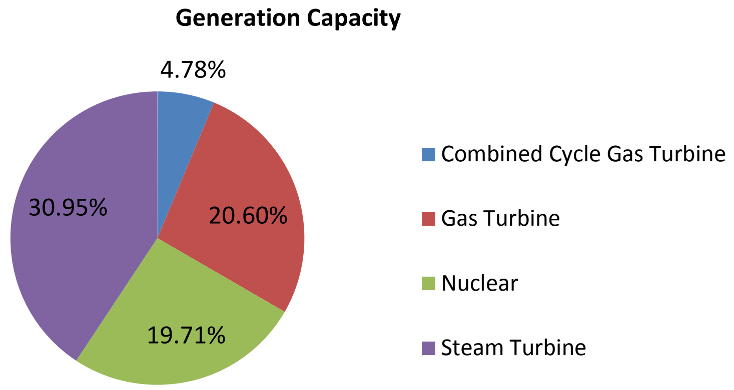
RT price and dispatch

Outline

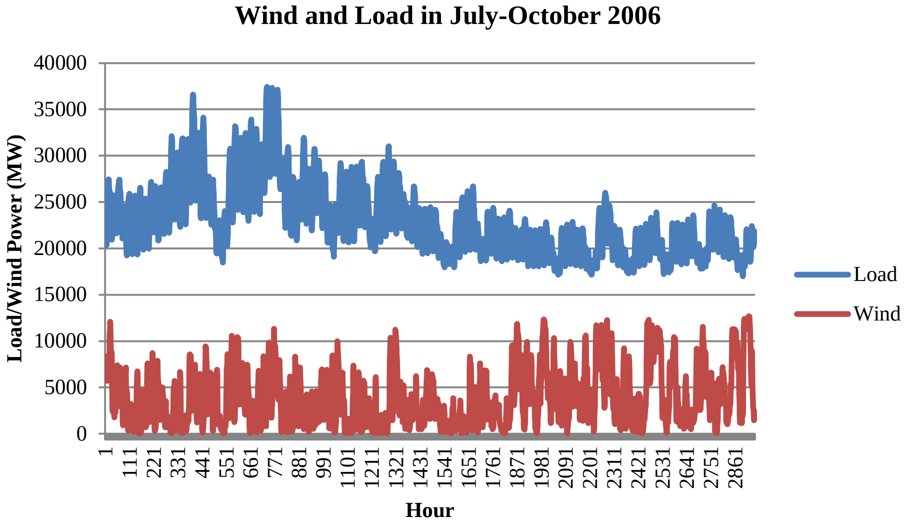
- **Background and Motivation**
- **Market Operation Model**
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- **Test Case**
  - IL Power System
  - System Operation Analysis
- **Conclusions**

Case Study Assumptions

- 210 thermal units: 41,380 MW
  - Base, intermediate, peak units
- Peak load: 37,419 MW
  - 2006 load series from Illinois
- Wind power: 14,000 MW
  - 2006 wind series from 15 sites in Illinois (NREL EWITS dataset)
  - 20% of load
- No transmission congestion
- 120 days simulation period (July 1st to October 31st, 2006)
  - Day-ahead unit commitment w/wind power point forecast
  - Real-time RAC w/ wind power scenarios



Generation Capacity



Wind and Load in July-October 2006

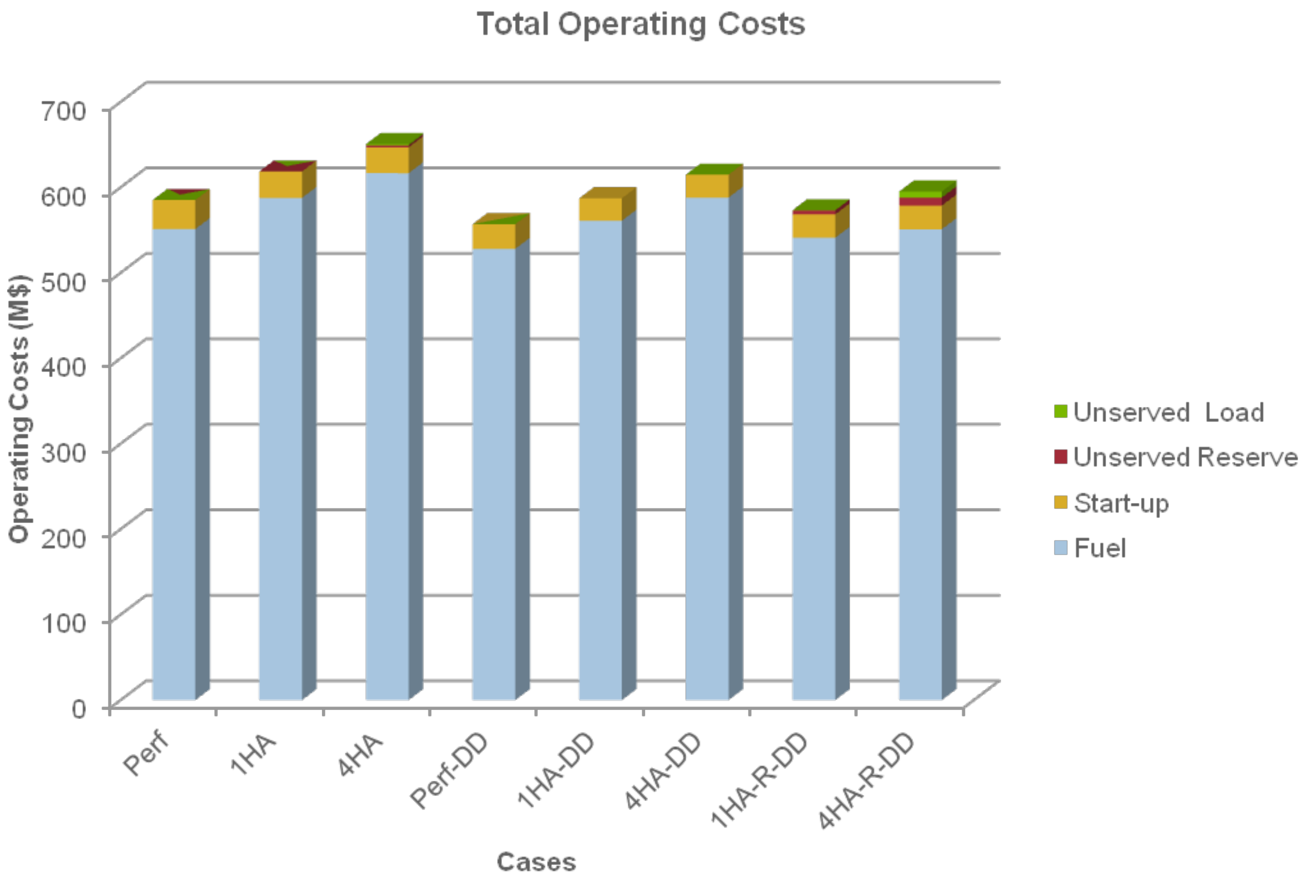
A. Botterud, et. al. "Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois," *IEEE Transactions on Sustainable Energy.*

Test Cases

Case	*WPF in DA*	*WPF in RAC*	*Wind reserves**	*Demand dispatch*
Perf	Perfect	Perfect	None	No
1HA	DA	1HA	Dynamic	No
4HA	DA	4HA	Dynamic	No
Perf-DD	Perfect	Perfect	None	Yes
1HA-DD	DA	1HA	Dynamic	Yes
4HA-DD	DA	4HA	Dynamic	Yes
1HA-R-DD	DA	1HA	Reduced	Yes
4HA-R-DD	DA	4HA	Reduced	Yes

* This additional reserve is applied at the RAC stage only to handle wind power uncertainty. All cases use a regular reserve, $OR_{reg,t}$, equal to the largest contingency (1146 MW).

Summary of Total Operating Cost



Summary of Curtailments

Case	Load		Spinning Reserve		Wind	
	MWh	hours	MWh	hours	MWh	hours
Perf	0	0	31.7	4	5206	17
1HA	0	0	2.5	1	14913	30
4HA	432.5	2	1962	5	45334	62
Perf-DD	0	0	0	0	3375	14
1HA-DD	0	0	0	0	9950	24
4HA-DD	0	0	0	0	38134	53
1HA-R-DD	49.2	1	4238	23	7048	21
4HA-R-DD	1998	4	8514	48	17462	25

Summary of Dispatch by Technology

Case	Nuclear	Steam	Comb. Cycle	Combustion	Wind	Total
Perf	30.44	25.37	0.45	0.56	11.33	68.33
1HA	30.12	25.24	0.48	1.00	11.32	68.33
4HA	29.89	25.09	0.44	1.45	11.29	68.33
Perf-DD	30.48	25.27	0.26	0.39	11.33	67.90
1HA-DD	30.18	25.41	0.31	0.72	11.33	68.12
4HA-DD	29.96	25.29	0.29	1.13	11.30	68.14
1HA-R-DD	30.27	25.32	0.32	0.48	11.33	67.90
4HA-R-DD	30.20	25.27	0.32	0.62	11.32	67.91

Summary of Start-ups for Thermal Units

Case	Nuclear	Steam	Comb. Cycle	Combustion	Total
Perf	0	2446	188	1061	3695
1HA	0	2208	220	4035	6463
4HA	0	2191	207	4999	7397
Perf-DD	0	2299	101	685	3085
1HA-DD	0	2082	119	2840	5041
4HA-DD	0	2077	118	3756	5951
1HA-R-DD	0	2195	143	1614	3952
4HA-R-DD	0	2180	141	2269	4590

Summary of Energy and Reserve Prices

Case	Energy		Spinning Reserve		Non-Spin Reserve	
	DA	RT	DA	RT	DA	RT
Perf	21.2	21.2	3.5	3.5	0.0	0.0
1HA	22.5	16.3	6.9	0.4	0.0	0.0
4HA	22.7	19.2	7.5	1.9	0.0	0.0
Perf-DD	19.7	19.7	2.9	2.9	0.0	0.0
1HA-DD	20.6	15.9	6.1	0.3	0.0	0.0
4HA-DD	20.6	15.6	6.1	0.2	0.0	0.0
1HA-R-DD	20.8	29.2	4.5	11.6	0.0	0.0
4HA-R-DD	20.7	40.6	4.4	20.8	0.0	0.0

Outline

- Background and Motivation
- Market Operation Model
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- Test Case
  - IL Power System
  - System Operation Analysis
- **Conclusions**

Conclusions

- **Demand Dispatch**
  - It reduces wind power curtailment.
  - Total operational costs are significantly reduced as well.
  - A modest amount of DD improves reliability in terms of reserve and load curtailment.
- **Probabilistic Wind Power Forecasting**
  - More accurate forecasts help reduce wind curtailment when making re-commitment decision
  - Lower operating costs, committed fewer thermal resources
- **Framework**
  - Relatively modest changes from current operational practices
  - Proposed market framework with dynamic reserves

Comments and Questions

Thank You

References:

1. A. Botterud, Z. Zhou*, et. al. "*Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois*," IEEE Transactions on Sustainable Energy.*
2. Z. Zhou, A. Botterud, *et. al.,* "Application of Probabilistic Wind Power Forecasting in Electricity Markets,", *Wind Energy*
3. R. Bessa, *et. al.* "Time-adaptive quantile-copula for wind power probabilistic forecasting", *Renewable Energy*.