Dynamic Scheduling of Operating Reserves in Electricity Markets with Wind Power

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

Staff Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software
Federal Energy Regulatory Commission

Outline

- **Background and Motivation**
- **Market Operation Model**
  - Wind Power Forecasting
  - Operating Reserve Demand Curve (ORDC)
  - System Operation with Wind Power Uncertainty and ORDC
- **Test Case**
  - IL Power System
  - System operation analysis
- **Conclusion and Future Work**

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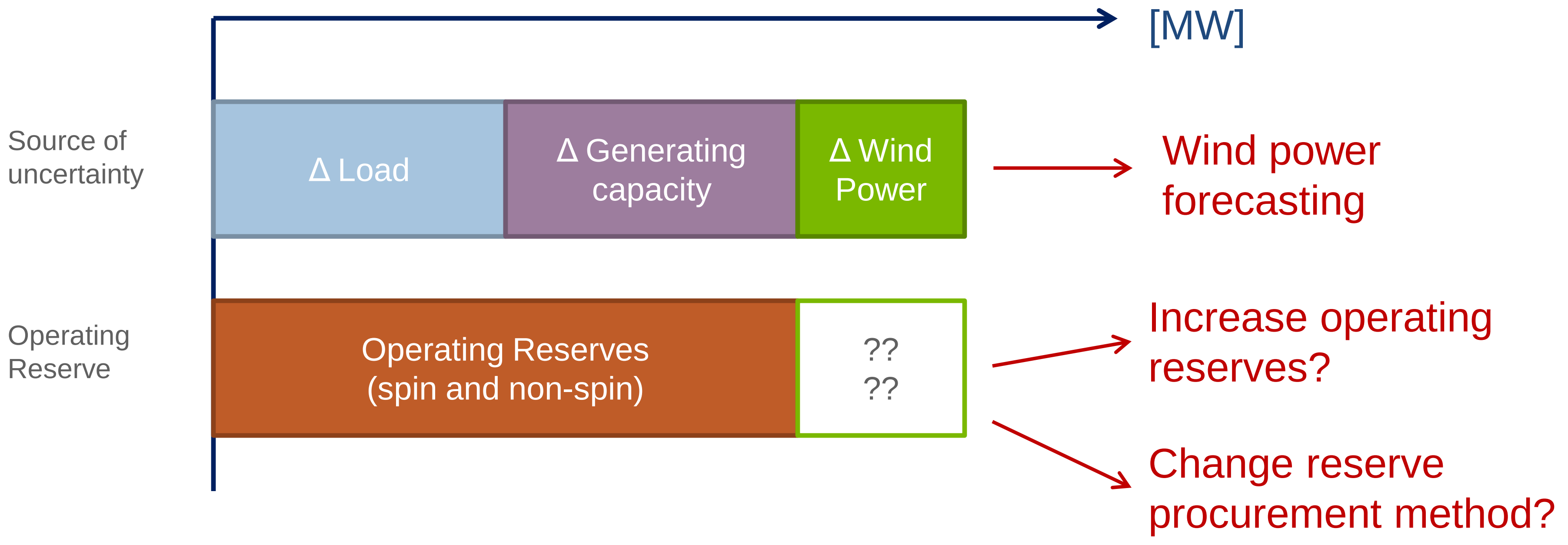
Background and Motivation

- Improved scarcity pricing
  - More accurate price signals to encourage investment in capacity
  - Sufficient revenue stream to cover costs

- How to optimally derive such demand curves
  - Represent the expected value of reserve to reliability in a probabilistic manner
  - Co-optimize energy and reserve by market mechanism

- Large scale uncertain and variable renewable energy integration
  - Renewable energy is uncertain and variable

Background and Motivation



- *What are the impacts on the system?*
  - *Reliability (curtailment,..)*
  - *Efficiency (system cost, price..)*

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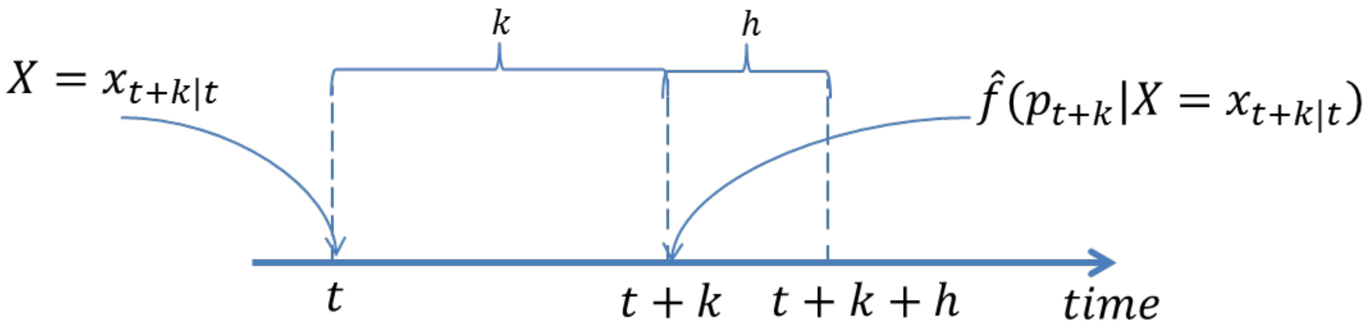
Wind Power Probabilistic Forecasting

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

- Problem description under wind power forecasting



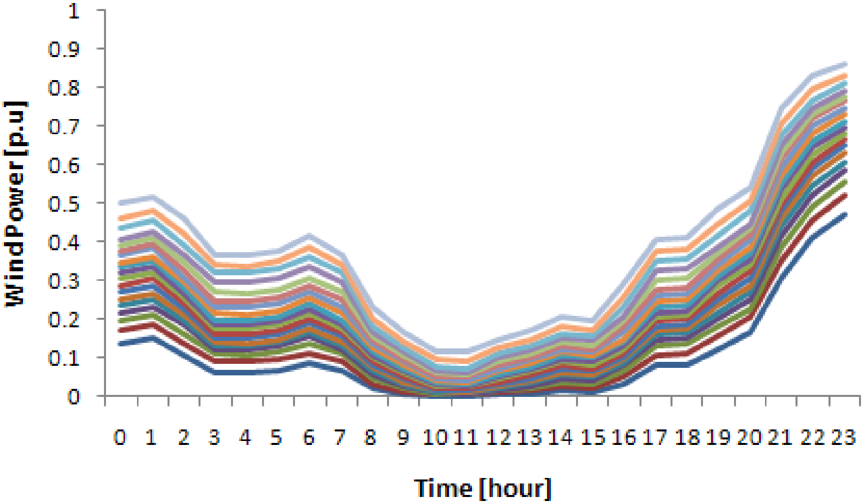
h: forecasting horizon
k: look ahead time step

- Formulation based on kernel density estimation

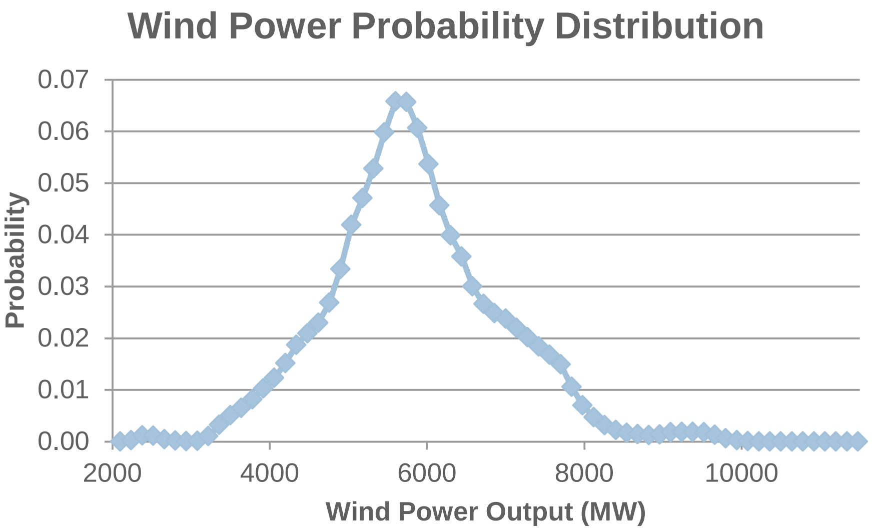
$$\hat{f}(y|X = x) = \frac{1}{N \cdot h_y} \cdot \sum_{i=1}^{N} K_y\left(\frac{y - Y_i}{h_y}\right) \cdot \frac{1}{N} \cdot \sum_{i=1}^{N} K_u\left(\frac{F_X^e(u) - F_X^e(U_i)}{h_u}\right) \cdot K_v\left(\frac{F_X^e(v) - F_X^e(V_i)}{h_v}\right)$$

Wind Power Uncertainty Representation

- Quantiles Sets



- Discretized hourly probability distribution



Operating Reserve Demand

- Idea:
  - Consider the uncertainty from both demand and supply
  - Estimate the risk of supply shortage
  - Link the cost of this risk to prices that a system operator will pay for reserves

- Uncertainty sources and representation
  - Wind power supply -> probabilistic forecasts (***W***)
  - Conventional generation units outage -> capacity outage probability table (COPT) (***G***)
  - Load -> Normally distributed forecasts error (***L***)

- Generation Margin (*M*)

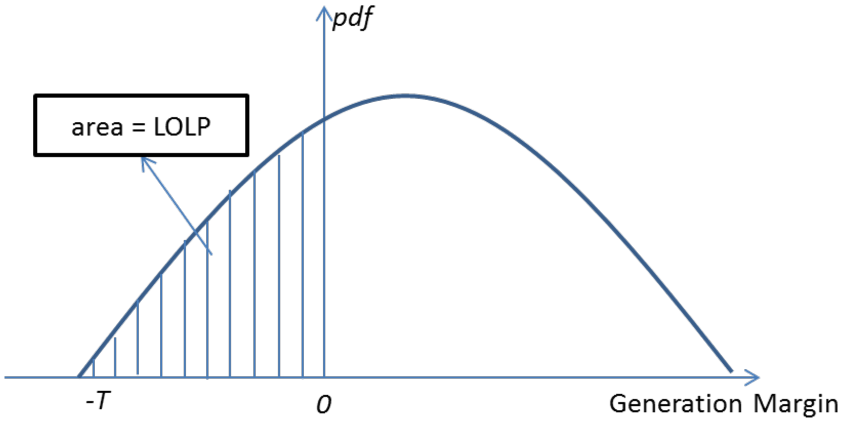
$$P_M(M = m) = P_M(W + G + (-L) = z)$$

$$= \sum_{l=-\infty}^{\infty} \sum_{g=-\infty}^{\infty} P_W(W = m + l - g) \cdot P_G(G = g) \cdot P_L(L = l)$$

From Generation Margin to Demand Curve

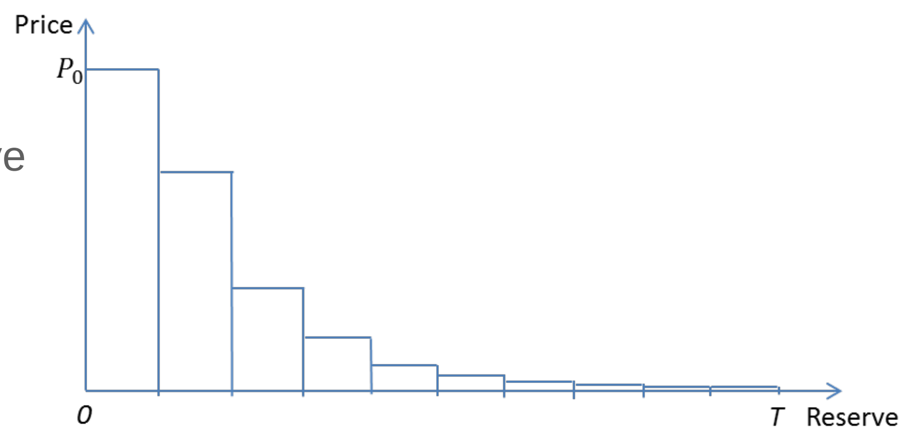
LOLP: Loss of load probability
VOLL: Value of lost load

Generation Margin Distribution



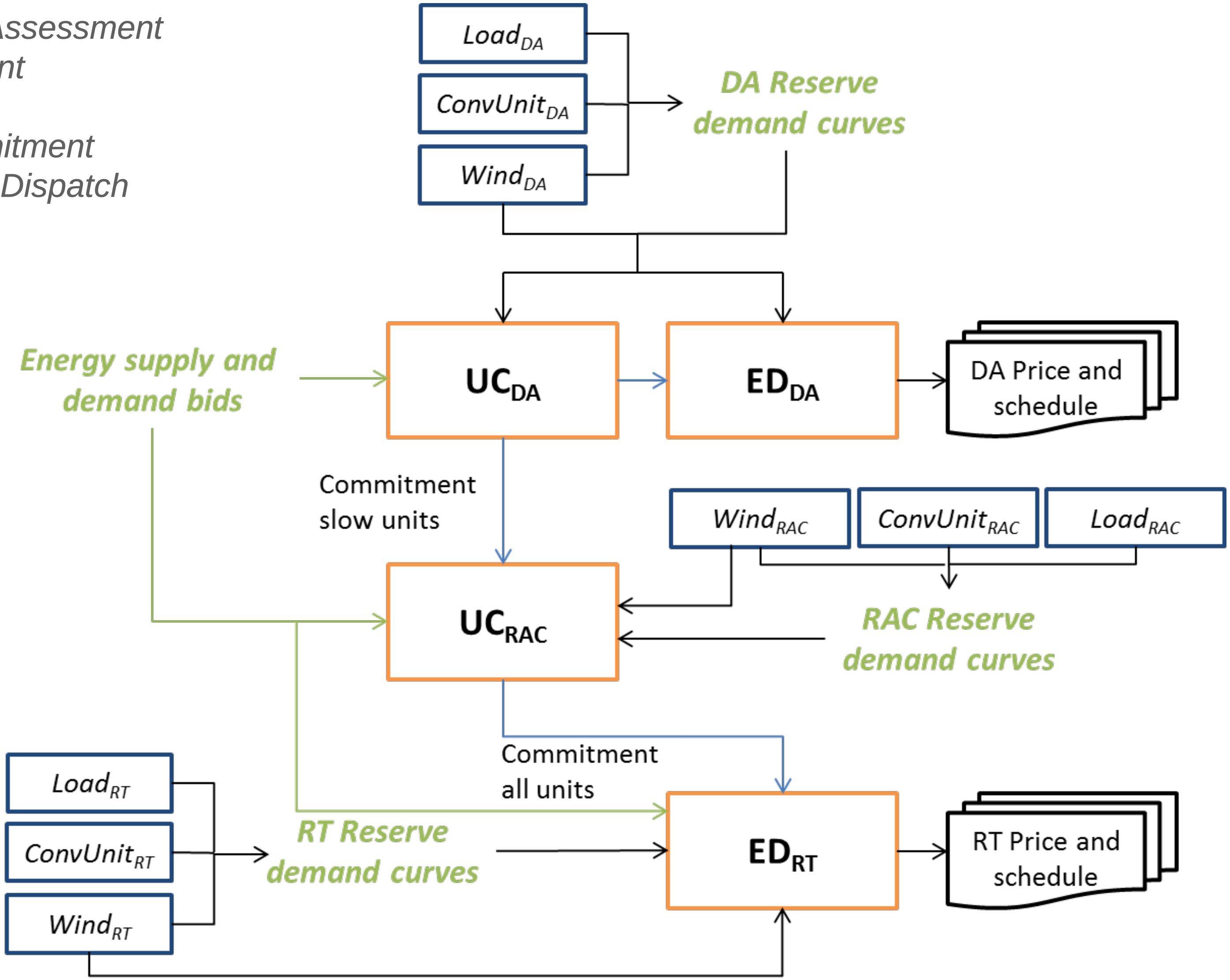
$$Price(r) = LOLP(r|m) * VOLL$$

Stepwise Operating Reserve Demand Curve



Market Operation Flow Chart

DA: Day-ahead
RAC: Reliability Assessment Commitment
RT: Real Time
UC: Unit Commitment
ED: Economic Dispatch



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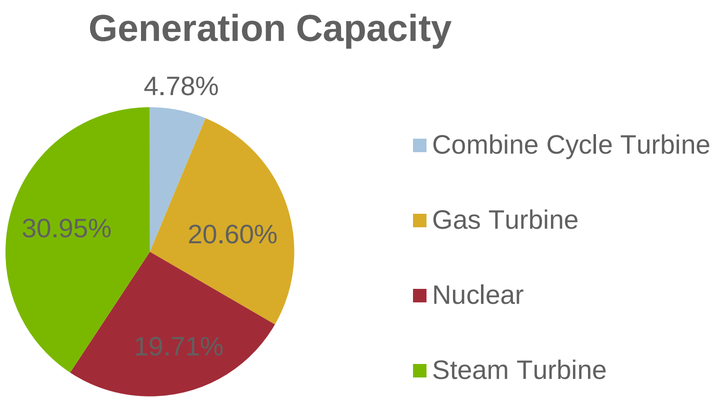
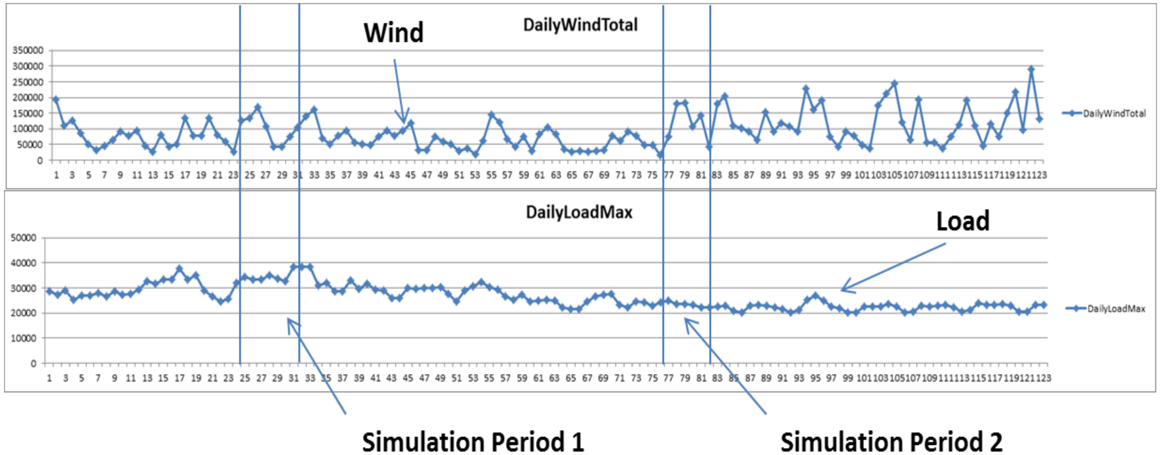
Test Case Assumptions

- 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 network
- Simulated period
  - *1*. July 24th to Aug. 2nd 2006
  - *2*. Sept. 14th to 20th, 2006
- Value of Loss Load: $3500/MWh





Case study focus is to compare:
- Various operating reserve strategies

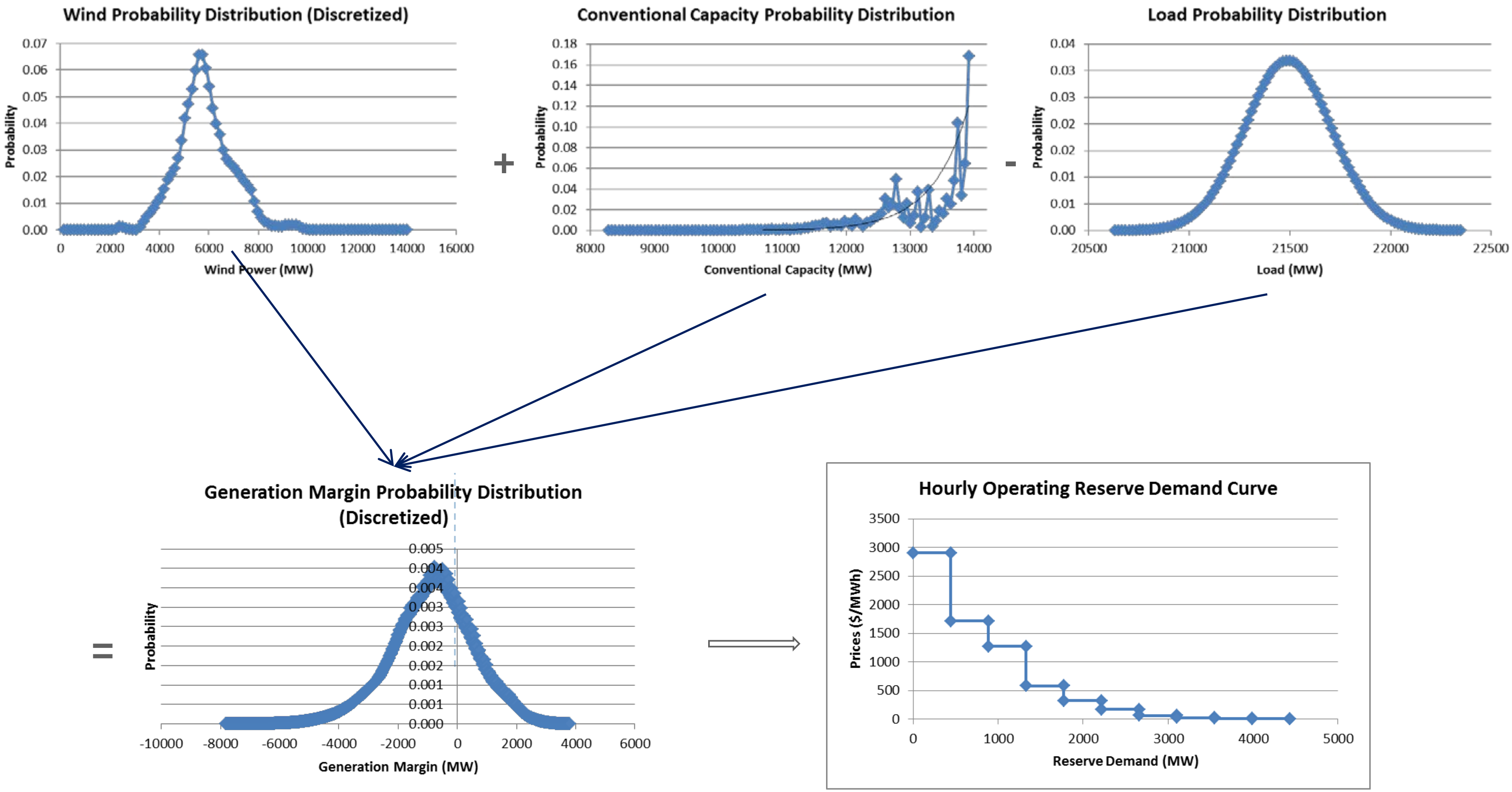
UC Case Study: Deterministic and Stochastic Cases

Case	Note	DA-UC	RAC (1 Hour-Ahead)	RT-ED
P0	**Perfect forecasts with no add. Reserve***	Perfect DA forecasts, no add. reserve*	Perfect 1 HA forecasts; no add. Reserve*	Realized wind; no add. Reserve*
P1	**No add. Reserve***	DA 50% quant., no add. reserve*	1 HA 50% quant., no add. reserve*	Realized wind; no add. reserve*
F1	**Fixed reserve**	DA 50% quant.; Fixed: DA avg. 50-5% quant.	1 HA 50% quant.; Fixed: 1 HA avg. 50-5% quant.	Realized wind; no add. reserve*
D1	**Dynamic reserve**	DA 50% quant.; DA hourly 50-5% quant.	1 HA 50% quant.; 1 HA hourly 50-5% quant.	Realized wind; no add. reserve*
DV	**Reserve curve**	DA 50% quant.; DA demand curve	1 HA 50% quant.; 1 HA demand curve	Realized wind; RT demand curve

* 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).

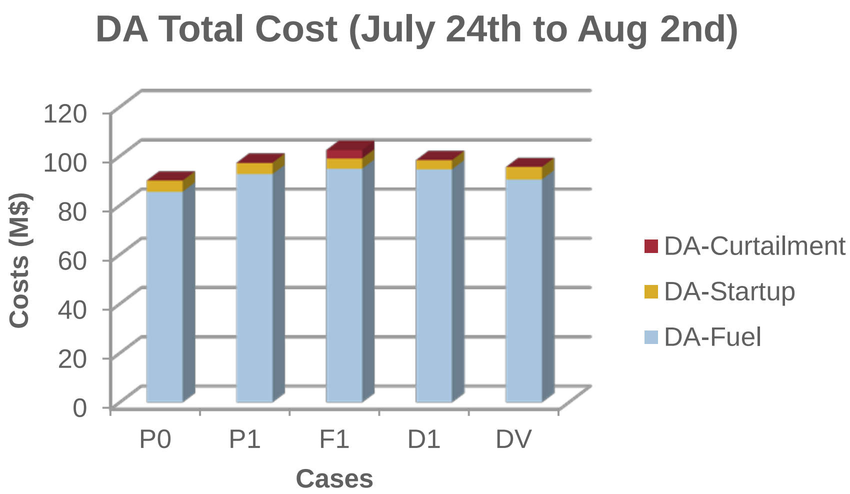
ORDC Development

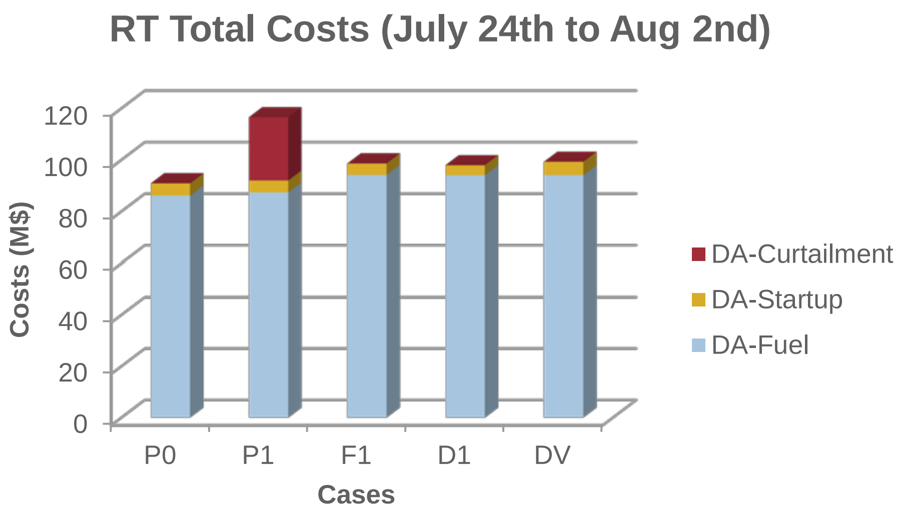
- Example of an operating reserve demand curve (1st hour on July 22nd, 2006)



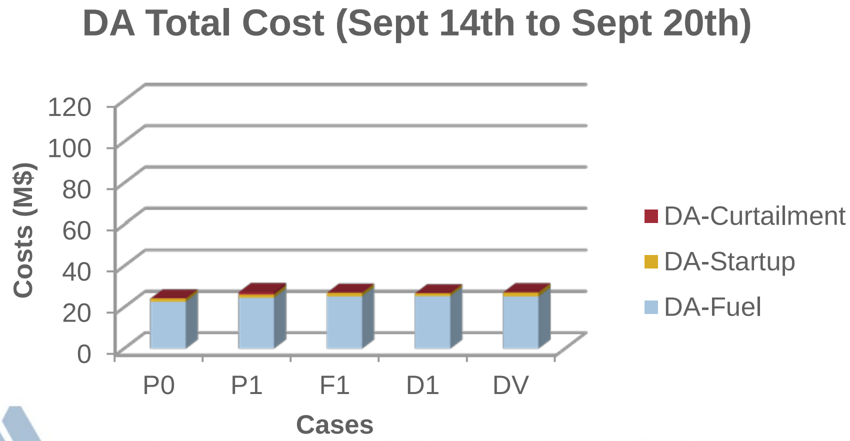
Overview of Total Operating Cost

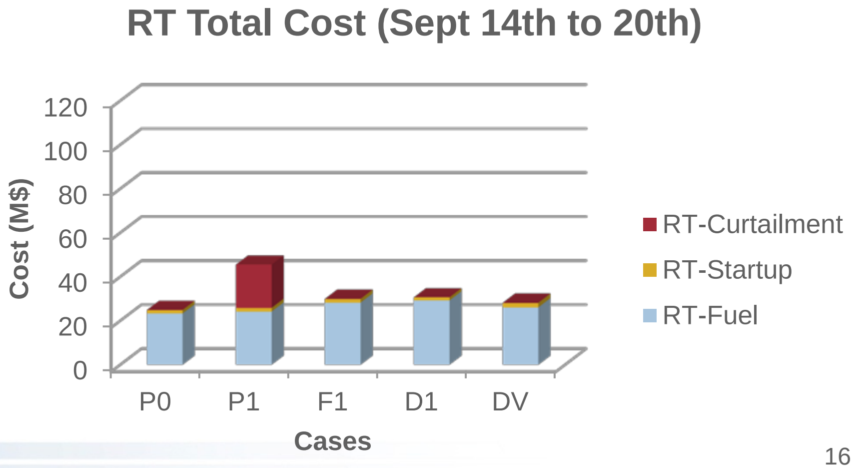
- Period July 24th to Aug. 2nd, 2006





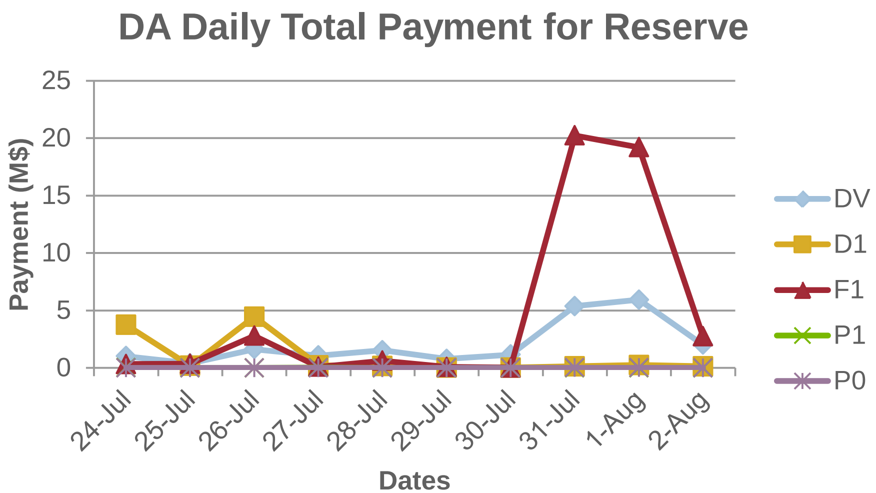
- Period Sept. 14th to Sept. 20th, 2006)

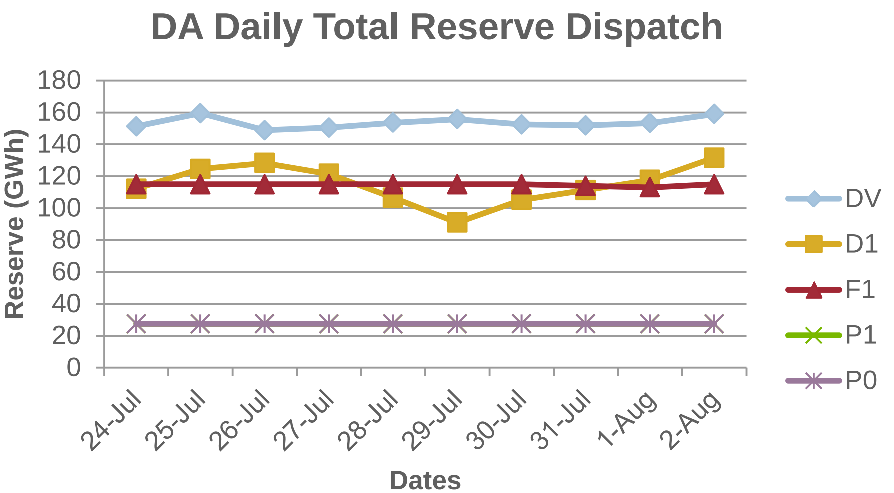




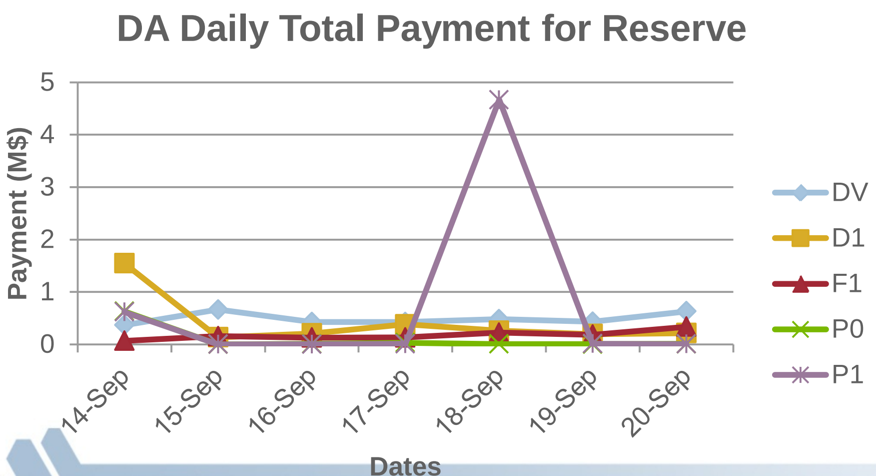
Overview of Dispatch and Payment for Reserve

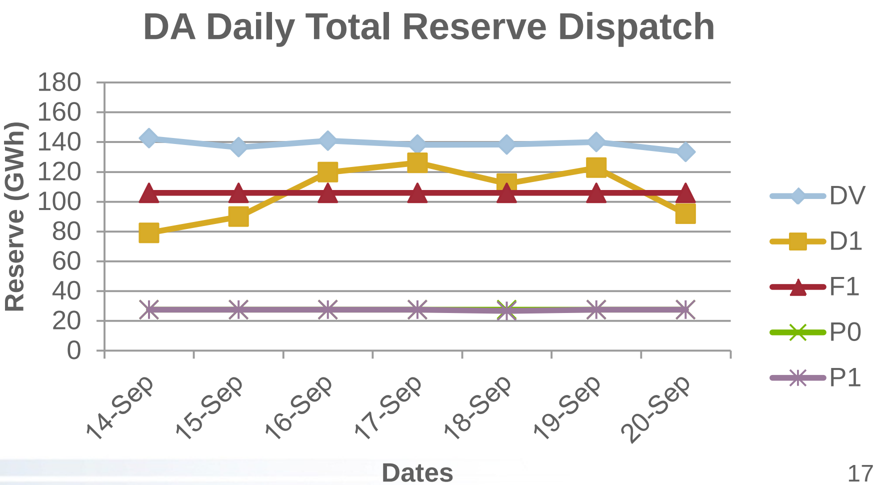
- Period of July 24th to Aug 2nd





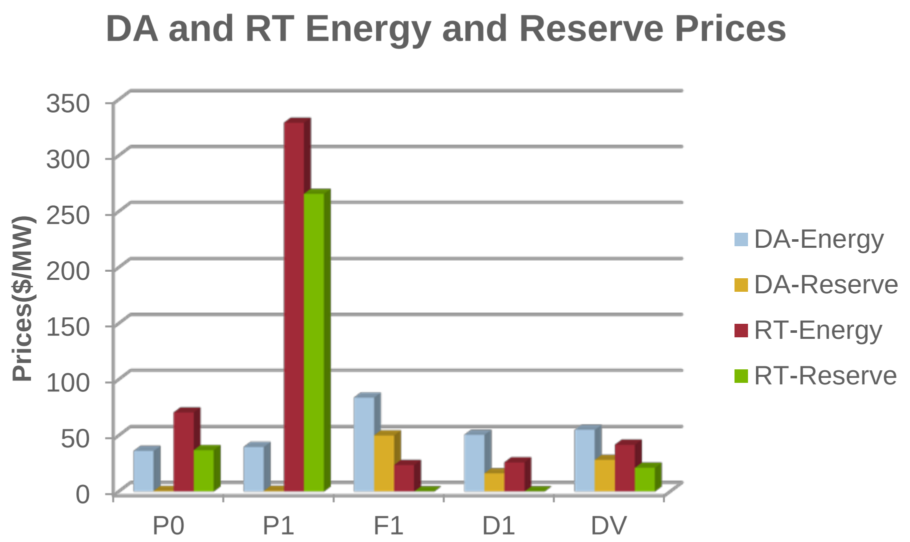
- Period of Sept 14th to 20th



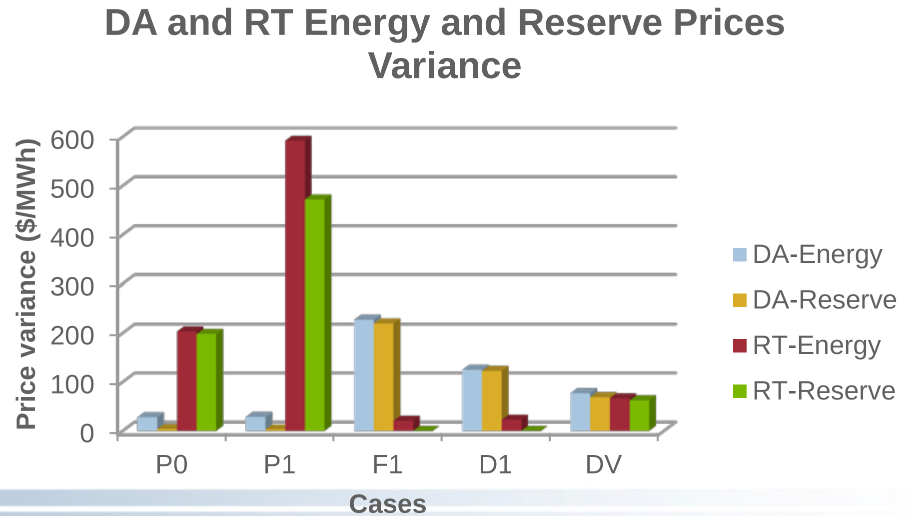


Overview of Energy and Reserve Prices

- Period July 24th to Aug 2nd, 2006



- Period Sept 14th to 20th, 2006



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Conclusions and Future Work

- ***Advantages of the proposed probabilistic ORDC***
  - *Improves scarcity pricing in electricity markets*
  - *Efficiently addresses uncertainty in wind power and other renewables*
    - *Less computational burden and better aligned with current practices than stochastic UC*

- ***Case Study Conclusions***
  - *Cases with ORDCs schedule more reserve, which make the system more reliable*
  - *All three tested reserve strategies can successfully avoid load curtailment*
  - *Cases with ORDCs have similar operating costs vs. cases with other reserve strategies*
  - *Cases with ORDCs have higher average reserve prices, but no extremely high prices*

- ***Future Work***
  - *Further investigation of impacts on DA and RT prices, revenue adequacy, and investment incentives*
  - *Derive locational ORDCs to account for transmission constraints*
  - *Introduce operating reserve supply curves*
  - *Better algorithms to calculate demand curve faster*

Comments and Questions.

Thank You

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