Optimization and Risk Management in Open-Access Electric Energy Markets

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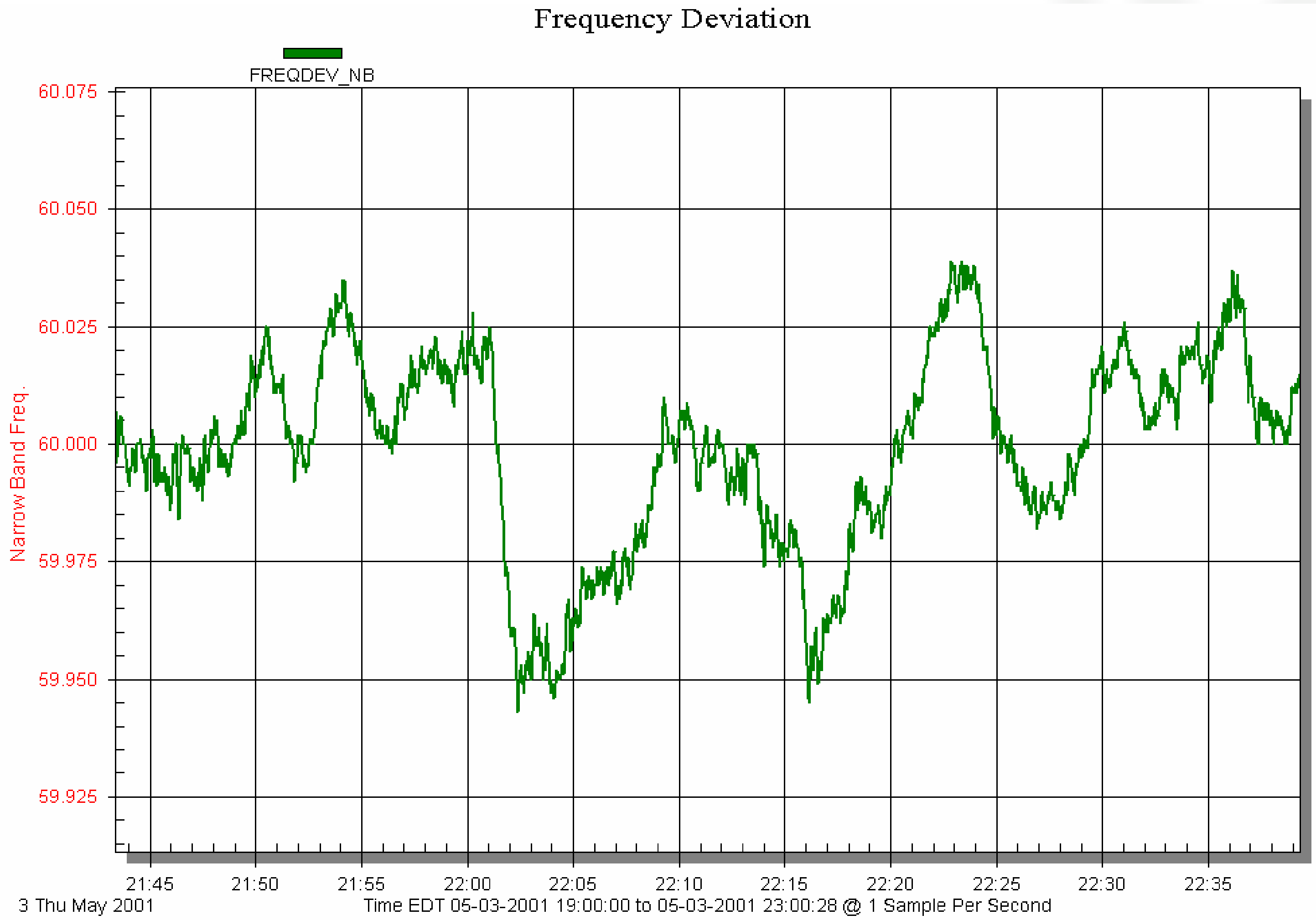
- For more information
  - Web site – www.nyiso.com

Survivor I – Last Episode



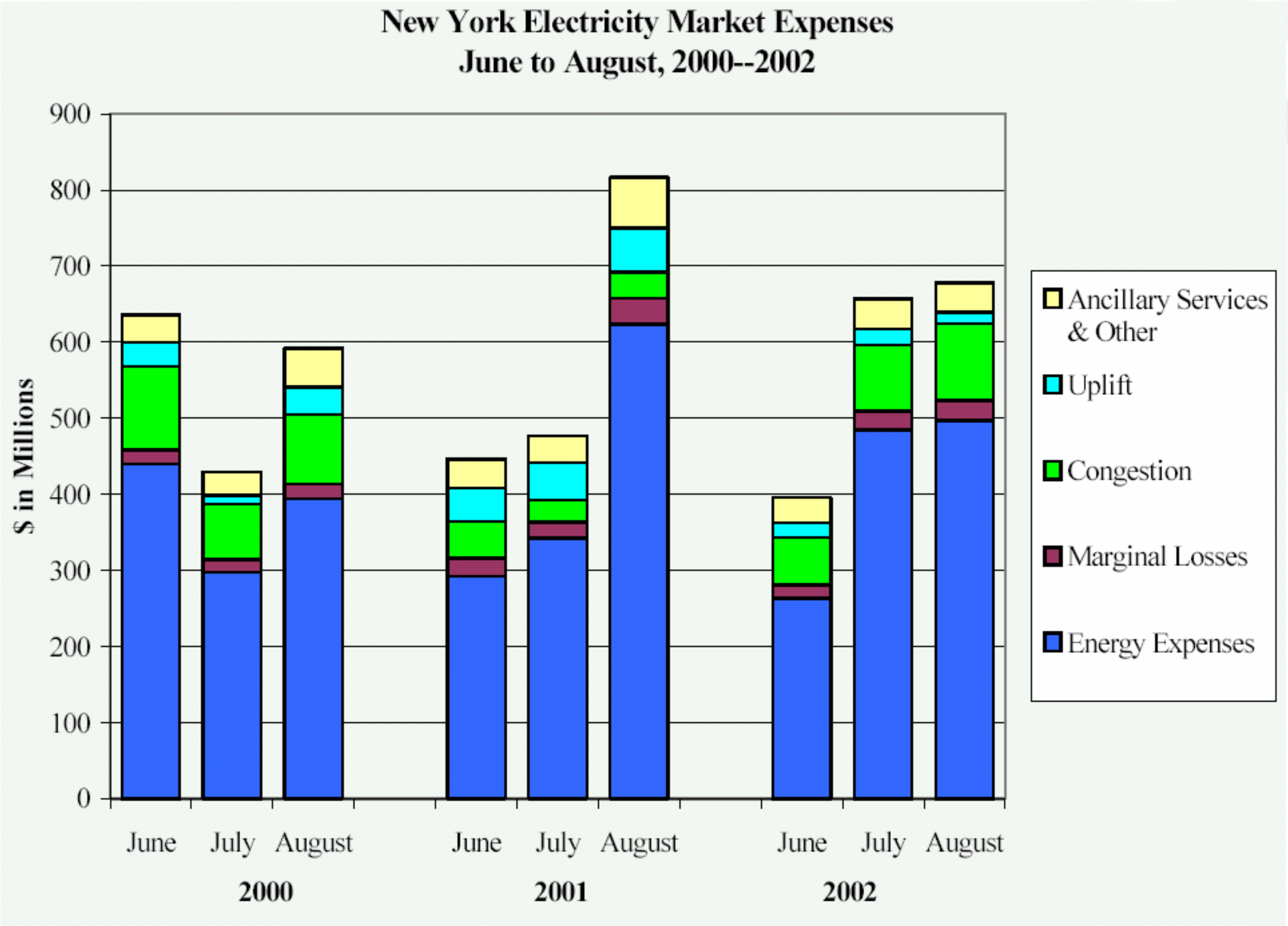
Topics

- New York deregulated energy market
- Market information structure
- Supplier optimization
- Consumer optimization
- Energy trader optimization
- Grid dispatch and market monitoring
- Research areas

New York Deregulated Energy Market

- Switch to NY Marketplace presentation

New York Electricity Market Expenses



Sources: www.nyiso.com (Summer 2002 Review of the NY Electricity Market, David B. Patton)

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Market Information Structure (1)

- System forecasted loads and scheduled equipment outages are announced to all MP
- Loads (LSE) bid in hourly forecasted load in the day-ahead market (DAM) – fixed and price-capped
- Suppliers (Generators) bid in minimum generation blocks and incremental energy blocks with increasing costs – the bids not based solely on the generation cost

Market Information Structure (2)

- All supply and demand bids are confidential
- Grid operator (ISO) accepts all supply and demand bids and performs an optimal bid-based unit commitment
- Hourly prices (LBMP, losses, congestions, uplifts) and loads committed for different zones are posted
- Generator dispatch schedules are known only to the individual generator owners

Market Information Structure (3)

- Historical price and dispatch data available from NYISO website
- Masked generator bids posted after 6 months
- Information structure encourages competitive bidding and discourages supplier gaming
- Nevertheless, historical data are useful to optimize bidding

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Aggregate Energy Supply and Demand

A Price-feedback Market Simulator

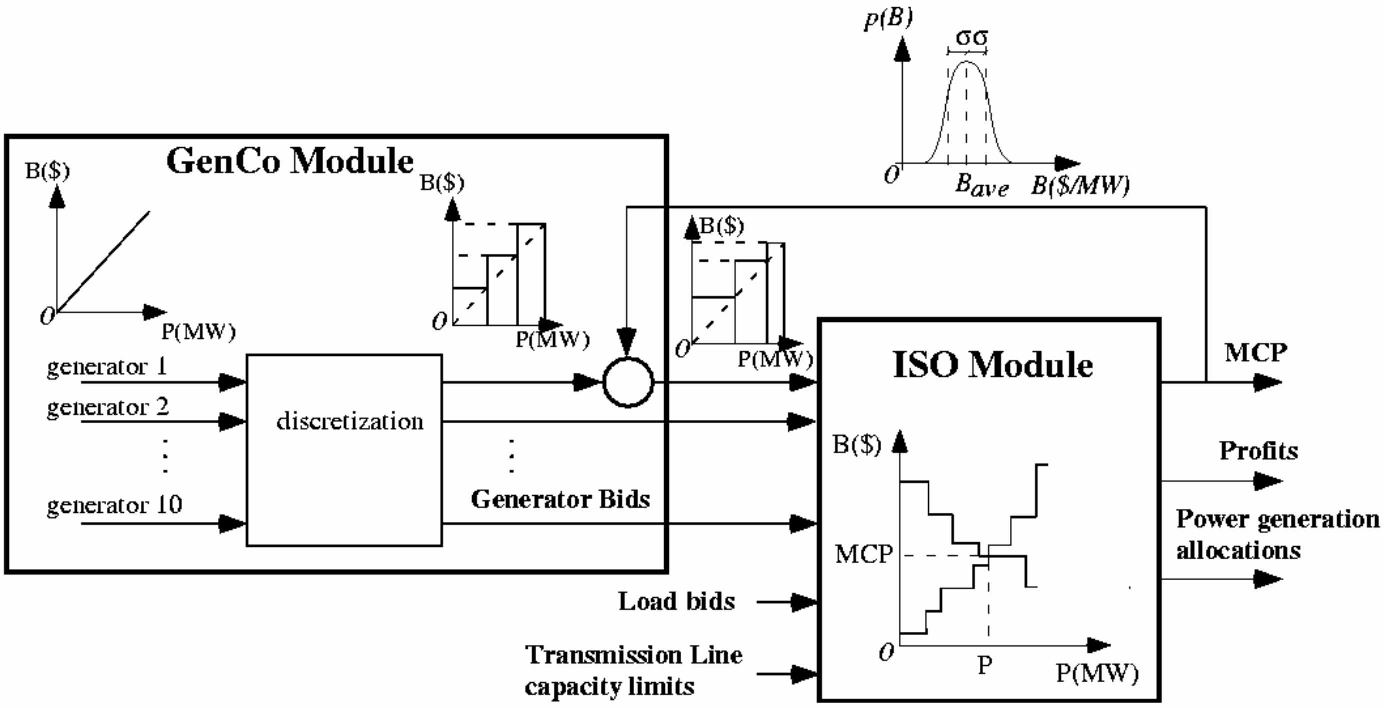


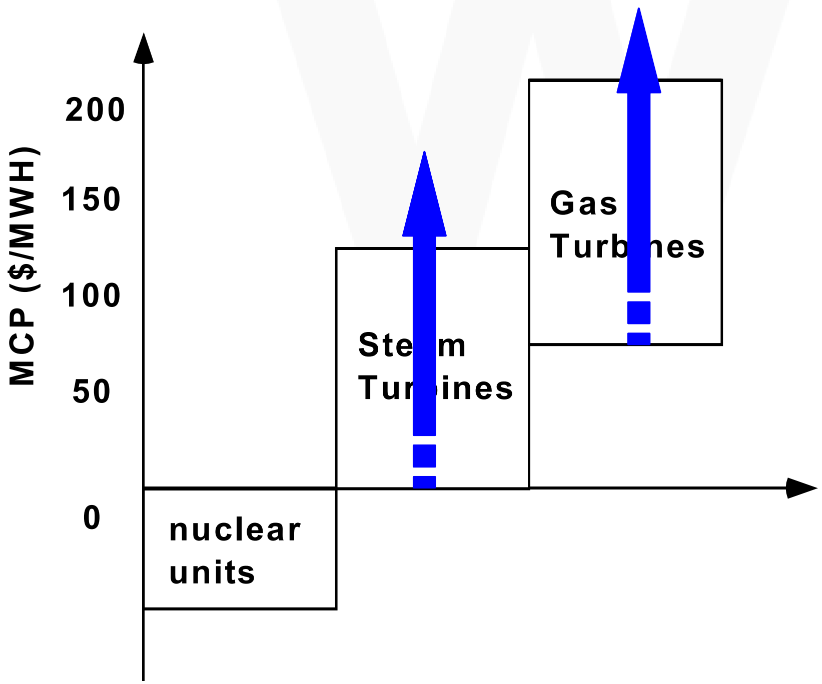
Figure 6.1: The price-feedback market simulator

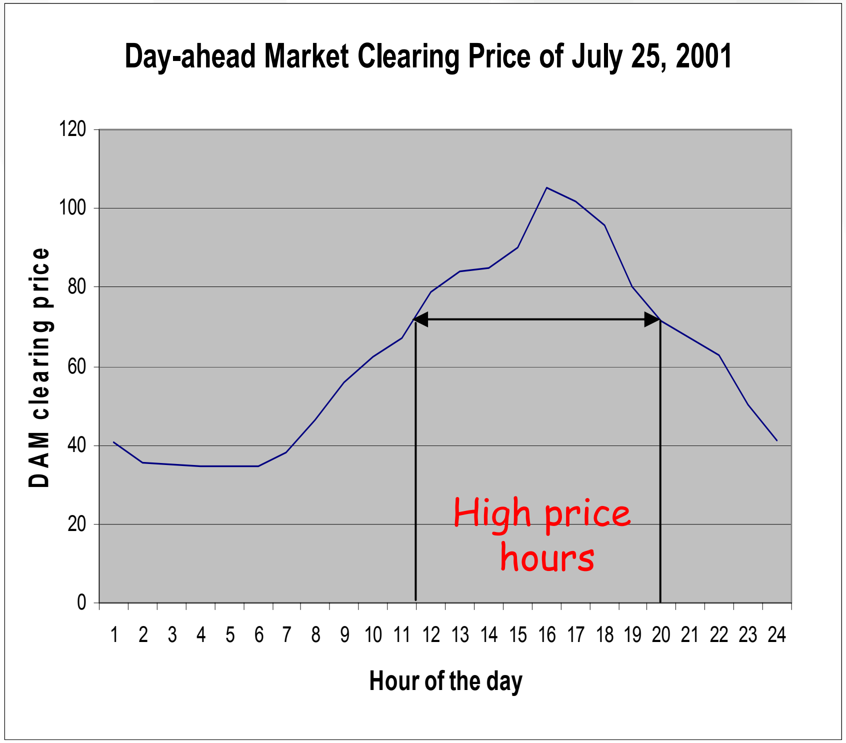
Supplier Optimization

In a deregulated power market with *uniform* energy clearing prices, there are many generator bidding strategies:

- Nuclear units – price takers, base-loaded, bid negative prices
- Gas turbines – opportunistic, bid high minimum generation and energy prices
- Hydro units – finite stored energy, bid regulation and reserve
- Steam turbines – most likely the price-setters, profits highly dependent on bidding strategies

Typical price ranges





Supplier Optimization

1. Developing bid curves based on generator cost curves
   - Breakeven
   - Maximum profit
2. Bidding with hedging
   - Two-settlement system – accounts for generator availability and derating
3. Block bids
   - Segments for expected maximum profit
4. Unit with limited capacities
   - Pump-hydro unit bidding strategies

Generator Cost Curves

- Quadratic or Cubic functions

$$C(P) = C_s + C_0 + \beta_1 (P - P_{min}) + \beta_2 (P - P_{min})^2 \qquad (1)$$

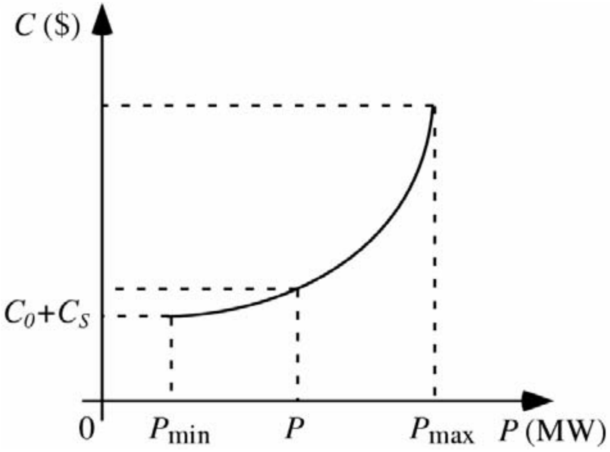
$$C(P) = C_s + C_0 + \beta_1 (P - P_{min}) + \beta_2 (P - P_{min})^2 + \beta_3 (P - P_{min})^3 \qquad (2)$$

P_{max} -- maximum generation.

P_{min} -- minimum generation,

C_s -- a start-up cost,

C_0 -- a “min-gen” cost.



A quadratic cost curve

Basic Bid Curves– Break-even

- Break-even bid curve

Revenue = Cost

$$R(P) = C(P) \quad (6)$$

$$R_{\min} + B(P)(P - P_{\min}) = C_s + C_0 + \beta_1(P - P_{\min}) + \beta_2(P - P_{\min})^2 \quad (7)$$

Denoting $P_c = P - P_{min}$ and assume that $R_{min} = C_S + C_0$

Block-power bid

Fixed payment covers Cs and C0

$$B_{BE}(P) = \beta_1 + \beta_2 P_c \quad (8)$$

Break-even bid curve

B(P) -- the bid curve as a function of the generation level *P*.

Basic Bid Curves– Maximum Profit

- Maximum Profit (MP) bid curve

$$\frac{d\pi_{MP}(P)}{dP} = 0$$

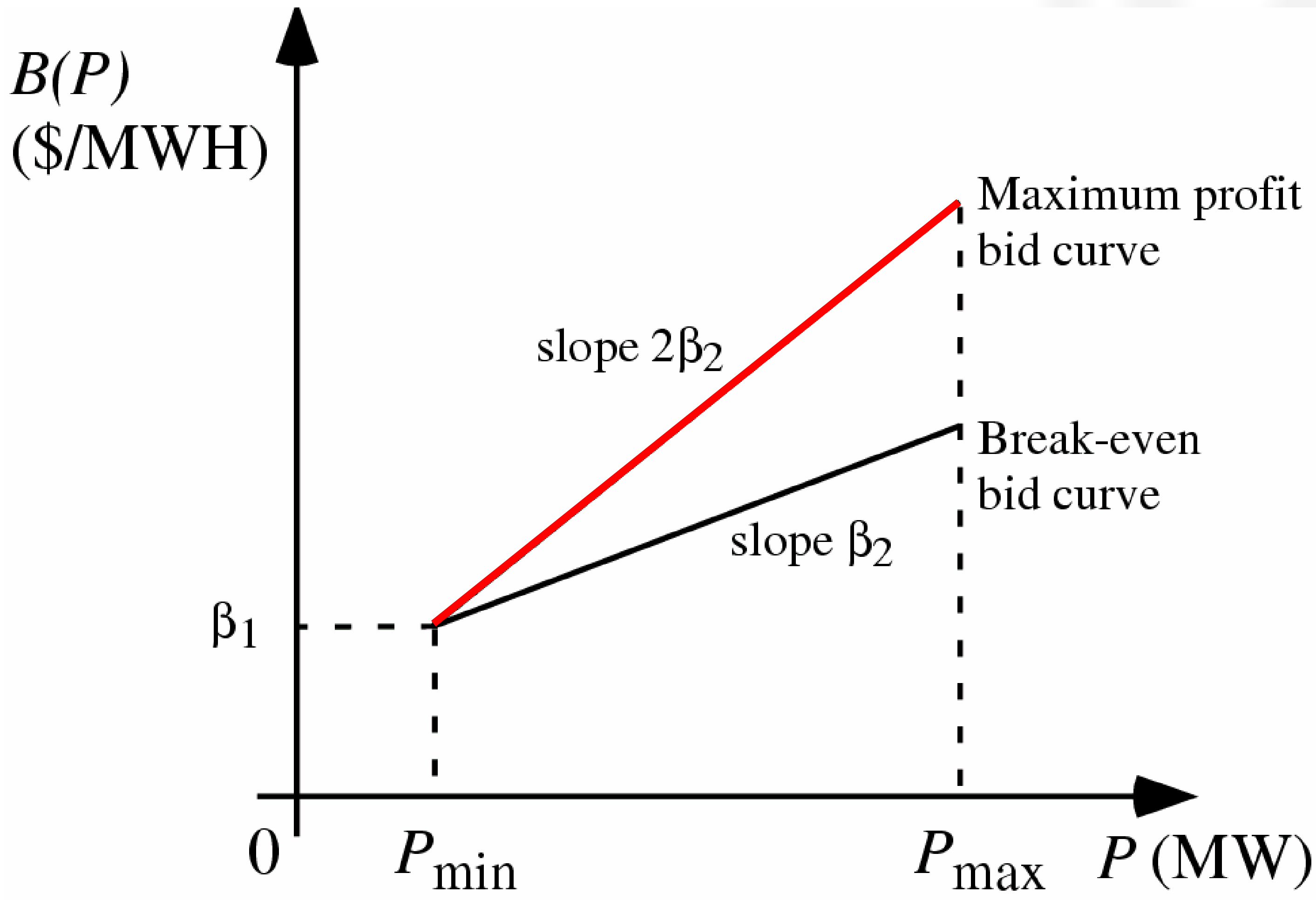
Incremental revenue = Incremental cost

Denoting $P_c = P - P_{min}$ and assume that $R_{min} = C_S + C_0$

$$B_{MP}(P) = \frac{dC(P)}{dP} = \beta_1 + 2\beta_2 P_c \qquad (9)$$

$$\underline{\pi_{MP}(P)} = \underline{B_{MP} P_c} - \underline{(\beta_1 P_c + \beta_2 P_c^{\,2})} = \beta_2 P_c^{\,2} \qquad (10)$$

Profit   Revenue   Cost of generation


B(P)
($/MWH)
Maximum profit
bid curve
slope 2β2
Break-even
bid curve
slope β2
β1
0
Pmin
Pmax
P (MW)

Supplier Optimization

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4. Unit with limited capacities
   - Pump-hydro unit bidding strategies

Generator Availability and Derating

- Two-settlement systems for energy
  - Unit commitment performed in the day ahead market (DAM)
  - Generators which fail to supply the committed power/energy in the real time (RT) market need to buy replacement power/energy
  - Risks: The RT energy prices may be significantly higher than that of the DA market
- Solutions
  - Bid in a curve taken this risk into account
  - Virtual trading (virtual bidding)

Generator Derating

- Generator Derating - a unit fails to deliver power at the committed level.
- An extreme case: the whole unit is lost.

Table 1: p_u with respect to P_c

p_u	100 MW	200 MW	300 MW	400 MW	500 MW	600 MW	700 MW	800 MW
100 MW	0.005	0.01	0.01	0.01	0.01	0.02	0.03	0.05
200 MW	0	0.005	0.01	0.01	0.01	0.01	0.03	0.05
300 MW	0	0	0.005	0.001	0.001	0.005	0.02	0.01
400 MW	0	0	0	0.005	0.001	0.005	0.01	0.01
500 MW	0	0	0	0	0.01	0.005	0.005	0.01
600 MW	0	0	0	0	0	0.02	0.005	0.01
700 MW	0	0	0	0	0	0	0.03	0.01
800 MW	0	0	0	0	0	0	0	0.05
Availability:	99.5%	98.5%	97.5%	97.4%	97.3%	93.5%	87%	80%

Insurance bid curves

Given the derating probabilities

$$p_a(P) + \sum_{i=1}^{n} p_u(i) = 1$$

The expected profit of a unit is

Day-ahead commitment profit

RT replacement

$$\pi_d(P) = p_a(P)(B_d P_c - (\beta_1 P_c + \beta_2 P_c^2)) + \sum_{i=1}^{n} [p_u(i)(B_d P_c - B_{RT} P_L(i)) - (\beta_1 (P_c - P_L(i)) + \beta_2 (P_c - P_L(i))^2)]$$

Assume the RT market price B_{RT} is proportional to the DAM price B_d

$$k(i) = \frac{B_{RT}(i)}{B_d(i)}$$

$$P_L(i) = k_L(i) P_c$$

A maximization of this expected profit of the unit yields

$$B_d = \frac{\beta_1 + 2\beta_2 P_c - \sum_{i=1}^{n} [p_u(i)(\beta_1 k_L(i) - 2\beta_2 k_L^2(i) P_c + 4\beta_2 P_c k_L(i))]}{1 - \sum_{i=1}^{n} p_u(i) k(i) k_L(i)}$$

Let

$$B_{\text{adjust}} = \beta_1 k_L(i) - 2\beta_2 k_L^2(i) P_c + 4\beta_2 P_c k_L(i)$$

$$k_{\text{adjust}}(i) = k_L(i) k(i)$$

A maximization of this expected profit of the unit yields

$$\frac{B_d}{B_{MP}} = \frac{1 - p_u^T \frac{B_{\text{adjust}}}{B_{MP}}}{1 - p_u^T k_{\text{adjust}}}$$

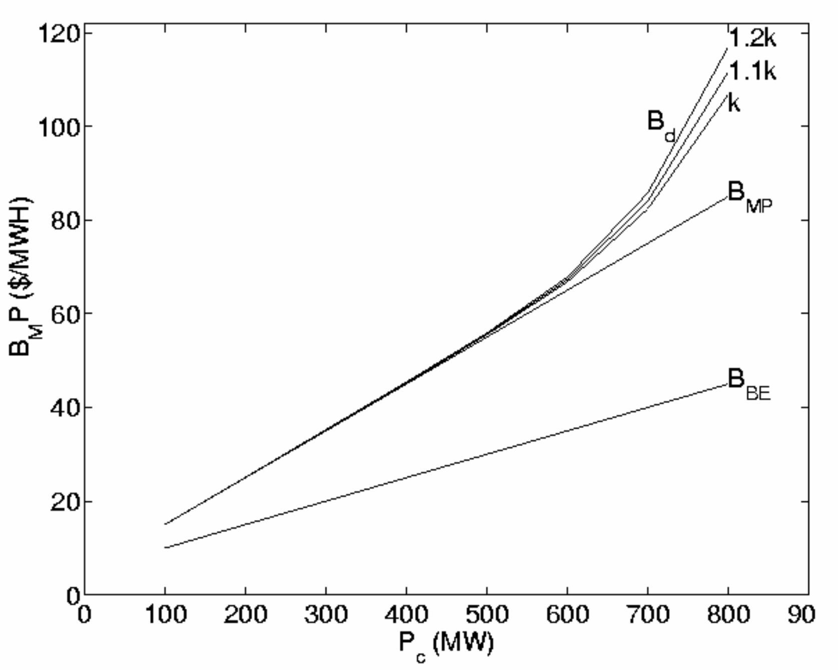
An example of insurance bids

k = Real-time market price / Day-ahead market price

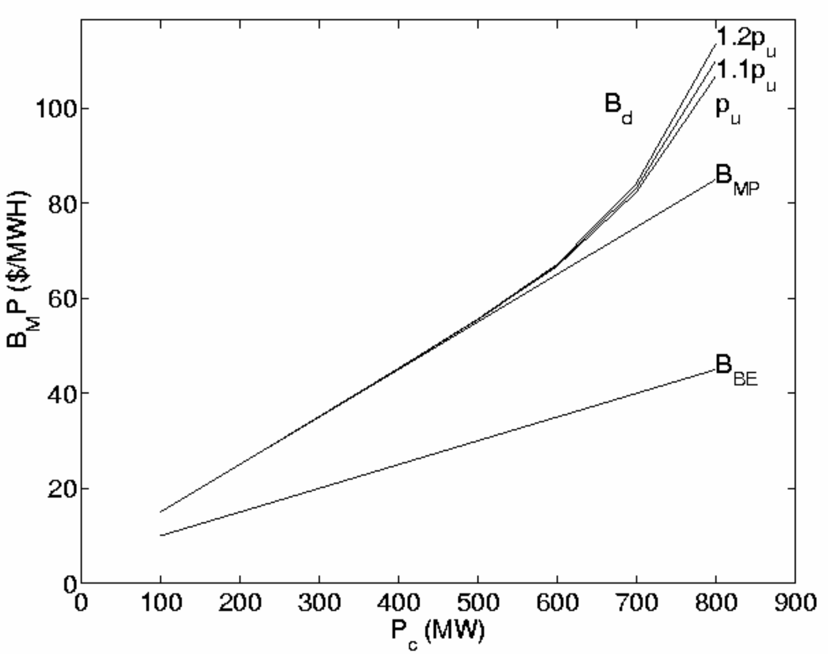
Table 3: k with respect to P_c

k	100 MW	200 MW	300 MW	400 MW	500 MW	600 MW	700 MW	800 MW
100 MW	1	1.2	1.3	1.3	1.3	1.5	2	3
200 MW	0	1.3	1.4	1.4	1.4	1.6	2	3
300 MW	0	0	1.5	1.5	1.5	1.6	2	3
400 MW	0	0	0	2	1.6	2	2	3
500 MW	0	0	0	0	2	2	2	3
600 MW	0	0	0	0	0	2	3	3
700 MW	0	0	0	0	0	0	3	3.5
800 MW	0	0	0	0	0	0	0	3.5

An example of insurance bids



$B_d(P)$ as a function of k and P



$B_d(P)$ as a function of p_u

If most bidders tend to be risk averse, then under an expectation of RT market price being greater than DA market price, applying insurance bids generally result in a higher MCP price in heavy load area than not taking derating into account

Supplier Optimization

1. Developing bid curves based on cost curves
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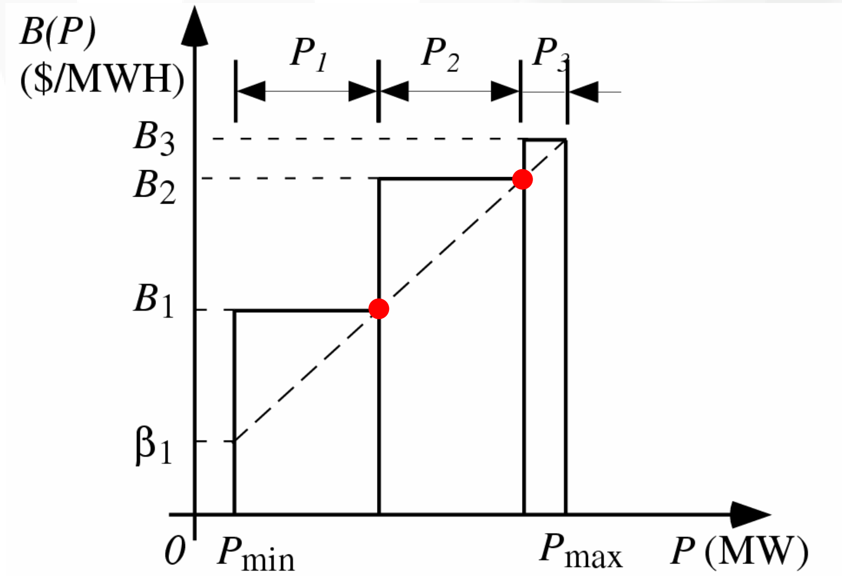
Optimization of Block Bids

- Allowable bid curves
  - Piecewise linear
  - Blocks
- Allowable number of bid curves
  - One per hour
  - One per day
- Multi-segment blocks
  - The goal is to find a set of optimized discretization points (break points) to maximize expected profit



Optimization of Block Bids

If we know the probability distribution function of the market clearing price (MCP):

$$p_{\mathrm{MCP}}(B), \quad \text{for} \quad B_{\min} \le B \le B_{\max}$$

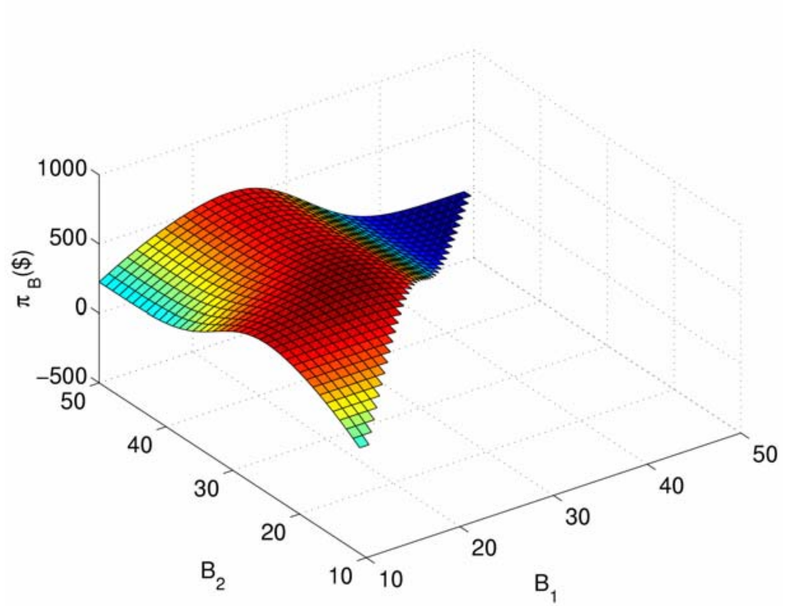
The expected profit can be calculated as the sum of three pieces, each having its own dispatch probability:

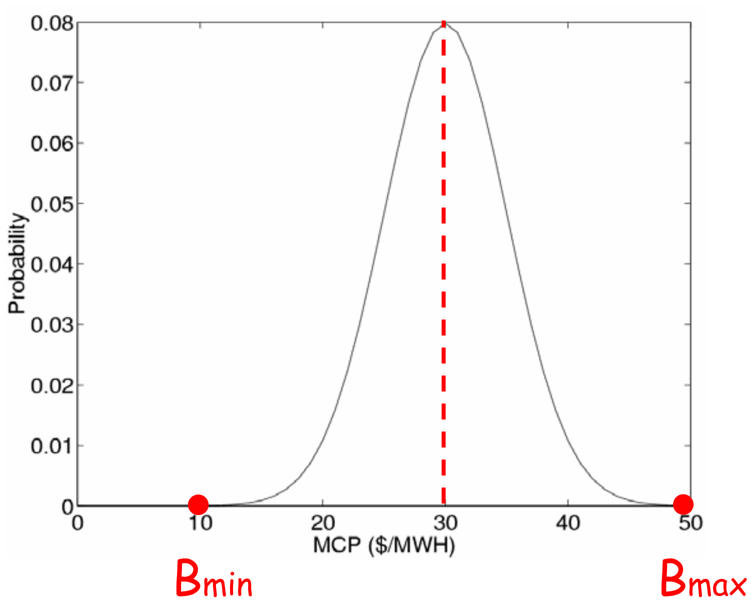
$$\pi_B(B_1, B_2) = \int_{B_1}^{B_2} p_{MCP}(B)[B\frac{B_1-\beta_1}{2\beta_2} - \beta_1\frac{B_1-\beta_1}{2\beta_2} - \beta_2(\frac{B_1-\beta_1}{2\beta_2})^2]dB$$
$$+\int_{B_2}^{B_3} p_{MCP}(B)[B\frac{B_2-\beta_1}{2\beta_2} - \beta_1\frac{B_2-\beta_1}{2\beta_2} - \beta_2(\frac{B_2-\beta_1}{2\beta_2})^2]dB$$
$$+\int_{B_3}^{B_{\max}} p_{MCP}(B)[B(P_{\max}-P_{\min}) - \beta_1(P_{\max}-P_{\min}) - \beta_2(P_{\max}-P_{\min})^2]dB$$

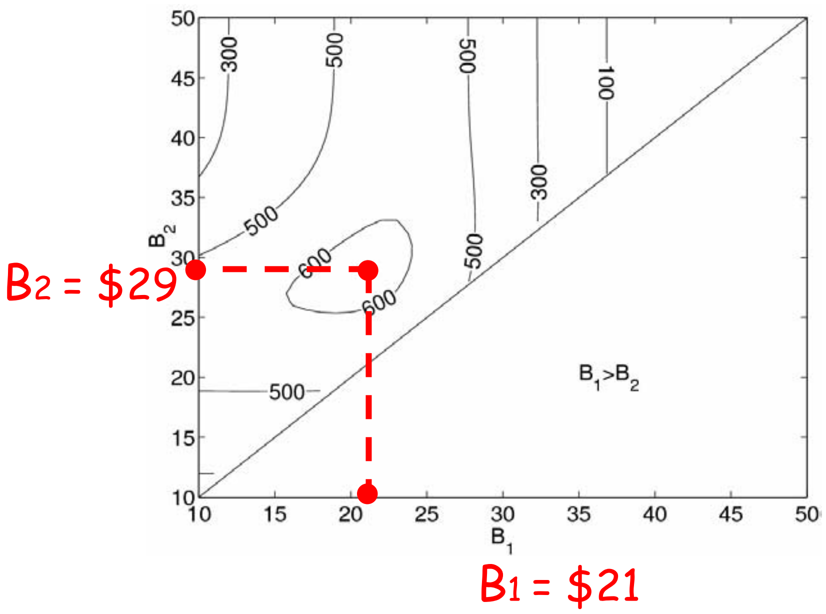
Solve for the optimal values of B1 and B2:

$$\frac{d\pi_B(B)}{dB_1} = 0, \qquad \frac{d\pi_B(B)}{dB_2} = 0$$

An Example of Normal Distribution







Observations

- The **lower break-point** is bid to ensure that the unit is dispatched with high probability.
- The **higher break-point** is bid at or slightly below the expected MCP.
- The bidding strategy relies on the fact that a unit is most profitable operating on the lower part of the cost curve given a high MCP. Not dispatching under such a circumstance results in lost profit opportunities of maximum profitability.

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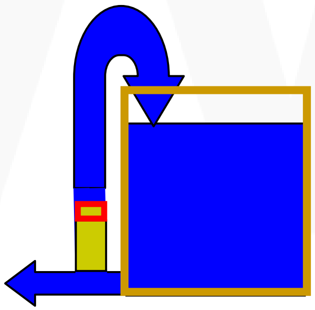
Operational Constraints of a Pump-hydro Unit

$$E_T = E_0 + E_{\text{in}} - E_{\text{out}}$$

Inflow Energy → $E_{\text{in}} = P_p t_p \eta$

Outflow Energy → $E_{\text{out}} = P_g t_g$



$$t_g = \frac{P_p t_p \eta - E_T + E_0}{P_g}$$

E_0- Initial Energy stored in the upper reservoir

E_T- The Energy at the end of an optimization cycle

η - The efficiency of the pumping and generating process

Pump-hydro Unit Bidding Strategies

- Limited water storage capacity

Revenue

$$R(P) = R_r + R_g$$

Reserve

$$R_r = P_r(T - t_g)B_r$$

Energy

$$R_g = P_g t_g B_g$$

Cost

$$C = C_0 + C_p$$

C_0 - a fixed O&M cost

Pumping water for storage

$$C_p = P_p t_p B_p$$

$$\max(\pi) = \max(\underbrace{R_g + R_r - C_0 - C_p}_{\text{profit}})$$

Step 1 : Obtain a weekly MCP curve

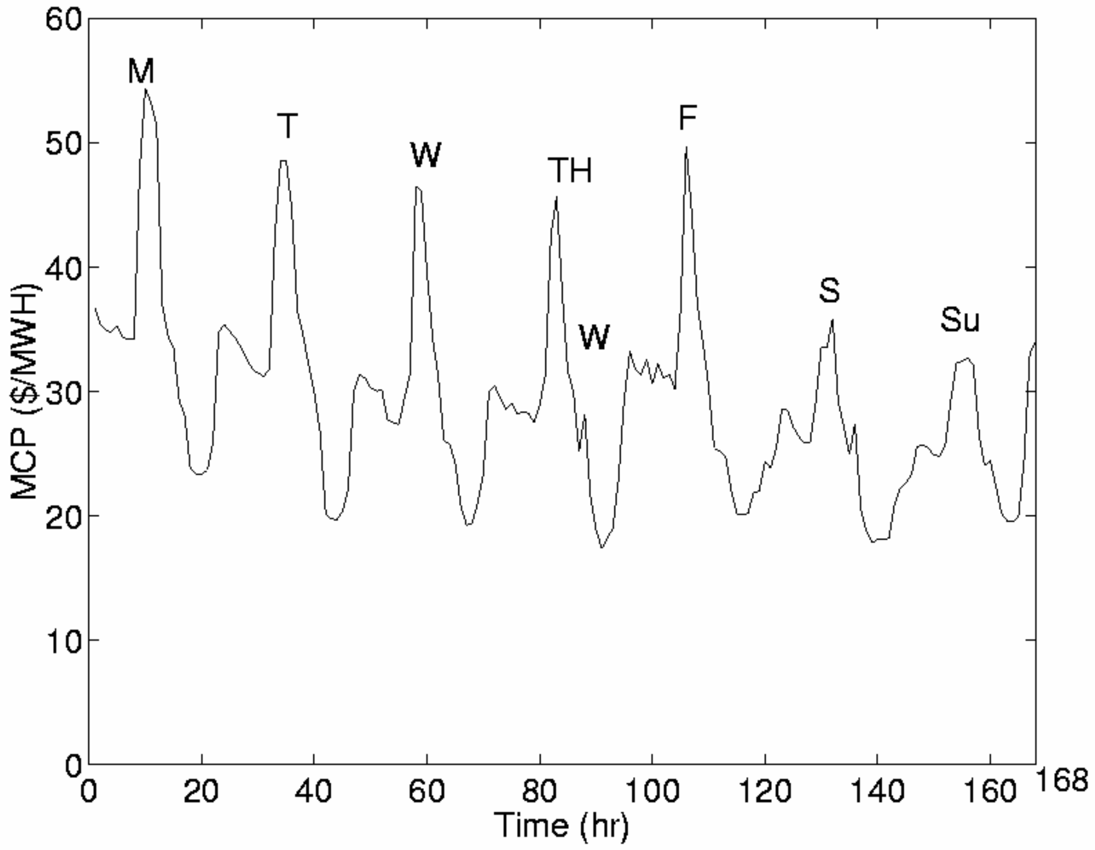


Figure 1: A weekly MCP curve

Step 2: Form a Weekly Composite MCP Curve

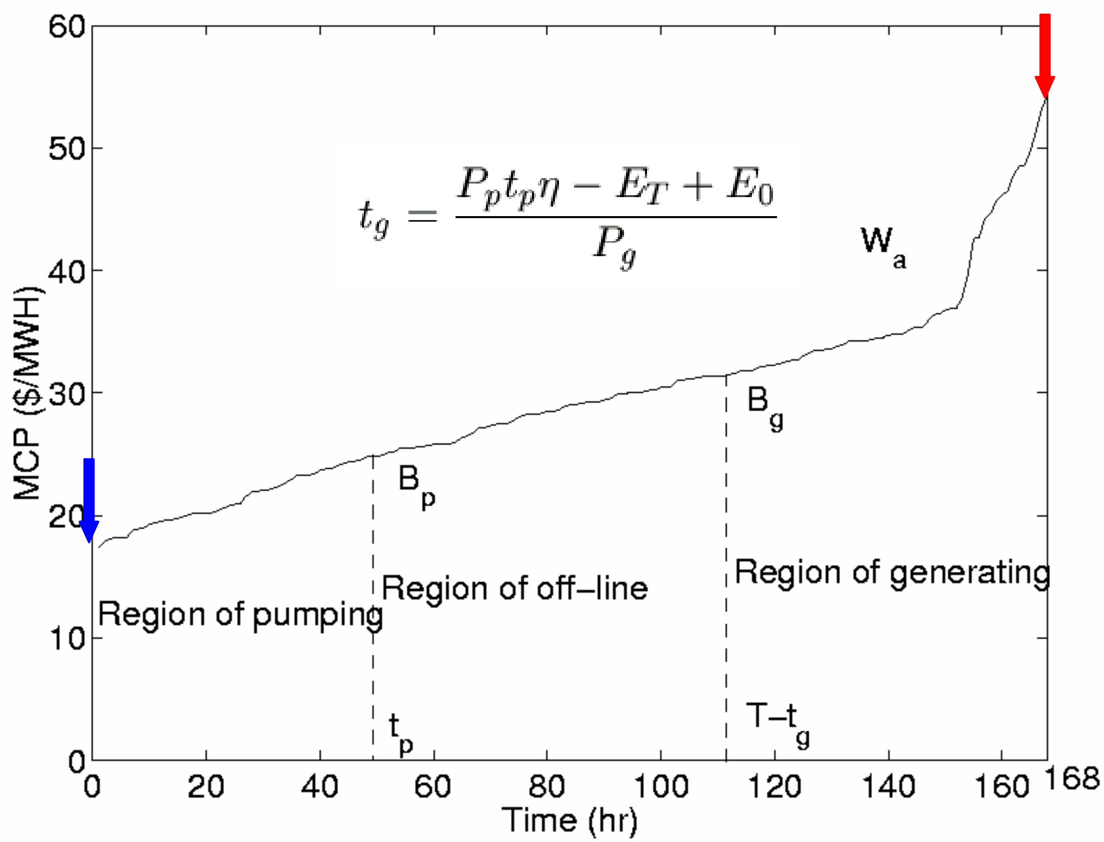
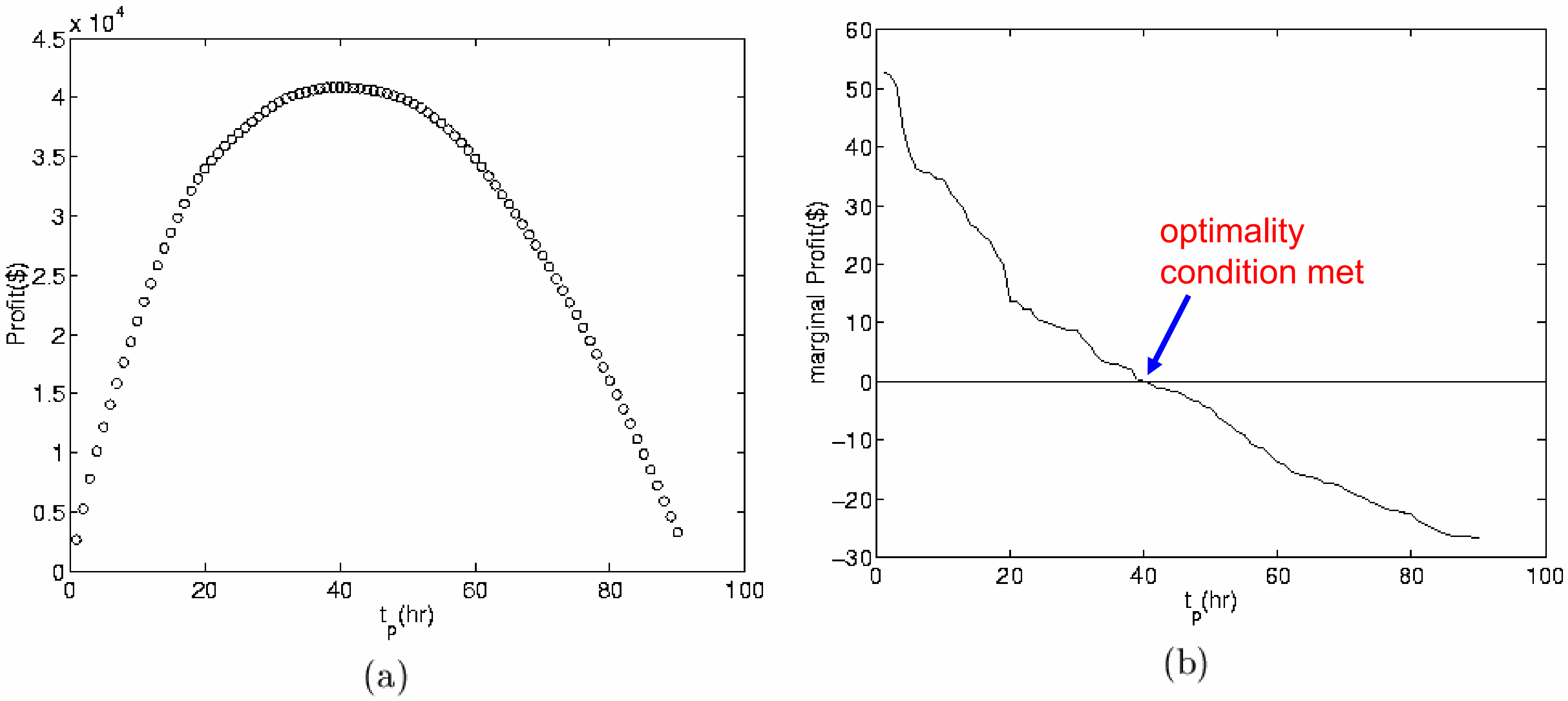
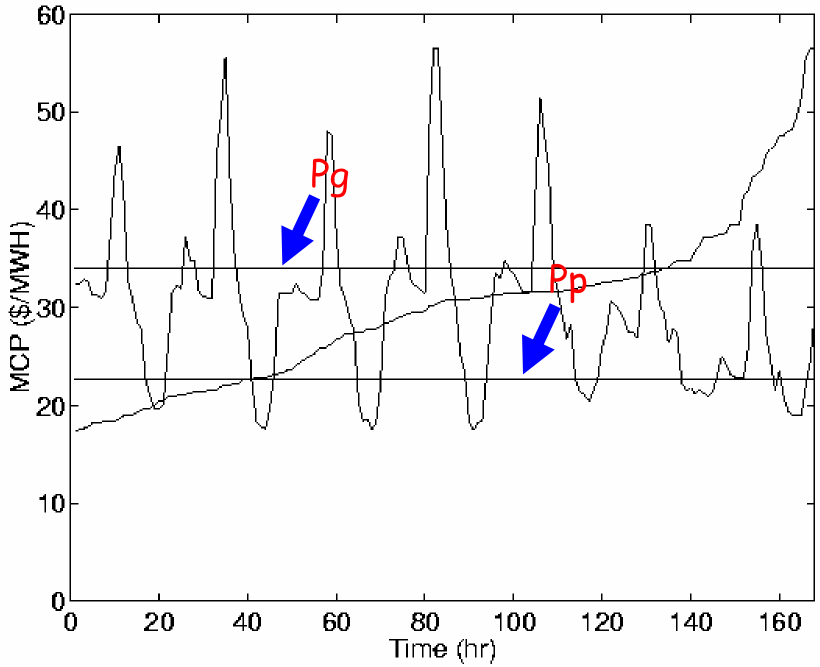


Figure 2: A weekly composite MCP curve

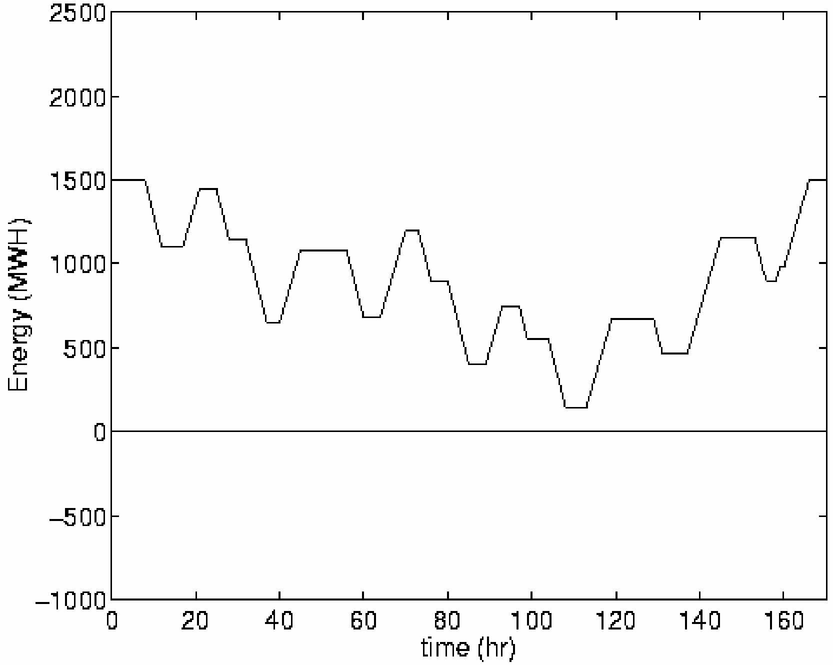
Step 3: Increase t_p(pumping time), till the optimality condition is reached, where the marginal profit of the pump-hydro unit is zero.



Case 1: Upper Reservoir Capacity not Exceeded

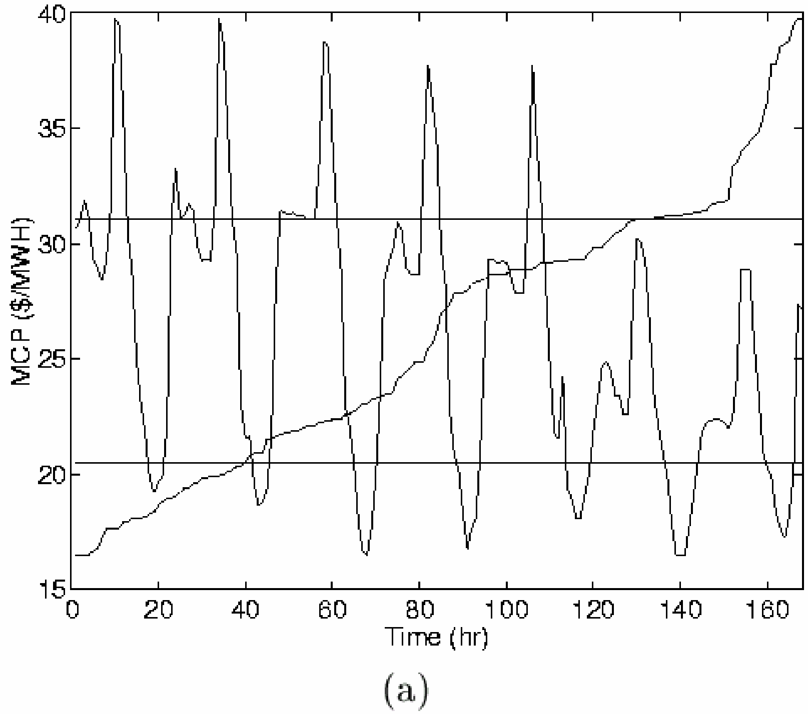


A weekly MCP curve



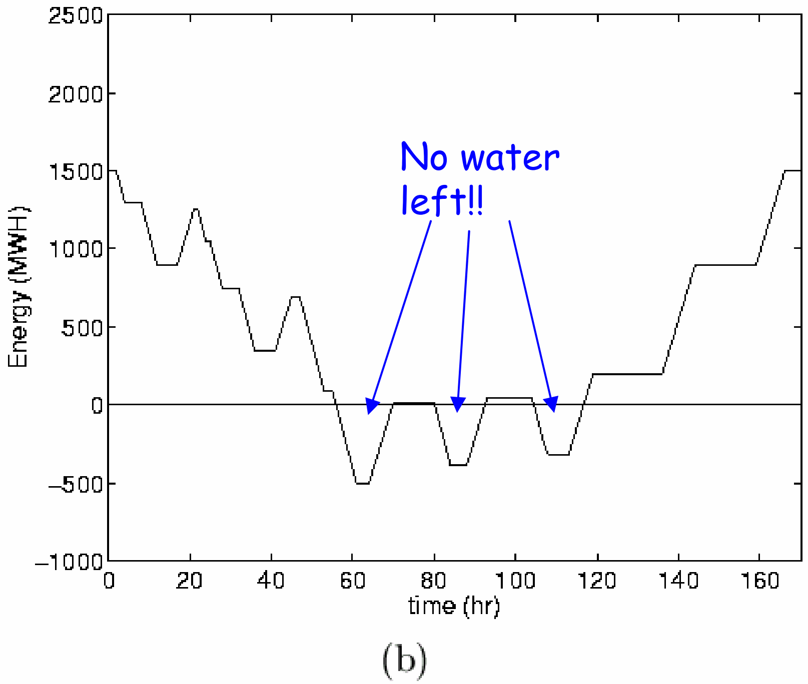
Optimal Operation schedule

Case 2: Upper Reservoir Capacity Exceeded



(a)

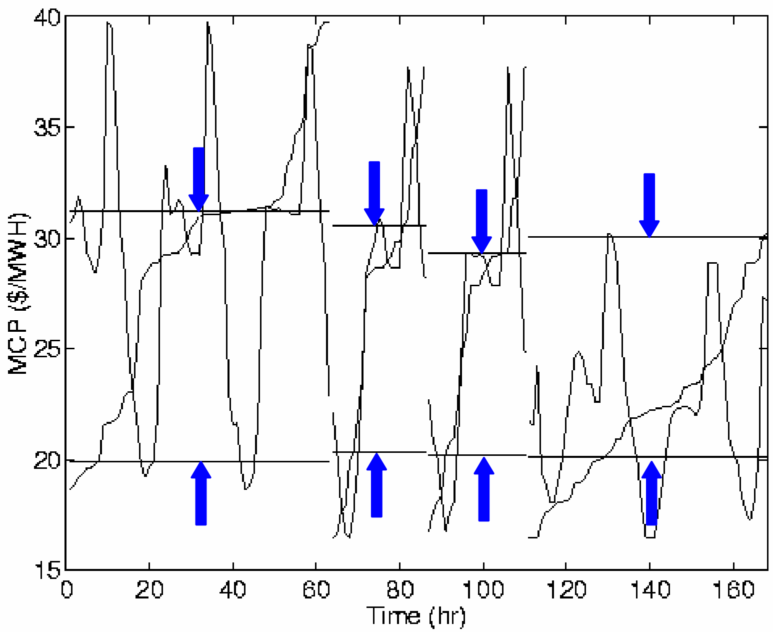
A weekly MCP curve



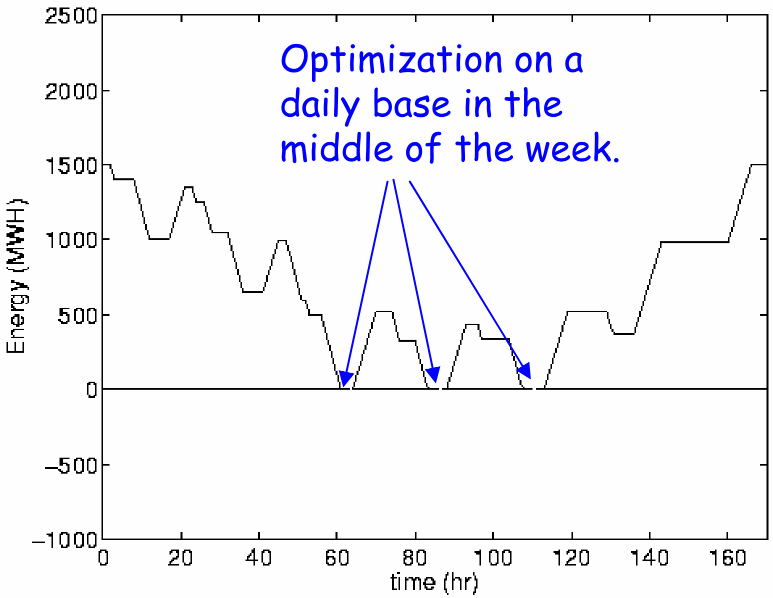
(b)

Optimal Operation schedule

Case 2: Upper Reservoir Capacity Exceeded



(c)

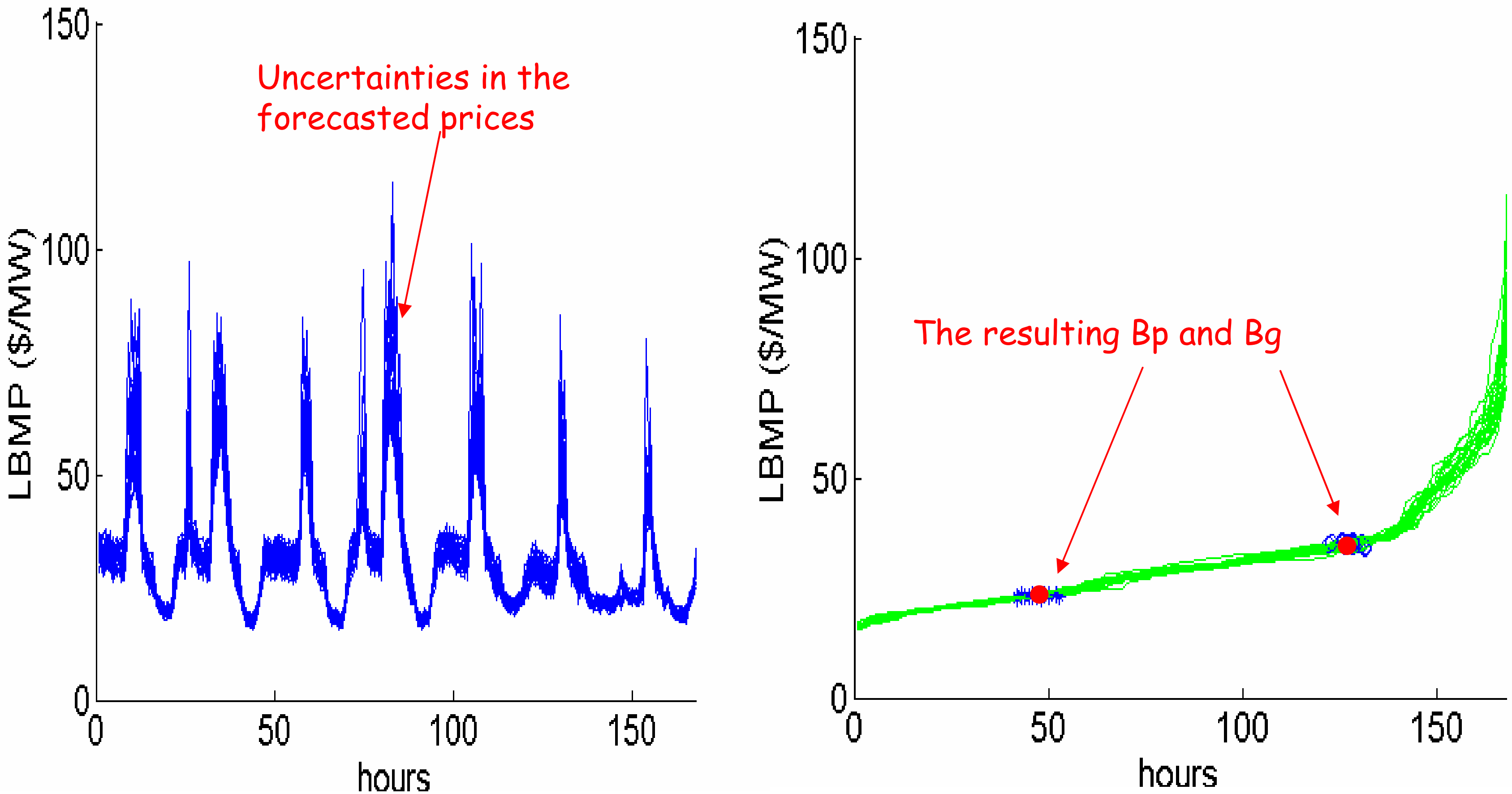


(d)

A weekly MCP curve

Optimal Operation schedule

Case 3. with incomplete information of market clearing prices



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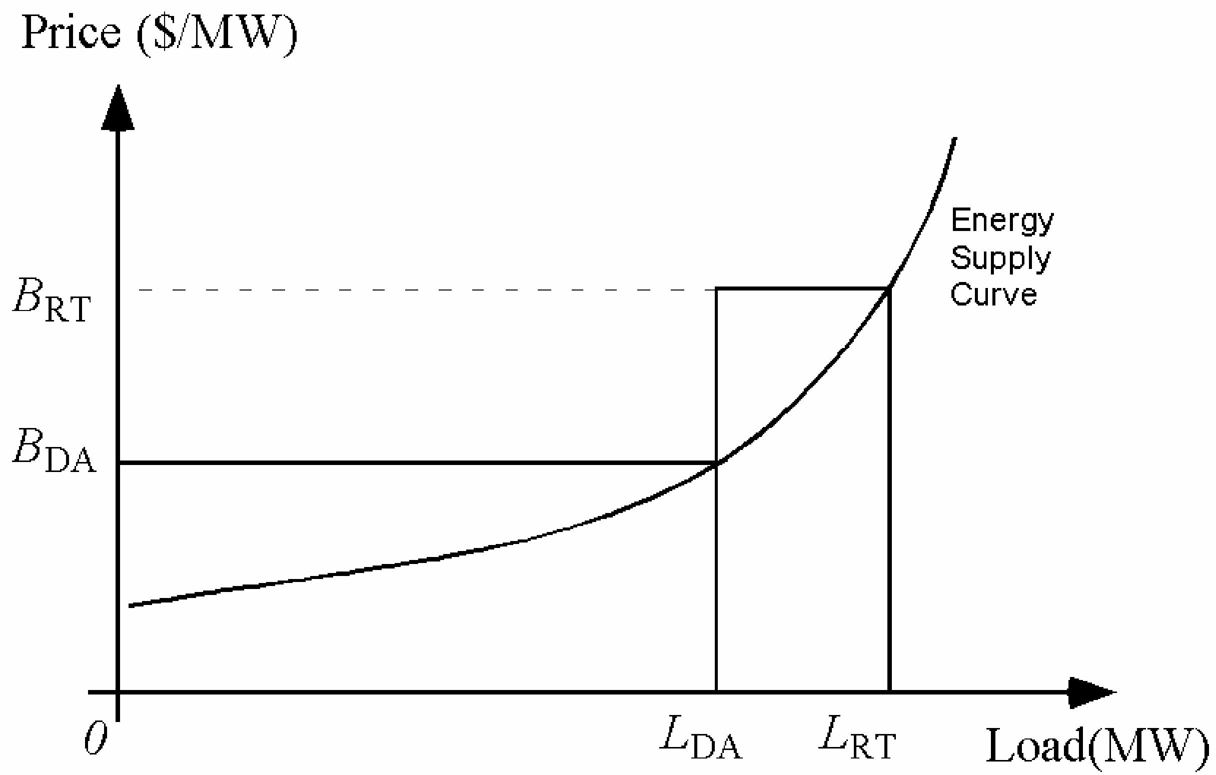
Consumer Optimization

- 2-settlement system: day-ahead load commitment and real time load
- Price-capped load bids

2-Settlement System

- DAM – in day-ahead market, loads bid in to secure supply for their forecasted loads
- RT market – balancing the deficit or surplus in load
- Optimization – minimize total (DA and RT) energy payment

Energy Payment in 2-Settlement System

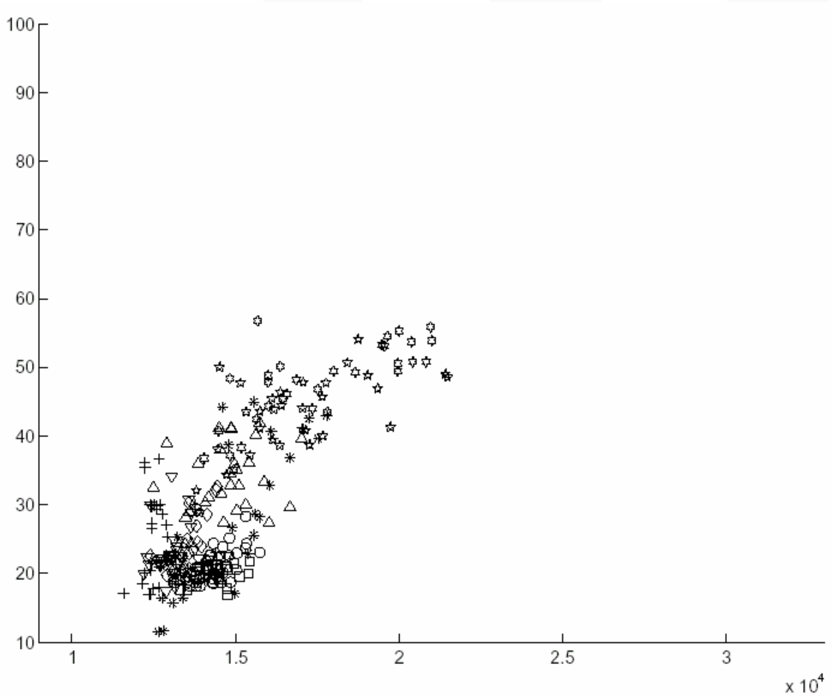


Total energy payment

$= B_{DA}L_{DA} + B_{RT}(L_{RT} - L_{DA}) + \text{Uplift}$

DAM MCP Estimation

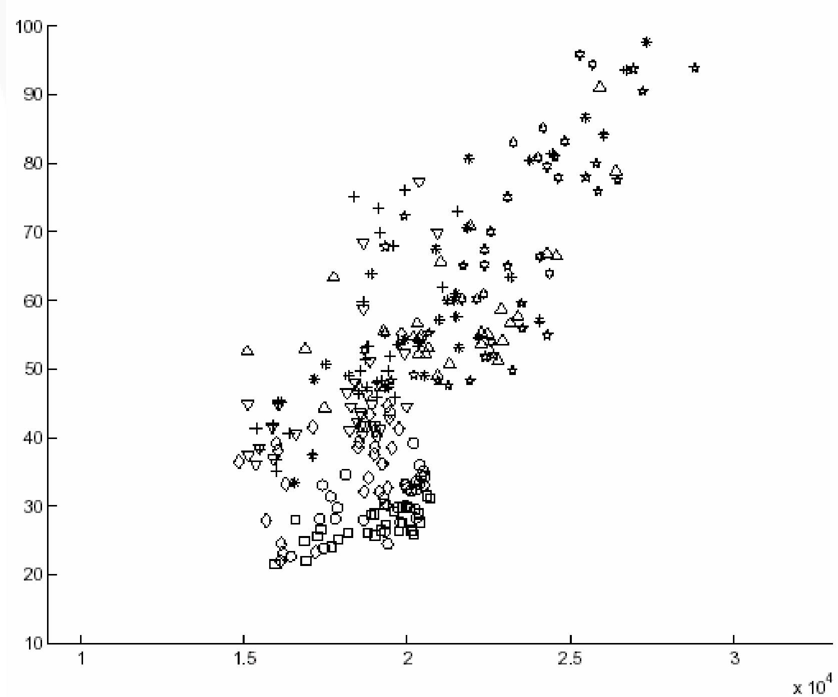
DAM Price ($/MWH)



Load forecast (MWH)

Light load DAM price

DAM Price ($/MWH)



Load forecast (MWH)

Heavy load DAM price

Source: www.nyiso.com OASIS.

Data points: Jan. - Sept. 2002

DA Load Bids

- Allow the commitment of generators at least 12 hours ahead of actual dispatch
- If not enough loads bid in DAM, ISO dispatches additional generators for reliability, resulting in uneconomic operations. The additional costs pass to consumers as a part of uplift cost.
- *DA load bids need to bid enough load to avoid uplifts, requiring data and suitable strategies to deal with load uncertainties*.

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Virtual Transactions (1)

- Energy traders – no physical assets (generating plants or physical loads)
- Every trader (with posted collaterals) is allowed to bid supply (generation) or consumption (loads) in DAM. Their DA positions will be reconciled in RT market.
- Virtual transactions increase market liquidity.
- *Virtual supply* bidders will profit if DA LBMP > RT LBMP; *virtual load* bidders will profit if DA LBMP < RT LBMP. Require load and price forecast information to be competitive.

Virtual Transactions (2)

- Market rules to deter gaming behavior
- Physical loads can bid with price cap
- Virtual load bidding is by zones – to avoid large load bids on certain buses to cause congestions
- Virtual suppliers pay uplifts – to avoid large supply bids resulting in committing physical generators at minimum generation for reliability concerns

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Grid Dispatch and Market Monitoring (ISO)

- Day-ahead unit commitment – large-scale optimization problem
- Real time dispatch – short-term supplemental optimization with updated load prediction
- Market monitoring and mitigation – prevent gaming behavior; data mining to find unusual dispatch and price patterns

Market Monitoring

- Certain generator owners by their generation location and concentration can dictate prices - market power
- Weaknesses in market rules and computer programs may be exploited by market participants
- To prevent gaming
  - Reference bids
  - Conduct and impact tests
  - Portfolio analysis – overall energy position
  - Rapid price correction if necessary

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Research Areas

- **Data analysis, aggregation, mining, forecasting, …**
- Load and price forecasting - crucial to all bidding strategies
- Supply bidding – risk-minimized bidding, block segment optimization, pump-hydro bidding
- Load bidding – DAM bidding to minimize expected overall energy costs
- Virtual bidding – risk management
- Market monitoring – data mining to find anomalies