Energy Procurement Portfolios and Production Planning

EWO Spring Meeting '11

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An Update to the Old Project

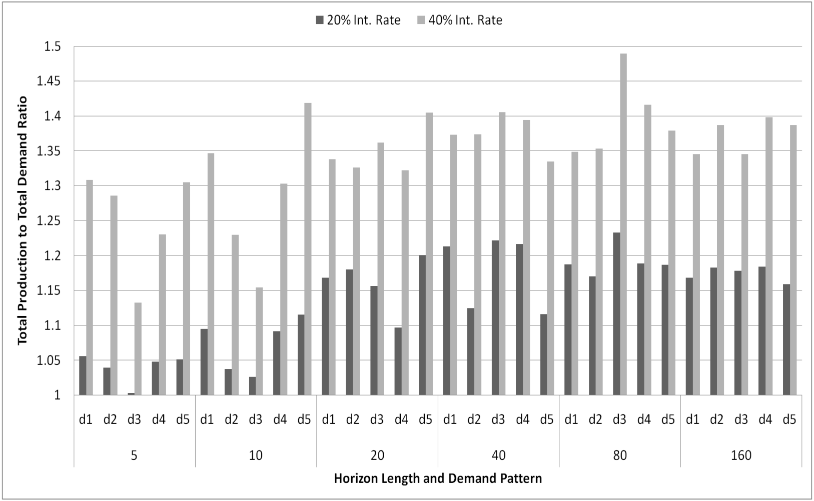


Figure: Total Production to Total Demand Ratio

New Project

Production Setting

- consider a single product, single plant
- manufacturing requires only energy
- deterministic demand
- stockouts are not allowed
- the plant has an energy storage system (ESS)

Contracts

- fixed price (FP or f)
- quantity-based tiered contracts (QB or q)
- time-based tiered contracts (TB or b)
- spot market access (SP or s)

New Project

Objective

- Minimize production costs
- Find a portfolio of contracts
- Find the optimal power import schedule

Contract Attributes

- enabled demand charge for all contracts
- modified TB contract to use a generic subset of hours
- enabled energy storage right from the start
- all of the contracts can be active simultaneously

Similar Models

Chan et al., 2006

Time zone (TZ) contract and loading curve (LC) contract

Conejo et al., 2006

- Spot market, bilateral contracts similar to TB contract and self-production. Uncertainty is related to electricity pool prices.
- Markovitz type
- Price volatility

Carrion et al. 2007-2010

- Same setting as above.
- Stochastic programming (price scenarios)
- CVaR: the expected cost of the procurement in the worst (greater cost) α% of the price scenarios

Model Notation

Sets

$\mathcal{A}$	contract categories	$:= \{f, q, b, s\}$
$\mathcal{D}$	set of days in planning horizon	$:= \{1, \ldots, 7\}$
$\mathcal{T}$	set of hours per day	$:= \{1, \ldots, 24\}$
$\mathcal{T}_1$	set of peak hours	$:= \{9, \ldots, 13\} \cup \{17, \ldots, 21\}$
$\mathcal{T}_2$	set of off-peak hours	$:= \mathcal{T} \setminus \mathcal{T}_1$

Hours

$$\begin{aligned} \mathcal{H} &:= \mathcal{D} \times \mathcal{T} \\ &:= \{1, \ldots, 168\} \end{aligned} \qquad \text{set of hours}$$

Model Parameters

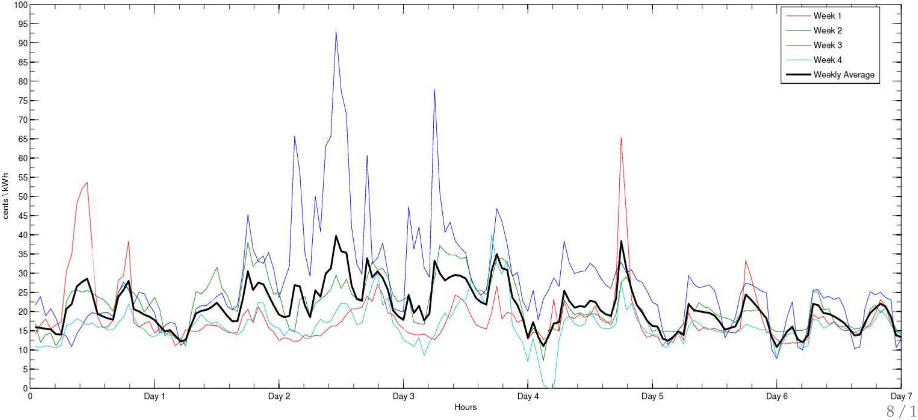
Contract Cost Parameters

c_f	flat rate (¢/kWh)
c_b^1, c_b^2	peak, off-peak rate (¢/kWh) requires $\mathcal{T}_1, \mathcal{T}_2$
c_q^1, c_q^2	before-qlimit, after-qlimit rate (¢/kWh) requires $qlimit$
c_s	expected hourly spot market rate (¢/kWh) requires $[V^s]$
$[V^s]$	sample price covariance matrix $(¢/\text{kWh})^2$

Data

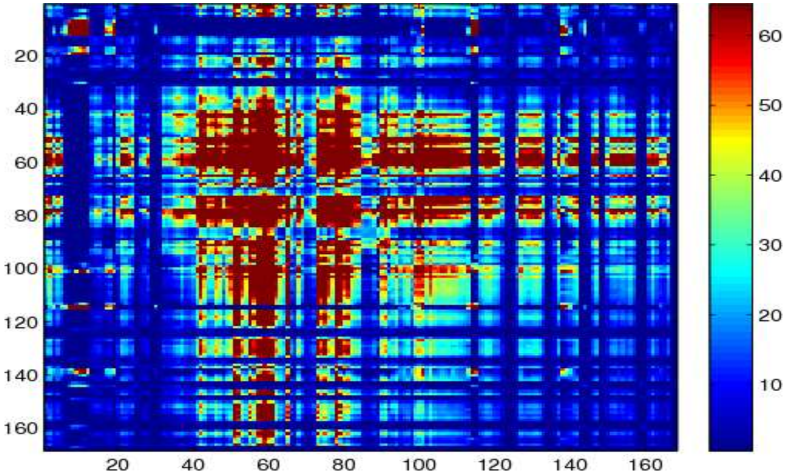
	Fixed Price	Time Based	Quantity Based	
Demand Charge	1000	1000	1000	\$
Tier 1	20	(peak) 35	($\leq$ 500 kW) 15	¢/ kWh
Tier 2	20	(off-peak) 15	($>$ 500 kW) 35	¢/ kWh

Table: Pricing Schemes



Data

Figure: Sample Covariance Matrix



Other Parameters

α	risk aversion coefficient
dc_a	demand charge imposed by contract a ($)
ub_a	max power that can be procured from contract a (kW)
M	big M
	Production Parameters
η	electricity to product conversion factor (unit/kWh)
dem_d	demand for end product faced on day d
inv_0	initial inventory for end product
	ESS Parameters
ξ_c, C_c	ESS charging loss coefficient and capacity
ξ_s, C_s	ESS storage loss coefficient and capacity
ξ_i, C_i	ESS discharging loss coefficient and capacity

Variables

Continuous Variables

$P_{h,a}$	power purchased from contract a at hour h
P_h^u	power used for production at hour h
P_h^e	power stored at ESS at hour h
P_h^f	power discharged from ESS at hour h
inv_d	inventory at the end of day d
ess_h	ESS charge level at hour h
K_h	auxiliary variable for modeling QB cost component

Binary Variables

x_a	1 if contract a is ever used in planning horizon
y_h	auxiliary variable for modeling QB cost component

Model

$$
\begin{aligned}
\min \quad & \sum_{h\in\mathcal{H}}(c_f P_{h,f} + c_s P_{h,s} + K_h) + && (1)\\
& \sum_{h\in\mathcal{H}_1} c_b^1 P_{h,b} + \sum_{h\in\mathcal{H}_2} c_b^2 P_{h,b} + && (2)\\
& \alpha \sum_{h_1\in\mathcal{H}} \sum_{h_2\in\mathcal{H}} P_{h_1,s}[V^s]_{h_1,h_2} P_{h_2,s} + \sum_{a\in\mathcal{A}} x_a dc_a && (3)\\
s.t. \quad & && \\
\forall h\in\mathcal{H}, a\in\mathcal{A} \quad & P_{h,a} \le M x_a && (4)\\
\forall h\in\mathcal{H} \quad & \sum_{a\in\mathcal{A}} P_{h,a} = P_h^u + P_h^e && (5)\\
\forall d\in\mathcal{D} \quad & inv_d = inv_{d-1} + \textstyle\sum_{t\in\mathcal{T}} \eta(P_h^u + \xi_i P_h^f) - dem_d && (6)\\
\forall h\in\mathcal{H} \quad & ess_h = \xi_s ess_{h-1} + \xi_c P_h^e - P_h^f && (7)
\end{aligned}
$$

Model

$$K_h = \begin{cases} c_q^2 P_h^q & \text{if } y_h = 1 \\ c_q^1 P_h^q & \text{o.w.} \end{cases}$$

$$\forall h \in \mathcal{H} \qquad \sum_{\substack{\hat{h} \in \mathcal{H} \\ \hat{h} \leq h}} P_{\hat{h},q} - qlimit \leq My_h \tag{8}$$

$$\forall h \in \mathcal{H} \qquad M + K_h \geq c_q^2 P_{h,q} + My_h \tag{9}$$

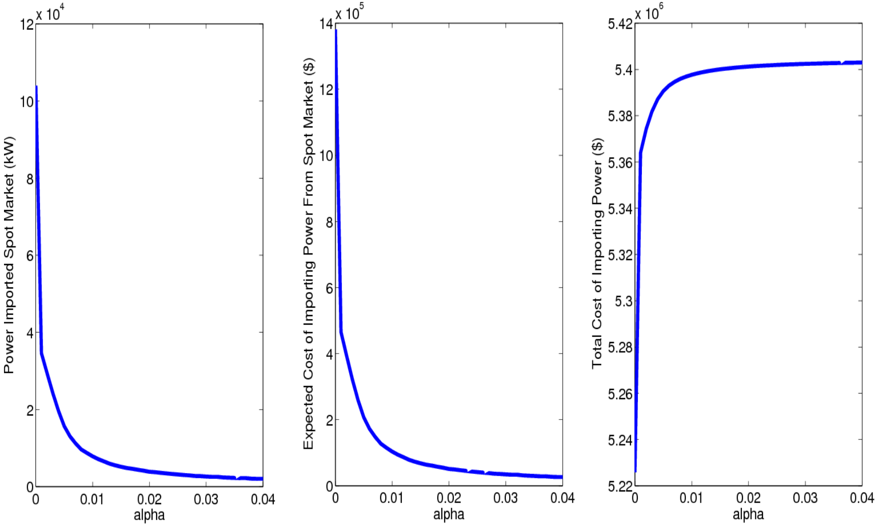
$$\forall h \in \mathcal{H} \qquad My_h + K_h \leq c_q^2 P_{h,q} + M \tag{10}$$

$$\forall h \in \mathcal{H} \qquad M + K_h \geq c_q^1 P_{h,q} + M(1 - y_h) \tag{11}$$

$$\forall h \in \mathcal{H} \qquad M(1 - y_h) + K_h \leq c_q^1 P_{h,q} + M \tag{12}$$

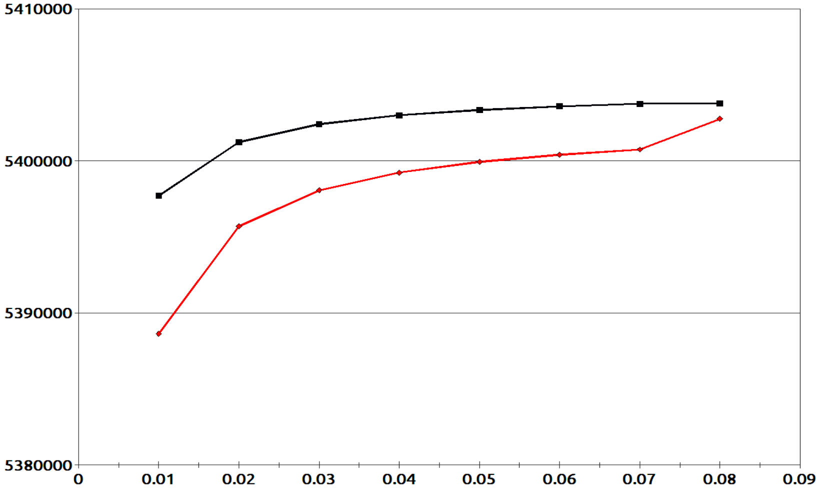
$$\forall h \in \mathcal{H} \qquad y_h \geq y_{h-1} \tag{13}$$

Preliminary Results



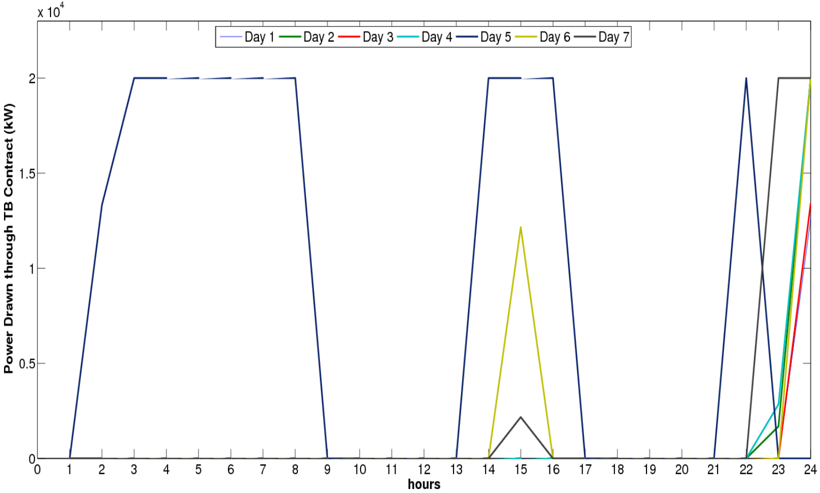
Preliminary Results

Figure: Objective Function Value for Different α Levels



Preliminary Results

Figure: Procurement Plan Avoids Peak Hours



Solution Techniques

Proposed Solution Techniques

- Improved Formulation by Symmetry Breaking Inequalities
- MIQP Branch and Bound with Warm Starting

Symmetry Breaking Inequalities

In some instances:

- Gurobi 4.0.0 and CPLEX 12.1 both reduced duality gap to 25% and stalled within the 2 hour limit
- Adding symmetry breaking constraints $y_h \geq y_{h-1} \quad \forall h \in \mathcal{H}$ reduced the solution time to 4 seconds

Proposed Solution Techniques

MIQP Branch and Bound with Warm Starting

- A Good Initialization Heuristic
  - Setting x_s =0 and $x_b = 0$ reduces the problem to an LP.
  - Start from the optimal basis and the objective is an upper bound for B&B scheme.
- A Relaxation Strategy
  - Linear relaxation at each node is a QP. Efficiently solvable by using
    - Interior point methods (such as a predictor-corrector method)
    - Active-set methods
  - This provides us a lower bound for B&B scheme.
- A Branching Rule
  - First branch on all x variables
  - Reduces the size of the search tree

Questions?

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