Optimal Short-Term Bidding Strategies for a Generation Company in the MIBEL

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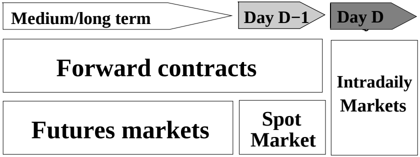
June, 20th 2006

Introduction and motivation

- Most of the liberalized power markets around the world has some kind of futures market
- The next creation of short term futures markets in the MIBEL
- Analyze hedging in electricity markets and interaction between physical production and electricity futures contracts
- The fact that coordination between short term futures and spot markets is necessary for a GENCO aiming to hedging energy prices

Futures market in the MIBEL

MIBEL:



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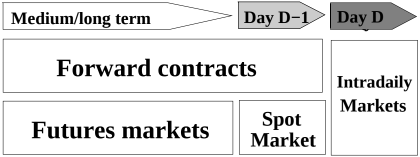

BOCG,25/01/05:

- *Future markets, which include exchanges of energy blocks with delivery date minimum one day after the closing contract day. With either physical-delivery or contracts for difference.*

Other futures markets

Nord Pool Futures Market:

- Day Contracts, Base Load.
- Week Contracts, Base Load.

Australia's National Electricity Market (NEMMCO):

- Base Load Quarter Electricity Futures.
- Peak Period Quarter Electricity Futures.

Base Load Futures Day Contracts (FDC)

Definition:

- A *Base Load* FDC for day d consists in a pair (L^d, λ^d)
  - L^d: amount of energy to be procured on day d
  - λ^d: hedging price of the contract.

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Procurement:

- **Physical**: physical-delivery of energy at futures price
- **Financial**: the company is credited/debited an amount equal to the difference between the spot market price and the futures contract's price
- At day $d-2$ the GENCO has to decide the kind of delivery

Problems associated to the Daily Futures Market

Optimal Bidding (trading period, until day $d-2$)

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Physical-delivery contracts selection (day $d-2$):

- Given F^d, the portfolio of FDC for day d
- At day $d-2$ it has to be decided which contracts will be procured with physical-delivery and which ones will be maintained as financial contracts.

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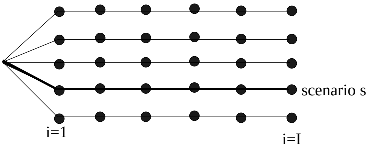
Energy procurement L^d (day $d-1$):

- Given the portfolio F^d of FDC with physical-delivery for day d
- The GENCO has to decide how to allocate optimally the energy L^d among the offer to the spot market

Model characteristics (1/2)

The model currently developed is restricted to:

- A *Price Taker* Generation Company
- A set of thermal generation units T
- An optimization horizon of 48h, with two successive periods of 24h, I^1 and I^2
- A set of equiprobable spot market price scenarios S for I^1 and I^2 (λ_i^{Ds})



Model characteristics (2/2)

Day 1 (I^1):

- Set of physical FDC known
- Commitment for the thermal units set in advance

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Day 2 (I^2):

- FDC portfolio known

Formulation

Find

economic dispatch for day 1

unit commitment for day 2

set of FDC with physical-delivery for day 2

Which maximize

E_λ(spot market expected profits day 1 and 2

taking into account the incomes of futures contracts)

Subject to

Operational constraints of thermal units T

Futures-spot market coupling rules for portfolio F^1 and F^2

Problem formulation: parameters (1/2)

- $I = \{I^1 \cup I^2\}$: set of intervals
- T: number of thermal units
- T_i^1: committed thermal units set, $\forall i \in I^1$
- F^2: number of futures contracts for I^2
- S: number of spot market price scenarios
- $\mathcal{U}^t$: operational domain of unit t for I^1

Problem formulation: parameters (2/2)

- L^1: total energy of futures contracts to procure in I^1
- L_j^2: futures contract amount of energy (MW), $j \in F^2$
- λ_j^F: futures contract price, $j \in F^2$
- λ_i^{Ds}: spot market price $\forall i \in I, \forall s \in S$
- $\overline{\lambda}_i^D$: spot market price forecast $\forall i \in I^2$
- P^s: scenario probability, $s \in S$
- c_{on}^t, c_{off}^t: on/off costs, $t \in T$
- c_l^t, c_q^t: lineal and quadratic procurement costs, $t \in T$
- $\underline{P}_t, \overline{P}_t$: operational minimum and maximum limits, $t \in T$
- min_{on}, min_{off}: operational minimum on/off time, $t \in T$

Problem formulation: variables

- p_i^{ts}: energy for free-bidding in the spot market $\forall i \in I, \forall t \in T, \forall s \in S$
- q_i^t: energy of futures contracts allocated to unit t, $\forall t \in T, \forall i \in I^1$
- u_i^t, a_i^t i e_i^t: binary variables, fix the state of the unit, $\forall i \in I^2, \forall t \in T$
- $\hat{q}_{ij}^t$: energy of futures contract j allocated to unit t,$\forall j \in F^2$, $\forall i \in I^2$, $\forall t \in T$
- y_j: binary variable, indicates if a futures contract will be physically delivered, $\forall j \in F^2$

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Problem formulation: o.f.

$$\text{mín}\Big[\sum_{i\in I^1}\Big(\sum_{t\in T_i^1}(c_l^t q_i^t + c_q^t (q_i^t)^2 +$$

$$\sum_{s\in S} P^s((c_l^t - \lambda_i^{Ds})p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} q_i^t)))\Big)+$$

Problem formulation: o.f.

$$
\begin{aligned}
\text{mín}\Big[\sum_{i\in I^1}\Big(\sum_{t\in T_i^1}(c_l^t q_i^t + c_q^t (q_i^t)^2 + \\
&\sum_{s\in S} P^s((c_l^t - \lambda_i^{Ds})p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} q_i^t)))\Big) + \\
+\Big(\sum_{i\in I^2}\sum_{t\in T}(c_{on}^t e_i^t + c_{off}^t a_i^t + c_b^t u_i^t + c_l^t \sum_{j\in F^2}(\hat{q}_{ij}^t) + c_q^t \sum_{j\in F^2}((\hat{q}_{ij}^t)^2) + \\
&\sum_{s\in S} P^s((c_l^t - \lambda_i^{Ds})p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} \sum_{j\in F^2}(\hat{q}_{ij}^t))))-
\end{aligned}
$$

Problem formulation: o.f.

$$\min \Big[\sum_{i \in I^1} \Big(\sum_{t \in T_i^1} (c_l^t q_i^t + c_q^t (q_i^t)^2 +$$

$$\sum_{s \in S} P^s ((c_l^t - \lambda_i^{Ds}) p_i^{ts} + c_q^t (p_i^{ts})^2 + 2 c_q^t (p_i^{ts} q_i^t))) \Big) +$$

$$+ \Big(\sum_{i \in I^2} \sum_{t \in T} (c_{on}^t e_i^t + c_{off}^t a_i^t + c_b^t u_i^t + c_l^t \sum_{j \in F^2} (\hat{q}_{ij}^t) + c_q^t \sum_{j \in F^2} ((\hat{q}_{ij}^t)^2) +$$

$$\sum_{s \in S} P^s ((c_l^t - \lambda_i^{Ds}) p_i^{ts} + c_q^t (p_i^{ts})^2 + 2 c_q^t (p_i^{ts} \sum_{j \in F^2} (\hat{q}_{ij}^t)))) -$$

$$\sum_{j \in F^2} (\lambda_j^F \sum_{t \in T} (\hat{q}_{ij}^t) + (1 - y_j)(\lambda_j^F - \overline{\lambda}_i^D) L_j^2) \Big) \Big]$$

Problem formulation: constraints (1/4)

Operational limits (I^1):

$$q_i^t + p_i^{ts} \geq \underline{P}^t \qquad \forall i \in I^1 \quad \forall t \in T_i^1 \quad \forall s \in S \qquad (1)$$

$$q_i^t + p_i^{ts} \leq \overline{P}^t \qquad \forall i \in I^1 \quad \forall t \in T_i^1 \quad \forall s \in S \qquad (2)$$

Futures contracts (I^1):

$$\sum_{t \in T_i^1} q_i^t = L^1 \qquad \forall i \in I^1 \qquad (3)$$

Problem formulation: constraints (2/4)

On/off process (I^2):

$$a_i^t + e_i^t \leq 1 \qquad \forall i \in I^2 \quad \forall t \in T \qquad (4)$$

$$u_i^t + u_{i-1}^t - e_i^t + a_i^t = 0 \qquad \forall i \in I^2 \quad \forall t \in T \qquad (5)$$

$$a_i^t + \sum_{j=i+1}^{i+min_{off}} e_j^t \leq 1 \qquad \forall i \in I^2 \quad \forall t \in T \qquad (6)$$

$$e_i^t + \sum_{j=i+1}^{i+min_{on}} a_j^t \leq 1 \qquad \forall i \in I^2 \quad \forall t \in T \qquad (7)$$

Problem formulation: constraints (3/4)

Operational constraints (I^2):

$$\sum_{j \in F^2} (\hat{q}_{ij}^t) \geq \underline{P}^t u_i^t \qquad \forall i \in I^2 \quad \forall t \in T \quad \forall s \in S \qquad (8)$$

$$\sum_{j \in F^2} (\hat{q}_{ij}^t) + p_i^{ts} \leq \overline{P}^t u_i^t \qquad \forall i \in I^2 \quad \forall t \in T \quad \forall s \in S \qquad (9)$$

Futures contracts (I^2):

$$\sum_{t \in T} \hat{q}_i^t = \sum_{j \in F^2} L_j^2 \, y_j \qquad \forall i \in I^2 \qquad (10)$$

Problem formulation: constraints (4/4)

Variable domain:

$$u_i^t, a_i^t, e_i^t \in \{0,1\} \cap \mathcal{U}^t \qquad \forall i \in I^2 \quad \forall t \in T \qquad (11)$$

$$y_j \in \{0,1\} \qquad \forall j \in F^2 \qquad (12)$$

$$q_i^t \geq 0 \qquad \forall i \in I \quad \forall t \in T \qquad (13)$$

$$\hat{q}_{ij}^t \geq 0 \qquad \forall i \in I \quad \forall t \in T \quad \forall j \in F^2 \qquad (14)$$

$$p_i^{ts} \geq 0 \qquad \forall i \in I \quad \forall t \in T \quad \forall s \in S \qquad (15)$$

Case study characteristics

- October, 24th and 25th 2005
- 10 thermal generation units (7 coal, 3 fuel) from a generation company with daily bidding to the Spanish Electricity Market

S	I	T	F($\%\overline{P}$)	v.b.	v.c.	$\overline{CPU}(m)$
4	48	10	50	246	5280	1.22
6	48	10	50	246	6240	4.57
10	48	10	50	246	8160	4.11
15	48	10	50	246	10560	14.22
20	48	10	50	246	12960	11.12

Price scenario generation

- Price Spot Market, λ_i^{Ds}, is treated as a stochastic variable
- Model ARIMA $(23,1,13)(14,1,21)_{24}(0,1,1)_{168}$:

$$(1+0{,}033B^{12}-0{,}25B^{13}-0{,}014B^{23})$$

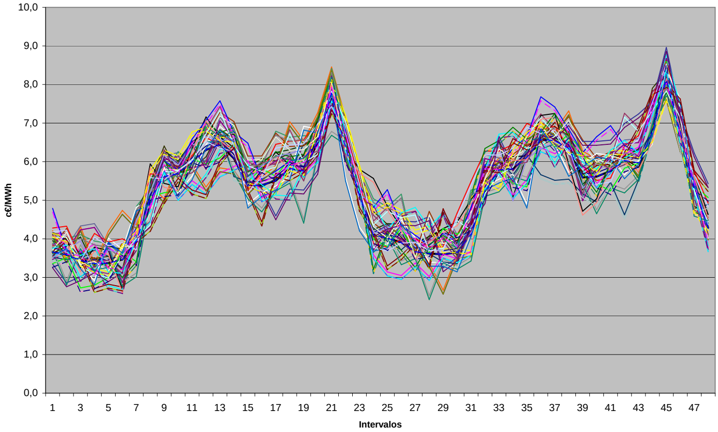
$$(1-0{,}09B^{96}-0{,}11B^{120}-0{,}08B^{144}-0{,}54B^{168}-0{,}03B^{336})ln(\lambda_i^{Ds}) =$$

$$(1+0{,}23B^{1}+0{,}13B^{2}+0{,}09B^{3}+0{,}08B^{4}+0{,}05B^{5}+0{,}06B^{6}+0{,}30B^{13})$$

$$(1-0{,}19B^{24}-0{,}12B^{48}-0{,}11B^{72}+0{,}42B^{168}-0{,}04B^{504})(1+0{,}98B^{168})Z_t$$

- Price scenario generation by simulation

Price scenario generation



Results I^1 (1/2)

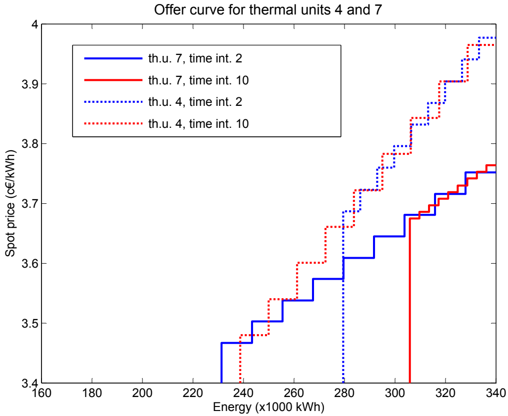
Procurement of physical-delivery contracts

Unit \ Interval	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	100	100	100	100	100	100	100	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
2	0	0	0	0	0	0	0	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
3	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
4	72	72	72	72	72	72	72	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
5	0	0	0	0	0	0	0	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43
6	78	78	78	78	78	78	78	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57	57
7	71	71	71	71	71	71	71	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LEGEND	
100%	red
(100 – 50) %	orange
[50, 25) %	yellow
[25, 0) %	white

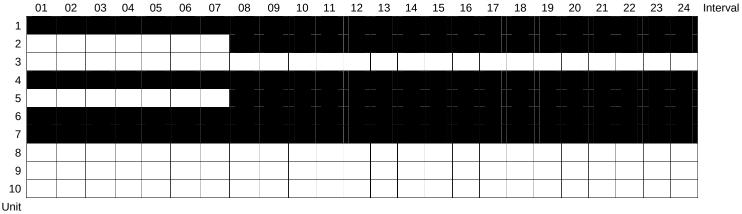
Results $I^1(2/2)$

Optimal bid



Results I^2 (1/2)

Unit commitment



Results I^2 (2/2)

Physical-delivery contracts selection

Example 1

λ^d	L^d	y^d
4.5	20	0
6	150	1
6.5	320	1
4.5	50	0
4.5	200	1
5.5	150	1

Example 2

λ^d	L^d	y^d
4.5	20	0
6	150	1
6.5	320	1
5	100	1
5.5	200	1
5.5	100	1

Example 3

λ^d	L^d	y^d
	20	1
	150	1
	320	1
	50	1
	200	1
	100	1

Conclusions (1/2)

- The model developed allows the GENCO to:
  - Select optimal physical-delivery futures contracts portfolio for day 2
  - Unit commitment for day 1
  - Optimal generation of physical-delivery futures contracts for day 1
  - Optimal bid for the spot market at 0€/MWh

Conclusions (2/2)

- Further developments:
  - Improve of futures contracts model
  - Improve scenarios generation
  - Include optimal futures daily market bidding
  - Include emissions rights trading
  - Inclusion of hydro units
  - Introduction of risk terms

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