

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

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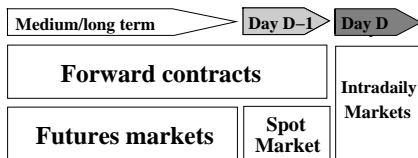
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Introduction and motivation

- ▶ 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

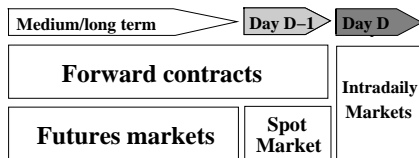
Futures market in the MIBEL

MIBEL:



Futures market in the MIBEL

MIBEL:



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.

Others...

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

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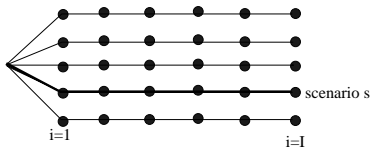
Energy procurement L^d (day $d - 1$):

- ▶ 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

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})



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 futures contracts hedged incomes)

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 : set of futures contracts for I^2
- ▶ S : number of spot market price scenarios
- ▶ \mathcal{U}^t : operational domain of unit $t \in T$ 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, $j \in F^2$
- ▶ λ_j^F : futures contract price, $j \in F^2$
- ▶ λ_i^{Ds} : spot market price $\forall i \in I, \forall s \in S$
- ▶ $\bar{\lambda}_i^D$: 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, $t \in T$
- ▶ $\underline{P}_t, \bar{P}_t$: 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 t ,
 $\forall i \in I^2, \forall t \in T$
- ▶ \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, $\forall j \in F^2$

Problem formulation: first and second stage 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, e_i^t : binary variables, fix the state of the unit t ,
 $\forall i \in I^2, \forall t \in T$
- ▶ \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, $\forall j \in F^2$

Problem formulation: o.f.

$$\begin{aligned} \min \left[\sum_{i \in I^1} \left(\sum_{t \in T_i^1} (c_i^t q_i^t + c_q^t (q_i^t)^2 + \right. \right. \\ \left. \left. \sum_{s \in S} P^s ((c_i^t - \lambda_i^{Ds}) p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} q_i^t))) \right) \right] + \end{aligned}$$

Problem formulation: o.f.

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

Problem formulation: o.f.

$$\begin{aligned}
 \min & \left[\sum_{i \in I^1} \left(\sum_{t \in T_i^1} (c_i^t q_i^t + c_q^t (q_i^t)^2 + \right. \right. \\
 & \quad \left. \left. \sum_{s \in S} P^s ((c_i^t - \lambda_i^{Ds}) p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} q_i^t)) \right) \right) + \\
 & + \left(\sum_{i \in I^2} \sum_{t \in T} (c_{on}^t e_i^t + c_{off}^t a_i^t + c_b^t u_i^t + c_i^t \sum_{j \in F^2} (\hat{q}_{ij}^t) + c_q^t \sum_{j \in F^2} ((\hat{q}_{ij}^t)^2) + \right. \\
 & \quad \left. \sum_{s \in S} P^s ((c_i^t - \lambda_i^{Ds}) p_i^{ts} + c_q^t (p_i^{ts})^2 + 2c_q^t (p_i^{ts} \sum_{j \in F^2} (\hat{q}_{ij}^t))) \right) - \\
 & \quad \left. \sum_{j \in F^2} (\lambda_j^F \sum_{t \in T} (\hat{q}_{ij}^t) + (1 - y_j) (\lambda_j^F - \bar{\lambda}_i^D) L_j^2) \right) \Big]
 \end{aligned}$$

Problem formulation: constraints (1/3)

Operational limits:

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

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

$$\sum_{j \in F^2} (\hat{q}_{ij}^t) \geq \underline{P}^t u_i^t \quad \forall i \in I^2 \quad \forall t \in T \quad \forall s \in S \quad (3)$$

$$\sum_{j \in F^2} (\hat{q}_{ij}^t) + p_i^{ts} \leq \overline{P}^t u_i^t \quad \forall i \in I^2 \quad \forall t \in T \quad \forall s \in S \quad (4)$$

Futures contracts:

$$\sum_{t \in T_i^1} q_i^t = L^1 \quad \forall i \in I^1 \quad (5)$$

$$\sum_{t \in T} \hat{q}_i^t = \sum_{j \in F^2} L_j^2 y_j \quad \forall i \in I^2 \quad (6)$$

Problem formulation: constraints (2/3)

Start-up/Shut-down process:

$$a_i^t + e_i^t \leq 1 \quad \forall i \in I^2 \quad \forall t \in T \quad (7)$$

$$u_i^t + u_{i-1}^t - e_i^t + a_i^t = 0 \quad \forall i \in I^2 \quad \forall t \in T \quad (8)$$

$$a_i^t + \sum_{j=i+1}^{i+min_{off}} e_j^t \leq 1 \quad \forall i \in I^2 \quad \forall t \in T \quad (9)$$

$$e_i^t + \sum_{j=i+1}^{i+min_{on}} a_j^t \leq 1 \quad \forall i \in I^2 \quad \forall t \in T \quad (10)$$

Problem formulation: constraints (3/3)

Variable domain:

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

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

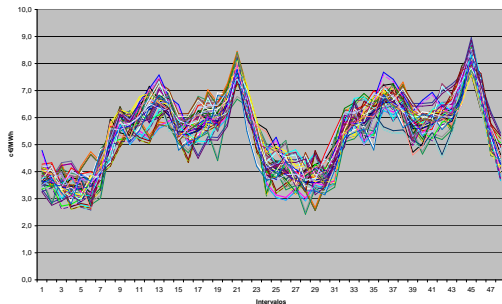
$$q_i^t \geq 0 \quad \forall i \in I \quad \forall t \in T \quad (13)$$

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

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

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
- ▶ Price scenario generation by simulation



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	v.b.	v.c.	$\overline{CPU}(m)^1$
4	48	10	246	5280	1.22
6	48	10	246	6240	4.57
10	48	10	246	8160	4.11
15	48	10	246	10560	14.22
20	48	10	246	12960	11.12

- ▶ CPLEX 9.0, AMPL, Opteron 64 bit, 2.4 GHz

¹Mean of computational times for instances with different futures contracts data





Results I^1 (1/2)

Procurement of physical-delivery contracts

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Interval
1	0	100	100	100	100	100	100	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	
2	0	48	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	
3	100	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	
4	100	82	73	73	73	73	73	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	
5	100	0	0	0	0	0	0	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	
6	0	0	79	79	79	79	79	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	
7	100	72	72	72	72	72	72	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	

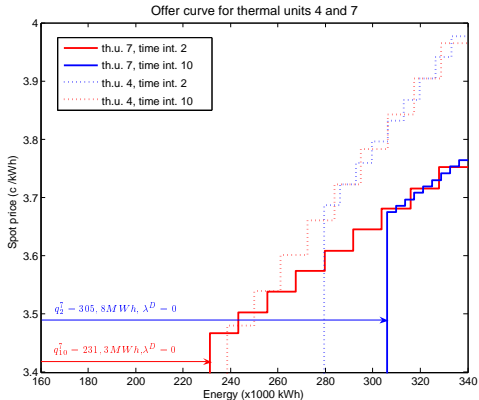
Unit

LEGEND

100%	
(100 - 50) %	
[50, 25) %	
[25, 0) %	

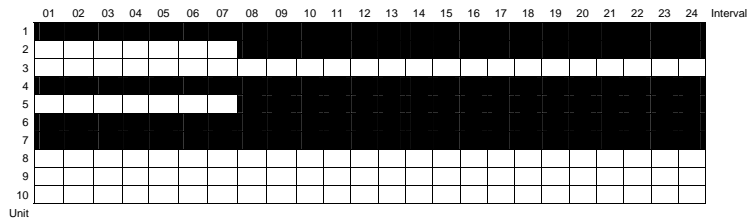
Results $I^1(2/2)$

Optimal bid



Results I^2 (1/2)

Unit commitment



Unit

Results I^2 (2/2)

Physical-delivery contracts selection

Example 1

λ^d (c€/MWh)	L^d (MWh)	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 (c€/MWh)	L^d (MWh)	y^d
4.5	20	0
6	150	1
6.5	320	1
4.5	100	1
5.5	200	1
5.5	100	1

Example 3

λ^d (c€/MWh)	L^d (MWh)	y^d
4.5	100	1
6	150	1
6.5	320	1
5	100	1
5.5	200	1
5.5	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 2
 - ▶ Optimal generation of physical-delivery futures contracts for day 1
 - ▶ Optimal bid for the spot market at 0€/MWh, the rest of the power capacity can be offered at the unit's marginal cost

Conclusions (2/2)

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

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