A mixed-integer stochastic programming model for the day-ahead and futures energy markets coordination

Cristina Corchero F. Javier Heredia
cristina.corchero@upc.edu f.javier.heredia@upc.edu
Departament d'Estadística i Investigació Operativa
Universitat Politècnica de Catalunya

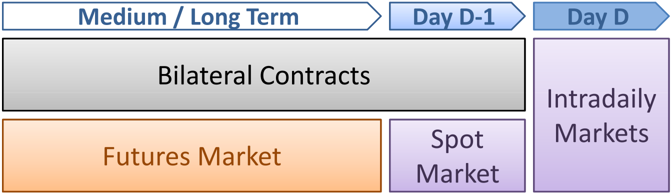
July, 2007

This work was supported by the Ministerio de Educación y Ciencia of Spain under Projects DPI2005-09117-C02-01 and MTM2004-21648-E

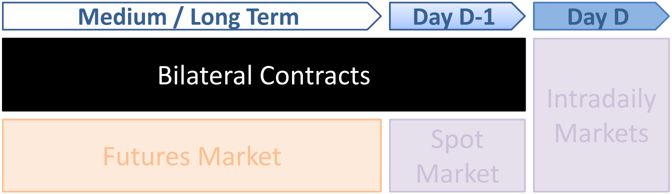
Introduction and motivation

- The recent creation of short term futures markets in the MIBEL and its particular rules
- The existence of futures market in most of the liberalized power markets around the world
- The fact that coordination between short term futures and spot markets is necessary for a GENCO
- Analyze hedging in electricity markets and interaction between physical production and electricity futures contracts

Electric Energy Iberian Market: MIBEL



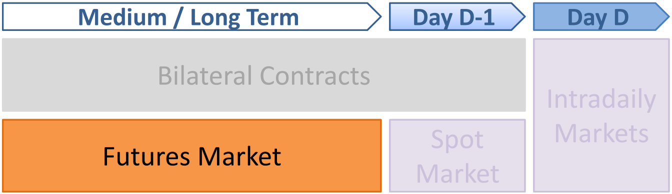
Electric Energy Iberian Market: MIBEL



Main characteristics of bilateral contracts:

- Non organized market
- Physical bilateral contracts
- Minimum contract duration one year

Electric Energy Iberian Market: MIBEL



OMIP's main characteristics:

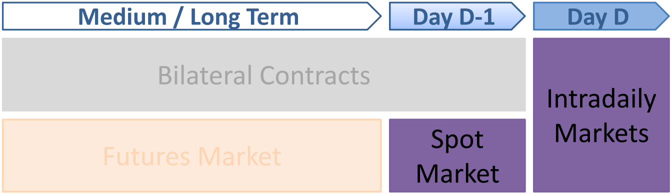
Physical Contracts

Physical Settlement
Positions are sent to OMEL's Mercado Diario for physical delivery
Financial Settlement
OMIClear cash settles the differences between the Spot Reference Price and the Final Settlement Price

Financial Contracts

Financial Settlement
OMIClear cash settles the differences between the Spot Reference Price and the Final Settlement Price

Electric Energy Iberian Market: MIBEL



OMEL's main characteristics:

- Organized markets
- Spot market:
  - The matching procedure takes place 24h before the delivery period
  - Hourly auction

MIBEL Futures Contracts

Main characteristics:

- Base load
- Physical or financial settlement.
- Delivery period: years, quarters, months and weeks.

MIBEL Futures Contracts

Main characteristics:

- Base load
- Physical or financial settlement.
- Delivery period: years, quarters, months and weeks.

Definition:

- A *Base Load Futures Contract* consists in a pair (L^f, λ^f)
  - L^f: amount of energy (MW) to be procured each interval of the delivery period.
  - λ^f: price of the contract (€/MW).

Physical Base Load Futures Contracts

Market physical settlement rules:[1]

- *At least two days prior to the physical delivery day, physical delivery futures contracts are entered as orders at 'acceptance price' in the call auction of OMEL's Mercado Diario*
- *Before the call auction each Physical Settlement Agent must specify which production/consumption units are to be allocated to the orders.*

[1] Omip/Omiclear Operational Guide

Problems associated to the Futures Market

Optimal bidding at futures market:

- During the trading period the GENCO could send bids for all products opened in the Futures Market.

Problems associated to the Futures Market

Optimal bidding at futures market:

- During the trading period the GENCO could send bids for all products opened in the Futures Market.

Physical or financial delivery contracts selection:

- Given the open positions of futures contracts the GENCO has to build the physical-delivery portfolio and the financial one.

Problems associated to the Futures Market

Optimal bidding at futures market:

- During the trading period the GENCO could send bids for all products opened in the Futures Market.

Physical or financial delivery contracts selection:

- Given the open positions of futures contracts the GENCO has to build the physical-delivery portfolio and the financial one.

Futures contract energy allocation:

- Given the portfolio of futures contracts with physical-delivery the GENCO has to decide how to allocate the energy among the offer to the spot market.

Characteristics of the study

- The model currently developed is restricted to:
  - A *Price Taker* generation company
  - A set of thermal generation units, T
  - An optimization horizon of 24h, I
  - A fan of spot market price scenarios, S
- It has been implemented with AMPL, without exploiting the structure of the problem, and it has been solved with CPLEX.
- The main objective of the computational tests is to evaluate the coherence of the proposed methodology.

Optimal bid curve for thermal unit t (I/II)

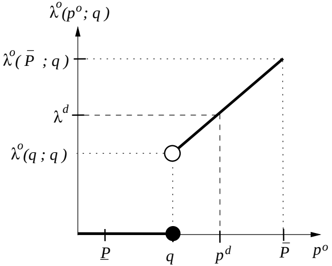
- Let q_i^t be the generation of thermal t at time i allocated to all the physical contracts of the portfolio.
- The market rules forces each generator to send the amount q_i^t to the day-ahead market through an *instrumental price bid* (bid at zero price).
- For a given value q_i^t, the *optimal bid curve* is the function $\lambda_i^{o,t}(p_i^{o,t}; q_i^t)$ that provides the energy-price pairs $(p_i^{o,t}, \lambda_i^{o,t})$ that maximize the benefit function for any given spot price λ_i^d

Optimal bid curve for thermal unit t (II/II)

- The expression of the optimal bid curve for thermal unit t at time interval i, for a given q_i^t, is:

$$\lambda_i^{o,t}(p_i^{o,t}; q_i^t) = \begin{cases} 0 & \text{if} \quad 0 \leq p_i^{o,t} \leq q_i^t \\ 2c_q^t p_i^{o,t} + c_l^t & \text{if} \quad q_i^t < p_i^{o,t} \leq \overline{P}^t \end{cases} \quad (1)$$

graphically:



Matched energy (I/II)

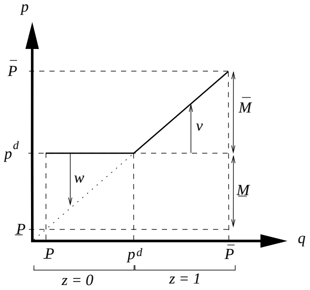
- Given a spot price $\lambda_i^{d,s}$, corresponding to scenario s, and a value q_i^t, the *matched energy* p_i^{ts} is completely determined through expression (1), and depends on the comparison between q_i^t and $p^{d,ts}$:

$$p_i^{ts} = \begin{cases} q_i^t & \text{if } q_i^t \geq p_i^{d,ts} \\ p_i^{d,ts} & \text{otherwise} \end{cases} \tag{2}$$

where the constant $p_i^{d,ts}$ is the generation that maximizes the benefit function for a given spot-price $\lambda_i^{d,s}$.

Matched energy (II/II)

- Expression (2) defines the matched energy p_i^{ts} as a piece-wise linear function of the zero priced bid q_i^t



- This non-differential expression can be conveniently expressed through an equivalent mixed-linear formulation.

Two-stage stochastic program formulation

- **Scenarios:** spot prices $\lambda^{d,s} \in \Re^{|I|}$, $s \in \mathcal{S}$
- **First stage variables:** $\forall t \in T$, $\forall i \in I$
  - **Instrumental price offer bid :** q_i^t
  - **Scheduled energy for contract** j: f_{ij}^t , $\forall j \in F$
  - **Unit commitment:** u_i^t , a_i^t , e_i^t , $\forall i \in I$, $\forall t \in T$
- **Second stage variables:** $\forall t \in T$, $\forall i \in I$, $\forall s \in S$:
  - **Matched energy:** p_i^{ts}
  - **Auxiliary variables:** $z_i^{ts}, v_i^{ts}, w_i^{ts}$

Objective function

$$\min_{q,f,u,a,e,p,z,v,w} \sum_{\forall i \in I} \sum_{\forall t \in T} c_{on}^t e_i^t + c_{off}^t a_i^t + c_b^t u_i^t + \sum_{s \in S} P^s \left[(c_l^t - \lambda_i^{d,s}) p_i^{ts} + c_q^t (p_i^{ts})^2 \right] \quad (3)$$

Associated constants: $c_{on}^t, c_{off}^t, c_b^t, c_l^t, c_q^t, P^s, \lambda_i^{d,s}$

Physical Future contracts constraints

Physical future contract covering:

$$\sum_{t \in T} f_{ij}^t = L_j \; , \; \forall j \in F \tag{4}$$

Instrumental price bid:

$$q_i^t \geq \sum_{j \in F} f_{ij}^t \; , \; \forall t \in T \; , \; \forall i \in I \tag{5}$$

Associated variables: $q_i^t, f_{ij}^t \in 0 \cup [\underline{P}^t, \overline{P}^t]$

Associated constants: L_j

Start-up/Shut-down constraints: $\forall i \in I$, $\forall t \in T$

$$a_i^t + e_i^t \leq 1 \tag{6}$$

$$u_i^t - u_{i-1}^t - e_i^t + a_i^t = 0 \tag{7}$$

$$a_i^t + \sum_{j=i+1}^{i+min_{off}} e_j^t \leq 1 \tag{8}$$

$$e_i^t + \sum_{j=i+1}^{i+min_{on}} a_j^t \leq 1 \tag{9}$$

Associated variables: $u_i^t, a_i^t, e_i^t \in \{0,1\} \cap \mathcal{U}^t$

Definition of the matched energy: $\forall s \in S$, $\forall i \in I$, $\forall t \in T$

$$p_i^{ts} = p_i^{d,ts} u_i^t + v_i^{ts} \quad (10)$$

$$v_i^{ts} - w_i^{ts} = q_i^t - p_i^{d,ts} u_i^t \quad (11)$$

$$v_i^{ts} \leq \overline{M}^{ts} z_i^{ts} \ , \ w_i^{ts} \leq \underline{M}^{ts} (1 - z_i^{ts}) \quad (12)$$

$$\underline{P}^t u_i^t \leq p_i^{ts} \leq \overline{P}^t u_i^t \quad (13)$$

$$p_i^{d,ts} u_i^t + \underline{M}^{ts} \left(z_i^{ts} - 1 \right) \leq q_i^t \leq p_i^{d,ts} u_i^t + \overline{M}^{ts} z_i^{ts} \quad (14)$$

$$\sum_{s \in S} z_i^{ts} \leq |S| u_i^t \quad (15)$$

Associated variables: $p_i^{ts}, \in 0 \cup [\underline{P}^t, \overline{P}^t]$, $z_i^{ts} \in \{0,1\}$, $v_i^{ts}, w_i^{ts} \geq 0$

Associated constants: $p_i^{d,ts}, \overline{M}_i^{ts} = \overline{P}^t - p_i^{d,ts}, \underline{M}_i^{ts} = p_i^{d,ts} - \underline{P}^t$

Price scenario generation

- Price Spot Market, $\lambda_i^{d,s}$, is a stochastic variable, in particular, a time serie.
- Time series study results in a ARIMA model: ARIMA $(23, 1, 13)(14, 1, 21)_{24}(0, 1, 1)_{168}$[2]
- Price scenario construction:
  - Generation of 350 scenarios by time series simulation
  - Reduction of the number of scenarios [3]

[2] Amell et Bernáldez *Previsió de preus i planificació de la producció al MIBEL*

[3] Gröwe-Kuska et al. *Scenario Reduction and Scenario Tree Construction for Power Management Problems*

Case study characteristics

- October, 24th and 25th 2006
- 10 thermal generation units (7 coal, 3 fuel) from a generation company with daily bidding to the MIBEL

$[\overline{P} - \underline{P}]$ (MW)	160-243	250-550	80-260	160-340	30-70
min_on/off (h)	3	3	3	4	4

$[\overline{P} - \underline{P}]$ (MW)	60-140	160-340	90-340	110-157	110-157
min_on/off (h)	3	3	4	4	4

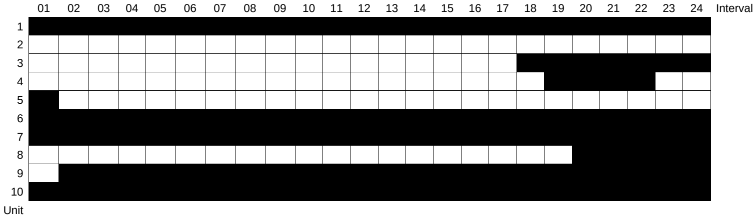
- 6 physical futures contracts

L_f (MW)	20	150	320	50	200	150
λ_f (c€/KW)	5.12	4.96	6.60	5.35	5.09	5.00

- 10 spot-market price scenarios

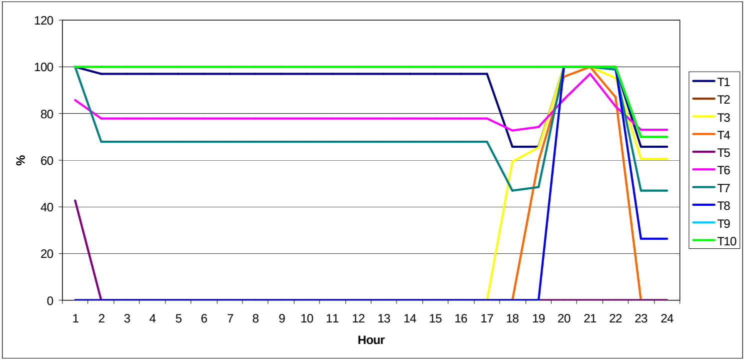
Results (I/IV)

Unit commitment



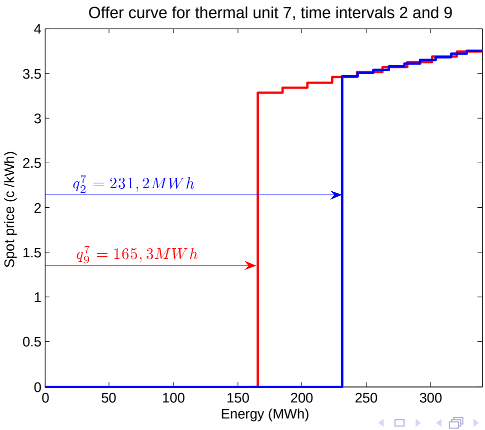
Results (II/IV)

Procurement of physical-delivery contracts



Results (III/IV)

Optimal bid



Results (IV/IV)

Futures contracts covering

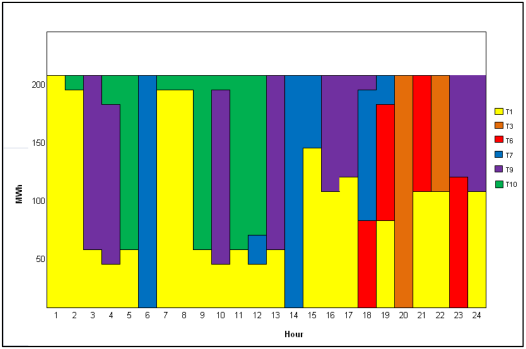


Figure: Futures contract #6

Conclusions (I/II)

- It has been build an Optimal Bidding Model for a *price-taker* GENCO following in detail the MIBEL rules.
- The stochasticity of the spot price has been took into account and it has been fully represented by the scenario tree.
- The model developed gives the GENCO:
  - Optimal bid for the spot market: quantity at 0€/MWh and the rest of the power capacity at the unit's marginal cost
  - Unit commitment
  - Optimal allocation of the physical futures contracts among the thermal units

Conclusions (II/II)

- Further developments:
  - Exploitation of the problem structure
  - Coordination with mid-term strategies
  - Inclusion of hydro units
  - Inclusion of emissions rights trading
  - Introduction of risk terms

A mixed-integer stochastic programming model for the day-ahead and futures energy markets coordination

Cristina Corchero   F. Javier Heredia
cristina.corchero@upc.edu   f.javier.heredia@upc.edu
Departament d'Estadística i Investigació Operativa
Universitat Politècnica de Catalunya

July, 2007

This work was supported by the Ministerio de Educación y Ciencia of Spain under Projects DPI2005-09117-C02-01 and MTM2004-21648-E