Optimal day-ahead bidding strategy with futures and bilateral contracts. Scenario generation by means of factor models

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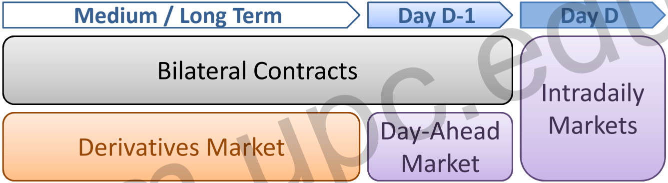
Electric Energy Iberian Market: MIBEL



Derivatives Market

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

Bilateral Contracts

Organized markets
- Virtual Power Plants auctions (**EPE**) - Distribution auctions (**SD**) - International Capacity Interconnection auctions - International Capacity Interconnection nomination
Non organized markets
- **National** BC **before** the spot market - **International** BC **before** the spot market - **National** BC **after** the spot market

Day-Ahead Market

Day-Ahead Market
Hourly action. The matching procedure takes place 24h before the delivery period. Physical futures contracts are settled through a zero price bid.

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Characteristics of Physical Futures and Bilateral Contracts

Base Load Futures Contract

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

Bilateral Contracts

- A *Bilateral Contract* consists in a pair $(L_i^{BC}, \lambda_i^{BC})$ $i \in I$
  - L_i^{BC}: amount of energy (MWh) to be procured each interval i of the delivery period.
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Integration of the futures and bilateral contracts in the day-ahead bid

The energies L^{FC} and L_i^{BC} should be integrated in the MIBEL's day-ahead bid respecting the two following rules:

1. If generator t contributes with f_{itj} MWh at period i to the coverage of the FC j, then the energy f_{itj} must be offered to the pool for free (instrumental price bid).
2. If generator t contributes with b_{it} MWh at period i to the coverage of the pool of BCs, then the energy b_{it} must be excluded from the bid to the day-ahead market. Unit t can offer its remaining production capacity $\overline{P}_t - b_{it}$ to the pool.

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Day-ahead market model: definitions

Definition (Bid function)

A bid function for the thermal unit t is a non-decreasing function defined over the interval $[0, \overline{P}_t - b_{it}]$ that gives, for any feasible value of the bid energy p_{it}, the asked price per MWh from the day-ahead market:

$$\begin{array}{rccc} \lambda_{it}^{b}: & [0, \overline{P}_t - b_{it}] & \longrightarrow & \Re^{+} \cup 0 \\ & p_{it} & \longmapsto & \lambda_{it}^{b}(p_{it}) \end{array}$$

Day-ahead market model: definitions

Definition (Matched energy function)

The matched energy associated to the bid function λ_{it}^{b} is defined as the maximum bid energy with an asked price not greater than the clearing price λ_i, and is represented by the function:

$$p_{it}^{M}(\lambda_i) \stackrel{\text{def}}{=} \max\{p_{it} \in [0, \overline{P}_t - b_{it}] \mid \lambda_{it}^{b}(p_{it}) \leq \lambda_i\}$$

Day-ahead market model: assumption

Assumption

For any thermal unit i committed at period t there exists a bid function λ_{it}^{b} such that:

$$p_{it}^{M,s*} = p_{it}^{M}(\lambda_i^s) \quad \forall s \in S \tag{1}$$

with $p_{it}^{M,s*}$ the optimal value of the matched energy variable $p_{it}^{M,s}$

Problem definition

The objective of the study is to decide:

- the **optimal economic dispatch of the physical futures and bilateral contract** among the thermal units
- the **optimal bidding at Day-Ahead Market** abiding by the MIBEL rules
- the **optimal unit commitment** of the thermal units

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Problem definition

Model characteristics

- Stochastic mixed integer quadratic programming model
- *Price-taker* generation company
- Set of thermal generation units, T
- Optimization horizon of 24h, I
- Set of physical futures contracts, F, of energy L_j^{FC} $j \in F$.
- A pool of bilateral contracts of energy L^{BC}.
- Set of day-ahead market price scenarios, λ^s , $s \in \mathcal{S}$

Variables

First stage variables: $\forall t \in T, \forall i \in I$

- Unit commitment: $u_i^t, \; c_t^u, \; c_d^t \in \{0,1\}$
- Instrumental price offer bid : q_i^t
- Scheduled energy for futures contract j: $f_{itj} \quad \forall j \in F$
- Scheduled energy for bilaterals contract: b_{it}

Second stage variables $\forall t \in T, \forall i \in I, \forall s \in S$

- Matched energy: $p_{it}^{M,s}$
- Total generation: p_{it}^{s}

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Physical Future and Bilateral Contracts model

Physical future contract coverage:

$$\sum_{t \in T} f_{itj} = L_j^{FC} \, , \forall j \in F \, , \forall i \in I$$

$$f_{itj} \geq 0 \, , \forall j \in F \, , \forall t \in T \, , \forall i \in I$$

Bilateral contract coverage:

$$\sum_{t \in T} b_{it} = L_i^{BC} \, , \forall i \in I$$

$$0 \leq b_{it} \leq \overline{P}_t \, , \forall t \in T \, , \forall i \in I$$

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Day-ahead market model: constraints

Matched energy:

$$p_{it}^{M,s} \leq \overline{P}_t - b_{it} \ , \forall t \in T \ , \forall i \in I \ , \forall s \in S$$

$$p_{it}^{M,s} \geq q_{it} \ , \forall t \in T \ , \forall i \in I \ , \forall s \in S$$

Instrumental price bid:

$$q_{it} \geq \underline{P}_t - b_{it} \ , \forall t \in T \ , \forall i \in I$$

$$q_{it} \geq 0 \ , \forall t \in T \ , \forall i \in I$$

$$q_{it} \geq \sum_{j \in F_i} f_{itj} \ , \forall t \in T \ , \forall i \in I$$

Total energy generation:

$$p_{it}^{s} = b_{it} + p_{it}^{M,s} \ , \forall t \in T \ , \forall i \in I \ , \forall s \in S$$

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Day-ahead market model: constraints

Other set of constraints:

- Unit commitment constraints: including the start-up and shut-down costs and the minimum operation and idle time control taking into account the initial state of the units.
- Operational limits for the total generation.

Objective function

Maximization of the day-ahead market clearing's benefits

$$\max_{p,q,f,b} \sum_{t\in T} \sum_{i\in I} \Big(-c^u_{it} - c^d_{it} - c^b_{it} u_{it} + \\ + \sum_{s\in S} P^s \left[\lambda^{Ds}_t p^{M,s}_{it} - (c^l_i p^s_{it} + c^q_i (p^s_{it})^2) \right] \Big)$$

Incomes from Futures and bilateral contracts:

- **Futures contracts:** $\sum_{t\in T} \sum_{j\in J} \left(\lambda^{FC}_j - \lambda_t \right) L^{FC}_t$
- **Bilateral contracts:** $\sum_{t\in T} \lambda^{BC}_t L^{BC}_t$
- They don't depend on the decision variables.

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Summary of the model

Problem OBIFUC

(Optimal bid with BIlateral and FUtures Contracts)

Max Day-ahead market clearing's benefits

s.t: Physical future contract coverage

Bilateral contract coverage

Matched energy

Instrumental price bid

Total energy generation

Unit commitment

Optimal Matched Energy

Lemma

Let $x^{*\prime} = [p^*, p^{M,*}, q^*, f^*, b^*]'$ be an optimal solution of problem (OBIFUC). Then for any thermal unit i the optimal value of the matched energy $p_{it}^{M,s*}$ can be expressed as:

$$p_{it}^{M,s*} = \max\{q_{it}^*, \rho_{it}^s(b_{it}^*)\} \quad (2)$$

Bid's functions Optimality Conditions

Definition (Bid functions's optimality conditions)

Let $x^{*\prime} = [u^*, c^{*u}, c^{*d}, p^{M,*}, p^*, q^*, f^*, b^*]'$ be an optimal solution of the (OBIFUC) problem. The bid function λ_{it}^{b*} of a thermal unit i committed at period t (i.e. $i \in U_t$) is said to be optimal w.r.t. the (OBIFUC) problem and solution x^* if the value of the matched energy function associated to any scenario's clearing price λ_t^s, $p_{it}^M(\lambda_t^s)$, coincides with the optimal matched energy $p_{it}^{M,s*}$, that is:

$$p_{it}^M(\lambda_t^s) = p_{it}^{M,s*} = \max\{q_{it}^*, \rho_{it}^s(b_{it}^*)\}$$

OBIFUC's optimal bid function

Lemma (Optimal bid function)

Let $x^{*\prime} = [u^*, c^{*u}, c^{*d}, p^{M,*}, p^*, q^*, f^*, b^*]'$ *be an optimal solution of the (OBIFUC) problem and* i *any thermal unit committed on period* t *at the optimal solution (i.e.* $i \in U_t$*). Then the bid function:*

$$\lambda^*_{it}(p_{it}; b^*_{it}) = \begin{cases} 0 & \text{if } p_{it} \leq q^*_{it} \\ 2c^q_i\left(p_{it} + b^*_{it}\right) + c^l_i & \text{if } q^*_{it} < p_{it} \leq (\overline{P}_t - b^*_{it}) \end{cases} \quad (3)$$

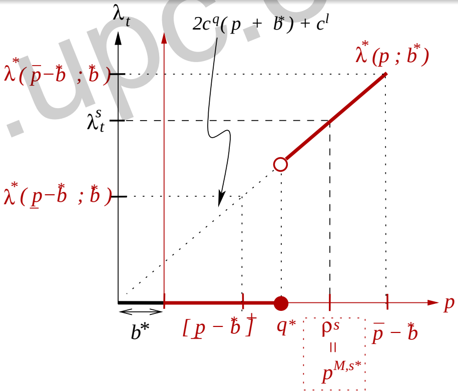
is optimal w.r.t. the (OBIFUC) problem and the optimum x^*.

OBIFUC's optimal bid function graphical representation

Matched energy at scenario s:

$$p_{it}^{M}(\lambda_t^s) = p_{it}^{M,s*} = \max\{q_{it}^*, \rho_{it}^s(b_{it}^*)\} \tag{4}$$

$$q_{it}^* \leq \rho_{it}^s(b_{it}^*) \implies$$
$$\implies p_{it}^{M,s*} = \rho_{it}^s(b_{it}^*)$$

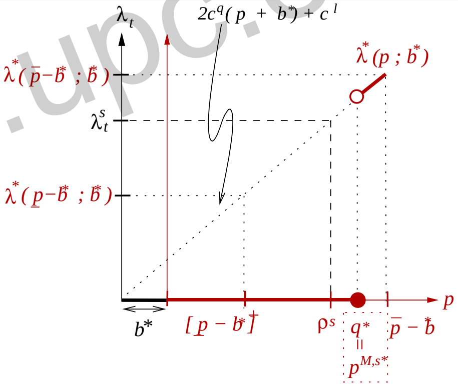


OBIFUC's optimal bid function graphical representation

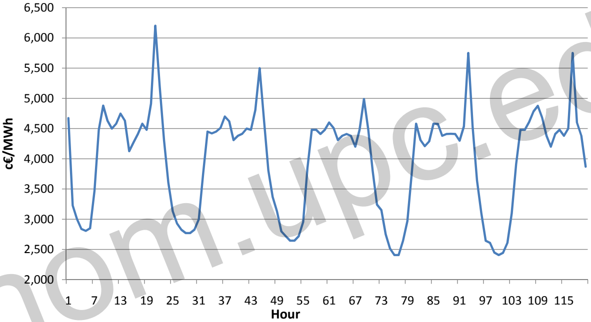
Matched energy at scenario *s*:

$$p_{it}^{M}(\lambda_t^s) = p_{it}^{M,s*} = \max\{q_{it}^*, \rho_{it}^s(b_{it}^*)\} \quad (4)$$

$$q_{it}^* \geq \rho_{it}^s(b_{it}^*) \Longrightarrow p_{it}^{M,s*} = q_{it}^*$$



Price characteristics



Electricity spot prices exhibit:

- Non-constant mean and variance
- Daily and weekly seasonality
- Calendar effects
- High volatility and presence of outliers

Factor Model Approach

To apply the methodology of factor models in the next way:

- The spot price is interpreted not as a single time series but a set of 24 time series, one for each hour.
- The factor model allows to identify common unobserved factors which represent the relationship between the hours of a day.
- The forecasting model provide suitable scenarios for the optimization model.

Schema

Hourly electricity prices

↓

Factor analysis

⇓

One-step-ahead forecast price and confidence interval

⇓

Scenario generation

⇓

Optimization model

Time Series Factor Analysis

Time Series Factor Analysis

Time Series Factor Analysis [a] (*TSFA*) estimates measurement model for time series data with as few assumptions as possible about the dynamic process governing the factors. It estimates parameters and predicts factor scores.

[a] Gilbert P.D., Meijer E. (2005). Time Series Factor Analysis with an Application to Measuring Money

Factor Model Estimation

Let y_t be a M-vector of observed time series of length T and k unobserved factors ($k << M$) collected in the K-vector ξ. The relationship between the observed time series and the factors is assumed to be linear and described by equation:

$$y_t = \alpha_t + B\xi_t + \epsilon_t$$

where α_t is an M-vector of intercept parameters, B is an Mxk matrix parameter of loadings, assumed time-invariant, and ϵ is a random M-vector of measurement errors.

Parameters are estimated by maximum likelihood.

Forecasting model

The factors obtained have to be implemented into a forecasting model in order to obtain the price forecasts.

A one-step-ahead forecasting model is specified and estimated as a linear multiple regression model with the factors as predictors[1]:

$$y_{t+1} = \beta \hat{\xi}_t + \alpha(L) y_t + \varepsilon_{t+1}$$

The out of the sample forecast for $y_{T+1|T}$ is given by the conditional expectation

$$y_{T+1|T} = \hat{\beta} \hat{\xi}_T + \hat{\alpha}(L) y_T$$

[1] Stock J., Watson M.W. (2002). Forecasting Using Principal Components From a Large Number of Predictors

Data analysis

- Random variable: Iberian Day-Ahead Market electricity prices
- Data set: work days from January 1^{rts}, 2007 to March 30^{th}, 2008.
- 3 significant factors, based on eigenvalues of the sample correlation matrix.
- The data has been analyzed using R (version 2.7.0) with the library TSFA available at CRAN (*www.cran.r-project.org*).

Iberian Day-Ahead Electricity Market price

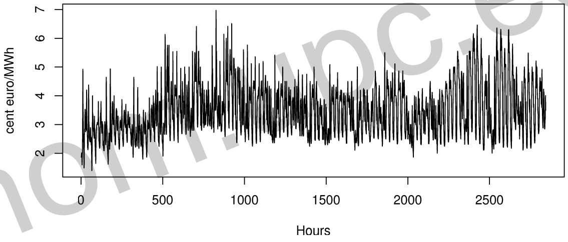


Figure 1: Iberian Day-Ahead Electricity Market price (January 1rst, 2007 - March 30th, 2008)

24 Time Series

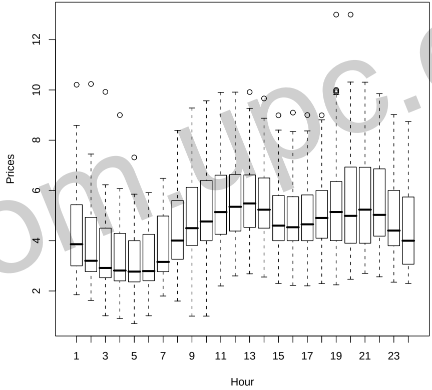


Figure 3: Iberian Day-Ahead Electricity Market price for each hour(January 1rst, 2007 - March 30th, 2008)

Factor model results

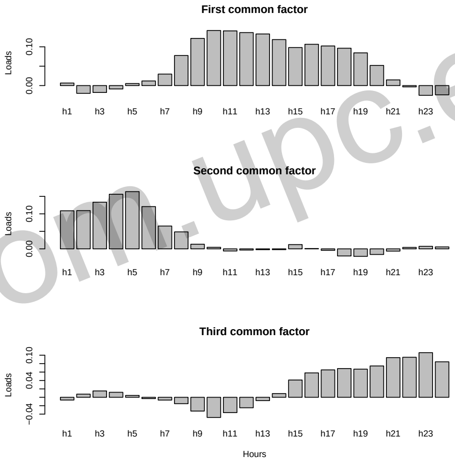


Figure 6: Loads of the common factors

Out of sample forecasting results (I/II)

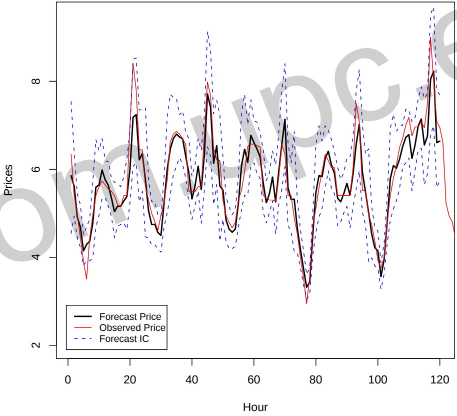


Figure 7: One-step-ahead forecast prices

Out of sample forecasting results (II/II)

Hour	1	2	3	4	5	6
R^2	99.1	95.3	97.1	99.8	99.8	97.6
MSE	0.017	0.004	0.003	0.003	0.002	0.002
Hour	7	8	9	10	11	12
R^2	96.0	99.6	99.7	99.8	96.3	98.3
MSE	0.003	0.008	0.008	0.004	0.003	0.001
Hour	13	14	15	16	17	18
R^2	99.9	97.7	99.8	99.9	99.9	97.1
MSE	0.002	0.002	0.004	0.002	0.002	0.002
Hour	19	20	21	22	23	24
R^2	99.7	96.6	94.2	99.7	99.7	95.1
MSE	0.006	0.005	0.007	0.007	0.007	0.005

Table 1: Summary of the forecast models for each hour

Case Study characteristics

- Real data from the Spanish Market about the generation company and the market prices.
- 9 thermal generation units (6 coal, 3 fuel) from a Spanish generation company with daily bidding in 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	110-157	110-157
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- Model implemented and solved with AMPL/CPLEX 11.0.

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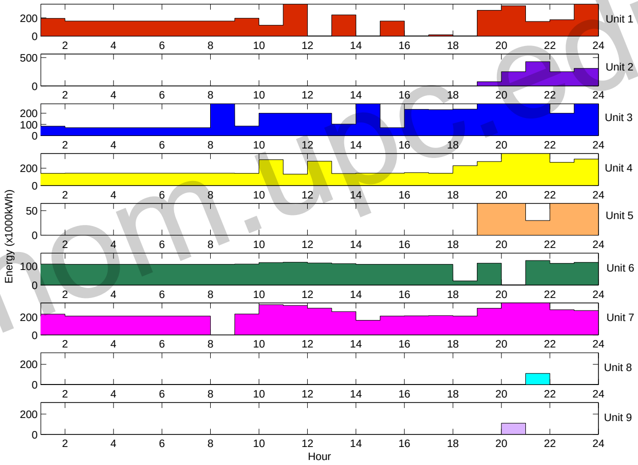
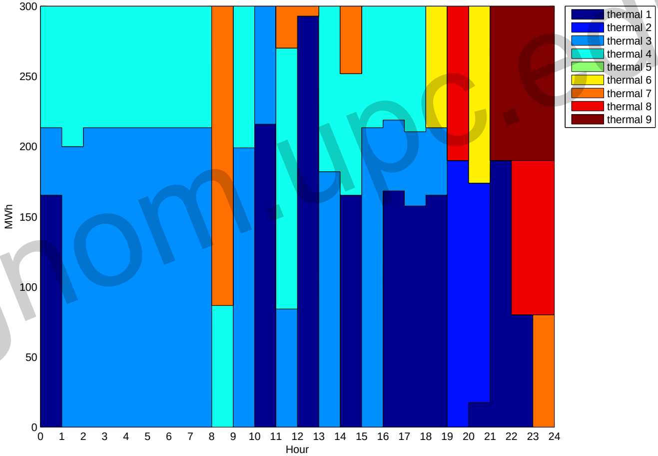
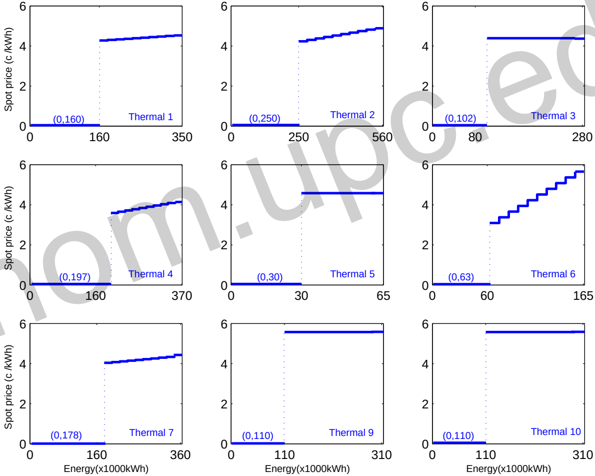
Results: unit commitment and zero price bid



Results: procurement of bilateral contracts



Results: optimal bidding curves



Conclusions

- The forecast procedure based on factor models gives suitable results, equivalent to the ones obtained through an ARIMA model.
- The advantage of the procedure presented lies in its simplicity, easy to implement and to present.
- The improved forecasts have been used to successfully generate a set of scenarios to feed the stochastic optimization model.

Conclusions

- It has been built an Optimal Bidding Model for a price-taker generation company operating both in the MIBEL Derivatives and Day-Ahead Electricity Market.
- The model developed gives the producer:
  - 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

  following in detail the MIBEL rules.

Optimal day-ahead bidding strategy with futures and bilateral contracts. Scenario generation by means of factor models

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