Optimal Day-Ahead Bidding in the MIBEL's Multimarket Energy Production System

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***Abstract*—A Generation Company (GenCo) can participate in the Iberian Electricity Market (MIBEL) through different mechanisms and pools: the bilateral contracts, the physical derivatives products at the Derivatives Market, the bids to the Day-Ahead Market, the Intraday Markets or the Ancillary Services Markets. From the short-term generation planning point of view, the most important problem to solve is the bidding strategy for the Day-Ahead Market (DAM) given that the 85% of the physical energy traded in Spain is negotiated in it, but this participation cannot be tackled independently of other subsequent markets.**

***Index Terms*—electricity spot markets, bidding strategies, stochastic programming, physical futures contracts, bilateral contracts.**

I. Introduction

With the reorganization of the electricity industry, a new market framework was set up including not only the Day-Ahead Market but also a sequence of independent and successive markets. In the case of the MIBEL, this sequence includes a Day-Ahead Market (DAM), a Reserve Market (RM) and a set of six Intraday Markets (IM). The Generation Companies (GenCos) that participate in the electricity market could increase their benefits by optimizing its participation in this sequence of electricity markets. Specifically, the DAM bidding strategies cannot be independent of the expected benefits obtained from the next markets. Thus, the objective of the generators in the short-term framework is to maximize its expected profits from selling energy into the Day Ahead Market, the Reserve Maket and the Intraday Market. Moreover, the GenCo has to take into account its Bilateral Contracts and the result of its participation in the Derivatives Physical Markets.

The objective of this work is to build a model that gives the GenCo the optimal bidding strategy for the DAM considering the benefits and costs of the participation in the next markets and including both the Physical Futures Contracts (FC) and the Bilateral Contracts (BC).

Several researchers have proposed optimal bidding models in the day-ahead market for thermal units under the price-taker assumption. Some researchers [3] presented a mixed-integer programming model to optimize the production schedule of a single unit with a simple bidding strategy. The mixed-integer stochastic programming model [7] distinguishes the variables corresponding to the *bid energy* and those representing the *matched energy*, though in a price-maker framework and without BC. In another model [12], a stochastic unit commitment problem with BC was solved by maximizing the day-ahead market benefit. In the work [13] the authors define the short-term bidding strategy for a GenCo abiding the MIBEL's rules regarding to the integration of the BC's energy in the generations DAM bid. Among the studies that deal with DAM bidding strategies, there are few that tackled the problem of a sequence of electricity markets. The work in [15] is one of the first works that defines a bidding strategy for a GenCo participating in a sequence of three spot markets, the unit commitment is consider known but it is possible to engage a unit in the automatic generation control market. They build three models that are solved successively for obtaining bidding strategies for each market considering the expected benefits of the next markets. The work in [14] considers a multistage stochastic model where there is decided the unit commitment and the capacity allocation in each market but there is not defined any bidding strategy. Furthermore, [17] proposes a stochastic model to obtain the bid curve to be submitted in each market, the bidding strategies are obtained based in the residual-demand curves, that represents the influence of the generation offers in the clearing price. The last published work in this framework, [16], can be consider as a extension to [14], it is added a risk aversion tool and the satisfaction of the committed bilateral contracts.

Several different approaches to the inclusion of futures contracts in the management of a GenCo can be found in the electricity market literature. The work in [1] describes in a theoretical framework the integration of futures contracts into the risk management of a GenCo. The paper [2] presents a bidding decision making system for a GenCo taking into account the impacts of several types of physical and financial contracts. Furthermore, the work in [4] optimizes the forward physical contracts portfolio up to one year taking into account the day-ahead bidding.

The main contributions of this work are:

- To include the optimal economic dispatch of the physical futures and bilateral contracts into the market sequence model.
- To build optimal bids for the Day-Ahead Market abiding the MIBEL rules in all the market sequence.

In section II, the sequence of markets of the MIBEL is presented. In section, III the stochastic programming model for the coordination between day-ahead bidding taking into account the market sequence and the futures and bilateral contracts settlement and the thermal unit operational constraints is presented. In section IV, a first approximation case study is solved and analyzed. Finally, in section V, some conclusions

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are presented.

II. Market structure

The model presented in section III follows the MIBEL structure with three different markets which are cleared in the following order (Fig. 1):

- DAM (Day-Ahead Market) is the main market where the most important part of the energy transactions are negotiated. It takes place the day before the delivery day. It has 24 simultaneous auctions, one for each hour of the next day. The DAM matching process is coordinated with the BCs and the physical FCs as it will be explained later.
- RM (Reserve Market) takes place after the DAM matching process. It is an ancillary service market where the participants send bids to increase or decrease the matched energy of the units in the DAM. If a bid is matched in the RM then the unit must be available to change its generation level in a given time interval on the real-time operation. For this reason, the units that participate in this market must have some specific operational characteristics that allows them to increase or decrease the generation level in a given time interval.
- IM (Intraday market) takes place just before and during the delivery day, it is composed of 6 consecutive markets with 24 auctions each one. In this markets the GenCos can either send or buy electricity, that is, they can participate as buyers or sellers of energy. It works exactly as the DAM and it is used by the GenCos to change the DAM resulting generation scheduling. It is important to remark that in one session and one hour a unit can only submit buy or sell offers, not both, but in different hours this role can change. One unit can participate in these markets either if its bids have been matched at the DAM or it is producing energy to settle BCs.

A. *Reserve and Intraday Market*

For this first approach we assume some hypothesis about the Reserve and Intraday Market. First, we suppose that if the GenCo participates in the RM, then it will bid always the AGC (Automatic Generation Control) capacity of the unit. The AGC capacity is an operational characteristic of each unit that indicates the quantity that the unit is able to increase or decrease in a given time. Thus, in our model the quantity submitted to the Reserve Market is not optimized but is always equal to the AGC capacity. We will optimize the participation or not in the RM. This hypothesis follows the real behavior of some GenCos observed in the MIBEL. Second, we work only with the first Intraday Market session, this is the session in which the most part of the energy is negotiated and, therefore, the one that affects the most the generation scheduling of the GenCo. Finally, we suppose that all the energy that is bid to the RM or the IM will be matched. This can be easily force by some bidding strategies, but this point is not faced in this work. This hypothesis do not limit the correct representation of the MIBEL's market sequence and they can be easily changed or adapted to different situations.

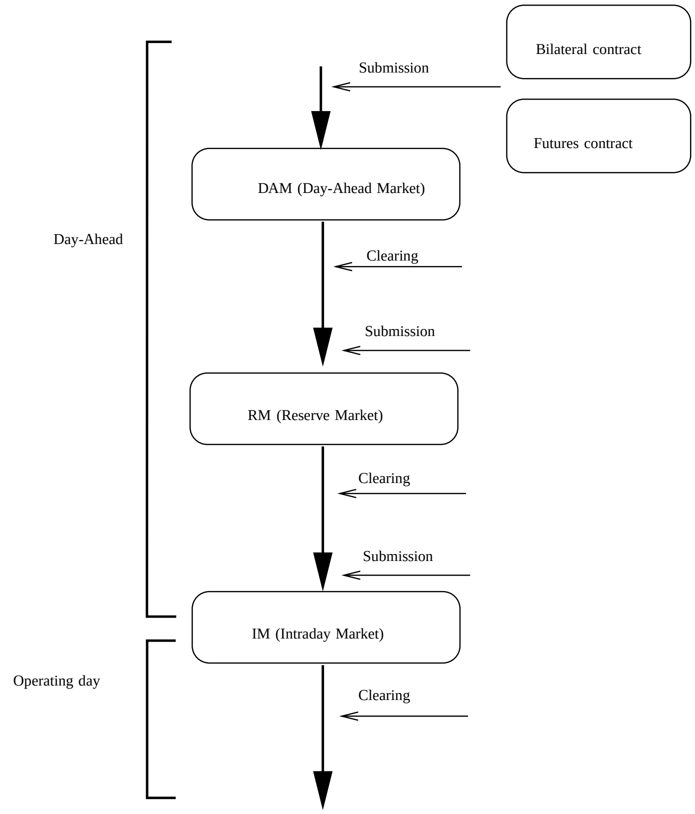

Figure 1. Representation of the system under study at period i

B. *Bilateral and Futures Contracts*

As it has been we have mentioned, the MIBEL rules force the GenCo to include in the DAM bid process the settlement of the energy from other market mechanisms. In this work, the National Bilateral Contracts and the Futures Physical Contracts matched at the Derivatives Market are included.

The coordination between the physical futures contracts portfolio and the Day-Ahead bidding mechanism (Fig. 2) is structured in the following three phases:

1) For every derivatives contract the GenCo is interested in, it has to define the Term Contract Units (UCP in the MIBEL's notation) which are virtual units allowed to offer in the Derivatives Market. Each UCP is formed by the subset of the physical units of the GenCo which will generate the energy to cover the corresponding contract. For each contract, a physical unit can only participate in one virtual UCP.
2) Two days before the delivery date the GenCo receives from the Derivatives Market Operator, OMIP [10] the quantity that every UCP has to produce for the matched futures contracts covering. This information is also send to the Day-Ahead Market Operator, OMEL [9].
3) OMEL demands every GenCo to commit the quantity designed to futures contracts through the Day-Ahead Market bidding of the physical units that form each UCP. This commitment is done by the so called *instrumental price offer*, that is, a sale offer with a bid price of 0€/MWh (also called *price acceptant*).

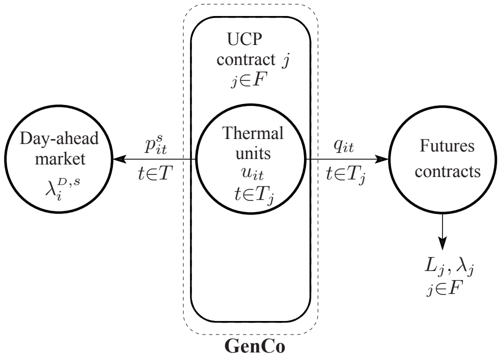

Figure 2. Representation of the system under study at period i

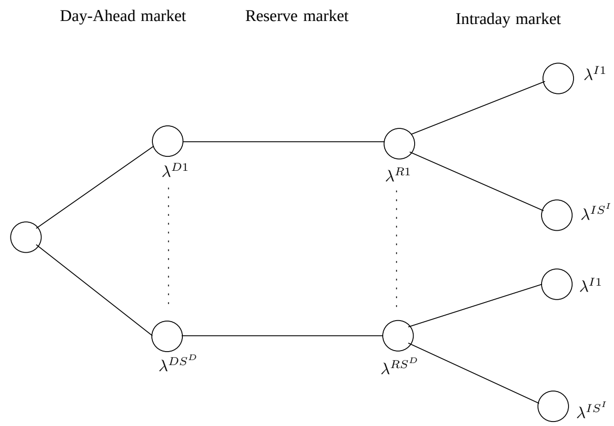

Figure 3. Representation of the system under study at period i

That regulation implies the GenCo has to determine its optimal bid taking into account those instrumental price offers. Due to the algorithm the market operator uses to clear the Day-Ahead Market, all instrumental price offers will be matched (i.e. accepted) in the clearing process, that is, this energy shall be produced and will be remunerated at the spot price.

Bilateral Contracts in the MIBEL has the classical characteristics, they are agreements between a generation company and a qualified consumer to provide a given amount of electrical energy at an stipulated price along a delivering period. The characteristics of the bilateral contracts (energy, price, delivering period) are negotiated before the DAM and the energy that is destined to the BC is excluded from the DAM bid. Accordingly to the MIBEL rules, the DAM bid of each unit must include the whole available energy not allocated to the BC contracts.

Thus, the GenCo has to determine its unit commitment in order to be able to cover those obligations, the ones from the portfolio of F physical futures contracts and the pool of bilateral contracts.

III. Optimization model

The model is build for a price-taker GenCo owning a set of thermal generation units *I*, the relevant parameters of each thermal unit are:

- linear generation costs with constant, linear coefficients, c_i^b (€), c_i^l (€/MWh) respectively, for the i^{th} unit.
- $\overline{P}_i$ and $\underline{P}_i$ the upper and lower bound, respectively, on the energy generation (MWh) of a committed unit i.
- ACG capacity g_i(MW) for the i^{th} unit.

The thermal units bid to the $t \in T = \{1, 2, .., 24\}$ hourly auctions of the DAM, they all have the characteristics needed to participate in the RM, and finally they can bid to the T hourly auction of the IM if they have been engaged to settle BCs or matched in the DAM. U_t represents the committed units at interval $t \in T$.

A. Uncertainty characterization

The three market prices can be characterized as random variables and they can be used to generate a multistage scenario tree (Fig. 3). For this first approximation, the scenario tree has been build from the reduction of available historical data. The probability of each scenario is equal to the product of the probabilities of the each vector of prices.

It must be noted that there is only one scenario of the third stage (RM) for each scenario of the second stage (DAM), this is because of the model for the RM (Sec. II-A). In the Reserve Market, the decision variable is to bid or not, the quantity bid is an operational data independent of the RM price. Thus, there is not needed a representation trough scenarios of the RM price but the expected one. For this reason, the first part of the scenario tree is a 48 prices vector, the first 24 components correspond to the DAM prices and the next 24 correspond to the RM prices. At the next stage, there are S^I scenarios of the 24 IM prices for each scenario of the DAM-RM prices. The resulting optimization problem will be a stochastic mixed integer linear programming model.

B. Physical Futures and Bilateral Contracts in the MIBEL

A base load physical futures contract j in the MIBEL consists in a pair $(L_j^{FC}, \lambda_j^{FC})$ where

- L_j^{FC}: amount of energy (MWh) to be procured each interval of the delivery period by the set U_j of generation units, which are the generation units of each UCP.
- λ_j^{FC}: price of the contract (c€/MWh).

A bilateral contract k in the MIBEL consists in a pair $(L_{kt}^{BC}, \lambda_k^{BC})$ $t \in T$ where:

- L_{kt}^{BC} represents the amount of energy (MWh) to be procured at interval t of the delivery period by the whole set of generation units.
- λ_k^{BC} represents the price of the contract (c€/MWh).

The energies L_j^{FC} and L_{kt}^{BC} should be integrated in the MIBEL's day-ahead bid observing the two following rules:

1) If generator i contributes with f_{itj} MWh at period t 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 i contributes with b_{it} MWh at period t to the coverage of the BCs, then the energy b_{it} must be excluded from the bid to the day-ahead market. Unit i

can offer its remaining production capacity $\overline{P}_i - b_{it}$ to the pool.

C. Variables

For every time period $t \in T$ and thermal unit $i \in I$, the first stage variables of the stochastic programming problem are:

- The instrumental price offer bid variables: q_{it}.
- The scheduled energy for futures contract j variables: f_{itj}.
- The scheduled energy for bilaterals contract variables: b_{it}.

and the second stage variables associated to each scenario $s \in S$ are:

- Total generation: p^s_{it}
- Matched energy in the day-ahead market: $p^{M,s}_{it}$
- Reserve market related variables: $r1^s_{it}$, $r2^s_{it}$ and $r3^s_{it}$ (binary)
- Intraday market related variables: w^s_{it} and y^s_{it} (continuous), v^s_{it} (binary)

D. Bilateral and future contracts constraints

Both the physical future and bilateral contracts coverage must be guaranteed:

$$
\begin{aligned}
\sum_{i \in U_{jt}} f_{itj} &= L^{FC}_j \ , \ j \in F \ , \ t \in T && (1)\\
\sum_{i \in U_t} b_{it} &= L^{BC}_t \ , \ t \in T && (2)\\
f_{itj} &\geq 0 \ , \ j \in F \ , \ i \in U_t \ , \ t \in T && (3)\\
0 \leq \ b_{it} &\leq \overline{P}_i \ , \ i \in U_t \ , \ t \in T && (4)
\end{aligned}
$$

E. Day-Ahead Market model constraints

The MIBEL's rules affecting the day-ahead market establishes a given relation between the variables representing the energy of the bilateral contracts b_{it}, the energy of the future contracts f_{itj}, the instrumental price offer bid q_{it} and the matched energy $p^{M,s}_{it}$. This relation can be formulated by means of the following set of constraints:

$$
\begin{aligned}
p^{M,s}_{it} &\leq \overline{P}_i - b_{it} \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (5)\\
p^{M,s}_{it} &\geq q_{it} \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (6)\\
q_{it} &\geq \underline{P}_i - b_{it} \ , \ i \in U_t \ , \ t \in T && (7)\\
q_{it} &\geq \sum_{j | i \in U_{jt}} f_{itj} \ , \ i \in U_t \ , \ t \in T && (8)\\
q_{it} &\geq 0 \ , \ i \in U_t \ , \ t \in T && (9)
\end{aligned}
$$

where:

- (5) and (6) ensures that the matched energy $p^{M,s}_{it}$ will be between the instrumental price bid q_{it} and the total available energy not allocated to BC.
- (7) and (8) guarantee respectively that the instrumental price bid will be not less than the minimum generation output of the unit, and that the contribution of the unit to the FC coverage will be included in the instrumental price bid.

F. Reserve market model constraints

As it has been explained previously, our modelization of the RM assumes that, should the unit bid to the RM, it will bid its fixed AGC capacity. In this framework, the only decision to be optimized is wether the unit participates in the RM or not.

It is known that a unit can only use its AGC capacity if its generation level is constant, that means, if the unit is not increasing or decreasing its production in the corresponding interval or, equivalently, if the production level p^s_{it} has not changed between two consecutive intervals. This is controlled by the auxiliary variable Δp^s_{it}, the difference between the production level in two consecutive intervals. In practice, it is allowed for this value to be nonzero but within an operational range $[-k, k]$ for the units participating in the RM. The binary variable $r1^s_{it}$ is introduced to trace this situation, being $r1^s_{it} = 1$ whenever $\Delta p^s_{it} \in [-k, k]$. The binary variables $r2^s_{it}$ and $r3^s_{it}$ indicates that the unit is ramping up or down respectively:

$$
\begin{aligned}
&\text{If } \Delta p^s_{it} \in [-k, k] \Rightarrow r1^s_{it} = 1\\
&\text{If } \Delta p^s_{it} \geq k \Rightarrow r2^s_{it} = 1\\
&\text{If } \Delta p^s_{it} \leq -k \Rightarrow r3^s_{it} = 1
\end{aligned}
$$

This is modeled by the following constraints:

$$
\Delta p^s_{it} = p^s_{it} - p^s_{i,(t-1)}, i \in U_t, t \in T \setminus \{1\}, s \in S \qquad (10)
$$

$$
\begin{aligned}
(k - \Delta p^s_{it}) &\geq M^R(r1^s_{it} - 1), i \in U_t, t \in T, s \in S && (11)\\
(k + \Delta p^s_{it}) &\geq M^R(r1^s_{it} - 1), i \in U_t, t \in T, s \in S && (12)\\
(\Delta p^s_{it} - k) &\geq M^R(r2^s_{it} - 1), i \in U_t, t \in T, s \in S && (13)\\
(\Delta p^s_{it} + k) &\leq M^R(1 - r3^s_{it}), i \in U_t, t \in T, s \in S && (14)
\end{aligned}
$$

$$
\begin{aligned}
&r1^s_{it} + r2^s_{it} + r3^s_{it} = 1 \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (15)\\
&r1^s_{it}, r2^s_{it}, r3^s_{it} \in \{0, 1\} \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (16)
\end{aligned}
$$

G. Intraday market model constraints

Our modelization considers the possibility of either sell or buy energy at the IM. Variable y^s_{it} represents the energy of a sell offer while variable w^s_{it} corresponds to the energy of a buy bid. At a given interval t a unit can only participate as seller or buyer. This decision is modelled through the binary variable v^s_{it} and the following set of constraints:

$$
\begin{aligned}
w^s_{it} &\leq M^I v^s_{it} \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (17)\\
y^s_{it} &\leq M^I (1 - v^s_{it}) \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (18)\\
v^s_{it} &\in \{0, 1\} \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (19)\\
y^s_{it}, w^s_{it} &\geq 0 \ , \ i \in U_t \ , \ t \in T \ , \ s \in S && (20)
\end{aligned}
$$

where M^I represents any known upper limit to w^s_{it} and y^s_{it}.

H. Total generation constraints

Finally, the total generation level of a given unit i, p^s_{it}, is defined as the addition of the allocated energy to the BC plus the matched energy of the DAM and IM. Note that the energy submitted to the RM is not actually produced but reserved:

$$p^s_{it} = b_{it} + p^{M,s}_{it} - y^s_{it} + w^s_{it} \;,\; t \in T \;,\; i \in U_t \;,\; s \in S \quad (21)$$

The total generation must remain between the operational limits $\underline{P}_i$ and $\overline{P}_i$, but if we participate in the RM, the total generation limits change because of the energy that we must reserve to be able to produce it at the moment that the system operator asks:

$$\underline{P}_i - g_i r1^s_{it} \le p^s_{it} \le \overline{P}_i - g_i r1^s_{it} \,,\, t \in T \,,\, i \in U_t \,,\, s \in S \quad (22)$$

I. Nonanticipativity constraints

Nonanticipativity constraints for the DAM:

$$p^s_{it} = p^{\hat{s}}_{it} \quad \forall s, \hat{s} : (\lambda^{Ds} = \lambda^{D\hat{s}}) \;\forall t \in T \quad (23)$$

Nonanticipativity constraints for the RM:

$$r1^s_{it} = r1^{\hat{s}}_{it} \quad \forall s, \hat{s} : ((\lambda^{Ds}, \lambda^{Rs}) = (\lambda^{D\hat{s}}, \lambda^{R\hat{s}})) \;\forall t \in T \quad (24)$$

J. Objective function

The linear function that represents the expected benefits of the GenCo after the participation in the three market:

$$\max_{p,q,f,b} \sum_{t \in T} \sum_{i \in U_t} \sum_{s \in S} P^s \left[\lambda^{Ds}_t p^{M,s}_{it} + \lambda^{Rs}_t r1^s_{it} g_i + \right.$$
$$\left. + \lambda^{Is}_t y^s_{it} - \lambda^{Is}_t w^s_{it} - c^l_i p^s_{it} \right] \quad (25)$$

where λ^{Ds}_t, λ^{Rs}_t, λ^{Is}_t are the price scenarios for the t^{th} Day-Ahead, Reserve or Intraday Market respectively.

IV. Numerical Examples

The model (1)-(25) has been tested with real data of a Spanish GenCo and MIBEL market prices. The model has been implemented in AMPL [18] and solved with CPLEX [19] using a SunFire X2200 with two dual core AMD Opteron 2222 processors at 3 GHz and 32 Gb of RAM memory.

The data of this work is public and it has been either downloaded directly from the indicated web pages or calculated by using some other public data. The sources for all data used in the case studies are OMELs site [9], OMIPs site [10], and REE's site [11]. The information about the thermal units in the study belongs to a GenCo that bids daily in the DAM, RM and IM, it also participates in the Derivatives Market.

A set of computational tests has been performed in order to validate the proposed model. The instances used in the test have 10 thermal units and 24 hourly bids. One of the objectives of the tests is to prove the influence of the sequence of markets in the DAM bid. As it has been explained, the DAM bid of a price-taker GenCo will be fixed by the quantity committed to bilateral contracts, that will be excluded from the DAM bid, and the quantity committed to futures contracts, that must be bid at *instrumental price*. Thus, we focus on the two variables

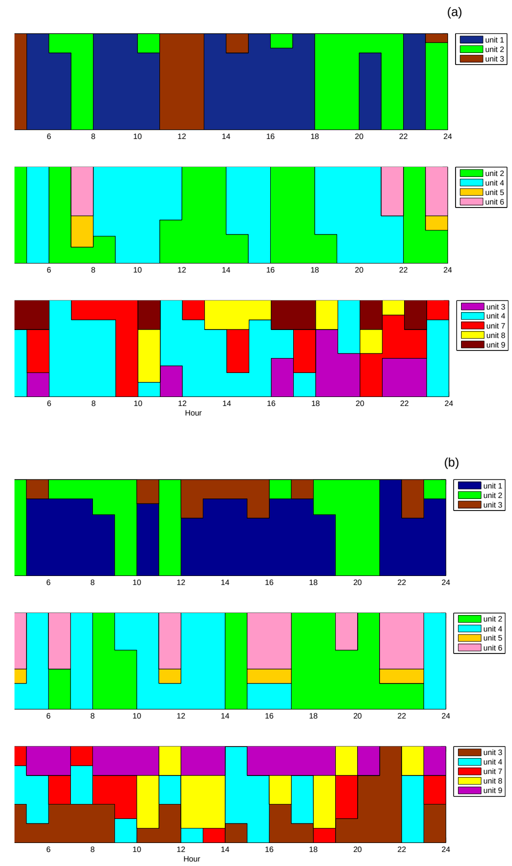

Figure 4. Economic dispatch of each futures contracts, f_{itj} (a) taking into account market sequence (b) only with DAM

that represents this quantities to study its optimal value if we take into account the sequence of markets or not.

In Figure 4 it is represented the economic dispatch of each physical futures contract among the units that participate in it. It can be observed differences between the optimal value taking into account the sequence of markets (Fig. 4(a)) or not (Fig. 4(b)). In the monthly contract, for example, unit 4 settles the great part of the contract in some intervals when it is included the sequence of markets. On the other hand, in the case of the optimal value without including the sequence of markets, in the same intervals the settlement of the monthly contract is distributed between the four units that participate in it.

The other important variable is one that represents the energy submitted to bilateral contracts because this energy will be excluded from the market bidding process. In Figure 5 it is represented the economic dispatch of the bilateral contracts, i.e., the quantity each unit commit to the bilateral contracts for each interval t. There are also big differences between the optimal economic dispatch if we include the RM and the IM in the optimization model (Fig. 5(a)) or not (Fig. 5(b)). Those differences will lead to different offer curves for each unit and interval.

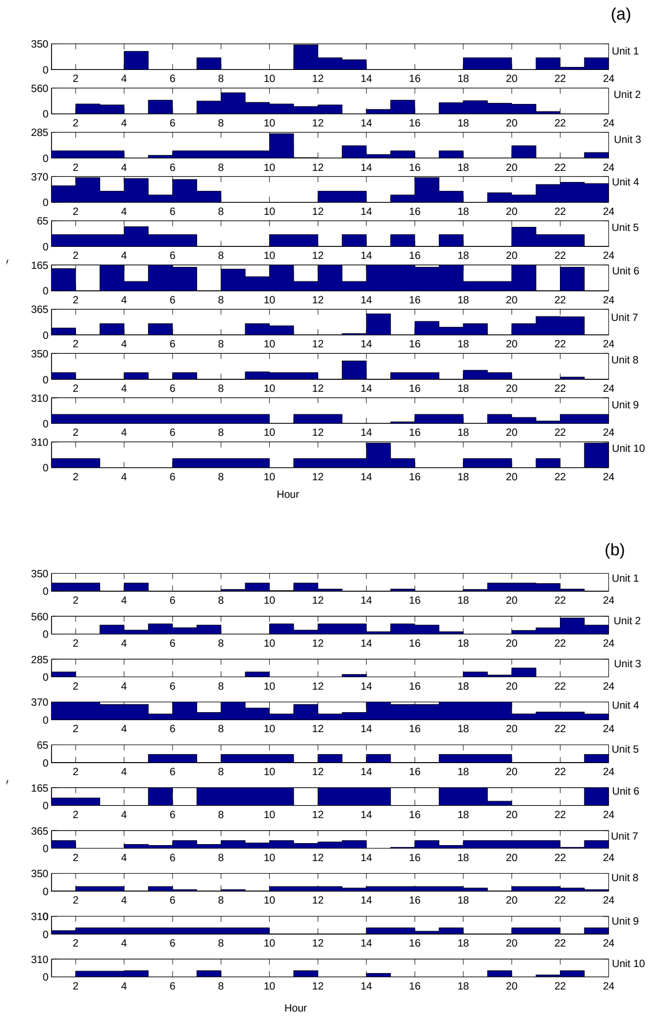

Figure 5. Economic dispatch of each futures contracts, f_{itj} (a) taking into account market sequence (b) only with DAM

V. Conclusion

This work has developed a new linear mixed-integer stochastic programming model, for the optimal Day- Ahead Bid with Future and Bilateral Contracts taking into account the Reserve and the Intraday Market. The optimal solution of our model determines the optimal instrumental price bidding strategy and the optimal economic dispatch for the BCs and the committed FCs for each hour. The model maximizes the expected benefits of the sequence of electric markets while satisfying the thermal operational constraints and the MIBELs rules. The model was implemented and solved with real data of MIBEL market prices and a Spanish generation company. The results of the computational tests validate the model and show the influence in the optimal bidding strategy of the generation company of the sequence of markets, showing a short-sight effect if we optimize the DAM bid without taking into account the possibilities of the next markets.

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