Clearing procedures for day-ahead Italian electricity market: are complex bids really required?

Davide Poli and Mirko Marracci

Abstract— Many technical debates discussed in the last years the market structure that can be considered as optimal for electricity in a deregulated environment. Simplicity and market transparency do not always comply with the intrinsic complexity of the electrical system, due to technical constraints and security requirements. The mechanism for bid selection in the day-ahead market is one of the most discussed topics, because it strongly influences both the economical revenues of operators and the physical feasibility of the dispatching schedules set by the market.

Usual production bids, only detailing hourly prices and quantities ("simple bids"), do not transfer to the clearing mechanism important technical-economical integral constraints, like the minimum daily revenue required by the operator or the power ramp limitation of generating units; in this case, adjustment sessions follow the primary energy market, to correct undesired or unfeasible outcomes.

In some markets, such additional constraints are already expressed in the so-called "complex bids", thus avoiding or minimizing the need for adjustment sessions. Nevertheless, the clearing mechanism of the day-ahead market results strongly complicated and the system transparency decreases; the effectiveness of this solution must be then carefully assessed.

In this paper, we present an analysis of the possible quantitative impact of complex bids in the Italian electricity day-ahead market, in order to evaluate possible benefits and drawbacks.

Keywords - Clearing Procedure, Energy Market, Market Rules.

I. INTRODUCTION

IN the liberalized electricity market, one of the most discussed issues is the mechanism for bid selection in the day-ahead energy market. The method used to define electricity price and accepted quantities must aim to simplicity and transparency, essential requirements to allow an adequate development and a constant monitoring of the market; on the other hand, it must consider the physical and security requirements of the electric system, translated into specific technical-economical constraints.

The definition of suitable market rules has been object of long discussions within the scientific community [1], [2], [3], [4], [5].

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An efficient bid auction system is essential to ensure a correct market behavior [6] and to reduce price volatility [7], [8]. On the other hand, a too complex bid system could have a strong impact on market transparency and controllability, encouraging strategic behaviors [9], [10].

The selection mechanism based on the so-called "simple bids", used at present for example in the Italian Market, enables the producers to submit sale proposals containing only the indication of offered amount and requested price. In this case, the target of obtaining a production profile consistent with the technical performances of his own power plants, and economically profitable as well, is left to the bidding skill of each single generating company.

Precise critics have been addressed to this methodology, because this mechanism does not take into account some technical aspects about generation units (max load gradient, technical minimum, etc.) or economical issues not directly expressed by the price-quantity curves (no-load costs, start-up costs, etc.).

On the basis of these considerations, some electricity markets, like in Spain, are providing for the possibility of producers to submit so-called "complex bids", containing technical-economical specifications in addition to the indications provided by the simple price/quantity pairs.

This paper proposes a quantitative approach to compare the economical and technical effects of simple and complex bids. By means of a market simulation tool, the possible impact of complex bids in the Italian electricity market has been estimated.

II. STRUCTURE AND FEATURES OF SIMPLE BIDS

The Italian Market Rules require that the hourly bid submitted to the daily market by the operators must contain, at least, the following data:

1. the identification code of the operator;
2. the identification code of the market session;
3. the identification code of the grid node;
4. the relevant period;
5. the kind of bid (buy/sell);
6. the eventual indication of "predefined bid";
7. the offered/requested quantity;
8. the requested/offered price.

The first six points refer to the kind of bid and to the operator who is submitting it; the economic parameters of the bid, described by the last two points, are limited to the quantity and to its relative price: it's a typical example of "simple bid".

In some markets, as in Italy, it is possible to submit particular simple bids, called "multiple bids". Multiple bids, even though they do not include technical or economic information other than the quantity and the relative price, can be constituted by more pairs of such values. Multiple bids are in fact represented by a series of quantity-price pairs ("blocks"), which describe a step-line bid curve, decreasing or increasing depending on the kind of bid.

The possibility of submitting multiple bids enables the operators to prepare more structured purchase and sale bids, so to optimize their business strategies. For example, multiple bidding enables a share of the energy of a certain generation unit to be offered at zero price; having such energy the maximum probability of acceptance by the market, this technique guarantees, except in case of over-generation (when the sum of bids submitted at zero price overtakes the energy demand, [9]), the dispatch of a quantity higher than the technical minimum of the production unit.

The presence of multiple bids does not modify the market solution procedure, i.e. a bid of N steps could always be displaced by N simple bids having price and quantity values equal to those of the single considered step. In particular, the presence of multiple bids does not imply the application of iterative computational processes; the only computational increase is constituted by the number of variables of the problem, which becomes equal to the total number of steps present in the bids.

III. Structure and Features of Complex Bids

With a "complex bid" the owner of a production plant can define specific technical-economic conditions that constraint the acceptance of his offer.

Generally speaking, production side there are some technical-economic restrictions ("complementarities" or "non-convexities") that the producers must take into account in order to assure a correct and safe operation of theirs plants. Complementarities arise, for example, due to ramping rates (start-up, ramp-up, shut-down and ramp-down speeds), minimum and maximum energy available (for example in pumped hydro storage) and minimum stable load (thermal plants mainly). Other constraints can be economical, due for instance to the start-up and shut-down costs of power plants or to the guarantee to the supplier a minimum income. Checks about these constraints can be done by the producers after the day-ahead market (when a further market is available to correct unattended results), or can be directly included in the day-ahead market clearing procedure, if the producer is allowed to submit "complex bids" that include these technical and economical constraints.

Complex bids are allowed for example since 1998 in the Spanish market, which constitutes the main reference for the following description [12].

Such a market, which enables also multiple sale bids with a maximum of 25 steps for each reference period, provides for the possibility to specify additional acceptance conditions, as detailed in the following.

A. *Condition of indivisibility*

This condition means that the first block of the bid (the cheapest one) is indivisible. Thus the producer has the guarantee that, if the block is accepted by the Market Operator, it's for the whole offered amount and not for a part of it.

This condition was introduced in the Spanish Market to enable the operators to declare the power limit relative to technical minimum of production units as indivisible, in order to ensure in case of acceptance a technically feasible dispatch.

B. *Minimum income condition*

The producers can include, as a necessary condition for the acceptance of the sale bid of a single unit, the so-called "minimum income condition". This way, they can declare to the Market Operator that a bid is to be considered valid only if the owner of the production unit achieves, for that plant, a minimum daily income indicated via a fixed term and a term proportional to the assigned energy.

This condition introduces the so-called combinatorial auctions, which establish a inter-temporal links between hours, so that the acceptance or rejection of the bid in one hour depends on the linked hours. If a bid does not fulfill the linking condition, all the hours in the bid are entirely rejected. In this case, new market clearing prices are calculated and bids with inter-temporal links (except the one rejected) are checked again for compliance.

Producers typically use this condition to cover their start-up costs or fixed costs.

C. *Scheduled stop condition*

This is the condition that sellers may include in the sale bids they submit for each production unit, so that, in the event that these bids are not matched due to the application of the minimum income condition, they can be treated as simple bids in the first block of the first three hours of the daily scheduling horizon. The bid that includes the scheduled stop condition shall be decreasing during the above-mentioned three hourly scheduling periods.

Thanks to this condition, a production unit excluded by the energy market can make a scheduled stop with a maximum length of three hours.

D. *Load gradient condition*

This condition enables producers to declare, for each generation unit, the maximum variation of average power that can be technically realized by their plant between two consecutive hours (increasing and decreasing ramp). Such a condition limits the energy that can be produced at a certain hour by the considered unit, depending on the energy accepted in the previous or following hour.

This condition is not applied to bids that are subject to the Scheduled stop condition.

IV. Market clearing procedure

The mechanism used for market clearing is the algorithm that defines on an economical basis the merit order list of the bids submitted to the market, identifying the quantity accepted for each bid and the relative remuneration.

The possible algorithms are strictly dependent on the market rules:

- energy remuneration: national/zonal/nodal price;
- presence of complex bids.

In the following, the impact of complex bids on the market resolution algorithm is analyzed.

A. Simple bids

In the presence of solely simple bids, the Market Operator (MO) can use a clearing mechanism that can independently work for each relevant period. Anyway, the algorithm is different as long as the market rules provide for a national price of electricity (Spain) or a zonal pricing, like in the Italian system.

1) Market not subdivided into geographical zones

The Market Operator (MO) proceeds in three conceptually distinct phases:

- definition of the supply curve;
- definition of the demand curve;
- crossing procedure.

In order to determine the aggregated supply (demand) curve, the MO identifies on an economical basis the merit order list of bids, starting from the one with the lowest (highest) price and progressively proceeding towards the higher (lower) priced bid. Multiple bids with N blocks are treated as N simple bids. If two bids have the same price, the market rules nevertheless define a priority order between them, based on different criteria other than price.

The procedure used to cross the demand and supply curves is composed by the following steps, performed independently for each relevant period:

- determination of the intersection point of the demand and supply curves;
- definition of the system marginal price, that is the price of the last sale bid, whose acceptance is necessary to satisfy the electricity demand;
- definition of quantities assigned to each generation unit (quantities offered at a price lower or equal to the system marginal price;
- definition of quantities assigned to each buyer (quantities requested at a price higher or equal to the system marginal price).

The market clearing procedure therefore determines the quantity sold and bought, as well as their price. For example, in Figure 1 the crossing procedure relative to hour 1 of the 4th April 2011 for the Iberian peninsula market is shown.

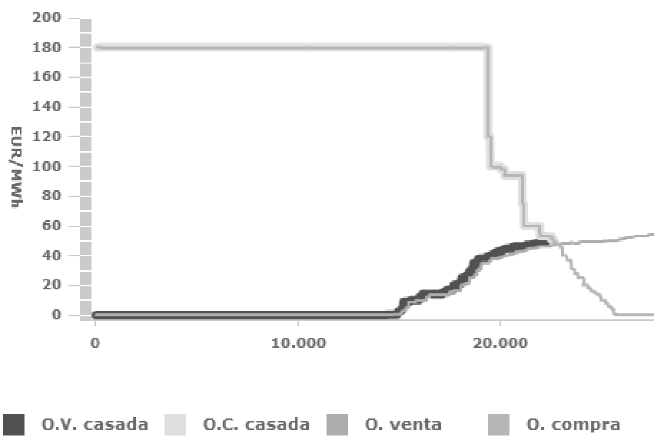

Figure 1 - Market clearing procedure in the Iberian Market (Source: OMEL)

2) Market divided in geographical zones

The zonal pricing of electricity requires an ex-ante subdivision of the grid into “geographical zones”, the areas with potentially different energy prices. A geographical zone is a portion of the grid, for which physical energy exchange limits with the surrounding areas are recognized.

The right definition of geographical zones results from a correct analysis of the high voltage transmission grid: the power flows on the grid in the most frequent situations, the location of the production plants across the national territory and the imports of electricity from abroad.

While the definition of geographical zones fixes the maximum possible sectioning of the system in distinct price areas, the aggregation of these areas in actual “market zones” is determined from the hourly demand-supply crossing.

Zonal pricing makes the market clearing procedure, based on the simple crossing of the demand and supply curves, not appropriate. In fact, in case of zonal pricing, the constraint of maximum power flow between the zones must be introduced into the market procedure.

In this case, the matching algorithm corresponds to the resolution of a constrained problem: the maximization of an objective function, the so-called Social Welfare (SW), respecting equality constraints (energy balance) and inequality constraints (accepted quantities must be in a given range; inter-zonal flows must respect the physical transport limits).

If buying and selling bids are expressed in terms of monotone step curves in the price-quantity plane, SW is defined as below:

$$SW = \sum_k PA_k \cdot c_k - \sum_i PV_i \cdot g_i \qquad (1)$$

where:

- PA_k is the hourly price of the k-th buying bid step;
- c_k is the accepted quantity of such a step;
- PV_i is the hourly price of the i-th selling bid step;
- g_i is the accepted quantity of such a step;
- the sums are extended to all the steps of selling and buying bids.

The technical and economic constraints take the following form:

$$\begin{aligned} &0 \le g_i \le g_{max\ i} \quad , \forall\ i \\ &0 \le c_k \le c_{max\ k} \quad , \forall\ k \\ &z_{min\ j} \le z_j \le z_{max\ j} \quad , \forall\ h \\ &G = C \end{aligned} \tag{2}$$

where:

- $g_{max\ i}$ is the width of the i-th selling bid step;
- $c_{max\ k}$ is the width of the k-th buying bid step;
- $z_{min\ j}$ and $z_{max\ j}$ are the flow limits of the j-th equivalent transmission link between two zones;
- z_j is the flow on such a link;
- G is the total accepted production, i.e. the sum of g_i;
- C is the total accepted load, equal to the sum of c_k.

If the connection topology of geographical zones is branched and not meshed, the flows on the equivalent inter-zonal links can be evaluated in a cascade, by simply imposing the energetic balance to the single zones, without having to formulate a real load flow problem.

It is to be noted that the transmission losses do not explicitly appear in the last of eq.(2). The market operator can take the losses into account for example by correcting the offered power quantities via nodal loss coefficients, defined by the System Operator.

The zonal prices correspond to the value of the marginal bid which would have to be accepted to satisfy a unitary load increase in the considered area. The union of adjacent geographical zones, whose interconnections are not at the transit limit, constitutes an area characterized by the same energy price, that is to say a “market zone”.

As easily predictable, the resolution procedure becomes more complicated compared to the simple determination of the curves’ intersection point, but the absence of complex bids nevertheless allows dispatching the system with a maximum Social Welfare in a single iteration.

B. Complex bids

In the presence of complex bids, the Market Operator must include additional conditions in the “matching algorithm”, that means in the clearing mechanism. This substantially modifies the market resolution procedure, with a substantial computational increase. For example, the presence of a load gradient condition excludes the possibility of solving the market independently for each hourly period, because each hourly production is constrained to the previous one. Furthermore, the minimum income condition of each production unit is extended to the whole day period.

The complexity of the market resolution procedure in presence of complex bids makes it necessary to sub-divide the method into a series of, theoretically distinct, simpler sub-problems; the definition of a maximum computational time (or a maximum number of iterations) retained acceptable for the market resolution, is also necessary; above such a limit, the process is interrupted and the best solution obtained until that point is considered as optimal.

In the Spanish market, for example, this process is carried out using the following steps.

1) Searching for an initial solution

The aim of this phase is to find a whichever daily market solution, which satisfies the conditions of indivisible bids, the restrictions due to the load gradient of production units, the conditions of scheduled shutdown and the minimum income conditions.

To achieve this goal, firstly the Market Operator applies the “simple matching method”, above described for simple bids, with the further condition of obtaining a solution that complies with all the constraints imposed by the complex bids, except for the minimum income condition. This method is called “simple conditioned matching”. Then, in order to satisfy the minimum income condition, the Market Operator uses an iterative procedure which performs several “simple conditioned matching”, successively eliminating all the sale bids corresponding to a production unit that does not comply with the minimum income condition, until all the complex conditions are satisfied.

In the simple conditioned matching, the load gradient condition limits the accepted quantity of a sale bid, when the power variation between two consecutive hourly periods exceeds the value stated in the bid. The condition is checked both with a forward analysis (by verifying each period respect to the previous one) and a backward analysis (by verifying each hourly period respect to the following one). The first check takes into account the rising gradients (production increase or start up) and the second the descending gradients (production reduction or stop), verifying that the eventual re-dispatch necessary to satisfy this last condition does not invalidate the results obtained form the first verification.

The indivisibility of bids and the scheduled stops are respected as a sub-product of the load gradient verification. The operational procedure of “simple conditioned matching” for the Spanish market is described in detail in [13].

For the fulfilment of the Minimum income condition, starting from the results of the “simple conditioned matching”, the Market Operator determines whether there are production units for which the eventual Minimum income condition is not satisfied.

In this case, the Market Operator calculates, for each of these units, the average price per kWh requested to satisfy the Minimum income condition, as well as the average price per kWh they would collect as the result of the simple conditioned matching.

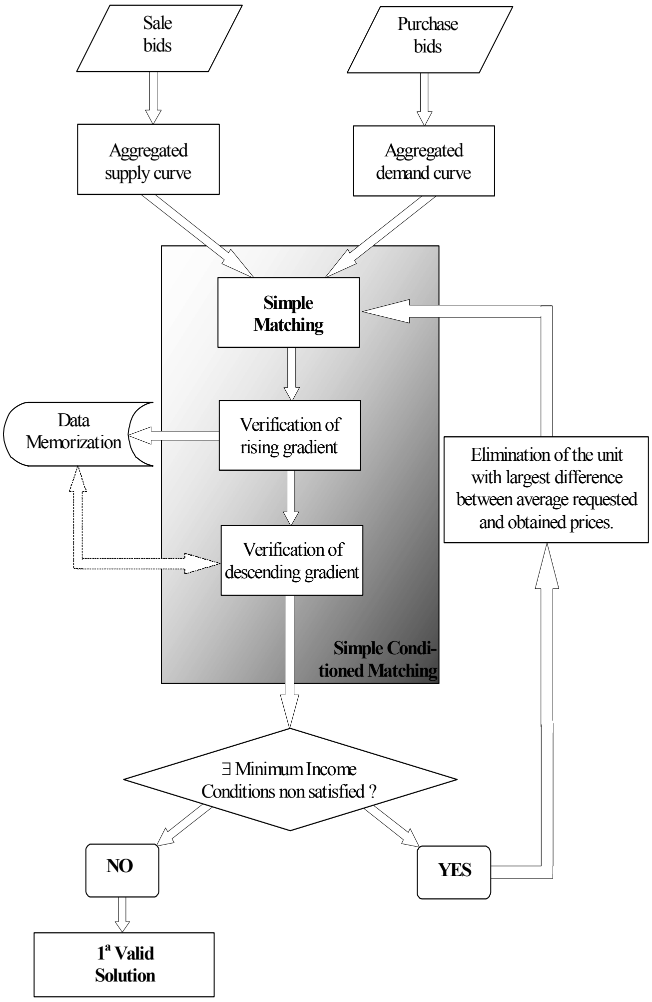

Figure 2 - Procedure used to obtain a First Valid Solution

The sale bid corresponding to the production unit which has the largest difference between the two calculated prices is eliminated, except for the blocks for which the Scheduled stop condition has been declared.

Once the sale bid corresponding to the above-mentioned production unit has been eliminated, the Market Operator repeats, for all the sale bids that were not eliminated, the "simple conditioned matching process".

The Market Operator performs this gradual elimination process, until a solution is reached in which all accepted sale bids respect the Minimum income condition.

This iteration process issues the so-called "First Valid Solution".

2) Improvement of the First Valid Solution

Once a first valid solution has been found, respecting all the constraints expressed by the accepted complex bids, the Market Operator begins the improvement phase of such a solution. This procedure is based on the identification of at least one production unit that, even though it has not been accepted in the First Valid Solution, has a positive difference between the income corresponding to the marginal market price and the minimum income requested by the unaccepted unit.

For a generic production unit up, such a margin is equal to:

$$MI(up) = \sum_{t=1}^{N} \sum_{h=1}^{24} E(up,t,h) * P_M(h) - R_{MIN}(up) \quad (3)$$

where:

- MI(up) is the income margin of unit up.
- E(up,t,h) is the energy of block t of the production unit, that the market would accept in a simple matching process, corresponding to the system marginal price $P_M(h)$; this term is not nil if the bid price of block t is lower or equal to $P_M(h)$;
- $R_{MIN}(up)$ is the minimum income requested by the production unit in its bid, calculated taking into account E(up,t,h).

In the Spanish market, a heuristic combinatory research algorithm is used to explore all the possible valid solutions. As Final Solution, the configuration with the smallest TMI value is selected, where:

$$TMI = \sum_{up=1}^{n} MI(up) \quad (4)$$

In the Spanish market, the process of seeking the final solution is limited in time (30 minutes) and in number of iterations (3000) [13].

The iterative procedure implemented to match the "complex" conditions can strongly increase the market price with respect to the results of a simple crossing between demand and supply curves, as reported in Fig. 3, representing the market result relative to hour 15 of the 4th April 2011 for the Iberian peninsula.

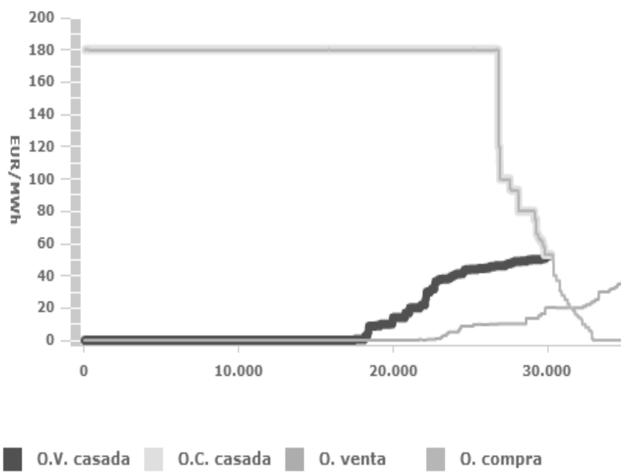

Figure 3 - Market clearing procedure in the Iberian Market (Source: OMEL)

In the previous picture, the increasing thin curve is relevant to the producers' bids that would be accepted in case of simple bids, while the bold increasing curve indicates the supply bids actually accepted by the market, due to the constraints imposed by complex bids.

The price increase is evident. Obviously, this increase should be compared to the additional costs that final customers would pay in the absence of complex bids, in order to compensate the recourse to an Adjustment Market.

V. Study Case

From the previous considerations, the increase in complexity, imposed by the presence of complex bids even in absence of zonal pricing, is evident.

In Italy, the introduction of a mechanism based on complex bids would be in addition to the solution, already articulated, of an electric market sub-divided into geographical areas, making the market clearing procedure even more complicated.

The adoption of such a mechanism for the Italian Energy Market must therefore be adequately justified, for example estimating the energy quantity that, in case of solely simple bids, would not respect the constraints related to reasonable complex bids.

Using this logic, an electricity market simulator, which operates on a yearly horizon, has been used to analyze a possible market dispatch relative to a year when the simple matching mechanism was employed.

Afterward, the energy quantity that would need to be re-dispatched in order to respect the technical or minimum income constraints imposed by assumed complex bids were estimated.

The simulation software generates the hourly energy bids of 137 thermal units, using a pre-defined bidding strategy based on a classical hydro-thermoelectric unit commitment.

On the basis of the hourly demand and on the sale bids, the simulator defines the hourly energy prices and the market dispatch.

A. *Verification of technical minimum of production units*

Such constraint can be efficaciously included in the simple bids, recurring to multiple bids that have a first energy block equal to the technical minimum of the unit, offered at an extremely low price (at worst, zero). With this expedient, the constraint is always respected even without the use of complex bids, except for the hours where the sum of technical constraints exceeds the load; in the performed study case, over-generation occurred only in one hour every two hundred.

B. *Verification of gradient constraints*

The gradient constraint is very difficult to be simulated. Each unit has in fact different gradient constraints, which are not easy to calculate, related to several technical factors. In the performed simulations, an average gradient of 1 MW/min has been assumed.

The verification of this constraint has been performed checking that the variation of the energy assigned in two consecutive hours to the same production unit was lower than 60 MWh. In the considered case study, the energy to be re-dispatched to respect this constraint resulted to be approximately 1% of the annual load; on average, in the single production unit the gradient constraint results to be violated in less than 3% of the hours.

C. *Verification of minimum income*

The constraint of minimum income represents potentially the most restrictive condition among those provided by the complex bids mechanism. The impact of such a constraint is potentially larger than other constraints, because its violation causes the elimination of the considered unit from the matching process.

The use of such a condition is strictly related to the bidding strategies of generating companies. In the study case, this constraint has been assumed violated when the daily earnings (considered as the difference between incomes for energy selling on the day-ahead market and production variable costs) of the considered unit result to be negative. In other words, we assumed that the producers indicate in the complex bid the request of a positive return during the considered day.

Figure 4 shows the amount of units that did not respect the constraint of minimum income.

Figure 5 summarizes the energetic volumes affected by the re-dispatch imposed by the respect of the constraints expressed in the complex bids.

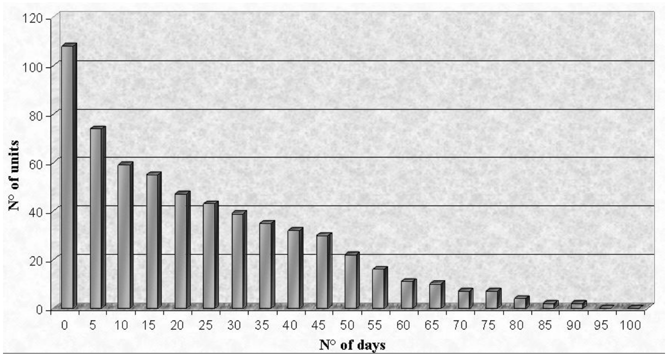

Figure 4 - N° of generating units with a minimum income violated in a number of days higher than those in the x axis

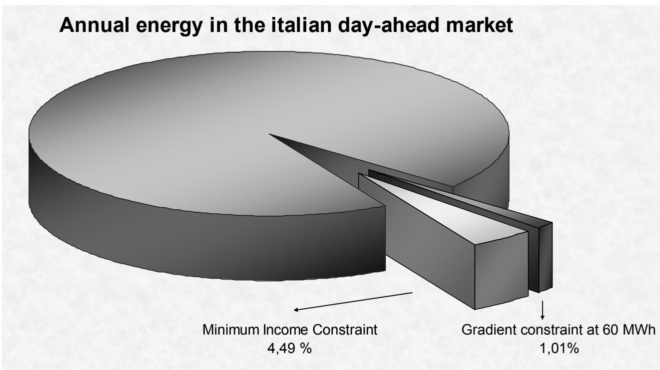

Figure 5 - Shares of yearly energy to be re-dispatched in order to respect the constraints expressed by complex bids

VI. Considerations about the Adjustment Market

In the electric systems where an Adjustment (Infra-daily) Market is present, the use of "balanced bids" is allowed. The aim of such bids is to give the operators a further tool to correct the schedules resulting from the day-ahead market. Balanced bids enable the operators to shift in a given hour a production block from one unit to another (even if they belong to different owners), as long as they are in the same geographical zone and no inter-zonal congestion is generated.

The benefit of balanced bids, respect to simple sale bids at zero price or simple purchase bids with no price indication, is their priority in the market clearing procedure, which means a high probability to be accepted [14], [15].

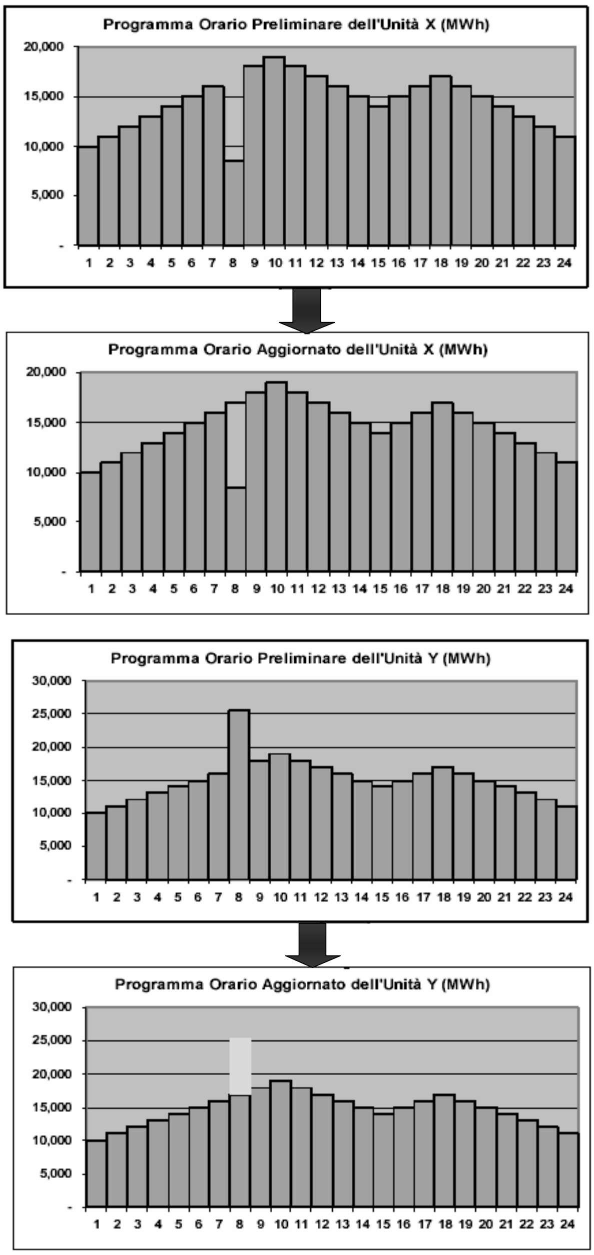

Figure 6 - Use of balanced bids on the Adjustment Market

Apart from balanced bids submitted by different operators, this kind of bids enable a producer with more than one unit in the same geographical zone to re-dispatch part of the energy assigned to him by the day-ahead market, or to solve problems of technical minimum or ramp issues, without additional costs. In figure 6 an example of application of this mechanism on the Adjustment Market is shown; energy is shifted from unit Y to unit X, in order to satisfy the ramp constraints of both units in hour 8.

It is clear that the use of balanced bids, even though it implies a variation of the optimum dispatch obtained in the day-ahead market, constitutes a fundamental tool for producers to respect constraints similar to those expressed in the complex bids, without additional costs. The energy amounts managed with balanced bids can be therefore eliminated from the total quantities to be re-dispatched, shown in Figure 5.

VII. Conclusions

The clearing procedure of the day-ahead electricity market, which defines the energy that each operator must produce or consume and its price, is one of the most crucial points of the operating rules of a deregulated system.

The possibility to add to the "simple bids" (quantity-price pairs) further physical-economical indications, like technical minimums, load gradients, minimum daily incomes and scheduled stops, can deeply affect and complicate the market clearing mechanism.

In this study, the rules being in use in the Spanish and in the Italian electricity market have been compared and discussed. The procedure adopted in Spain does not provide for zonal pricing of electricity, so the matching process is immediate and rather simple in computational terms. A market with complex bids, associated to the Italian zonal pricing, would make the matching procedure far more laborious.

On the basis of these considerations, the possible impact of possible complex bids in the Italian system has been here estimated [16].

The conclusions obtained in the study case have highlighted an extremely modest impact, in quantitative terms, related to the gradient constraint (about 1% of energy volumes). Furthermore, in order to respect such constraint the Italian market already puts a specific tool at producers' disposal, the so-called "balanced bids" of Adjustment Market.

Regarding the constraint of technical minimum of production units, it is to be noted that even with the simple mechanism such a condition can be efficiently included in the sale proposal, with the use of multiple bids.

The question related to the constraint of minimum daily income is more complex. Its impact on the Italian market, in the considered case study, involves about 5% of the annual energy. This constraint also constitutes the main cause of complexity increase in the market solution mechanism, requiring an iterative process to find the final solution. Basically, the introduction of this condition is aimed at minimizing the producer risk of not being able to recover the plant costs, or to guarantee a quick pay-back of the investment. On the other hand, the introduction of this constraint can constitute a valid tool for strategic or collusive behaviours of producers, decreasing the market transparency. Furthermore, generation companies can exploit other techniques to be sure to cover fix costs, like financial instruments or a good tuning of cost-related bids, intended as the sum of marginal costs and an opportune bid-up. This possibility increases when the clearing price is the marginal one and accepted quantities are not paid at the offered price (pay as bid).

In the Italian case, the performed analysis has shown that the market resolution mechanism based on complex bids, very complicated and difficult to be monitored by the competent authorities, seems to be not justified by the sporadic activation of the constraints expressed in the complex bids, nor by the reduced energy amount that such a mechanism would affect.

The paper was aimed at analysing the quantitative impact of complex bids in terms of involved volumes, i.e. the yearly amounts of electricity - obtained by means of simple bids - that would violate reasonable complex constraints. In our feeling, this is the correct indicator to be used to really quantify the real need of complex bids in an electricity market.

Since the inelastic nature of the demand curve, even in case of a small impact on volumes, the presence of complex bids can significantly affect the market clearing price, as clearly shown in Fig.3, this reducing the market Social Wellness. The effect on price of complex bids could be the task of a further investigation.

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