

# Price decoupling in a simple electricity market model with block and minimum income condition orders

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**Abstract**—We propose a simple market scenario with fill-or-kill, block and minimum income orders to test the effect of various clearing mechanisms in a computationally easy-to-handle environment. We consider two classical clearing-price based approaches as reference, which differ in the acceptance rules of block bids, and a novel clearing method, where we decouple demand and supply side prices. We show that if we apply price decoupling for, the total social welfare may be significantly increased.

## I. INTRODUCTION

Electricity markets are special from several points of view. First of all since, even today, electricity cannot be efficiently and economically stored, the generation must meet the consumption at every instance. Second, since transmission lines do have limited capacity, and the flows in the complex interconnected system of transmission lines are determined by the Kirchoff laws, inlets and outlets must be carefully designed to minimize losses and meet transmission constraints. In power engineering literature the fundamental problem of this topic corresponds to optimal power flow (for surveys see [1]–[3]). Regarding electricity markets, the transmission constraint phenomena is taken into account in market coupling problems [4], [5].

An other aspect, which makes electricity trading difficult is the inertia of generators and plants. On the one hand, the demand for electricity changes rapidly, thus it is desirable to make trading available on the level of hours or even tens of minutes. On the other hand, because of technological constraints it may be for example impossible for a generating unit to sell a significant amount at hour 1, then stand still for hour 2 and then trade in hour 3 again, even if the market clearing prices would imply this. In addition the cost profile of a generating unit may usually be described with a fix and a variable cost component, making the pricing of bids not trivial. The first approach for these problem is the concept of block orders [6], which, exactly for this reason incorporate multiple trading periods, and must be accepted in all or none of them. If a plant is bidding in the electricity market, it may include its fixed cost component in the price of the block orders as well to cover all the expenses of generation. If bids on the market

may be also partially accepted, modern methods allow very efficient market clearing [7], however fill-or-kill type bids and block orders always make the picture more complicated [8]. The aspects of truthful bidding and collusion-proofness are also an important questions in the design of electricity market mechanisms [9].

Generation costs of a generating block may be classified into two categories, constant and variable costs. Constant costs are usually related to the general process of running the plant, while variable costs reflect those expenses which depend upon the actual amount of electrical energy produced (eg. fuel costs). Variable costs are accounted for usually as a linear function of the actual produced quantity. The so called minimum income condition (MIC) has been recently proposed as an approach for the description of fixed and variable cost components [10], [11]. In these approaches, plants may submit data about their fixed and variable cost components in addition to conventional orders to ensure a minimal economic dispatch for themselves. However as the concept of MIC is quite novel, market analyses and efficient clearing algorithms corresponding to this concept are not prevalent in literature.

In this article we compare the conventional reference price-based clearing methods to a novel proposal. In the proposed scenario, we suppose that the market clearing prices for the demand and supply side are decoupled. This means that for each hour we suppose a demand price and a supply price. In this case in addition to conventional constraints (demand and supply amounts must match), we need to have an additional cost balance constraint. Namely the total income, determined by the hourly demand prices, must at least cover the total sum of expenses, composed by the cost of accepted supply orders and the cost of generation, corresponding to minimum income conditions.

## II. MATERIALS AND METHODS

We propose a simple framework of a small day-ahead market model with only two consecutive hours, which is on the one hand simple enough to evaluate even with exhaustive search methods in the case of conventional clearing, thus avoid the problems of computational limitations potentially

corresponding to clearing methods for large scale problems. On the other hand we consider only fill-or-kill offers on hour and two hour level (both on the demand and supply side). We call these fill-or-kill one hour supply or demand orders *standard orders* in the following, while we call the two-hour fill-or-kill bids block orders. Furthermore we consider block orders both at demand and supply side.

In addition to block orders we consider MIC bids, which are tailored to plants. In these bids the plant provides its fixed cost, which it requires in every case in which the plant is operating and its variable cost corresponding to the exact value of production. However, in the current setting we suppose that basically if plant submits such a MIC bid, it will not be considered together in addition to its other bids, but as a standalone offer. In other words, every plant must choose between the submission of conventional bids and possibly block bids or an MIC bid. On the other hand, let us remark that the submitted fixed and variable cost are not necessary equal to the real fixed and variable costs, they also may hold some margin, and are subject to bidding strategies in general. In addition for such orders, plants are also required to provide their minimal and maximal production value. Since apart from MIC bids, all orders do have the fill or kill property, MIC bids are the only one with amount flexibility, thus are key components of this market model.

For the aim of simplicity, load gradient constraints are not considered in this study. We begin with summing up the numbers of various offers for the simple market model and continue with the various clearing methods.

#### A. Bids

We consider the following bids in the simple market model

- 17 standard demand bids for hour 1, ranging from 25 to 80 MWs regarding amounts and 6 to 12 regarding price (e.g. EUR/MW), with a mean of 9.02.
- 16 standard demand bids for hour 2, ranging from 25 to 75 MWs regarding amounts and 7 to 13 regarding price, with a mean of 9.43.
- 3 block demand bids, ranging from 35 to 60 MWs regarding hourly amounts and 7.7 to 9.2 regarding price (we assume that block orders may have different price requirements for each hour), with a mean of 8.5.
- 8 standard supply bids for hour 1, ranging from 10 to 30 MWs regarding amounts and 7.3 to 11 regarding price, with a mean of 8.96.
- 8 standard supply bids for hour 2, ranging from 5 to 25 MWs regarding amounts and 8.1 to 11.9 regarding price, with a mean of 9.78.
- 2 block supply bids, of 20 to 40 MWs and 8.3 to 9.2 regarding price (we assume that block orders may have different price requirements for each hour), with a mean of 8.6333.
- 3 MIC bids, with fixed costs 600, 1000 and 300, variable costs 7.1 6.8 and 7.5, minimal production 100 250 50, and maximal production 250 400 150.

#### B. Conventional clearing mechanisms

In this subsection we present two possible clearing mechanisms for the simple market model based on [11]. Both of the proposed clearing mechanisms are price-focussed with global prices, which means that the set of accepted and declined offers is determined based solely on the market clearing prices (for hour 1 and 2), which are uniform for demand and supply side. The clearing prices allow the usage of the concept of social welfare (SW). The SW corresponding to an accepted demand bid in hour 1 may be computed as  $q_{db}(p_{db} - p_{mc}^1)$ , where  $q_{db}$  and  $p_{db}$  are the amount of the demand bid and the price of the demand bid respectively, and  $p_{mc}^1$  is the market clearing price in hour 1. Naturally we assume that a standard demand (supply) bid is accepted only, if the market clearing price of the corresponding hour is less (more) than the price of the bid. If a block bid is accepted its SW values may be computed hour-wise.

The two mechanisms differ basically in the handling of block bids:

- The first mechanism ( $C_1$ ) allows the acceptance of block bids only if the market clearing prices are appropriate in both of the periods. In the case of e.g. the demand bids, this means that the market clearing price must not exceed the bid price in either of the hours.
- The second mechanism ( $C_2$ ) allows the acceptance of block bids in the case when the *total resulting SW* of the bid is positive. This means that on the hour-level, a block bid may have negative SW in one period, if the positive SW component in the other hour is greater.

Both of the mechanisms include the following steps

- 1) Given the price vector, holding the market clearing prices in hour 1 and 2, the set of accepted standard and block bids are determined regarding both demand and supply side.
- 2) Given the set of accepted bids, the total required and supplied amount of power is calculated. If the supplied amount exceeds the required amount for any hour, the price vector is considered as infeasible.
- 3) If the difference of the required and supplied power amount is positive for every hour, a dispatch is calculated for all the MIC offers.
- 4) Regarding the dispatch method we consider the following calculation. The dispatch is calculated for all the feasible operation profiles. Under the expression *operation profile* we mean the set of plants in operation. Since in this small example we have only three plants (corresponding to the three MIC bids), this is computationally not demanding in this case. The dispatch algorithm calculates the production values which require the least total cost from the plants. This dispatch algorithm may be considered as a very simple unit commitment problem. Thus means the solution of a simple linear programming (LP) problem in this case, where the constraints originate from one hand the required power amounts, and on the other hand from the economic considerations which

describe that given the market clearing prices for each hour and cost components, every single plant must have at least the income to cover its production cost. Fixed cost components are determined by the operation profile, while variable cost components are determined by the actual dispatched production values (nonzero only in the case of operating plants). Once the production values and total cost of the generators are given, one may calculate their SW by determining the income of the generator  $j$  by

$$\sum_i p_{mc}^i g_j^i$$

where  $g_j^i$  is the production output of generator  $j$  in time period  $i \in \{1, 2\}$ . The SW of a generator is then computed as the difference between its income and costs.

We have to note that it is not common to have an embedded unit commitment problem in the dispatching mechanism, however in the case of the supposed bid structures it is straightforward to use such an approach for the dispatching of the MIC bids. Regarding the efficient solution of unit commitment problems one may refer to [12].

### C. Price decoupling clearing

In the case of the proposed price-decoupling clearing ( $PD$ ), the algorithm is very similar to the previous ones, the only significant difference is that we assume distinct demand and supply prices for each hour – in the case of the proposed small example this means that we have not 2 but 4 variables. The acceptance of demand bids do depend on the hourly demand prices, while the acceptance of supply bids do depend on the hourly supply prices. Block orders are cleared as in  $C_2$ . In the case of this clearing method only those price combinations are considered feasible, which result in an income amount from demand bids at least equal to the costs of supply bids and generation costs. We denote the market clearing demand and supply prices with  $p_{mc}^{di}$  and  $p_{mc}^{si}$  respectively.

As the clearing mechanisms described in subsection II-B use only two variables for the two hours, it is easy to compute the SW and all corresponding values (e.g. generation) for all possible price combinations. Determining the prices which imply the maximum total SW is trivial in these cases. In contrast, since in the  $PD$  clearing method the number of variables is already four, which results in a large number of possible combinations, we apply a numerical approach to find the maximal total SW. In this experimental setting we handled the scenario as a general global optimization problem, where in the case of infeasible setups the SW is considered to be equal to 0. Setups are considered infeasible if the supply amount from bids exceeds the demand amount from bids or when the demands are such that the generators can not be dispatched – eg. 25 MW in any hour, which is below the minimal production level of any generator) Such a formulation is very unlucky in the case of large scale problems, for on one hand the integer properties are not explicitly formulated, and

on the other hand the convergence properties are expected to be very bad, but as we will see, even this dummy approach will do the job in our case. For the numerical optimization the particle swarm optimization [13] through the toolbox OPTI [14] of MATLAB was used.

## III. RESULTS AND DISCUSSION

First, we may depict the total SW in the case of  $C_1$  and  $C_2$ , in Figs 1 and 2. In infeasible regions we suppose that the SW is equal to 0.

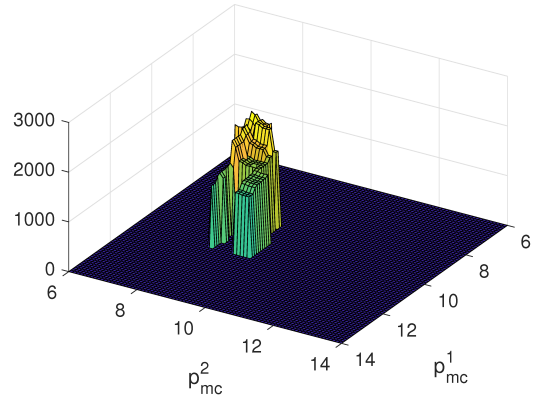


Fig. 1. Total SW, assuming clearing mechanism  $C_1$ .

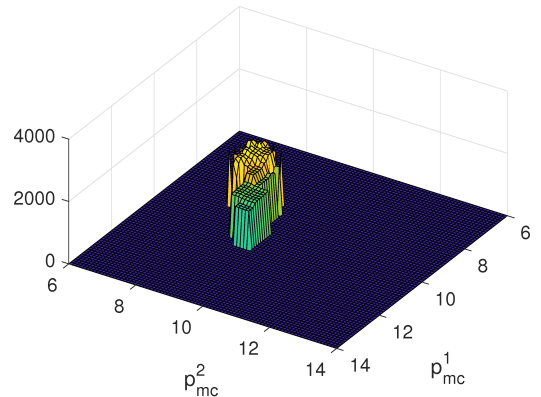


Fig. 2. Total SW, assuming clearing mechanism  $C_2$ .

We may see that the feasible region is somewhat larger in the case of  $C_2$ , however the feasible region of  $C_1$  is not a subset of the feasible region corresponding to  $C_2$ .  $C_1$  and  $C_2$  differs in the acceptance of block bids, more precisely according to  $C_2$ , block bids are more likely to be accepted. It is possible however that the acceptance of a certain block bid implies a small difference between demand and supplied power, thus results in an infeasible scenario regarding the unit commitment problem (power demand is below minimum production values).

The maximal total SW (the sum of SW by demand and supply bids and generation), is 2098 in the case of the clearing

method  $C_1$  and 2125 in the case of the clearing method  $C_2$ . The market clearing prices are  $p_{mc}^1 = 8.2$ ,  $p_{mc}^2 = 8.8$ , and  $p_{mc}^1 = 8.5$ ,  $p_{mc}^2 = 9$  in the cases of the clearing method  $C_1$  and  $C_2$  respectively. The generation values are

$$\begin{pmatrix} 0 & 378 & 150 \\ 0 & 358 & 150 \end{pmatrix}$$

in the case of  $C_1$  (rows correspond to hours, columns correspond to plants), and

$$\begin{pmatrix} 0 & 385 & 0 \\ 0 & 383 & 0 \end{pmatrix}$$

in the case of  $C_2$ . As we see the different consideration of block bids significantly affects the parameters of the optimum, regarding the market clearing prices and generated amounts as well.

In the case of the clearing method  $PD$ , as the problem includes already 4 variables and, as mentioned earlier, we obtained the maximal SW by optimization. We get the following market clearing prices.

$$p_{mc}^{d1} = 7.94 \quad p_{mc}^{d2} = 9.39 \quad p_{mc}^{s1} = 13 \quad p_{mc}^{s2} = 7.47$$

We can see that in hour 1 the price of the supply side exceeds the demand side, while in hour 2, the tendency is the opposite. These prices result in an income of 9177 from demand bids, a cost of 3036 of supply bids and a generation cost of 6141, induced by the generation values

$$\begin{pmatrix} 0 & 383 & 0 \\ 0 & 373 & 0 \end{pmatrix}$$

In this case we get a social welfare of 4129.

Table I sums up the results regarding social welfare.

clearing method	$C_1$	$C_2$	$PD$
maximal SW	2098	2125	4129

TABLE I

TOTAL SOCIAL WELFARE IN THE CASE OF VARIOUS CLEARING METHODS

Regarding the results described in Table I, we may observe the following. The fact that we get the highest SW value in the case of  $PD$  is not surprising, since  $C_2$  may be considered as a special case of  $PD$ , where the demand prices are equal to the supply prices. In other words the  $PD$  approach allows significantly more feasible setups. However, the difference between the conventional and the  $PD$  approach is remarkable, the total social welfare generated by the decoupling approach is almost twice as much as in the case of  $C_1$  or  $C_2$ .

#### IV. CONCLUSIONS

In the classical case, where partial acceptance of standard demand and supply bids is possible, and no block orders are present, the decoupling of demand and supply prices makes no sense, since the cost balance implies that one may only increase the demand price or lower the supply price, both resulting in lower social welfare compared to the classic curve-intersection based equilibrium point. As the proposed model

shows, this is definitely not the case if the bid set is composed of fill-or-kill orders, block orders or minimum income condition bids. In general it is very important to study market mechanisms with these type of bids, since they originate from technological characteristics of power plants thus are more able to represent the physical aspects of electricity production in the market mechanism.

As we have shown in this simple example, the decoupling of demand and supply prices may have significant economical and conceptual consequences, but as the illustrated case shows, the benefits regarding social welfare may be very remarkable. According to the presented initial results, it is plausible to assume that this increase in the total social welfare correlates with the ratio of block and MIC bids in the analyzed market.

#### A. Future work

Regarding the small market model with the described bids, one possible application of the proposed framework is exactly to test variable optimization based clearing solutions and more heuristics in a small scale environment, where several aspects of the examples can be efficiently visualized to enhance deeper understanding of the underlying processes and phenomena. In addition the described scenario shall serve also as a benchmark to test experimental market rules and analyze their effect on the SW profile and solvability properties of the market problem. As the proposed clearing methods rely on the unit commitment subproblem, it would be clearly desirable (if not unavoidable) to explicitly include the unit commitment in the clearing mechanism which determines the prices of the market.

Furthermore the proposed framework can be considered also as playground for agent based models, and serve as a tool for market power analysis. One may examine for example, that in a given environment which is more favorable for a plant: To submit conventional block bids, or the submission of minimal income orders.

Regarding the price decoupling based clearing method, the next straightforward task is the mixed integer problem formulation of the method in the case of the proposed offer structure, to get a description formalism for which the clearing may be efficiently computed for large scale systems in a reasonable time frame.

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