A WHOLESALE ELECTRICITY MARKET SIMULATION TOOL

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Abstract – Several years have passed since the first efforts to restructure the electricity sector. Today many countries have already introduced electricity restructuring reform laws, a process commonly referred as deregulation. The arguments for deregulation include expected increased competition, new system efficiency, lower average costs to consumers and the promise of future improvement as markets grow in size and sophistication. The restructuring process has gone beyond the point of no return. In the European Union there are clear directives that impose the member states deadlines to implement competitive markets. Such is the case of Portugal and Spain, whose governments have decided to establish an Iberian electricity market.

This paper presents a simulation prototype of a competitive wholesale daily market, including pool and bilateral transactions, inspired on the system that has been successfully performing in Spain and is about to prevail in the recently established MIBEL. The simulator provides users a means to obtain a deeper knowledge and awareness of a competitive electricity market.

Keywords: Electricity market, Simulation model.

I. INTRODUCTION

For the past few years many countries have undertaken the restructuring of the electricity sector. Following the first efforts pioneered by Chile, Argentina and England and Wales, several countries around the world, namely U.S. states and European Union state members, have introduced electricity restructuring reform laws, a process commonly referred as deregulation. Most experiences have been a qualified success, resulting in gains in terms of economic efficiency, but some have led to failure, the implemented market rules being unable to provide lower costs [1] or assure reliability and safety (California is an example).

The move toward an electricity market environment has the essential purpose of enhancing competition and inducing efficiency and lower electricity costs [2]. Although national experiences differ as regards trading rules, market operations, and the extent to which deregulation is carried out, the very same entities arise as performing a role in the new competitive framework: the regulator, the power producers, the selling agents and buyers, the market and system operators, and the consumers.

No matter what market model is adopted, electricity, seen as a good, should be separated from the services needed to deliver it to consumers. This perspective does not modify the physical flow of electricity from producers to consumers, but it certainly changes the way one sells, buys and trades electricity.

Abandoning the traditional vertically integrated power utilities – production, transmission and distribution activities within a single monopolist entity - the new organization of the markets foresees the splitting of the commercial and technical dimensions. New distinctive business areas emerge, with their own products and services.

The restructuring process, however, is strongly limited by the nature of the electricity activities - there are physical laws that differentiate the electricity business from others. Furthermore, there is a difficulty in adopting the principles of a free competitive market in a sector that favors the formation or maintenance of monopolies. The nature of electricity does not allow to abandon neither regulation, nor the need of a central coordination of the electrical system, remaining the activity of transmission a monopoly. The organization and the rules of the market must assure the conditions that, together with the regulatory aspects, lead to a competitive environment as much as possible, from which every player in the industry – consumers included – will eventually benefit.

Having recognized the new market environment, the question lies on how does one implement a structure that is able to assure a competitive framework, given a significant number of constraints, both of economic and technical nature.

As suggested by Flechner [3], one can consider the electricity sector as having two dimensions: a real dimension, that has to do with the physical flow of electricity, and a virtual dimension, related to the trading of electricity. Within the virtual dimension, buyers and sellers establish contracts, either physical contracts (which intend to provide for real electricity) or not physical contracts (designed to hedging risk through buying and selling futures and options). Both dimensions are intimately connected, but still a separation must be drawn in order to build an operational competitive environment.

The time dimension of the transactions in an open electricity market is of extreme importance. Either through a power exchange or a pool mechanism, or through bilateral contracts, electricity transactions can be made within different markets at the same time: spot markets, forward markets, future markets, swap markets and planning markets [4].

The simulator described in this paper addresses a market structure where forward bilateral contracts to deliver certain amounts of electricity for a particular day are known, as well as an auction mechanism that allows buyers and sellers to post their bids for that same day. An independent operator clears the market and produces a dispatch for that day.

II. A WHOLESALE MARKET ORGANIZATION

A. Electricity wholesale market

In a competitive electricity market one can find an independent system operator (ISO), whose task is to keep the physical integrity of the transmission system while providing nondiscriminatory access to all participants in the market [5]. It is expected of the ISO to settle an optimal operation schedule at every time, given the physical constraints of the transmission lines. As in the Spanish electricity market, one can separate this mission into two distinct roles. A first role is that of a market operator, who must ensure that all participants are able to access the system and who should produce a feasible dispatch based on the information of price and quantity from sellers and buyers. A second role is that of a system operator, that must check the feasibility of the transactions, taking into account the physical transmission capacity and other technical constraints.

There are two main models for a market structure: the pool and the bilateral market. The pool is a market structure, with which suppliers and buyers transact. Some sort of auction is implemented [6], and, based on the quantities and prices offered by suppliers and buyers, a market operator should clear the market, dispatching the least expensive suppliers. In a bilateral market, sellers and buyers transact directly with each other, which implies that the participants should look themselves for information about prices.

There are arguments in favor of the pool system, and in favor of the bilateral system. Nevertheless, both systems can exist at the same time, provided that the ISO ensures the necessary coordination. This combined system thus implements an auction through which suppliers submit their production bids and buyers submit their demand bids. A certain price will clear the market and a certain amount of electricity is to be accepted for production and consumption. The bilateral contracts are then taken into account, and those that are feasible will be part of the dispatch. This mechanism must be performed on a regular basis (hourly auctions are frequent) and adjustments are often necessary to ensure that the dispatch is feasible.

B. A wholesale daily market

In real time there must be a completely centralized coordination, as supply must equal demand at every second. This coordination has to balance the system continuously, at all times [7].

In many real markets there is a day-ahead market (DA). Most transactions are cleared in the DA market for each hour of the next day. The risk of the participants of the market, who can see the spot price change significantly along the day, can be managed through contracts for differences (CFD), which cover the differences between the price of the transactions in the DA market and the spot prices in real time (that is, on the next day, when the physical transaction is to take place).

The Spanish system relies on such a market structure. There is an organized part that includes the electricity market (a daily and an intra-daily market) and market for ancillary services, and a non-organized part, to carry out bilateral transactions. In the day-ahead market, suppliers submit their selling bids and prices for each hour of the day, using an e-commerce marketplace, and buyers submit their demand bids as well. These bids are processed using a matching algorithm: the selling bids are ordered by increasing prices, and the demand bids are ordered by decreasing prices, resulting in an aggregated supply curve and an aggregated demand curve. The intersection of these curves determines the market clearing price (that of the last accepted selling bid). The market operator (MO) then broadcasts the dispatch, which states the matching bids. The system operator works closely with the market operator to determine the electricity transactions to take place and the commitment of the generators needed to carry out the economic transactions.

The sellers are allowed to include some degree of complexity in their bids. In fact, there might be constraints of indivisibility (thermal units frequently have such constraints, as they face significant start-up costs). Also, the first quantity a generator bids is always indivisible, which means that if a bid is accepted, it should be for the total quantity and not for just a part of it. There might be a minimum up-time, as well: once a thermal unit is on, it should be committed for a certain amount of time. These conditions are placed by the seller together with the price/quantity bids.

After the market matching is done, the system operator analyses the physical feasibility of the market operator dispatch. If necessary, ancillary services are used and corrections are introduced. As a result, in the day-ahead market every transaction for each hour of the next day is programmed. From then on, as time goes by, an intra-daily market allows for adjustments.

III. A WHOLESALE MARKET SIMULATION TOOL

This paper presents a market simulation model that we have developed to provide deeper knowledge of the operations of a day-ahead wholesale market. Figure 1 shows the flow of operations that have been implemented.

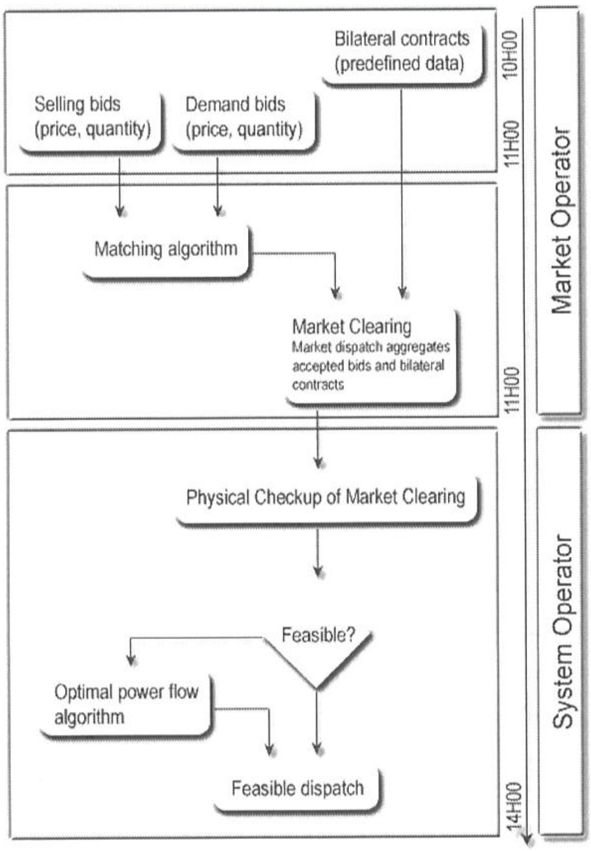

Figure 1- Flow of operations implemented in the simulation process

A. *Simulator web-based interface*

In order to permit participants to interact simultaneously, a standard web-based interface has been chosen. The simulator has been written in VB Script language and uses Active Server Pages technology.

The user interacts with a browser and participates assuming the role of a seller, a buyer or a ISO. Both sellers and buyers are requested to post their bids, but neither will have access to information other than historic data and results of the market operator's dispatch. One participant only can assume the ISO's role, gaining access to all data, including, of course, the bids that are posted in the DA market and the bilateral contracts previously placed for the next day. The ISO player will not interfere with the bidding process, except when he or she decides to change the parameters of the simulation itself (for example, the rules of generator's bidding).

The information posted by bidders, as well as the data that defines the electrical network, the transmission lines and the generators characteristics, are registered in a Microsoft Access database. This database also contains predefined historic time series data of bilateral contracts, which are used to set bilateral transactions of electricity for the next day. So far, users cannot interfere with this predefined set of bilateral contracts, but the simulation can be set up to randomly generate other sets of bilateral contracts, according to a selectable probabilistic distribution.

Generators are allowed to produce up to five-block bids for every hour. The simulation can be set up to accept the extra condition not to divide the first block bid of a generator. An imperative condition for a seller to participate in the auction is to produce at least one block bid for every hour.

Buyers also place their demand bids. These can be price/quantity bids or simple quantity bids (in this case the simulator assumes the bidder is paying the maximum price allowed for each unit of energy, which is a parameter that can be set in the simulation).

B. *Matching algorithm and economic dispatch*

Once the bids are posted, the market operator checks whether any generator that bids is violating its operational constraints. Then he activates a matching algorithm that considers all bids to be simple.

The matching algorithm sorts all selling bids from bottom price to top price, and all demand bids from top price to bottom price. As there are complex selling conditions, a seller may post up to five block bids, in ascending order of price. These block bids are considered simple and treated independently by the matching algorithm. After sorting all selling and demand bids, which produces two curves (figure 2) for aggregated supply and demand, the algorithm calculates the intersection of these curves to establish the clearing price. However, if there has been declared a non-divisibility of the first block of a selling bid, a correction may be produced to avoid such a situation. This situation can happen if the intersection of the curves is such that the demand curve splits the supply curve segment at the intersection point. In that case, the selling block bid that is intersected is ignored and the next block bid that fits the needs of demand is considered, and a new intersection is calculated. The process goes on until an equilibrium is achieved and the complex conditions met. The market clearing is then produced, being this process repeated for each of the 24 hours of the day-ahead.

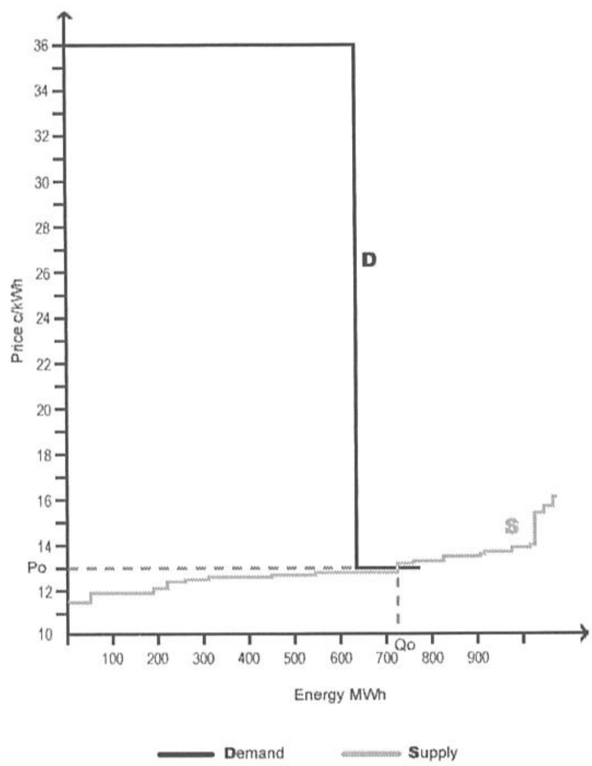

Figure 2- Example of supply and demand curves matching: energy transacted and clearing price for 10 a.m. of the day-ahead

The results of the matching process are published, stating the matching bids and the uniform price that has cleared the market for each hour of the next day. The market operator combines the resulting dispatch with the bilateral contracts for the next day.

The predefined bilateral contracts details and historic data follow a typical daily load curve. The system operator then investigates the physical feasibility of the market clearing, by performing a technical validation of the contracts that have been accepted by the market operator. A DC model is used to determine whether the power lines' transmission capacity is exceeded. If that is the case, an optimal power flow algorithm finds a feasible dispatch, and the results are, again, published, listing the definitive accepted bids and what energy is to be transacted at what price.

IV. APPLICATION EXAMPLE

The example we present here is based on the network diagram of figure 3. There are six nodes to which six different buyers are associated as well as six generators, associated to six sellers.

All sellers and buyers post their selling and demand bids. These bids are listed by seller and buyer and can be viewed using the appropriate simulator views. In figure 4 a view of the example selling bids for the 10th hour is shown.

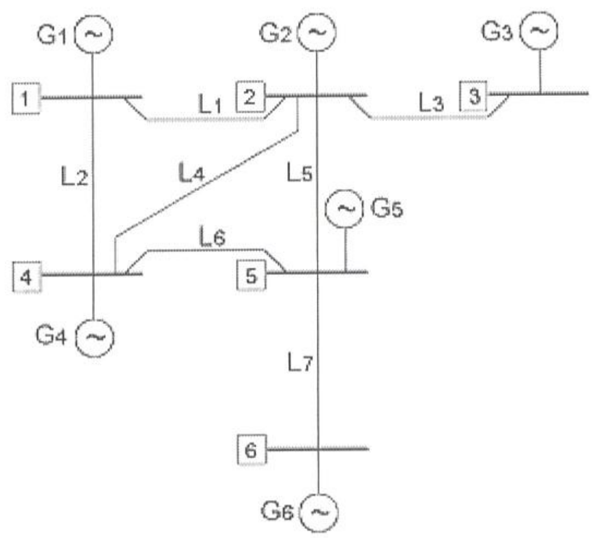

Figure 3- Example: network diagram.

As referred before, the selling offer of a seller can be complex, in the way that it can include more than one block bid (up to five) and there can be a restriction not to divide the first block bid when matching supply and demand. A seller should place offers for every hour of the day, but there is no need to place five block bids per offer.

Figure 4 shows the energy bids of seller number 2, for the 24 hours of the day-ahead. Figure 5 shows the price for each block bid for the 24 hours of the day-ahead.

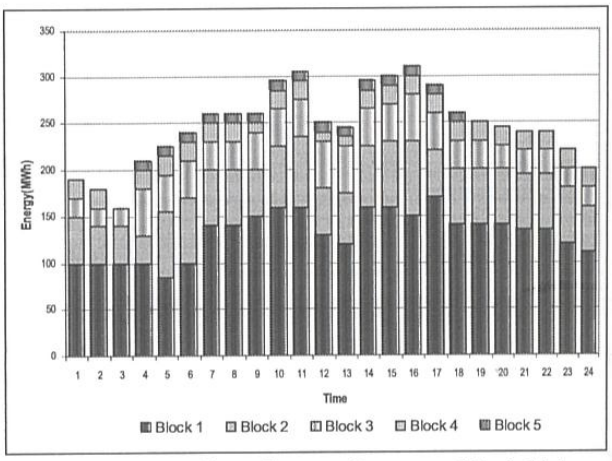

Figure 4- Example: seller no. 2 energy block bids placed for the day-ahead.

Summary

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Total energy MWh	730	725	700	750	775	690	870	900	1020	1075	1125	1005	1000	1075	1105	1130	1070	920	870	860	855	845	800	620
Price min. c/kWh	3.2	2.8	2.7	2.7	2.7	3	4	6	7.8	11.5	13.8	8	8	11.5	13.8	14.6	11.5	7.6	4	3.9	3.9	3.9	3.8	3.9
Price max. c/kWh	5	5	4	4	5.2	5.2	6.6	10	13.5	16.1	18	13.5	13.4	16.1	16.7	17.2	15.9	10	6.7	6.5	5.8	5.5	5.3	5

Generator - Seller: G1 - Node 1
[Pmax = 500 MW]

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy MWh	90	90	90	90	100	80	120	120	130	140	150	140	130	140	150	150	140	130	120	120	115	115	100	90
Price c/kWh	3.4	3.2	3.1	3	3.2	3.2	5.4	6.8	8.9	12.6	14	8	8	12.6	14.6	14.9	12.8	7.8	5.6	4.8	4.7	4.5	4.1	3.9
Energy MWh	50	50	50	50	50	50	50	50	60	60	70	65	75	60	60	70	60	50	50	45	50	50	50	50
Price c/kWh	3.6	3.3	3.2	3.3	3.6	3.6	5.5	6.9	9.5	13.5	14.2	9.2	9.2	13.5	14.7	15.5	13.6	7.9	5.7	4.9	4.8	4.6	4.3	4
Energy MWh	30	30	30	20	30	30	30	30	40	40	50	30	30	40	40	40	40	30	30	30	30	30	30	30
Price c/kWh	4.1	3.8	3.5	3.4	4.1	4.1	5.6	7.3	9.8	13.9	15.2	9.6	9.6	13.9	14.9	16.1	13.9	8.3	5.8	5.3	5.1	4.9	4.4	4.2
Energy MWh	-	-	-	-	-	-	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	-	-
Price c/kWh	-	-	-	-	-	-	6.3	8	10.7	15.4	16.7	10.1	10.1	15.4	15.6	16.6	15.4	9	6.3	6	5.8	5.5	-	-
Energy MWh	-	-	-	-	-	-	-	10	10	-	-	10	10	-	10	10	-	10	-	-	-	-	-	-
Price c/kWh	-	-	-	-	-	-	-	9	12	-	-	11.9	11.9	-	16.3	17.2	-	9.5	-	-	-	-	-	-

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Generator - Seller: G2 - Node 2
[Pmax = 500 MW]

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy MWh	100	100	100	100	85	100	140	140	150	160	160	130	120	160	160	150	170	140	140	140	135	135	120	110
Price c/kWh	3.6	3.3	3.2	3.1	3.2	3.5	5.5	6.6	8.1	12.8	14.3	8.1	8.1	12.8	13.9	14.6	13	7.6	5.3	4.9	4.9	4.7	4.2	4
Energy MWh	50	40	40	30	70	70	60	60	60	65	75	50	55	65	70	80	50	60	60	60	60	60	60	50
Price c/kWh	4.2	3.6	3.5	3.3	3.6	3.6	5.6	6.7	8.8	13.3	15.1	8.8	8.8	13.3	14.3	15.2	13.3	7.7	5.6	5	5	4.8	4.6	4.4
Energy MWh	20	20	20	50	40	40	30	30	40	40	40	50	50	40	40	50	40	30	30	25	25	25	20	20
Price c/kWh	4.5	4.2	3.8	3.6	3.9	3.9	5.7	6.9	9	13.7	15.8	9	9	13.7	14.7	15.9	13.7	7.9	5.8	5.2	5.1	5	4.7	4.7
Energy MWh	20	20	-	20	20	20	20	20	10	20	20	10	10	20	20	20	20	20	20	20	20	20	20	20
Price c/kWh	5	5	-	3.8	4	4	5.8	8.1	9.6	15.7	16.8	9.6	9.6	15.7	15.7	16.4	15.7	9.1	5.9	5.5	5.2	5.1	5	5
Energy MWh	-	-	-	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	-	-	-	-	-	-
Price c/kWh	-	-	-	4	4.6	4.6	6.4	10	11	16.1	17.3	11	11	16.1	16.6	16.9	15.9	10	-	-	-	-	-	-

Figure 5- Example: Selling bids.

Both energy and price curves follow the expected demand for the 24 hours of the day-ahead, surging twice during the day.

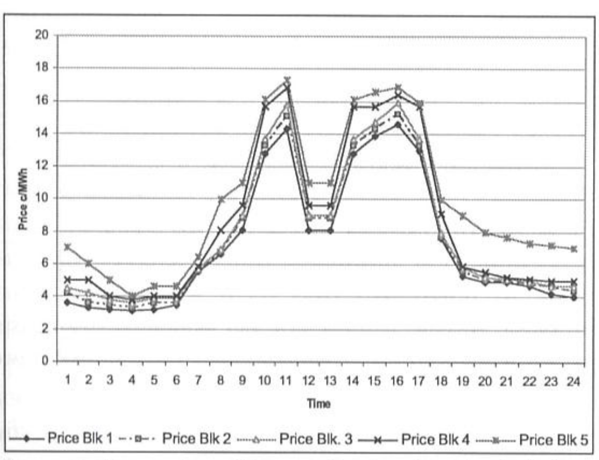

Figure 6- Example: seller no. 2 price for block bids placed for the day-ahead.

The results of the simulation process reveal the feasible selling and demand bids, including bilateral contracts. The graphic of figure 7 shows the overall results in terms of energy and price negotiated for the 24 hours.

The results view lists the total amount of energy that has been dispatched for each hour of the day-ahead, as well as the clearing price for every transaction (uniform price), as shown in figure 8.

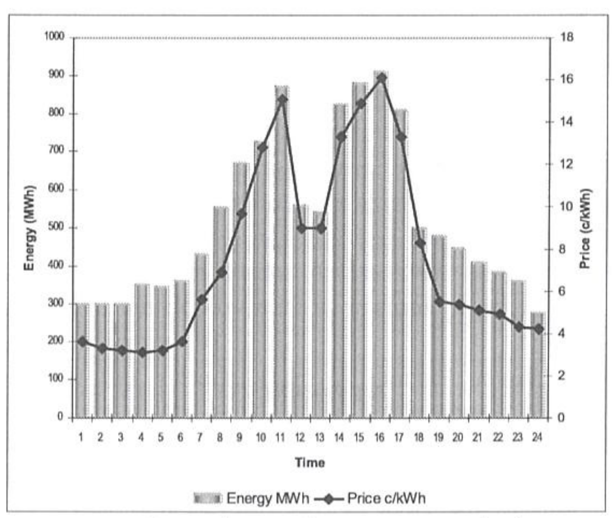

Figure 7- Example: results – energy and price negotiated for the 24 hours of the day-ahead.

The user can also view other results: the selling bids that have been accepted for transaction for every hour of the day-ahead, as well as the accepted demand bids; the rejected selling and demand bids; the economic dispatch results, the power flow results (DC model) and even alert signals that enhance situations where the capacity of the transmission lines has been exceeded (in this case, an optimal power flow is used to produce a feasible dispatch).

V. CONCLUSION

In order to participate in a deregulated competitive wholesale daily market one must understand the new structures and roles that are put in place. A simulation model of an electricity wholesale market can be a valuable tool that provides training and deeper knowledge of the processes that are involved, namely at the economic dimension of the electricity sector. The simulation prototype that has been developed is a first approach to simulate a day-ahead market, already including some complexity in terms of the bids that are posted by participants. It will be progressively enriched with intra-daily market sessions, more complex bid conditions and flexibility. Alternative algorithms are to be included, namely an AC model to consider losses. The main objective is to establish a simulation tool that will predict the actual behaviour of the agents in the wholesale market, providing a more realistic approach.

ELECTRICITY MARKET SIMULATOR

Home I Nebwok infoe I Selling bids I Demand bids I Bilateral contracts I Run simulation I Options

Date: Quinta, 15 de Abril, 2004 | Ntw: Rede 2
User: Teresa Alexandra Nogueira | Status: ISO

Simulation >

Clearing price and total demand negotiated

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Price c/kWh	3.6	3.3	3.2	3.1	3.2	3.6	5.6	6.9	9.7	12.8	15.1	9	9	12.8	14.9	10.1	13.3	8.3	5.5	5.4	5.1	4.9	4.3	4.2
Energy MWh	300	300	300	350	345	380	430	555	670	725	870	560	540	725	880	910	810	500	480	445	410	385	360	275

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Accepted selling bids

Time:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Position	1º																							
Seller	4	4	4	4	4	5	4	4	4	4	4	1	1	4	4	2	4	2	4	4	4	4	4	1
Node	4	4	4	4	4	5	4	4	4	4	4	1	1	4	4	2	4	2	4	4	4	4	4	1
Bid index	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Energy MWh	60	50	60	60	60	60	60	50	50	50	50	140	130	50	50	150	50	140	60	60	60	60	60	90
Price c/kWh	3.2	2.8	2.7	2.7	2.7	3	4	6	7.8	11.5	13.8	8	8	11.5	13.8	14.6	11.5	7.6	4	3.9	3.9	3.9	3.8	3.9
Position	2º																							
Seller	4	5	6	5	4	4	4	5	2	3	1	2	2	3	2	3	4	2	4	4	4	4	4	1
Node	4	5	6	5	4	4	4	5	2	3	1	2	2	3	2	3	4	2	4	4	4	4	4	1
Bid index	2	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
Energy MWh	30	60	50	60	30	60	30	60	150	140	150	130	120	140	160	140	30	60	30	30	30	30	30	50
Price c/kWh	3.2	2.9	2.8	2.7	2.8	3.1	4.3	6.3	9.1	11.9	14	8.1	8.1	11.9	13.9	14.8	12.1	7.7	4.3	4.2	4.1	4	3.9	4
Position	3º																							
Seller	4	4	4	4	5	1	5	6	4	4	3	3	3	4	4	1	5	1	5	5	5	5	1	2
Node	4	4	4	4	5	1	5	6	4	4	3	3	3	4	4	1	5	1	5	5	5	5	1	2
Bid index	3	2	2	2	1	1	1	1	2	2	1	1	1	2	2	1	1	1	1	1	1	1	1	1
Energy MWh	10	30	30	30	60	80	60	50	30	30	150	140	140	30	30	150	50	130	60	60	60	60	100	110
Price c/kWh	3.3	3	2.9	2.8	2.9	3.2	4.5	6.5	9.3	12.1	14.1	8.6	8.6	12.1	14.1	14.9	12.4	7.8	4.5	4.4	4.4	4.4	4.1	4
Position	4º																							
Seller	1	1	6	1	4	4	4	2	5	5	4	2	2	5	2	2	6	4	4	1	1	1	2	1
Node	1	1	6	1	4	4	4	2	6	5	4	2	2	6	2	2	6	4	4	1	1	1	2	1
Bid index	1	1	2	1	3	2	3	1	1	1	2	2	2	1	2	2	1	1	3	1	1	1	1	3

Figure 8- Example: results view.

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