Paper

Market Model Considering Bilateral Transactions in the Deregulated Electricity Market

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This paper proposes an algorithm to simulate the transactions that take place in a free market of electricity. The algorithm presented is used for Bilateral Transaction Matrix (BTM) creation assuming that a day ahead load forecast is previously known. Bids can be made by both the generation side and the demand side to determine transaction prices, then the algorithm allocates the transactions according to market rules until the demand is satisfied. This creates feasible BTMs that can be used to study system security and to find future methods to regulate bilateral transactions through market mechanisms like the application of penalties to the transactions that affect the system's security. Results show that the proposed algorithm is a good option for electricity market analysis. The proposed algorithm provides system planners with a practical tool for data creation to further study the effects of bilateral transactions in a deregulated electricity market.

Keywords: Bilateral Transactions, deregulation, energy supply, linear programming, load forecasting

1. Introduction

In the last decade, the topic of deregulation has gained a lot of attention and several countries have deregulated their electric utility industry (1), adopting different models like the Pool model and the Wholesale competition model. In this context, bilateral transactions between generators and distributors or big consumers of electricity has created some attention and new concepts like the Bilateral Transaction Matrix (BTM) have been created in Ref. (2) and (3). Security analysis using the BTM concept has been made in Ref. (4) and (5), using the Monte Carlo simulation method to create feasible BTMs, but a bidding or an auction is not considered as part of the process to create feasible BTMs. Therefore, a method that incorporates a bidding process must be considered in a simulation of the electric energy market and produce feasible BTMs that satisfy the system's demand and benefits both sellers and buyers. A feasible BTM is one in which the sum of all the energy sold by all generators to node i equals node i's demand and the sum of all the energy sold by generator j to all nodes is less than or equal to generator j's maximum generation limit.

An application of auctions and the transportation problem to the interchange of electricity has been made in Ref. (6), which shows an example of how auctions might be implemented. The advantages of double sided auctions are presented in Ref. (7), which uses a linear programming approach to calculate BTMs, considering different kinds of auction models for electricity markets. Single round auctions and multi round auctions are compared in Ref. (8) showing that the highest social welfare is obtained by an iterative market simulation.

The purpose of deregulation is to stimulate competition among generators and distributors and guarantee a nondiscriminatory open access to the transmission grid for all participants in a free market for electricity. Bilateral transactions are financial contracts between buyers and sellers, written on the basis of physical energy transfers, where the quantities traded and the prices are at the discretion of the market participants, buyers and sellers have the ability to negotiate directly in the market place with little intervention from the Independent System Operator (ISO). The ISO is the entity responsible for guaranteeing nondiscriminatory access to transmission, establishes rules and pricing policies, and operates the power system (9).

This paper proposes an algorithm to simulate a free market of electricity, which is administrated by the Independent System Operator (ISO). In this market model, both buyers and sellers can bid a price in the market and set the price of the transactions by means of price adjustments according to the buyer's demand and the seller's availability of power. This is done by the bidding process explained in section 2.1, in which the price of transactions is determined before the power is allocated by means of the selling process explained in section 2.2. The only type of transactions considered are bilateral transactions between market participants, which are defined as generators and distributors or big users of energy with a demand of at least 1MW; energy brokers or other intermediaries were not considered.

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The study of bilateral transactions is important for system planning and security under deregulation and is useful to prevent trouble transactions from occurring. The creation of rules and mechanisms for a secure system operation is one of the responsibilities of the ISO in a deregulated electricity market. The proposed algorithm provides system planners with a practical tool for data creation to further study the effects of bilateral transactions in a deregulated electricity market.

The BTM results that can be obtained by the method proposed in this paper has been used as the initial data for a market mechanism for line congestion clearance Ref. (10), (11), (12), developed by the authors, where line limits and line losses have been considered as the physical and operational constraints; applying penalties to the transactions that cause congestion. The market mechanism clears congestion by redefining the transactions using the method proposed in this paper.

2. Proposed Algorithm

2.1 Bidding Process The proposed algorithm has two main parts; the bidding process and the power allocation process. In the bidding process, the prices of transactions between generators and demand nodes (distributors or big users of electricity) are decided before generators and nodes make a transaction, this is necessary to establish which generators will run to satisfy the forecasted demand and allow market participants to define their transactions in a free market environment. These transactions define the BTM, which becomes the dispatch schedule for the next day. The ISO has to verify that the BTM does not cause line congestion or other problems to the power system, using the BTM as scheduled transactions and running a power flow to verify that the system constraints are not violated by the BTM. If violations exits, then the ISO cannot authorize the transactions and a new BTM has to be defined by means of a market mechanism. The authors have developed a market mechanism for line congestion clearance, where the method proposed in this paper is applied to the system operation, details of the market mechanism can be found in Ref. (10)~(12).

Fig. 1 shows the flow chart of the bidding process, which begins by reading the load forecast for the next 24 hours and the starting prices, equivalent to the market open prices of the stock market, with the difference that only one product is being traded.

In this paper the authors consider electricity as an heterogeneous product with different prices for each node and different prices for each generator. The bids are for nodal prices that include the cost of transmission, therefore each node has bid prices for each and every generator in the system and each generator has bid prices for each and every node; this allows generators to choose freely the nodes to which they sell their power and it also allows nodes to choose freely the generators from which the nodes buy their energy.

The bidding process is coordinated by the ISO who provides generators with a load forecast for the day ahead electricity market according to the information

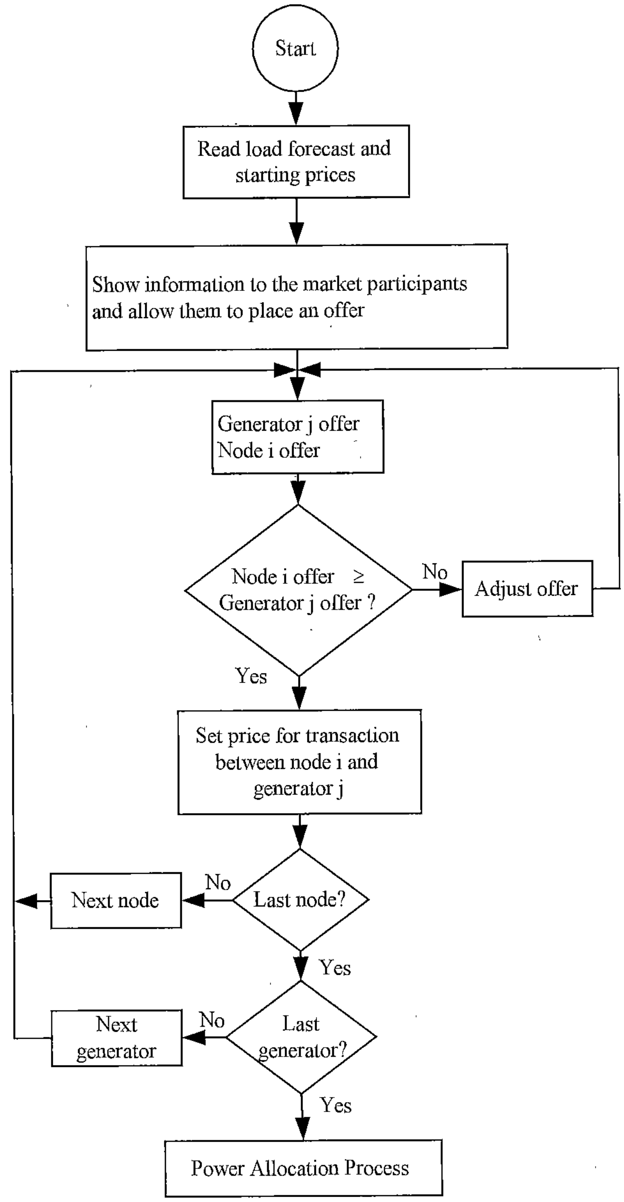

Fig. 1. Bidding process

provided by the demand side. Knowing this information, all generators place selling offers and buyers make buying offers according to the changes in demand, which reflect the law of supply and demand; if the demand increases, prices also increase and if the demand decreases, prices also decrease. Equations (1) and (2) are the buying and selling offer prices respectively.

$$NO_{ijt} = NP_{ijt} + W_i * \Delta P_{it} \quad \cdots\cdots (1)$$
$$GO_{jit} = NP_{ijt} + W_j * \Delta P_{it} \quad \cdots\cdots (2)$$

where NO_{ijt} is the bidding offer made by node i to generator j at time t. GO_{jit} is the bidding offer made by generator j to node i at time t. NP_{ijt} is the start asking price for time t, at which generator j is willing to sell its energy to node i. ΔP_{it} is the change in the demand of node i between time t and time t-1. W_i and W_j are the demand factors of node i and generator j respectively. These factors represent the price adjustments made by node i and generator j to adjust their offer to the change

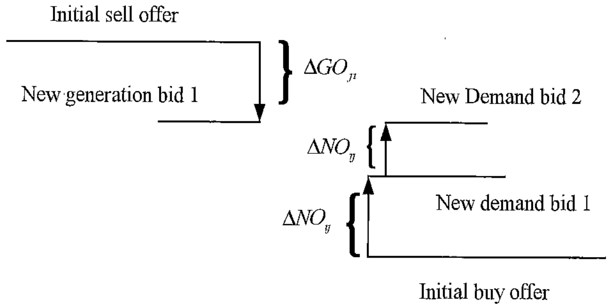

Fig. 2. Price setting procedure

in demand. W_i and W_j are generated randomly to simulate the behavior of buyers and sellers during the price offering process at the beginning of the bidding process for each hour of the load forecast. W_i and W_j can have any value between 0 and 0.001. These values were found to be adequate to adjust the dimensions of the demand in MW to a \$/MWh value.

The price setting procedure is shown in Fig. 2. After initial offers are made by node i and generator j according to equations (1) and (2), node i and generator j adjust their offers by increasing or decreasing the prices until a price is set. Equations (3) and (4) describe the bidding price adjustments made by node i and generator j respectively.

$$NO_{ijt}^{new} = NO_{ijt} + \Delta NO_{ijt} \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

$$GO_{jit}^{new} = GO_{jit} - \Delta GO_{jit} \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where NO_{ijt}^{new} and GO_{jit}^{new} are the new offer prices of node i and generator j respectively for time t. ΔNO_{ijt} and ΔGO_{jit} are the changes in price that node i and generator j make at each moment during the iteration process. The price between node i and generator j is set when $NO_{ijt}^{new} \geq GO_{jit}^{new}$ and the price becomes NO_{ijt}^{new}. If the price is not set, ΔNO_{ijt} and ΔGO_{jit} are generated randomly, every time that a new price is required until $NO_{ijt}^{new} \geq GO_{jit}^{new}$ which sets the price of the transaction between generator j and node i. ΔNO_{ijt} and ΔGO_{jit} have values between 0 and 0.01; this range of values was used to prevent selling bids and buying bids from having a big difference between each other and reach a fast convergence. If the generator's price is too high, then the generator lowers its price by ΔGO_{jit}. If the node's offer is too low, then the node increases its offer by ΔNO_{ijt}; these price adjustments continue until $NO_{ijt}^{new} \geq GO_{jit}^{new}$ and the price of the transaction between generator j and node i is set. Then the price setting process continues with the next node until all nodes have a price that corresponds to generator j. The same process is repeated for the next generator, until all generators have set a price for each and every node in the system.

After all nodal prices for all generators have been set, the power allocation process starts; this process is explained in the next section.

2.2 Power Allocation Process In this part of the algorithm nodes and generators decide the amount of power that they buy and sell; nodes decide from which generators they buy and generators decide to which nodes they sell. Fig. 3 shows the flow chart for the power allocation process. This process begins with generators ordering nodes from the highest priced node (HN) to the lowest, and nodes order generators from the cheapest generator (CG) to the most expensive. Prices do not change during the power allocation process, therefore generators want to maximize their profit by selling power to the highest bidder and nodes want to minimize their cost by buying power as cheaply as possible. Each generator tries to sell its power to the HN and each node tries to buy from the CG.

FERC recommends a policy of first come, first served to allocate transactions (13)(14); the same policy is used in this paper to decide the order of contracts. The behavior of the market participants is simulated by randomly choosing which generator and which node come first. The result of this selection is generator j and node i, then the corresponding HN and CG have to be chosen. First generator j is chosen randomly to simulate FERC's policy of first come, first served, then node i is chosen by making HN of generator j = node i, then If CG of node i is generator j, HN and CG correspond to each other and node i and generator j are selected for a transaction, then power is sold according to the availability of power that generator j has. During the selection process, if CG of node i does not correspond to generator j, then the selection process continues with the next HN for generator j until HN and CG correspond to each other as shown in Fig. 3.

Once a generator and node pair has been selected, a transaction is set between node i and generator j if the demand of node i is less than or equal to the power that generator j has available for sale. When the demand of node i is greater than the power that generator j has available for sale, node i buys all the power that generator j can sell and then continues the search for more power with the next CG. The process is repeated until all the demand is satisfied, assuring in this way that a feasible BTM is obtained.

The power allocation process can be better illustrated with an example. Table 1 shows the prices of a small system of three nodes and two generators after the bidding process, then generators order nodes from the highest bidder to the lowest as shown in Table 2. K is the order of nodes, PHN is the price of the highest node in \$/MWh and HN is the highest node. The HN of generator 1 is node 3 and the HN of generator 2 is node 2.

Nodes order generators from the cheapest generator to the most expensive as shown in Table 3. L is the order of generators, PCG is the price of the cheapest generator in \$/MWh and CG is the cheapest generator. The CG of node 1 is generator 1, the CG of node 2 is generator 1 and the CG of node 3 is generator 2.

Now assume that in the order of contracts generator 1 is the generator that comes first, then generator 1 tries to sell its power to its HN which is node 3, but the CG for node 3 is generator 2, then generator 1 cannot sell its energy to node 3, therefore it offers its energy to the next HN, which is node 2. The CG for node 2 is generator 1, therefore HN of generator 1 and CG of node

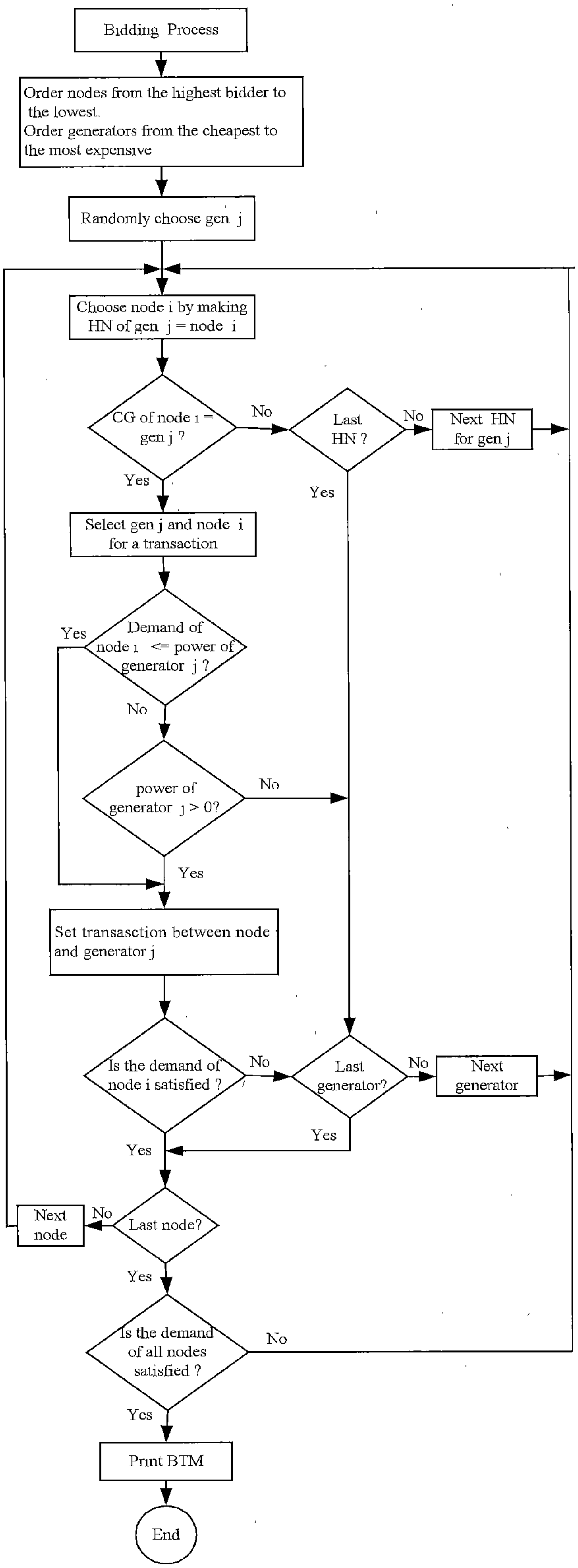

Fig. 3. Power allocation process

Table 1. Prices (\$/MWh) and demand of a 3-node, 2-generator system

	Gen. 1	Gen. 2	Demand
Node 1	10	13	3 MW
Node 2	11	15	4 MW
Node 3	14	12	8 MW
Gen. Cap.	5 MW	10 MW	

Table 2. Generator's allocation order

Allocation Order	Generator 1		Generator 2	
	PHN	HN	PHN	HN
K=1	14	3	15	2
K=2	11	2	13	1
K=3	10	1	12	3

Table 3. Node's allocation order

Allocation Order	Node 1		Node 2		Node 3	
	PCG	CG	PCG	CG	PCG	CG
L=1	10	1	11	1	12	2
L=2	13	2	15	2	14	1

Table 4. BTM (MW) for a 3-node, 2-generator system

	Gen. 1	Gen. 2	Demand
Node 1	1	2	3 MW
Node 2	4	0	4 MW
Node 3	0	8	8 MW
Gen. Cap.	5 MW	10 MW	

2 correspond to each other and this generator and node pair is selected for a transaction, since the demand of node 2 is 4 MW and generator 1 has 5 MW available for sale, a transactions is made and node 2 buys 4 MW from generator 1, which satisfies the demand of node 2.

Generator 1 still has 1 MW available for sale therefore it offers its power to the next HN, which is node 1. The CG of node 1 is generator 1 therefore another generator and node pair is selected for a transaction, but this time the demand of node 1 is greater than the power that generator 1 has available for sale. Therefore, node 1 buys all the available power from generator 1, which is 1 MW. This does not satisfy the demand of node 1, therefore node 1 wants to buy power from the next CG, which is generator 2.

The HN for generator 2 is node 2, but node 2 has satisfied its demand, therefore generator 2 offers its energy to the next HN, which is node 1. This time node 1 and generator 2 correspond to each other therefore generator 2 sells 2 MW to node 1 and satisfies the demand for node 1. The remaining HN for generator 2 is node 3 and the CG for node 3 is generator 2, therefore HN of generator 2 and CG of node 3 correspond to each other. This defines another generator and node pair and a transaction is made, since the available power of generator 2 is equal to the demand of node 3, node 3 buys all the available power of generator 2.

The result of this process is the BTM shown in Table 4, which fully satisfies the demand of the three node, two generator system.

The bidding and power allocation processes described in sections 2.1 and 2.2 respectively are repeated for each hour of the forecasted load, obtaining one BTM for each hour. In this paper a 24 hour day ahead load forecast was considered for the simulation and applied to the IEEE 14 bus and IEEE 300 bus systems. The simulation results are explained in section 4.

3. Cost and Profit

The profit of buyers and sellers is calculated based on Sheblé's model for an electricity auction as a heterogeneous product [7] trading as bilateral contracts with prices specified by both buyers and sellers. The following formulation is used to calculate the profit for each hour.

Maximize

$$\sum_{i=1}^{m}\sum_{j=1}^{n}(c_{bij} - c_{sij})\,x_{ij} \cdots\cdots (5)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \leq S_i \quad (i = 1, 2, 3, \ldots, m) \cdots\cdots (6)$$

$$\sum_{i=1}^{m} x_{ij} = D_j \quad (j = 1, 2, 3, \ldots, n) \cdots\cdots (7)$$

$$x_{ij} \geq 0 \quad (i = 1, 2, 3, \ldots, m, j = 1, 2, 3, \ldots, n) \cdots\cdots (8)$$

where, c_{sij} is the price specified by seller i to buyer j, c_{bij} is the price specified by buyer j to seller i, c_{bij} and c_{sij} correspond to the initial prices for buyers and sellers obtained by the proposed method, ($c_{bij} = NO_{ij}$ and $c_{sij} = GO_{ij}$). x_{ij} is the amount of power sold from seller i to buyer j, S_i is the supply capacity of seller i and D_j is the demand of buyer j, m and n are the number of sellers and buyers respectively. Equation (7) guarantees that the demand is always satisfied. The value obtained by equation (5) is the maximum profit of buyers and sellers.

In every market, the final consumer is the one that pays the final price of a product or service after the retailers have transferred all their costs to the final consumer. In the electricity market, the final consumer is represented by the consumers that buy their power from a distribution company (DISCO). This group of consumers has no participation in the transactions between generation companies (GENCOs) and distribution companies (DISCOs), but pays the final cost of electricity to the DISCO from which the final consumers buy their energy. In this paper the final consumer is defined as the consumer with less than 1 MW of demand.

The total cost for the final consumers can be calculated by modifying equation (5) and defining the average price as the market clearing price. Since this model does not include a bidding mechanism and prices have to be provided as data, equation (5) is modified to obtain the minimum cost for the final consumer. The following formulation shows this modification.

Minimize

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{c_{bij} + c_{sij}}{2}\right) x_{ij} \cdots\cdots (9)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \leq S_i \quad (i = 1, 2, 3, \ldots, m) \cdots\cdots (10)$$

$$\sum_{i=1}^{m} x_{ij} = D_j \quad (j = 1, 2, 3, \ldots, n) \cdots\cdots (11)$$

$$x_{ij} \geq 0 \quad (i = 1, 2, 3, \ldots, m, j = 1, 2, 3, \ldots, n \cdots\cdots (12)$$

Equations from (5) to (8) and from (9) to (12) are linear programming models for double sided auctions in which buyers and sellers can adjust their bids to maximize their own profits. The disadvantage of this method is that the bid prices depend on the pricing method, which is external to the linear programming problem and are given as data to solve the problem. This could be lessened if reservation prices are allowed.

This paper proposes an alternative solution for a double sided auction in which bidding prices are determined as a part of the auction mechanism. The proposed algorithm has been described in section 2 of this paper. The simulation results are explained in section 4.

4. Simulation

The IEEE 14 bus sample system with 5 generators and 11 demand nodes and the IEEE 300 bus sample system with 69 generators and 193 demand nodes were used for the simulation. The demand and maximum generation for the IEEE 14 and IEEE 300 bus systems are shown in the appendix.

Initial nodal prices for buyers and sellers corresponding to a 24 hour load forecast were used as data for the proposed method and the linear programming methods of equations from (5) to (12). The maximum profit method and the average minimum method produce only one BTM that corresponds to the maximum profit and the minimum cost respectively. The proposed algorithm simulates the behavior of market participants in a free market by means of the process explained in section 2. The behavior of market participants is unpredictable in a real life scenario; therefore BTMs change with the behavior of the market participants, this characteristic has been implemented in the proposed algorithm; for this reason the proposed method produces a different BTM each time that the algorithm is run. A total of 25 tests were made for each hour, therefore the average profit and the average cost of the proposed method are used to compare the results of the proposed algorithm with the results of the maximum profit method and the average minimum method.

Fig. 4 shows the profit in $ for the market participants of the IEEE 300 bus system during peak hours. The profit was calculated by substituting the BTM obtained by each method for x_{ij} in equation (5), where c_{bij} and c_{sij} correspond to the initial prices for buyers and

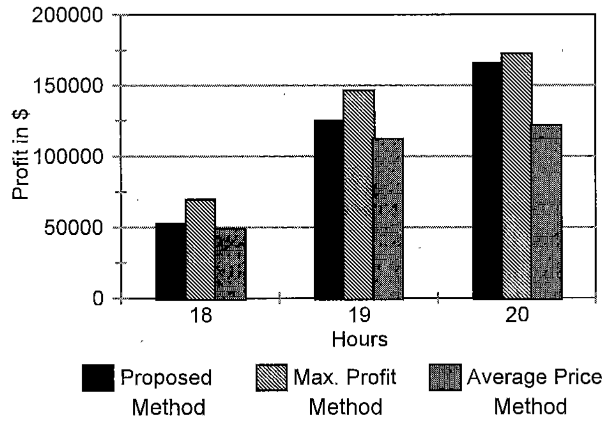

Fig. 4. Profit in $ for market participants for IEEE 300

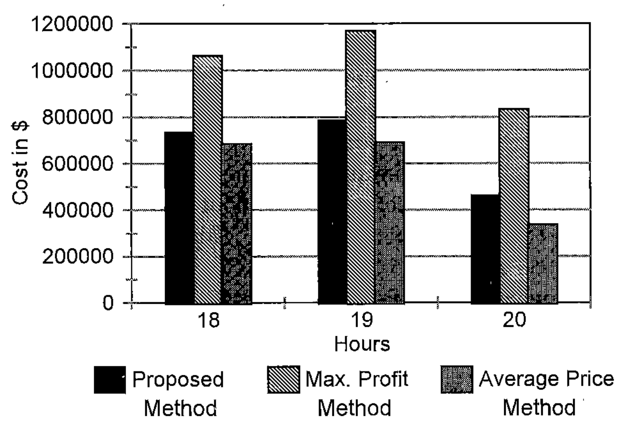

Fig. 5. Cost in $ for the final consumer for IEEE 300

sellers obtained by the proposed method, these prices were used as data for the linear programming problems. Fig. 5 shows the cost in $ for the final consumer. The cost was calculated by substituting the BTM obtained by each method for x_{ij} in equation (9).

The highest profit corresponds to the maximum profit method, as it is shown in Fig. 4, this method has the highest profit for market participants, but it also has the highest cost for the final consumers as shown by Fig. 5. This is because the method maximizes the profit for the market participants without considering the cost for the final consumer. The lowest profit and the lowest cost is obtained by the average price method, which solves the linear programming for a minimum cost at an average price between buyers and sellers. This method benefits the final consumers by offering the lowest cost as shown by Fig. 5, but it has the lowest profit for the market participants as shown by Fig. 4. This does not stimulate the market participants to trade energy in the market or to invest to improve the power system or the quality of power.

The proposed method (PM) offers a good option for the market participants and the final consumers, since this method has a good profit for market participants, that falls between the profit obtained by the other two methods as shown in Fig. 4 and the cost for the final consumers is not as high as the maximum profit method, as

Table 5. Maximum Profit method BTM for 19:00~20:00 hours of IEEE 14 system (MW)

Node	GEN-1	GEN-2	GEN-3	GEN-6	GEN-8	Demand
NOD-1	0.000	0.000	0.000	0.000	0.000	0.000
NOD-2	45.764	0.000	0.000	0.000	60.000	105.764
NOD-3	0.000	0.000	75.586	60.000	0.000	135.586
NOD-4	0.000	0.000	114.477	0.000	0.000	114.477
NOD-5	16.684	0.000	0.000	0.000	0.000	16.684
NOD-6	26.716	0.000	0.000	0.000	0.000	26.716
NOD-7	0.000	0.000	0.000	0.000	0.000	0.000
NOD-8	0.000	0.000	0.000	0.000	0.000	0.000
NOD-9	18.698	40.000	9.937	0.000	0.000	68.634
NOD-10	25.052	0.000	0.000	0.000	0.000	25.052
NOD-11	11.482	0.000	0.000	0.000	0.000	11.482
NOD-12	13.316	0.000	0.000	0.000	0.000	13.316
NOD-13	32.607	0.000	0.000	0.000	0.000	32.607
NOD-14	24.419	0.000	0.000	0.000	0.000	24.419
Total	214.737	40.000	200.000	60.000	60.000	574.737
Gen capacity	300.000	40.000	200.000	60.000	60.000	
Gen margin	85.263	0.000	0.000	0.000	0.000	
Gen sale	214.737	40.000	200.000	60.000	60.000	

shown by Fig. 5. The proposed method does not maximize profits nor minimizes cost. It is based on market rules that simulate the behavior of people making decisions for their own benefit, sellers try to sell their energy as high as possible and buyers try to buy as cheaply as possible, then buyers find a seller willing to sell at the accorded price and sellers find a buyer willing to buy. This balances the market in a way that the profit of the market participants is higher than the average price method that minimizes cost and the cost for the final consumers is not as high as the maximum profit method. Each method has a different objective; therefore the BTM obtained by each method is also different from the BTM obtained by any of the other two methods considered. The BTM of the IEEE 300 bus system is very large and given that the results of the simulation made with the IEEE 300 bus system are similar to the results of the IEEE 14 bus system, the 14 bus system will be used to explain the characteristics of the BTM obtained by each method.

The BTM for the transactions of the IEEE 14 bus system from 19:00 to 20:00 hours is shown in Tables 5~7 for the maximum profit, the average price and the proposed method respectively. The BTM is shown in a table form, which shows the amount in MW of the transaction between node i and generator j. The row labeled Gen Capacity is the maximum generation that each generator has. Gen Sale is the total amount of power sold by generator j and Gen Margin is the total amount of unsold energy.

The demand of every node is always satisfied in a feasible BTM, therefore a power balance is always obtained; generators compete with each other to sell their available power and nodes compete with other nodes to buy their energy as cheaply as possible, until all the demand is satisfied. The maximum power that generators can sell is limited by their maximum generation and the system's

Table 6. Average price method BTM for 19:00~20:00 hours of IEEE 14 system (MW)

Node	GEN-1	GEN-2	GEN-3	GEN-6	GEN-8	Demand
NOD-1	0.000	0.000	0.000	0.000	0.000	0.000
NOD-2	105.764	0.000	0.000	0.000	0.000	105.764
NOD-3	135.586	0.000	0.000	0.000	0.000	135.586
NOD-4	14.477	40.000	0.000	0.000	60.000	114.477
NOD-5	0.000	0.000	16.684	0.000	0.000	16.684
NOD-6	0.000	0.000	26.716	0.000	0.000	26.716
NOD-7	0.000	0.000	0.000	0.000	0.000	0.000
NOD-8	0.000	0.000	0.000	0.000	0.000	0.000
NOD-9	44.172	0.000	24.462	0.000	0.000	68.634
NOD-10	0.000	0.000	25.052	0.000	0.000	25.052
NOD-11	0.000	0.000	11.482	0.000	0.000	11.482
NOD-12	0.000	0.000	0.000	13.316	0.000	13.316
NOD-13	0.000	0.000	0.000	32.607	0.000	32.607
NOD-14	0.000	0.000	24.419	0.000	0.000	24.419
Total	300.000	40.000	128.815	45.922	60.000	574.737
Gen capacity	300.000	40.000	200.000	60.000	60.000	
Gen margin	0.000	0.000	71.185	14.078	0.000	
Gen sale	300.000	40.000	128.815	45.922	60.000	

Table 7. Proposed Method BTM for 19:00~20:00 hours of IEEE 14 system (MW)

Node	GEN-1	GEN-2	GEN-3	GEN-6	GEN-8	Demand
NOD-1	0.000	0.000	0.000	0.000	0.000	0.000
NOD-2	0.000	0.000	79.014	26.750	0.000	105.764
NOD-3	113.496	22.090	0.000	0.000	0.000	135.586
NOD-4	0.000	17.910	96.567	0.000	0.000	114.477
NOD-5	0.000	0.000	0.000	0.000	16.684	16.684
NOD-6	0.000	0.000	0.000	19.934	6.782	26.716
NOD-7	0.000	0.000	0.000	0.000	0.000	0.000
NOD-8	0.000	0.000	0.000	0.000	0.000	0.000
NOD-9	68.634	0.000	0.000	0.000	0.000	68.634
NOD-10	0.000	0.000	0.000	0.000	25.052	25.052
NOD-11	0.000	0.000	0.000	0.000	11.482	11.482
NOD-12	0.000	0.000	0.000	13.316	0.000	13.316
NOD-13	32.607	0.000	0.000	0.000	0.000	32.607
NOD-14	0.000	0.000	24.419	0.000	0.000	24.419
Total	214.737	40.000	200.000	60.000	60.000	574.737
Gen capacity	300.000	40.000	200.000	60.000	60.000	
Gen margin	85.263	0.000	0.000	0.000	0.000	
Gen sale	214.737	40.000	200.000	60.000	60.000	

demand, this can be observed in Tables 5~7 by comparing the Gen Capacity row with the Gen Sale row. In all cases the energy sold is equal or less than the maximum generation limit of each generator. The total demand is shown in the demand column, which is the summation of all transactions of node i and is equal to the demand of the corresponding hour. This can be confirmed by comparing the demand column of Tables 5~7 with the demand for hour 19 shown in app. Tables 1 and 2 shown in the appendix of this paper.

The main difference between the BTM obtained by each method is the individual transactions required to satisfy the demand of each node. In Table 5 generator 1 and generator 8 satisfy the demand of node 2, with generator 8 selling all of its power to node 2 and the remaining power that node 2 needs is satisfied by generator 1; this is the optimal solution for a maximum profit

Table 8. 8 CPU time for a 1.5G Hz machine

System	Linear Programming	Proposed Method
IEEE 14	5 seconds	1 second
IEEE 300	15 minutes	4 seconds

for market participants obtained by the maximum profit method, the demand of the remaining nodes is satisfied in a similar manner, with generators 2, 6 and 8 selling all of their capacity to a single node, generator 3 satisfies all of the demand of node 4 and the available power is sold to nodes 3 and 9, generator 3 sells all of its power. Generator 1 satisfies all of the demand of nodes 5, 6, 10, 11, 12, 13 and 14. The nodes that buy power from more than one generator are nodes 2, 3 and 9.

The BTM of Table 6 corresponds to the transactions obtained by the average price method that has an objective function to minimize cost. In Table 6, node 2 buys all of its power from generator 1; this is different from Table 1 where node 2 buys its power from generators 2 and 8. The reason for this difference is the objective function of the maximum profit method that maximizes profit and the objective function of the average price method that minimizes cost. In Table 6, generators 2 and 8 sell all their power to node 4, generator 1 sell all of its power to nodes 2, 3, 4 and 9; the rest of the demand is satisfied by generators 3 and 6. Generator 3 sells its power to nodes 5, 6, 9, 10, 11 and 14. Generator 6 sells its power to nodes 12 and 13. The nodes that buy power from more than one generator are nodes 4 and 9.

The BTM shown in Table 7 is one of the BTMs of the IEEE 14 bus system obtained by the proposed method, which produces a different and feasible BTM each time that the algorithm is run. This characteristic of the method is useful to generate data for the study of the effects that bilateral transactions have on the system's security and stability, by providing the ISO with a practical tool that always produces feasible BTMs that simulate the behavior of market participants in a real life scenario.

The BTM shown in Table 7 corresponds to one of the BTMs obtained by the proposed method. All generators sell power to more than one node, which differs from the BTMs obtained by the other two methods. This characteristic is particular of the BTM of Table 7 and does not represent the characteristics of other BTMs obtained by the proposed method; each BTM has its own characteristics, but all BTMs obtained by the proposed method satisfy the system's demand and power balance between generation and demand is always obtained by means of the power allocation algorithm explained in section 2.2. The CPU times required for the simulation using a 1.5 GHz machine are shown in Table 8, which shows that the proposed method is faster than the linear programming approach. For small systems like the IEEE 14, the time difference between the two methods is irrelevant, but in the case of large power systems, the linear programming approach can consume a considerable amount of time as it is illustrated by the IEEE 300 bus case. The time of computation is important in online or real time applications, therefore fast applications have to be considered by the ISO. Table 8 shows one more of the advantages of the proposed method.

5. Conclusions

The simulation results show that the proposed method is a good alternative for electricity auctions, since prices can be determined by the bidding process before power transactions are made. The other two methods can calculate the BTM, but bidding prices are fixed and cannot be modified by these methods. The proposed method solves this limitation.

The proposed algorithm presented in this paper provides system planners with a practical tool to create feasible Bilateral Transaction Matrixes (BTM) that can be used as data to further study the effects that bilateral transactions have on the system's security and stability and to find future methods to regulate bilateral transactions through market mechanisms like the application of penalties to the transactions that affect the system's security.

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Appendix

The data used for the simulation is shown in this section. app. Tables 1 and 2 show the 24 hour demands for all the nodes of the IEEE 14 bus system. The IEEE 14 is a small test system with 5 generators and 11 demand nodes.

The IEEE 300 bus system has 193 nodes with demand, therefore only the demands of some selected nodes are shown in app. Table 4 for the peak hours. The maximum generation is shown in app. Tables 3 and 5 for the IEEE 14 and IEEE 300 bus systems respectively.

All figures for demand and generation shown in this appendix are in MW.

app. Table 1. Demand in MW for nodes 2, 3, 4, 5 and 9 of IEEE 14 system

Hour	NOD-2	NOD-3	NOD-4	NOD-5	NOD-6	NOD-9
1	49.00	56.00	47.80	7.60	11.20	29.50
2	42.83	52.06	40.65	6.58	10.73	25.15
3	44.45	52.64	45.23	4.43	10.69	23.05
4	46.12	53.29	44.53	6.14	11.40	27.57
5	55.02	64.69	54.29	5.91	11.42	28.89
6	66.23	85.48	72.88	10.76	15.39	39.46
7	70.30	85.42	65.48	8.34	16.91	41.02
8	77.95	95.83	78.09	9.32	16.42	43.68
9	91.53	105.26	85.74	10.15	20.52	50.45
10	78.00	106.29	88.97	10.64	20.42	47.60
11	84.14	102.50	82.50	13.29	21.64	45.99
12	97.81	111.63	88.20	10.23	19.37	52.53
13	90.50	109.53	91.29	12.13	19.51	49.79
14	88.40	105.11	83.27	10.24	18.02	47.91
15	88.86	108.97	89.03	15.29	19.08	50.48
16	89.69	100.06	87.66	13.54	17.85	44.80
17	83.58	97.56	79.24	12.25	18.96	47.58
18	96.63	97.10	87.67	8.82	20.48	47.47
19	105.76	135.59	114.48	16.68	26.72	68.63
20	116.67	138.65	119.45	15.54	25.78	58.83
21	98.98	118.97	95.86	14.10	24.28	55.86
22	79.37	99.04	85.44	12.40	20.33	42.19
23	70.62	78.92	69.49	8.15	15.54	38.33
24	55.36	74.57	58.79	6.70	13.19	30.78

app. Table 2. Demand in MW for nodes 10, 11, 12, 13 and 14 of IEEE 14 system

Hour	NOD-10	NOD-11	NOD-12	NOD-13	NOD-14
1	9.00	3.50	6.10	13.50	14.90
2	9.83	4.36	3.45	13.82	11.01
3	9.56	1.52	1.44	10.77	9.27
4	5.97	4.93	1.66	15.03	9.85
5	10.67	6.19	8.00	13.03	17.79
6	9.51	5.51	2.17	15.97	20.63
7	16.29	3.69	2.75	15.72	25.73
8	10.06	5.45	4.67	24.81	24.92
9	18.04	10.12	2.81	19.38	18.98
10	14.42	5.69	8.32	22.93	28.28
11	19.58	8.20	15.08	26.77	24.98
12	16.82	9.71	13.25	22.02	18.33
13	18.99	9.86	5.05	18.18	31.33
14	18.10	6.35	15.33	18.16	23.23
15	18.57	6.08	3.20	19.80	24.57
16	21.12	8.51	11.20	26.99	20.64
17	18.59	5.58	8.41	25.83	30.09
18	11.26	9.45	13.87	18.21	24.25
19	25.05	11.48	13.32	32.61	24.42
20	17.89	14.35	8.50	27.89	27.69
21	23.92	10.10	7.58	26.56	29.22
22	15.68	5.85	11.60	18.43	27.03
23	8.67	4.37	8.97	14.34	24.84
24	11.19	4.39	6.53	18.80	21.33

app. Table 3. Maximum Generation in MW for IEEE 14 system

GEN-1	GEN-2	GEN-3	GEN-6	GEN-8
300	40	200	60	60

app. Table 4. Demand in MW for selected nodes of IEEE 300 system

Node	18:00	19:00	20:00	Node	18:00	19:00	20:00
NOD-1	172.95	178.07	171.97	NOD-43	74.94	77.16	74.52
NOD-2	107.61	110.80	107.00	NOD-44	374.72	385.82	372.60
NOD-3	38.43	39.57	38.22	NOD-47	111.46	114.76	110.83
NOD-5	678.35	698.43	674.51	NOD-48	78.79	81.12	78.34
NOD-6	230.60	237.43	229.29	NOD-49	176.79	182.03	175.79
NOD-8	111.46	114.76	110.83	NOD-51	9.61	9.89	9.55
NOD-9	184.48	189.94	183.44	NOD-52	117.22	120.69	116.56
NOD-10	284.41	292.82	282.80	NOD-53	132.59	136.52	131.84
NOD-11	159.50	164.22	158.60	NOD-54	19.22	19.79	19.11
NOD-13	111.46	114.76	110.83	NOD-55	42.28	43.53	42.04
NOD-14	307.47	316.57	305.73	NOD-57	188.32	193.90	187.26
NOD-15	243.47	250.68	242.10	NOD-58	26.90	27.70	26.75
NOD-17	1078.05	1109.96	1071.95	NOD-59	418.92	431.32	416.55
NOD-20	1143.39	1177.23	1136.92	NOD-61	436.22	449.13	433.75
NOD-21	147.97	152.35	147.13	NOD-63	134.52	138.50	133.75
NOD-22	155.65	160.26	154.77	NOD-70	107.61	110.80	107.00
NOD-23	40.35	41.55	40.13	NOD-71	222.91	229.51	221.65
NOD-25	86.47	89.03	85.99	NOD-72	109.53	112.78	108.91
NOD-26	53.81	55.40	53.50	NOD-73	430.45	443.19	428.02
NOD-27	132.59	136.52	131.84	NOD-76	399.70	411.54	397.44
NOD-33	105.69	108.82	105.09	NOD-77	142.20	146.41	141.40
NOD-37	163.34	168.18	162.42	NOD-79	92.24	94.97	91.72
NOD-38	297.86	306.67	296.17	NOD-80	53.81	55.40	53.50
NOD-40	88.40	91.01	87.90	NOD-84	71.10	73.21	70.70
NOD-41	165.26	170.15	164.33	NOD-89	84.94	87.45	84.46

app. Table 5. Maximum Generation in MW for IEEE 300 system

Generator	Limit	Generator	Limit	Generator	Limit
NOD-8	14.8	NOD-171	19.8	NOD-7002	1848.9
NOD-10	14.8	NOD-176	676.7	NOD-7003	3591.1
NOD-20	29.7	NOD-177	249.3	NOD-7011	694.5
NOD-63	19.8	NOD-185	593.6	NOD-7012	1104.0
NOD-76	19.8	NOD-186	3561.4	NOD-7017	979.4
NOD-84	1112.9	NOD-187	3561.4	NOD-7023	549.0
NOD-91	460.0	NOD-190	1409.7	NOD-7024	1216.8
NOD-92	860.7	NOD-191	5855.5	NOD-7039	1483.9
NOD-98	201.8	NOD-198	1258.4	NOD-7044	109.8
NOD-108	347.2	NOD-213	807.2	NOD-7049	1371.7
NOD-119	5727.9	NOD-220	296.8	NOD-7055	133.6
NOD-124	712.3	NOD-221	1335.5	NOD-7057	489.7
NOD-125	19.8	NOD-222	742.0	NOD-7061	1187.1
NOD-138	2745.3	NOD-227	899.2	NOD-7062	1187.1
NOD-141	834.0	NOD-230	1023.9	NOD-7071	344.3
NOD-143	2065.6	NOD-233	890.3	NOD-7130	3834.4
NOD-146	249.3	NOD-236	1780.7	NOD-7139	2077.5
NOD-147	644.0	NOD-238	742.0	NOD-7166	1641.2
NOD-149	305.7	NOD-239	1632.3	NOD-9002	12.5
NOD-152	1104.0	NOD-241	1705.9	NOD-9051	106.3
NOD-153	641.0	NOD-242	504.5	NOD-9053	78.6
NOD-156	19.8	NOD-243	249.3	NOD-9054	148.4
NOD-170	608.4	NOD-7001	1386.0	NOD-9055	23.7

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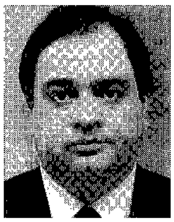

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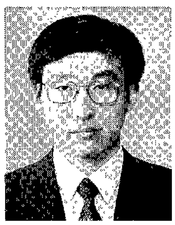

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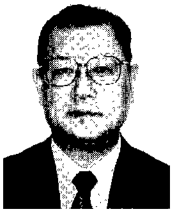

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