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BIDDING STRATEGY IN PAY-AS-BID POWER MARKETS

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ABSTRACT
In this paper a simple and efficient approach for developing bidding strategy in pay-as-bid electricity market is presented. In this method multi stairs bid is used to estimate the optimal bid. One stair is allocated to revenue earning and other stairs are allocated to information acquiring. Information acquiring stairs acquire required information from the market for estimating the optimal bid of the next day. The proposed method is applied to a specified unit in Iranian electricity market. It is shown that the total revenue of the unit will increase by thirty nine percent if the proposed method is used for bidding strategy.

KEY WORDS
Bidding strategy, Pay-as-bid electricity markets,

1. Introduction

In the last years, the power industry is undergoing massive changes due to restructuring. Different structures are used for electricity markets around the world. Market structures can be classified into a) pool-based electricity markets, b) pure bilateral contract markets, and c) hybrid markets [1-2]. Pricing system in pool-based electricity markets can be classified into a) uniform pricing, and b) pay-as-bid pricing. New issues both in operation [1-2] and planning [3-4] have been emerged in the new environment. Biding strategy is one of the most important issues which have been emerged for producers in pool-based electricity markets. Bidding strategy is determining the optimal bid for a specified producer in order to maximize his/her profit. Different approaches have been presented to develop bidding strategies for producers [5]. The presented approaches can be classified into a) forecasting market clearing price, and b) estimating the behaviour of other competitors.

In uniform pool-based electricity markets the generators which their bids is less than market clearing price (MCP) are dispatched and receive MCP. Hence, forecasting market clearing price is a proper approach to determine the optimal bid. In [6], time series is used to forecast MCP based on dynamic regression and transfer functions. Time series and artificial neural network is used to forecast electric energy price in [7]. In [8] probability density functions of hourly MCP are forecasted for the next day. The probability density functions are used in a self-scheduling profit maximization problem to determine the biding strategy. Combination of time series and stochastic forecasting is used to forecast MCP and develop biding strategy in [9]. Although the accuracy of price forecasting techniques is high [6], these techniques can not determine how individual suppliers influence the MCP. They also can not address transmission constraints and regional market power.

In electricity markets each participant react to strategies of other competitors to maximize his/her profit. Game theory, Probabilistic analysis, Fuzzy set theory, and Monte Carlo simulation are used to estimate the behaviour of other competitors. Two different approaches are used to develop bidding strategy using game theory [10-14]. In the first approach a few different discrete biding strategies are considered. Payoff matrix is computed using different combinations of bidding strategies. Then the equilibrium state of optimal strategy is determined. Since only a few discrete strategies are considered, there is no guarantee to exist equilibrium state solution. This approach is suitable for inaccurate analysis of strategic behaviour of competitors but not for developing bidding strategy. The second approach that uses Stakelbeg and Cournot models is suitable for market power analysis. This approach is not suitable for developing bidding strategy too. In [10] competition is formulated as a non-cooperative game with incomplete information. It is assumed that each competitor knows his own operation cost and does not know the operation cost of other competitors. The incomplete information game is converted into a complete, but imperfect, information game. In this method constraints are ignored and the Nash Equilibrium is determined using the expected payoff matrix. Competition is formulated as a non-cooperative game with complete information in [11-12]. In [11] the Nash Equilibrium solution is determined in a continuous domain. In [12] necessary and sufficient conditions of existing Nash Equilibrium state for bidding strategies are derived. In this paper Nash equilibrium is determined using optimization. The approach considers transmission loss and transmission charges. Although [11-12] takes into account more technical constraints, they are not realistic since the competition is formulated as a non-cooperative game with complete information. In [15] electricity auction is simulated by evolving trading agents using genetic algorithm (GA). Trading agents adapt their strategies at each GA generation. In [16] Monte Carlo simulation is used to develop the bidding strategies. The method is based on the estimation of competitor behaviours. Bidding strategies of a supplier participating in energy and spinning reserve markets are coordinated using Monte Carlo simulation and Genetic Algorithm in [17]. [16] and [17] assume incomplete information and ignore transmission constraints and load uncertainty. A discrete state and time Markov decision process is used to develop the optimal multi-period bidding strategies in [18]. The model takes into account uncertainty in load and rival behaviour but ignores transmission constraints. In [19] first a set of "good" strategies is selected using ordinal optimization. Then unit commitment is used to select the best bidding strategy. In [20-22] a two-level optimization problem is used to develop bidding strategies. In these methods suppliers and consumers try to maximize their profits under the constraint that market price is determined by maximizing social welfare. In [20-21] it is assumed that market participants have a single non probabilistic estimate of their competitors' behaviour. [22] assumes incomplete probabilistic knowledge of competitors' behaviour. The method considers uncertainty in load and correlation among loads of different buses. The expected profit is calculated using a Monte Carlo simulation and the optimal bidding strategy is developed either by means of exhaustive search, for small size problems, or genetic algorithm for larger scale problems.

In this paper a simple and efficient method for developing biding strategy in pay-as-bid electricity markets is presented. The paper is organized as follows. In section II bidding strategy in pay-as-bid electricity markets is discussed. Section III describes how the principal component of the optimal bid is estimated. The proposed method is applied to a specified unit of Iranian electricity market in section IV. Conclusion in section V closes the paper.

2. Bid Decomposition

In pay-as-bid electricity markets producers and consumers submit their bids to the market. The market constructs supply curve by aggregating the producers' bids. It constructs the demand curve by aggregating the consumer's bids too. System operator determines the won producers and consumers by crossing the supply and demand curves. In spite of uniform market, which all won producers are paid MCP and all won consumers pay MCP, in pay-as-bid markets each won producer (consumer) is paid (pay) the price that he/she has submitted. To determine the optimal bid in a uniform market, producers should estimate MCP and bid under the MCP, while in a pay-as-bid market producers should estimate MCP and bid an ε under the MCP. Where ε is a small value. Therefore bidding strategy in pay-as-bid markets is much more important than uniform markets. In pay-as-bid markets producers need a high accuracy for MCP estimation. If transmission network is constrained, determining the won producers and consumers is more complicated and is committed by optimal power flow (OPF) [3-4]. This paper proposes an efficient bidding strategy for pay-as-bid electricity markets with constrained network.

Let us to define max acceptable bid. Max acceptable bid for unit i at hour h is the price that if it is submitted by unit i, all power of the unit i will be bought by the power pool and if the submitted price is a little higher than max acceptable bid, all power of the unit i will not be bought by the pool. Max acceptable price is the optimal bid. The aim of this paper is to determine the optimal bid for a specified unit, say unit i. If load, bid of other producers, and network structure at hour h of day j+1 is the same as hour h of day j, the optimal bid of hour h of day j+1 is equal to the optimal bid of hour h of day j. Usually abovementioned conditions are different at hour h of days j+1 and j but the difference is negligible. Therefore the optimal bid of hour h of day j is a proper estimation for optimal bid of hour h of day j+1. In the other word, the optimal bid of hour h of day j+1 can be decomposed into two components: principal component, which is equal to the optimal bid of hour h of day j, and noise component, which is due to the changes in abovementioned conditions. The noise component is small in comparison with principal component and can be neglected. The optimal bid of unit i at hour h of day j+1 (bid_i^{j+1h}) is estimated using the optimal bid of hour h of day j (bid_i^{jh}) and market dispatch result for unit i on day j.

3. Estimating the Principal Component

In order to estimate bid_i^{j+1h} using bid_i^{jh} and market dispatch results for day j, bid_i^{jh} must satisfy the following conditions:

- bid_i^{jh} must acquire required information for estimating bid_i^{j+1h} form the market.
- bid_i^{jh} must not affect the revenue of hour h of day j due to information acquiring.

One stair of bid is allocated to revenue earning. This stair is named base stair. In order to satisfy the second condition, most of the power of unit i is allocated to base stair. In addition the price of base stair must be equal to the max acceptable price. To satisfy the first condition, bid^{jh} must use all allowable stairs to acquire the most information, which is possible, from the market. Suppose the max allowable stairs for biding is ten. Hence nine stairs are used for information acquiring. These stairs are called information acquiring stairs. Since acquiring infor

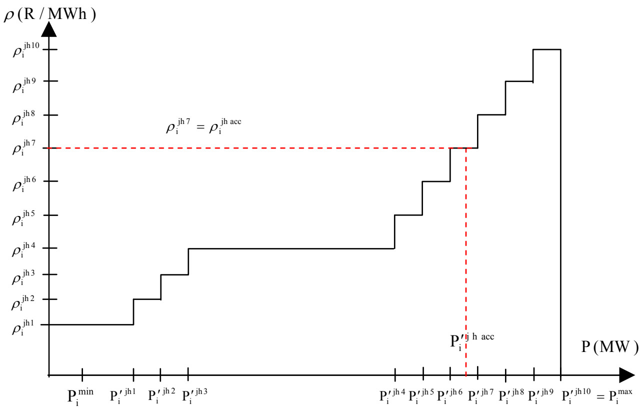

Fig. 1- Bid of unit i for hour h of day j

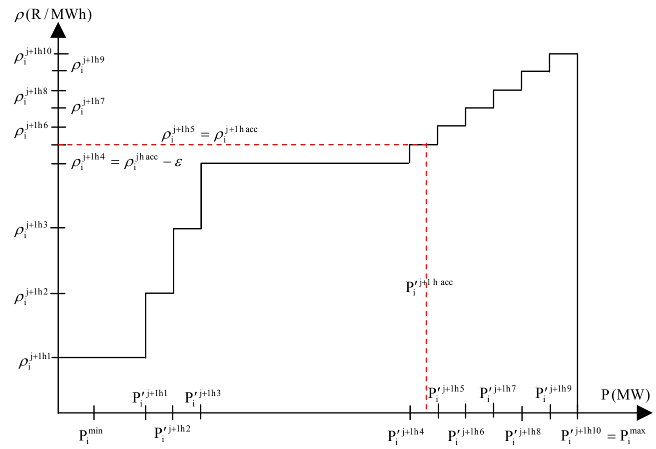

Fig. 2- Bid of unit i for hour h of day j+1

-mation about high prices is more important than low prices, three stairs are used for acquiring information about prices under the price of base stair and six stairs are used for acquiring information about prices above the base price. Information acquiring stairs must not affect revenue. Therefore the power that is allocated to these stairs must be small. According to the abovementioned conditions, in order to estimate bid_i^{j+1h} from bid_i^{jh} , bid_i^{jh} must be as the Fig. 1. Stair 4 is the base stair and its price is estimated using bid_i^{j-1h} and market dispatch results for day j-1. Suppose bid of Fig. 1 is submitted by the generator i at hour h of day j and power $P_i'^{\,jh\,acc}$ is accepted by the market. According to Fig 1 the max acceptable bid for unit i at hour h of day j is $\rho_i^{jh\,acc}$. Hence the optimal bid for unit i at hour h of day j is $\rho_i^{jh\,acc}$ but it is unknown for us until the market declare the dispatch result of day j. If it is assumed that change in load, bid of other generators, and network structure at hour h of day j+1 in comparison with hour h of day j is negligible, the optimal bid for unit i at hour h of day j+1 is $\rho_i^{jh\,acc} - \varepsilon$. Where ε is a small value. Considering a small value for ε guarantees that all power of the unit i is accepted by the market. Small ε does not affect revenue of unit i. Since bid_i^{j+1h} will be used for estimating bid_i^{j+2h} , acquiring information stairs must be considered in bid_i^{j+1h} . Therefore bid_i^{j+1h} should be as Fig 2. As Fig 2 shows, price of base stair is equal to $\rho_i^{jh\,acc} - \varepsilon$. Height of six information acquiring stairs, which are located after the base stair, is equal to:

$$\Delta\rho_i^{j+1\,h\,high} = \frac{\rho^{\max} - (\rho_i^{j\,h\,acc} - \varepsilon)}{6} \qquad (1)$$

Where $\rho^{\max}$ is the max allowable price for 1 MWh energy and $\rho_i^{j\,h\,acc}$ is the optimal bid or the max acceptable price for unit i at hour h of day j. Height of three information acquiring stairs, which are located before the base stair, is equal to:

$$\Delta\rho_i^{j+1\,h\,low} = \frac{(\rho_i^{j\,h\,acc} - \varepsilon) - \rho_i^{h\,\min}}{3} \qquad (2)$$

where $\rho_i^{h\,\min}$ is the min optimal bid for unit i at hour h. If generator i submits the bid of Fig 2 at hour h of day j+1 and power $P_i'^{\,j+1h\,acc}$ is accepted by the market, the optimal bid for hour h of day j+2 is $\rho_i^{j+1h\,acc} - \varepsilon$.

Since load at hour h of a workday is considerably different with the load at hour h of a weekend. Optimal bid of weekends are estimated form the bid of last similar weekend. The optimal bid of the first workday of the week is estimated from the bid of last workday.

4. Numerical Results

In this section the proposed approach is applied to Iranian electricity market which is a single sided pay-as-bid electricity market. Iranian electricity market has about 370 units. All units submit their bids for 24 hours of the next day. The power pool buys electricity from the units by minimizing total cost considering technical constraints of units and transmission network. To apply the proposed method a specified unit is considered, this unit is a 110 MW unit and is called unit i. Bid of unit i is estimated for each hour of November 2005. Bid of each hour is estimated using bid of corresponding hour of the previous day and market results of unit i at previous day. The bid of hour h of a weekend is estimated using the bid of corresponding hour of corresponding day of the previous weekend. For each day of November 2005 power pool optimization, which is committed to determine dispatch value of each won unit, is repeated. In this optimization all inputs data except bid of unit i are the input data that was used on November 2005.

At each hour on October 31, 2005 unit i was submitted a single stair bid. Since unit i did not consider information acquiring stairs in bids of October 31, it is not possible to estimate base price for different hours of November 1. Hence, single stair bids of October 31 minus ε are used as base prices for November 1. Width of each information acquiring stair is considered equal to 1 MW. At hour 7 on October 31 unit i submitted a single stair bid with price 35855 Rials/MWh. Assuming ε is equal to 1000 Rials, base piece for hour 7 of November 1 is 34855 Rials. Max allowable price in this market is 54000 Rials/MWh. According to (1) height of information acquiring stairs that allocated above base stair is 3190 Rials. Since we did not have information about $\rho_i^{h\,min}$, it is assumed that heights of all information acquiring stairs are equal. Fig 3 shows the bid of hour 7 of November 1. If market optimization is run, the first two stairs of unit i is dispatched, which is specified with a vertical line on Fig. 3. The highest accepted price for unit i is 28472 Rials. Therefore the base price for hour 7 of November 2 is 27472 Rials. Fig 4 shows the bid of hour 7 of November 2. Market result for unit i is specified with a vertical line on Fig 4. Figs 3 and 4 show although the presented method propose to decrease the base price of hour 7 from 34855 to 27472 Rials/MWh, the sale of the unit increases from 52 MW to 104 MW. Bids of hour 10 of November 1 and 2 are shown in Figs 5 and 6. These Figs show that at hour 10 of November 1 and 2 the unit i sell 105 MW, but the selling price increases on November 2 due to using the proposed biding strategy. Revenue of unit i that is yield from the proposed bidding strategy and the revenue that is

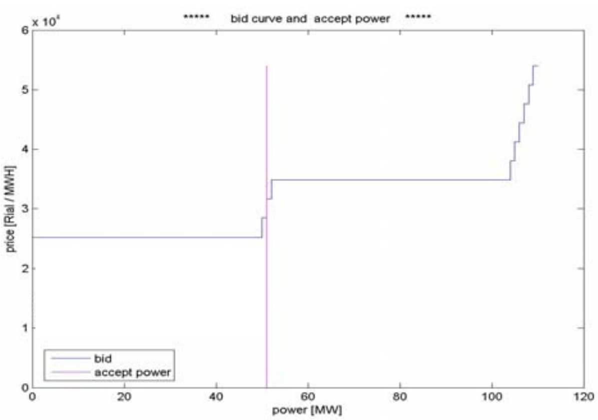

Fig. 3- Bid of unit i at hour 7 on November 1, 2005

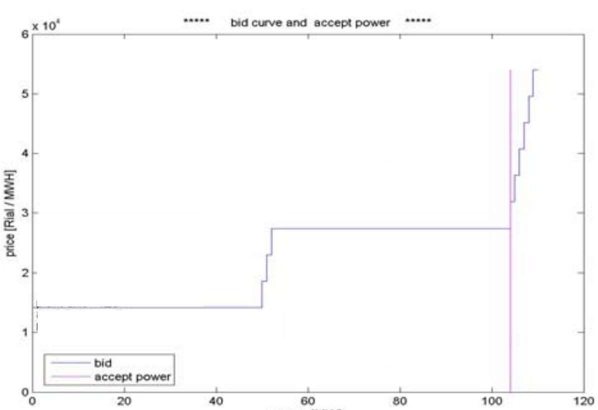

Fig. 4- Bid of unit i at hour 7 on November 2, 2005

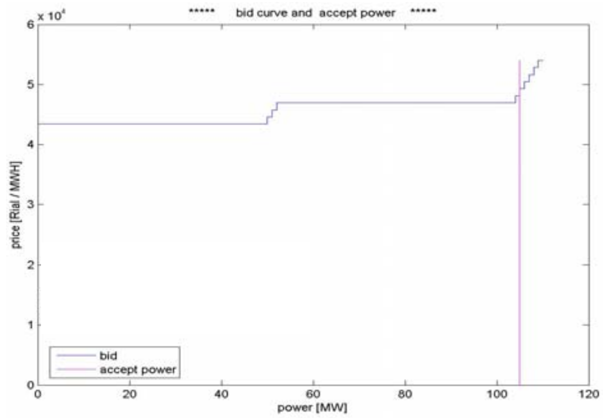

Fig. 5- Bid of unit i at hour 10 on November 1, 2005

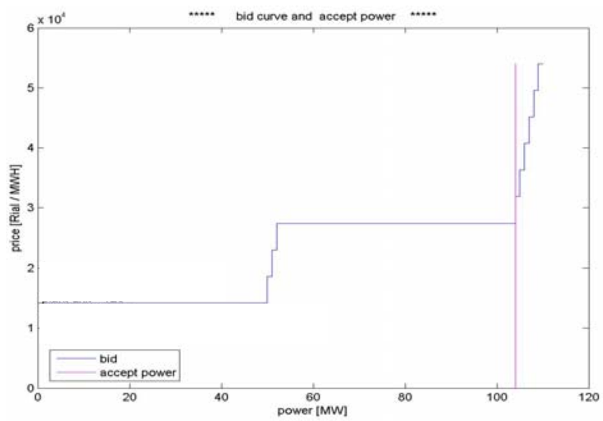

Fig. 6- Bid of unit i at hour 10 on November 2, 2005

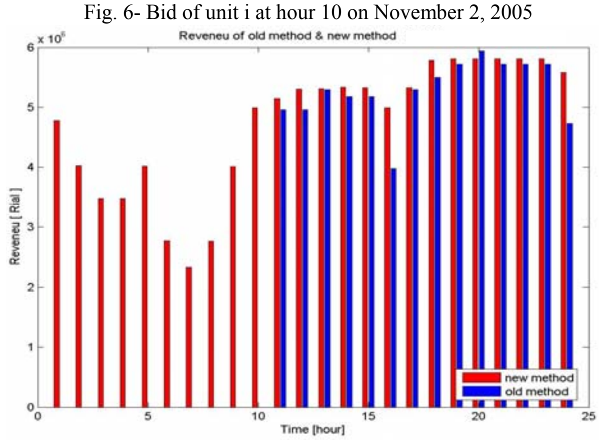

Fig. 7- Revenue of unit i at different hours on November 2, 2005

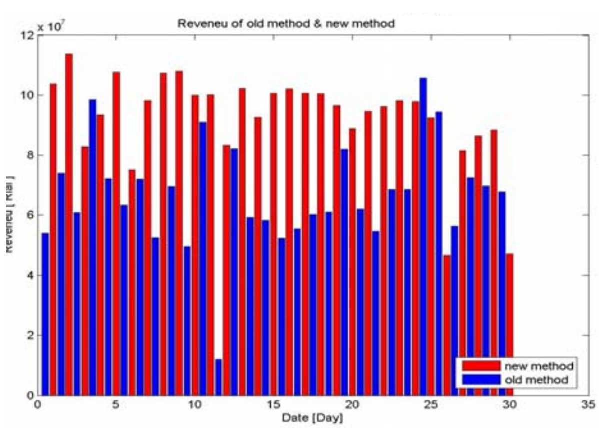

Fig. 8- Revenue of unit i on different days of November 2005

yield from the bids that were submitted by unit i on November 2005, for different hours of November 2 and different day of November 2005 are shown in Figs 7 and 8. Figs 7 and 8 shows that the revenue of unit i increases considerably if the proposed bidding strategy is used. Using the proposed bidding strategy method causes total revenue of unit i increases by 39 percent on November 2005.

5. Conclusion

In this paper a new simple and efficient approach for bidding strategy in pay-as-bid electricity markets is presented. The optimal bid is decomposed into principal and noise components. The noise component is neglected and the principal component is estimated by submitting multi stairs bids. One stair is allocated to revenue earning and other stairs are allocated to information acquiring. Information acquiring stairs acquire required information from the market for estimating the optimal bid of the next day. The proposed method is applied to a specified unit in Iranian electricity market. It is shown that the total revenue of the unit will increase thirty nine percent if the proposed method is used as bidding strategy.

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