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Strategic bidding of generating units in competitive electricity market with considering their reliability

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Abstract

In the restructured power systems, they are typically scheduled based on the offers and bids to buy and sell energy and ancillary services (AS) subject to operational and security constraints. Generally, no account is taken of unit reliability when scheduling it. Therefore generating units have no incentive to improve their reliability. This paper proposes a new method to obtain the equilibrium points for reliability and price bidding strategy of units when the unit reliability is considered in the scheduling problem. The proposed methodology employs the supply function equilibrium (SFE) for modeling a unit's bidding strategy. Units change their bidding strategies and improve their reliability until Nash equilibrium points are obtained. GAMS (general algebraic modeling system) language has been used to solve the market scheduling problem using DICOPT optimization software with mixed integer non-linear programming.

Keywords: Bidding strategy; Energy market; Nash equilibrium point; Reliability

1. Introduction

Recent changes in the electricity industry in several countries have led to a less regulated and more competitive energy market. In this condition, cost is replaced with the price and each generating unit will try to maximize its own profit. For a unit, it is critical to devise a good bidding strategy according to its opponents' bidding behavior, the model of demand and power system scheduling process. Power systems are typically scheduled at least cost subject to operational and security constraints. Generally, no account is taken of generator reliability when scheduling units. Recent studies show that, there are good reasons for considering reliability in the scheduling process [9]. When a generating unit is forced out, the system dynamics are aggravated which may cause load shedding or put the system in a state where load shedding is more likely to occur. Also, the replacement energy and reserve that must be procured are costly. If the unit's forced outage probabilities (FOP) are considered in the scheduling process, then the units with low FOPs will be rewarded by being scheduled for more MW h than those with high FOPs. So it can provide a further incentive to improve unit's reliability.

A generating unit's reliability is improved through regular maintenance and good operating practice. Since the maintaining of units has cost and lost revenue, it is necessary for units to compare their additional cost due to reliability improvement with the obtained benefit from selling more MW h energy in the market for finding the optimum point for their FOP. This can mean that units in the new condition of power system generation scheduling, should make good decisions for their price bidding strategies and reliability improving.

Generally there are different methods for developing bidding strategies in electricity markets. A non-cooperative

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incomplete game was employed in [1,4] to choose a generating company (Genco)'s optimal bidding strategy in deregulated power pools. Each pool participant knew its own operation costs but didn't know his or her opponents operation costs. The game with incomplete information was transformed into a game with complete but imperfect information and was solved using the Nash equilibrium idea. In [2], competitors' bids were known and the authors solved an optimization problem to find the Nash equilibrium based on bids sensitivities of these competitors. In [3] the genetic algorithm was used to develop bidding strategy for generator and distributor during the trading process. In [5], the bidding problem was modeled as a bi-level problem by assuming complete information on a Genco's opponents. A stochastic optimization method was proposed in [6] based on Monte Carlo method to find generators' optimal bidding strategies. A detailed literature review of bidding strategies in electricity markets was presented in [7]. Li and Shahidehpour [8] extend the proposed methods in [1,4] for developing a more general approach to Gencos' optimal bidding strategies with incomplete information in the electricity markets. The proposed methodology employed the supply function equilibrium for modeling a Gencos' bidding strategy. The competition was modeled as a bi-level problem with the upper subproblem representing the individual Genco and the lower subproblem representing the independent system operator (ISO). Flynn et al. [9] proposed a method of generation scheduling in a competitive market that considers the reliability of the generating units. The scheduling problem is formulated as an augmented lagrangian dual function and a new recurrent neural network is used to solve it.

The main contributions of this research compared to the works mentioned before are: (i) The generating units act strategically for both the economic (quantity and price) and technical (reliability) decision making problems; (ii) The model simulates a day-ahead energy market and not only one point of load distributions most of the research on the subject does; (iii) A new structure for energy market scheduling is used.

This paper proposes a method for obtaining the optimum value for reliability and price bidding strategies of generating units with incomplete information where the unit's reliability is considered in power system generation scheduling problem. The proposed methodology employs the supply function equilibrium for modeling a unit's bidding strategy. The generating units change their bidding strategy and reliability until no unit can increase its profit with deviating from its current strategy when its opponents do not change their strategies. This means the Nash equilibrium strategy, which is a central solution in game theory problem.

The paper is organized as follows: The problem formulation, and the basic concepts of game theory is given in Sections 2 and 3; the proposed solution method is shown in Sections 4 and 5 gives illustrative example with three units; Section 6 provides the conclusion.

2. Problem formulation

2.1. Estimating opponents unknown information

In this paper, it is supposed that each generating unit act as an independent company with an independent bidding strategy in energy market.

As previously mentioned, in the restructured power systems, generating units sell their outputs in the competitive electricity markets. Hence, for obtaining the maximum profit, they should choose their bidding strategies accurately. Since each unit's profit depends on the bidding behavior of its opponents, it is necessary for a unit to model them.

Generally, each generating unit knows about its payoff function, but it should model its opponents' unknown information. If it is supposed that the types of units is thermal, their most important parameters will be a, b and c coefficients of second order generating cost function as $aP^2 + bP + c$ where P is the active power output of a generating unit. All units try to hide this information from the others, so the opponents should estimate it based on the available information.

The available information of units about their opponents is incomplete and it is supposed that they are only aware of the minimum and maximum generation levels of their opponents as well as their fuels type. Ref.[10] has presented a method to obtain the fuel cost of a generator as a quadratic function of active power generation. This function is expressed as: $F(P) = \alpha P^2 + \beta P + \gamma$.

In this function $F(P)$ is measured in MJ/h or MBtu/h, so with considering the high heat value(HHV) of fuels and the fuel's price (in \$/m^3 or \$/lit), $F(P)$ is calculated in \$. So the fuel price should be forecasted for future time to obtain the fuel cost. We can define several scenarios with definite probability for the fuel's price, so the different types for α, β and γ coefficients will be resulted.

The total cost of operation includes the fuel cost, the cost of labor, supplies and maintenance. These costs except the fuel cost are expressed as a fixed percentage of the fuel cost. So the total generation cost can be expressed by $aP^2 + bP + c$ where a, b, and c include α, β, and γ plus some percentage due to the cost of labor, maintenance and supplies.

2.2. Market structure

In this paper, the day-ahead energy market is analyzed where its structure is a gross pool with centrally optimized scheduling. At this structure, each physically unit is dealt with as a separate entity. In this structure, ISO receives all of the unit's bid and a term accounting for unit's reliability. Then it forms an objective function and tries to minimize it subject to some constraints. The ISO's objective function in the scheduling problem of units is to maximize social welfare or to minimize consumer payments subject to technical constraints of units, power flow equa-