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A method for reserve clearing in disaggregated model considering lost opportunity cost

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Abstract

In this paper, a new formulation for clearing reserve market in a deregulated environment with separated energy and reserve market is introduced. In the proposed method, reserve market is cleared such that the costs associated with capacity reservation, producing energy in real-time, opportunity cost of those units which are accepted in the energy market and backed down from the accepted values to participate in the reserve market are minimized. This optimization problem is formulated and solved using linear programming method. Finally, the proposed method is applied to a six units test system to examine the applicability and effectiveness of the proposed method.

Keywords: Ancillary services; Deregulation; Opportunity cost; Reserve market

1. Introduction

One of the most important issues in the last decade in power system area is deregulation and restructuring. Deregulation and restructuring have recently taken place in most countries in the world, and is increasing more and more. In the new environment, a vertically integrated utility (VIU) is divided into its three main components of Generation companies (Genco), Transmission companies (Transco), and Distribution companies (Disco). Increasing efficiency using creation of competition is one of the most important objectives of deregulation, as competition can facilitate efficiency, price transparency and also supply-demand satisfaction.

Ancillary services are necessary to support transmission of power while maintaining system reliability and ensuring the required degree of quality and safety [1]. There are different types of ancillary services, such as spinning reserve (SR), non-spinning reserve, voltage and reactive support, black start, and, etc. [2]. Currently, there are two forms of market auctions, which are implemented in a deregulated environment for procuring of energy and ancillary services. In some countries, energy and ancillary services are aggregated and in others are not. In an aggregated framework, such as NYISO [3], PJM [4], ISO-NE [5] and new California market [6], the energy and ancillary service markets are cleared simultaneously. In a disaggregated framework, on the other hand, energy and ancillary service markets are cleared sequentially. In the latter case, energy market clearing does not incorporate any security considerations. That is, once the energy market is settled by the market operator (MO), the system operator (SO) procures ancillary services such that the reliability and security requirements (criteria) are met. In some power markets, such as Spanish electricity market, the system operator and the market operator are separate entities [7], while in others, such as Texas, both functions are performed by a unique entity [8]. In general, disaggregated framework can be categorized into sequential and simultaneous forms [9]. In the sequential form, a series of auctions is carried out by SO. In this form, an auction for the best quality service is carried out first followed by decreasing quality services auctions [10]. In the simultaneous form, all types of ancillary services are simultaneously cleared. This approach is also known as rational buyer in which various ancillary services scheduled simultaneously such that the requirement of each category is met [2].

In [11–13], an approach for procuring operating reserve has been presented using insurance theory. In [14], the generating

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units have been scheduled such that a given risk index is met. The optimal value of the risk index is determined using cost-benefit analysis. The concept in [14] has been applied to a traditional power system. In [15], using correlation between capacity and reliability, a scheme for procuring and pricing operating reserve in a deregulated environment has been proposed. In [16], the customers in a bilateral model have given the opportunity to purchase spinning reserve according to their needs using a well-being framework. A pool-based market clearing algorithm, which is based on the deterministic/probabilistic criterion for application in electricity market, has been introduced in [17]. In this context, the energy and reserve are simultaneously solved and units are committed such that loss of load probability (*LOLP*) or expected energy not supplied (*EENS*) is smaller than a predetermined value. A security constrained economic dispatch for optimal reserve allocation and pricing has been formulated in [18]. In [18], a system has been divided into different control areas where it is assumed that the amount of reserve required in each area is predetermined. Then, the optimal spot price of operating reserve has been calculated using the Lagrange multipliers. An integrated energy and spinning reserve market model has been presented in [19], in which market dispatch is carried out so that the total payment including both energy and spinning reserve and expected energy not served (EENS) is minimized. Reserve allocation in deregulated environments has been done in [20] using risk minimization approach. In [21], an approach for spinning reserve allocation considering reliability and cost in the deregulated environments has been proposed.

Disaggregated framework has advantage and disadvantages versus the aggregated one. Lower complexity and transparency of clearing results are advantages of a disaggregated framework. Aggregated market clearing treats as a “black box” in which justifying and explaining of schedules and prices are very hard [9]. Nevertheless, achieving higher social welfare is one of the great advantages of aggregated clearing method. The other weakness of disaggregated method is lack of existence of feasible solution to meet the reserve requirements.

In this paper, a method for clearing reserve (10 min operating reserve) market in a disaggregated framework is presented. This method, preserves the good features of disaggregated framework while tries to improve its performance via overcoming the above limitations. Using the proposed method, not only the total cost is less than the disaggregated method, but also there is a feasible solution for reserve market.

The rest of this paper is organized as follows. In Section 2, problem formulation is presented. The simulation results are given in Section 3. In Section 4, concluding remarks and discussions, concerning the proposed method are presented.

2. Problem formulation

In this section, the formulation of the proposed technique is described. For this, first the general assumptions about the market model are presented. The opportunity cost will then be modeled and finally the proposed market clearing technique is described.

2.1. Market model

The market structure is assumed to be a disaggregated pool model. In this market, the energy and reserve are cleared separately by a single entity, such as Texas or can be cleared by the separated entities, such as the Spanish power market. In the separated framework, market operator (MO) and system operator (SO) are respectively responsible for energy and reserve clearing market. Generators submit their offer curves for energy and reserve to the market. These curves must be monotonically increasing functions of prices. Then, according to the submitted energy curve, the energy market is cleared. After clearing the energy market, the reserve market is cleared such that the reserve cost is minimized. A bid based model is used in this paper and the proposed method is applicable for cost curve coefficient model.

The number of generating companies is assumed to be N. Each generating company submits individual bidding blocks both for energy and reserve as follows:

$$[E_i^j, \mathrm{BE}_i^j], \quad j = 1, 2, \ldots, n_{\mathrm{e}i}$$
$$[R_i^k, \mathrm{BR}_i^k], \quad k = 1, 2, \ldots, n_{\mathrm{r}i}$$

where E_i^j is the energy quantity offered by the ith generating company for the jth band, BE_i^j the energy price offered by the ith generating company for the jth band, R_i^k the capacity reservation quantity offered by the ith generating company for the kth band, BR_i^k the capacity reserve price offered by the ith generating company for the kth band, $n_{\mathrm{e}i}$ the number of energy bid bands offered by the ith generating company, $n_{\mathrm{r}i}$ is the number of reserve bid bands offered by the ith generating company.

If the payment mechanism in the energy market is pay-as-bid, then the energy payment to the ith generating unit can be expressed as:

$$\mathrm{EP}_i(P_i) = \sum_{j=1}^{c} E_i^j \cdot \mathrm{BE}_i^j + \left(P_i - \sum_{j=1}^{c} E_i^j \right) \mathrm{BE}_i{}^{c+1} \tag{1}$$

$$\sum_{j=1}^{c} E_i^j \leq P_i \leq \sum_{j=1}^{c+1} E_i^j \tag{2}$$

where EP_i is the energy payment to the ith generating company with the accepted energy equal to P_i in the energy market.

If the payment mechanism in the energy market is uniform, then all accepted generating companies in the energy market receive market clearing price (MCP) as:

$$\mathrm{EP}_i(P_i) = \mathrm{MCP} \cdot P_i \tag{3}$$

After clearing the energy market, the reserve market is cleared such that the reserve cost is minimized. In [22,23], four alternative energy/reserve market designs and payment mechanisms to the generating unit reserve providers are proposed for implementing in the ISO-NE. These payment mechanisms are: payment for availability, payment for opportunity cost, payment for availability and opportunity cost, and payment for availability or opportunity cost.