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A novel stochastic reserve cost allocation approach of electricity market agents in the restructured power systems

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ABSTRACT

In this paper, a new mechanism is proposed to apportion expected reserve costs between electricity market agents in the power system. The uncertainties of generation units, transmission lines, wind power generation and electrical loads are considered in this model. Hence, a Stochastic Unit Commitment (SUC) is used to apply the uncertainty of stochastic variables in the simultaneous energy and reserve market-clearing problem. Moreover, electrical customers can participate in the electricity market based on their desired strategies. In this paper, a novel method is proposed to allocate reserve costs between GenCos, TransCos, electrical customers and wind farm owners. Consequently, market agents are responsible for paying a portion of the allocated expected reserve costs based on the economic metrics that are defined for the first time in this paper. Finally, two cases including a 3-bus test system and IEEE-RTS are utilized to illustrate the performance of the proposed mechanism to share the expected reserve costs.

1. Introduction

1.1. Aims and motivation

Restructuring in the power systems provides more freedom for different agents to participate in the Electricity Markets (EMs). Electrical consumers are one type of the market agents that can behave strategically based on their aims in the EM [1,2]. Although some of the consumers compete in the EM to maximize their economic profits [2], providing their required electricity demands with high level of reliability is the main concern of other electrical consumers [3]. In other words, the electrical consumer prefers to disregard or reduce its required electrical demand to achieve more economic profit, if it competes in the EM based on the economic view. However, there is a group of consumers that are willing to lose economically while their desired electrical load is provided.

In the restructured power systems, in addition to the energy, other services are defined to supply the different system requirements, these are called Ancillary Services (ASs) [3]. Operating Reserves (ORs) are one kind of ASs that play an important role in providing standard reliability level of the power system especially when the Independent System Operator (ISO) is faced with contingency events or probability electricity production due to the renewable energies such as wind energy. Besides, the strategic behavior of the electrical customers can affect positively or negatively on ISO's decisions. If these effects are negative, they can increase the system operating costs. Moreover, uncertainty in gen-

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eration, transmission and electrical energy consumption causes an increase in the system's operating costs such as reserve cost. This uncertainty (e.g. uncertainty of generation, transmission and electrical load) in the power system makes the ISO unable to make decisions deterministically. Therefore, stochastic decision-making is needed to determine energy and reserve requirement in the stochastic power system.

1.2. Literature review

In the literature, different works present new methods to solve the Unit Commitment (UC) and Market-Clearing (MC) problems to achieve ORs and reserve costs under uncertainty of the power grid and wind power generation. In Ref. [4], Transmission Constrained Unit Commitment (TCUC) has been solved by a hybrid approach combined of stochastic and interval optimizations considering the net load uncertainty. In Ref. [5], an Improved Interval (II) method has been used to solve the TCUC problem under uncertainty of wind power generation. Besides, the computational burden and total operating costs have been compared in many different cases and the UC problem has been solved by Stochastic Programming (SP), Robust Optimization (RO), interval and II methods in Ref. [5]. In Ref. [6], another probabilistic method has been used to determine the operating reserve based on cost-benefit analysis that Interval Optimization (IO) method is used to model the uncertainty of wind power in the UC problem. In Ref. [7], the UC problem has been solved by reducing the operating reserve through wind power generation and in this way minimizing the operating costs. Besides, a parameter, deration rate, has been defined to directly influence the wind power output of the wind farm and the uncertainty of wind power generation.

In Ref. [8], SP has been used to enhance the performance of obtaining the requirement reserve to provide the reliability level in the Security-Constrained Unit Commitment (SCUC) problem. In Ref. [9], the probabilistic method is utilized to model the wind power uncertainty by a Triangular Approximate Distribution (TAD) in the SCUC problem. In Ref. [10], the multi-period optimization model has been used to determine the Spinning Reserve (SR). Also, authors solved the UC problem in each scenario due to the different states of the electrical loads and power units' capacities. In Ref. [11], an evolutionary optimization algorithm has been utilized to solve the UC problem to minimize the operating costs and emission level and maximize the reliability level of the power system. In Ref. [12], the performance of SUC, robust UC and interval UC problems have been compared according to different short-term time resolutions. Moreover, the RO method has been applied to obtain operating reserves in Refs. [13] and [14]. In Ref. [13], Conditional Value-at-Risk (CVaR) has been applied to the proposed problem, and reserves have been scheduled based on the uncertainty of wind energy generation. In Ref. [14], net load uncertainty has been considered in the proposed decision-making problem. In Ref. [15], obtaining the zonal reserve problem has been discussed under the uncertainty of stochastic generation of renewable energies, and the probabilistic and heuristic method has been stated in Ref. [15].

In Ref. [16], a probabilistic approach has been used to achieve the reserve under uncertainty of wind power generation, electrical demand, and power generation of conventional units. Besides, energy and reserve market are cleared independently, that the reserve market is cleared before energy market in Ref. [16]. In Ref. [17], the Transmission System Operator (TSO) is responsible for apportioning dynamic reserves in the power system. In Ref. [18], the convex optimization method has been applied to solve the simultaneous real-time MC problem considering the uncertainty of wind energy resources. In Ref. [19], the MC problem has been solved considering the Day-Ahead Market (DAM) and the Balancing Market (BM). In Ref. [20], a merit order has been defined to enhance the dispatching of the stochastic generations in the DAM. In Refs. [1] and [2], the stochastic complementarity model has been utilized to apply the optimal bidding strategy of consumers. Besides, the proposed models of Refs. [1,2] and [19,20] have been solved by bi-level programming. In Ref. [21], the network-constraint AC unit commitment problem has been solved considering the uncertainty of wind power generation based on a two-stage SP and Benders' decomposition methods. In Ref. [22], a two-stage SP has been presented to consider the uncertainty of wind energy integration to dispatch energy and reserve in the power system. Reserves have been obtained by generating units and flexible loads to cover the uncertainty of wind power in the smart grid environment in Ref. [22].

In Ref. [23], a novel method has been proposed to obtain optimal bidding of operating reserves in the sequential market mechanism of the Spanish electricity market. The flexible Expected Energy Not Supplied (EENS) criteria and the load point reliability of customers are presented to manage the reserves of the power system, respectively in Refs. [24] and [25]. In Ref. [26], authors state the algorithm to apportion the reserve costs through market agents based on the desired reliability level of electrical consumers and well-being analysis. In Ref. [27], the Value Of Lost Load (VOLL) of DisCos has been applied to the decisions of System Operator (SO) based on DisCos' desired reliability levels. Furthermore, an approach has been expressed to determine the operating reserve and apportion the reserve costs between electrical customers and GenCos under uncertainty of wind power generation in Ref. [3]. In Ref. [28], a novel mechanism based on the decentralized approach has been introduced to share reserve costs between consumers, generating units and SO in the simultaneous energy and reserve MC problem. In Ref. [29], a new approach has been presented to apportion the costs due to the demand response based on local marginal price. Besides, a fairness index has been introduced to assess the performance of the proposed method in Ref. [29].

1.3. Contributions

In the literature, different mechanisms that apportion reserve costs have been presented. However, their proposed methods have not followed this idea that the market's agent is responsible for paying a portion of the reserve costs who makes the need of reserve in the power system.

Additionally, different countries apply different mechanisms to allocate reserve costs. For instance, GenCos are responsible for paying the reserve costs in some electricity markets (e.g. Austria, Netherlands and Singapore) [35–37]. However, in Switzerland, according to the decision that has been made by the Swiss Federal Administrative Court on July 8, 2010, the reserve costs are not allocated to the GenCos that their power generation output is more than 50 MW [38]. Also, the demand-side participants, consumers or DisCos, have to pay the reserve costs in most of the electricity markets in the world [39]. On the other hand, in the UK electricity market, both GenCos and the electrical consumers are charged for reserve costs [40]. Furthermore, a successful implementation of the flexibility cost allocation method has been proposed in Ref. [41]. According to Ref. [41], the flexibility cost is allocated between California Independent System Operator (CAISO) and Western Energy Imbalance Market (EIM). This way, the apportioned flexibility cost to CAISO is allocated to electrical consumers and GenCos. However, the apportioned flexibility cost to the EIM is allocated to the EIM entity scheduling coordinator. The functioning of these mechanisms depends on the specific energy policies of each country which in turn rely on the country's infrastructure, industry and economy. Hence, it is not acceptable to apply a reserve cost allocation mechanism of one country to others without first evaluating and studying their electricity markets from all aspects. Some researchers state