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Market Equilibrium Based on Renewable Energy Resources and Demand Response in Energy Engineering

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Abstract

Smart grid enables the integration of large-scale renewable energy resources (RERs) into the power system, but the subsequent intermittency and uncertainty can have an adverse impact on the networks' reliability, safety and operation efficiency. Meanwhile, demand response helps greatly mitigate the negative impact associated with RERs. Hence, from the engineering's perspective, the complexity and intelligence of the power system have been on an unprecedented level. In such a complex and intelligent power system, it is essential to investigate the impact of RERs and demand response on the market equilibrium in order to help market participants to make scientific decisions. In this paper, firstly, an overall model of major market participants together with the constraints of transmission and generation is established. Then, the energy market is analyzed with RERs' uncertainties and demand response. Finally, a 4-bus network is utilized to validate theoretical results, indicating that as the uncertainties increase, power system's operation costs and equilibrium shift will be enlarged; and the effect of demand response can narrow the equilibrium shift and reduce RERs' integration costs.

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Keywods: renewable energy resources; energy engineering; market equilibrium; uncertainties; perturbation analysis

1. Introduction

With increasing concerns about global energy resources shortage, greenhouse gas effect and environmental pollution, smart grid has gained popularity globally for its unique advantages. Consequently, a large amount of smart technologies about renewable energy resources (RERs) generation and integration, storage technology, control signals to loads, energy efficiency and smart buildings have emerged. Admittedly, with the rapid development of RERs generation and integration technology, large-scale integration of RERs will bring about intermittency and randomness to the networks, which will certainly lead to integration costs. Meanwhile, demand response, which is aimed at guiding consumers' behaviors according to the price signal, plays a significant role in mitigating such integration costs. Therefore, from the engineering's perspective, the complexity and intelligence of the power system have been on an unprecedented level due to the comprehensive impact of RERs and demand response. So it is essential for us to investigate such impact on the market equilibrium to provide support for participants in the electricity market to make scientific decisions.

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Literature review about the impact of RERs and demand response on the power system is presented here. Firstly, it is known that RERs respond actively to deal with energy and environment problems, but they have the disadvantage of intermittency and uncertainty due to their physical characteristics. One of the most serious problems that may emerge is limited dispatchability of intermittent generation [1]. In particular, for wind farms, problems such as the variability in resource availability, errors in forecasting resource availability and loads should also be taken into consideration [2]. The frequency modulation, peak regulation and economic planning and operation of the overall power system may be influenced by the integration of RERs as well [3]. Secondly, in recent years, there is a rapid development and self-improvement in demand response, which plays a significant role in reducing potential forecast error and redispatch costs [4-6]. Load shape and operation efficiency will be improved using demand response [7]. It is assumed that the real-time pricing is implemented. When actual wind generation is less than forecast, consumer demand will decrease due to high costs associated with ancillary services used to compensate the generation shortage. Consequently, costs to meet consumer demand will fall. Similarly, when actual wind generation is more than forecast, since wind generation has zero marginal cost there is an increase in electricity demand [8, 9]. Nevertheless, none of the studies involved problems concerning the comprehensive impact of RERs and demand response on the market equilibrium point. Therefore, this paper concentrates on the market equilibrium analysis based on the integration of RERs and demand response.

The remainder of this paper is organized as follows: the general market equilibrium model based on agent behaviors is presented in Section 2. In Section 3, the market equilibrium in the absence of RERs and demand response is formulated and then perturbation analysis is given. Section 4 describes the suitability of the model using a case study and therefore the conclusion is obtained. Concluding remarks are shown in Section 5.

2. General market equilibrium model based on agent behaviors

Participants in the electricity market mainly consist of generating companies, consumer companies and independent system operator (ISO). In this paper, attention is merely paid to the corresponding agent behaviors of the three types of participants. Models of agent behaviors will be presented in this section, and then the market equilibrium is established. The key is to determine the generation of units and electricity demand of consumers, so that the market equilibrium can be obtained considering capacity constraints and the social welfare is maximized at the same time. It should be noted that the constraints that generating companies, consumer companies and ISO are subject to may conflict with each other, making the optimization problem more complex. For example, electricity price has links with both generating companies and consumer companies. As far as the consumers are concerned, low price means

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