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A novel power market clearing model based on the equilibrium principle in microeconomics

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ABSTRACT

Clean energy dominant and electricity centric is the inevitable trend of the future energy development. Electric power industry has entered into an increasingly competitive era in recent years due to the deregulation of power systems. However, power market should not be fully competitive and need to be regulated strictly to satisfy the safe and reliable operation of power systems. Base on the market equilibrium principle in microeconomics, a novel power market clearing model with limited competition was put forward, in which the limited competition power satisfies the power flow adjustment and the network losses distribution. Further, the free transaction ratio which can be regarded as the measurement of the degree of power market deregulation was analyzed according to the formulated market clearing model. Finally, three case studies were made on the IEEE-30 test system to verify the practicality and efficiency of the method. The results show that different transaction ratio has significant influence on the operation of power systems and the optimal transaction ratio can be determined.

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1. Introduction

Energy is the blood of the economy society. The large-scale development and utilization of fossil energy have resulted in a series of prominent issues, such as resource constraints, environmental pollution and climate change, which are huge challenges confronted by all human beings. To address these challenges, it is necessary to put forward global energy transition. Electricity is the cleanest and the most efficient energy. Clean energy dominant and electricity centric is the inevitable trend of the future energy development (Liu, 2015). In recent years, the electric power industry has entered into an increasingly competitive era due to the deregulation of power systems. The purpose of deregulation is to change the monopoly with the vertical integration over the past decades and perform the power market so that the competition mechanism can be introduced into power systems and the energy resources can be allocated efficiently. The main product in the power market is power or electricity. However, in order to guarantee the safe operation of power systems and the smooth running of power market, the commodities of power market also include

other ancillary services (Rebours et al., 2007a, b) like reactive power service, peak shaving and frequency regulation, etc. It can be said that the degree and the range of the openness of power market are very deep and wide.

In other words, the market-oriented reforms have penetrated deeply into all aspects of power systems in the process of the deregulation (Erdogdu, 2014). pointed out that power market reforms aimed at encouraging private investments in electricity infrastructure, enhancing security of electricity supply and making power industry operate in line with the requirements of the sustainable development. To achieve the goals of market reforms, it is necessary to properly balance the relationship between market regulation and deregulation. In the recent period, there are also a few related studies (Tian et al., 2015). focused the impacts of market deregulation on the promotion effect of gas power. Market deregulation and the environmental externality were considered together to develop a dynamic game-theoretic model (Du et al., 2016). focused on the impacts of carbon footprint and low-carbon preference on the market supply and demand. The environmental goals were attained and the effective scheduling was achieved through market regulation (Mou, 2014). analyzed coal-fired electricity efficiency from three levels: groups, provinces, and plants. The comparison indicated that competition at the national level would enhance the efficiency to a greater degree than competition

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at the national level.

The key issue in the study of power market is to integrate the market principle in economics into the practical operation of power systems. In the research of power market, the nodal pricing theory (Breuer et al., 2013; Green, 2007; Tang and Jain, 2013) is the most representative method applied not only in the bidding of the spot market, but also in the pricing of ancillary service. However, there is an obvious defect in the nodal pricing theory. The market-clearing results will generate revenue and expenditure imbalance and the surplus still needs redistribution among market participants, which would create unfair distribution problems. Therefore, power market cannot reach equilibrium state and allocate resources efficiently. Some papers have presented new market clearing mechanisms to solve these problems (Baghayipour and Foroud, 2013). developed a new approach to fairly clear the market and assess the amount of each participant's revenue in a deregulated power system through modifying the system nodal prices. However, the effect of transmission losses and its necessitated costs were ignored in this paper. Therefore, a fresh nodal pricing mechanism was presented in (Baghayipour et al., 2014) to resolve the previous drawbacks and establish a fair and comprehensive pricing framework. In (Wang et al., 2007), the impact of the network losses and congestion on the spot power market was analyzed in order to establish a brand new equilibrium model considering the network losses and transmission constraints. However, the model proposed in this paper is a man-made equilibrium model, which means that the equilibrium cannot be achieved automatically.

For the characteristics of the power industry, the implementation of power market is very difficult and the secure operation of power systems is also faced with a lot of hidden dangers. As a result, power market has to be regulated strictly in order to satisfy the requirements of the safe and reliable operation of power systems. Regulation and deregulation are two contrary concepts. When the degree of regulation is strengthened, the degree of deregulation is reduced and namely the degree of competition in the market is reduced. That is to say, power market is not fully competitive and not all the resources in the power market should be traded (Nepal et al., 2014). also pointed out that there existed flaws in the existing regulatory environment and economic efficiency. What's more, robust benchmarking techniques should be adopted in the incentive regulation framework for cost efficiency.

Considering the above literature review, the main contributions of this paper are three folds: 1) by introducing the principle of general equilibrium in microeconomics into the practical power market, the reason of power market failures such as power market losses and congestion is analyzed; 2) the paper proposes a market clearing model with limited competition which can achieve the power market equilibrium automatically and measure the degree of deregulation or competition of power market through the free transaction ratio; 3) in the proposed model, the power is divided into two parts: the power participating in the free market competition and the power not participating in the free market competition. The former is fully competitive and the latter is regulated only used to adjust the power flow and allocate the network losses.

The rest of the paper is organized as follows. Section 2 introduces the general equilibrium in microeconomics. Based on the nodal pricing theory, power market failures considering the characteristics of the power network are analyzed in Section 3. Then, Section 4 briefly introduces the regulation of power market. The power market clearing model with limited competition is proposed in Section 5. Section 6 defines the free transaction ratio and proposes the calculation method. In Section 7, three case studies are carried out on the IEEE-30 bus test system. Finally, the discussion and conclusions are drawn in Section 8 and Section 9, respectively.

2. Perfect competition market

The ordinary commodity market conforms to the principle of general equilibrium in microeconomics. In the ordinary commodity market, when the market reaches supply and demand equilibrium, the market price and trading volume determined by the intersection of the supply and demand curve is referred to as the market-clearing price and market trading volume, respectively. The principle of general equilibrium can be described by the following mathematical model:

$$\begin{aligned} F(C) = S(C) - D(C) &= 0 \\ CF(C) &= 0 \end{aligned} \quad (1)$$

where $F(C)$ represents the excess supply function; $S(C), D(C)$ is the supply and demand function respectively; C is the market price. Equation $F(C) = S(C) - D(C) = 0$ represents the supply and demand balance. And $CF(C) = 0$ represents the revenue and expenditure balance, which means the result of the market trading is clear without market surplus, as shown in Fig. 1.

This is also the manner to allocate resources in the perfect competition market as well as the operation model of the ideal market. When the market reaches general equilibrium, the market is considered to be efficient and the allocation of the market interests is also considered fair. The previous mentioned mathematical model can also be expressed as the following optimization form (Wang et al., 2007):

$$\begin{aligned} \min(\text{or max}) \quad & CF(C) \\ \text{s.t.} \quad & F(C) = S(C) - D(C) = 0 \end{aligned} \quad (2)$$

Eqs. (2) and (1) is equivalent. When not considering the power network characteristics, the model of spot power market can also be expressed in the above form. It should be stressed that the equilibrium is reached automatically, which is achieved through the "invisible hand". Since the market equilibrium is reached automatically, the market trading is not restricted by the market models. The appearance of the power pool and bilateral transaction (Jamash and Pollitt, 2005) in the process of the implementation of power market also indicates that the power market is not the perfect competition market.

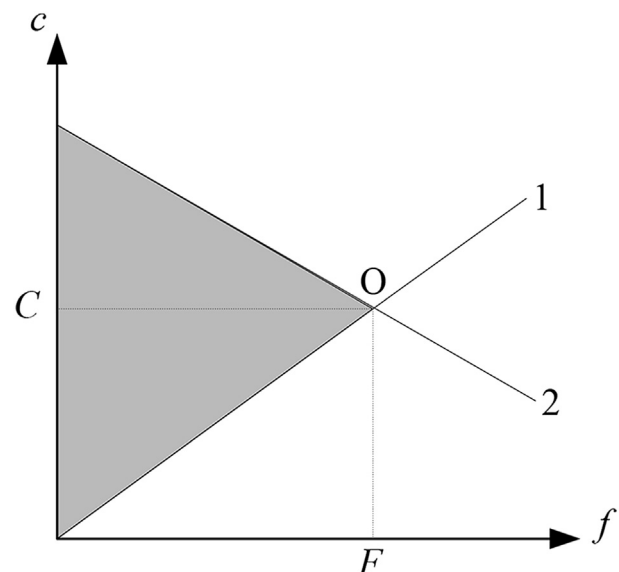


Fig. 1. Supply and demand equilibrium in the ordinary commodity markets.

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