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Residential electricity pricing in China: The context of price-based demand response

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ABSTRACT

As a secondary energy, electricity is an important channel between original energy and energy consumers. Electricity price is a critical factor for the interests of all involvers in the electric power market. It also plays an important role for the sustainable development of energy and environment. Smart grid is a new conception proposed in recent years to improve the intelligent level and increase the efficiency of electric power system operation. Smart grid combines and integrates information technology, communication technology and intelligent control technology with tradition power system. To achieve the many objectives of smart grid, Demand response (DR), as an effective technique of demand side management (DSM), refers to the changes in electricity consumption behavior of users in response to the dynamic price or incentive rewards. Price based demand response (PBDR) is one of the two major DR programs. In this paper, we first introduce the pricing theories in economics, the pricing of electricity and the development of electricity pricing in China. Then, we present a detailed discussion on the PBDR strategies in the DSM of smart grid. Also, the research status of PBDR is reviewed. Finally, it gives a summary of the whole paper in the last Section.

1. Introduction

During the past decades, with the rapid development of China's economy and society, fossil energy has been widely exploited and utilized. Due to the large scale fossil energy consumption and the consequent carbon emissions, energy and environment problems are becoming more and more prominent in China. Therefore, it is imperative to construct a safe, effective and sustainable energy system for China. Some new development concepts of energy system such as smart grid, energy internet and internet plus smart energy occurred in recent years [1–4]. Smart gird integrates information technology, network communication technology and intelligent control technology into traditional power system to achieve the interaction between supply side and demand side [5–8]. Smart grid also involves clean energy and distributed energy in the conventional power system. Smart grid can not only guarantee the security, quality and efficiency of energy supply, but also contributes to energy conservation and emission reduction [9]. Energy internet is a huge demand response network which is integrated with transportation system and natural gas system, based on the power system and the Internet technology [10–12]. Energy internet is the further development of smart grid [13].

Demand side management (DSM) is an important part of smart grid to achieve the management goals from demand side [14,15]. Specifically, as an effective technique of DSM, demand response (DR) refers to how the demand side response to pricing strategies or incentive measures from the supply side [16,17]. It is defined as "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [18,19]. DR is an effective way to optimize the electricity consumption, and the costs to implement DR is less than the cost to increase more generation capabilities to achieve peak shaving [20]. The implementation of DR can not only promote supply-demand balance, but also support the provision of cost-effective, high-quality and personalized services to demand side consumers [21]. Generally, DR can be divided into two categories, namely price-based demand response (PBDR) and incentive-based demand response (IBDR) [22]. For PBDR, exorbitant electricity prices not only increase the market cost, harm a country's competitiveness, but also suppress the domestic consumption, reduce the social welfare. Also, underpriced electricity prices will hinder the development of power industry and

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increase waste and pollution [11]. Therefore, how to develop optimal and appropriate electricity price is one of the key issues of smart grid. Currently, there have been some research efforts that focused on the electricity pricing around the world with many meaningful practices [23–27].

Similar to the pricing of other commodities, traditional electricity pricing methods add some profits on the cost [18]. However, it will lead to many problems such as more administrative interventions, monopoly of state-owned enterprises, lack of competition, low efficiency and difficulties to ensure the rights of consumers [28]. While introducing DR to demand side, electricity consumers will reduce peak electricity usage or move some of the peak consumptions to off-peak periods. It will greatly optimize the way of electricity consumption, significantly improve energy efficiency, effectively conserve resources and reduce pollution [29,30]. DR plays an increasingly important role in the interaction between supply and demand, which is the most important characteristic of smart grid compared with traditional power system [31]. Therefore, the objective of this paper is to provide a survey on the residential electricity pricing in China under the background of PBDR. We aim to summarize the development of electricity pricing in China, discuss the research status of PBDR, and further point out the challenges and opportunities of PBDR in China. This review contributes to the theories of DSM and the development of smart grid in China.

The rest of this paper is organized as follows. Section 2 presents the pricing theories in economics, pricing theories of electricity as a special product and the development of electricity pricing in China. Then, DSM and PBDR in smart grids, particularly the PBDR strategies and their research status, are discussed in Section 3. Finally, conclusions are drawn in the last Section.

2. Electricity pricing in China

2.1. Basic electricity pricing strategies

In economics, the equilibrium point is the result of spontaneous adjustment of supply and demand when supply equals demand in the market [32,33]. Supply and demand curves of market and firms are different due to different market types. The firm will get maximum profit when its marginal profit equals to marginal cost no matter it is a competitive firm or a non-competitive firm. In perfectly competitive market, single consumer or firm cannot influence the market price. Market can allocate economic resources effectively in perfectly competitive market. But there is rarely perfectly competitive market in practice.

Natural monopoly is a kind of monopoly with high degree of economies of scale [33,34]. Natural monopoly generally exists in utilities such as power sector, water sector and telecom sector, which have pretty high fixed cost and relatively small variable cost. It is more economical under monopoly when market is not so mature, but it will lead to high profit and low efficiency for a monopoly firm [35]. Thus the pricing of a monopoly product is often regulated by the government. The regulations of government will lead to some problems such as price stickiness which contorts the price mechanism. For example, the price will not change immediately even if the supply is excessive when there is regulation.

Electricity product follows the pricing theories in economics as a commodity. But it is a special commodity. Its specialties should be considered when developing electricity product pricing strategies. It differs from normal product in the following aspects.

First, electricity is electrons flow in a conduct under electric potential. It cannot be described by weight, size, color or shape as a normal commodity; either cannot be judged by touching, tasting or smelling. This is why consumers treat electricity product as a special commodity. Second, electricity product is difficult to be stored since power generation, transmission, distribution, substation and consumption are finished nearly at the same time and the supply-demand imbalance may result in serious consequences [36,37]. Besides, it is difficult to adjust energy generation immediately according to the demand of consumers since the power generation is not so flexible while the behaviors of consumers varied [38].

For the electricity pricing, there are static pricing strategies and dynamic pricing strategies for electricity product. Static strategies include traditional flat tariff and step tariff. Traditional flat tariff means a flat tariff with fixed rate plus the cost [39]. It is simple and easy to be implemented. But the flat tariff contorts the pricing mechanism and hinders power sector reform [40]. It is not fair and lack of efficiency to charge the same tariff for consumers with high salary, high power consumption and consumers with low salary, low power consumption [41]. Consumers usually do not have the desire to change their behaviors, such that resulting in grid overload during peak periods and electrical device idle during off-peak periods. Further, it may lead to great resource waste and environment pollution [42]. Step tariff, a.k.a. the tiered pricing, refers to charge with different standards according to the amount of consumption. The different standards are called “step” which is determined by experience and regional characteristics. There are increasing block tariff and decreasing block tariff. Generally it refers to the increasing block tariff [43,44]. Step tariff is able to reflect the marginal cost of electricity and the power demand elasticity of residents [41,44–46], so that it can improve the efficiency of energy usage, increase benefits of all producers and consumers. Step tariff can also promote the strengthening of residential energy-save awareness and reduce energy waste [41,47,48]. Step tariff represents an important advance towards power market reform.

Dynamic pricing strategies, which is also called PBDR pricing strategies in smart grid, include time-of-use pricing (TOU pricing), critical peak pricing (CPP), extreme day pricing (EDP), real time pricing (RTP), etc. TOU pricing divides a day into peak, valley and flat periods with different price standards according to the demand of consumers and the actual load of power grid to encourage consumers optimize their behaviors and improve efficiency of power grid [49,50]. Though some researchers believed that TOU pricing is static pricing strategy for its high stability [51], this paper mainly consider its characteristic of interaction between supply and demand. Dynamic pricing strategies, including TOU pricing and CPP, are all useful attempts from flat tariff to RTP. When the electricity price is closer to real time pricing, there will be less deadweight loss.

2.2. Development of electricity pricing in China

The electricity pricing in China has some unique characteristics. First, China has adopted cross-subsidy electricity pricing for several decades, which means that industrial electricity price subsidies residential electricity price. However, the cost of residential electricity is higher than industrial electricity in reality [52]. The cross-subsidy pricing mechanism improves residential living standards on the one hand, but it is harmful to the development of industries and may reduce the overall social welfare [53,54]. It is also believed that cross-subsidy goes against the basic principles of pricing. People with high salary and high electricity consumption usually receive more subsides which is not good for social fairness. Charging the same price during peak and valley periods will result in overload during peak periods and idle devices during off-peak periods. Second, the mechanism of coal-electricity price linkage was implemented since 2004. It refers to that the electricity price is adjusted when coal price changes 5% more than the last period. The period is within six months. If the varied range of coal price is less than 5% than the last period, it will be calculated to next period until it reaches 5% [55]. Electricity tariff was raised twice, first in May 2005 and then in June 2006. But the mechanism of coal-electricity price linkage was suspended as a result of rising concerns over inflation [56]. Coal is the most important resource for power generation in China at the time and in the predictable future. Electricity