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Real-time electricity pricing mechanism in China based on system dynamics

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ABSTRACT

As an important means of demand-side response, the reasonable formulation of the electricity price mechanism will have an important impact on the balance between the supply and demand of electric power. With the introduction of Chinese intelligence apparatus and the rapid development of smart grids, real-time electricity pricing, as the frontier electricity pricing mechanism in the smart grid, will have great significance on the promotion of energy conservation and the improvement of the total social surplus. From the perspective of system dynamics, this paper studies different real-time electricity pricing mechanisms based on load structure, cost structure and bidding and analyses the situation of user satisfaction and the total social surplus under different pricing mechanisms. Finally, through the comparative analysis of examples under different real-time pricing scenarios, this paper aims to explore and design the future dynamic real-time electricity pricing mechanism in China, predicts the dynamic real-time pricing level and provides a reference for real-time electricity price promotion in the future.

1. Introduction

With the rapid development of smart grids and large-scale access of all kinds of renewable energy, real-time electricity pricing, as an economical means of demand-side management, is playing an increasingly important role. The real-time electricity pricing mechanism is a kind of dynamic electricity pricing mechanism that describes the price level of each period of the day. Ref. [1] notified the price level of each period to the user one day in advance in its' practical application. Moreover, through the user response to the price, Ref. [2] stated that effective pricing mechanism could realize the transfer of power in each period, promote the reasonable power utilization of users and help the consumption of renewable energy sources in off-peak time. Ref. [3] proposed that electricity demand may increase steeply during the morning hours and decrease steeply during the evening hours which should be considered in real-time pricing mechanism. However, at present, the pilot of real-time electricity price had not been promoted in China and the design of the real-time electricity pricing mechanism has not been unified, so it is thus urgent to analyse more in depth the reasonable policy of real-time electricity pricing and design the optimal real-time electricity pricing system.

System Dynamics (SD) adopt information theory and methods to study complex feedback system, and think that their behaviour and characteristics are depended on their internal structure and the dynamic feedback mechanism. It is the way to solve the problem by reunifying qualitative analysis and quantitative analysis, which studies the problem from the internal mechanism and micro-structure of the system to analyse system model. SD studies the dynamic behaviour of the system structure by using computer simulation technique, seeking to find solutions and solve the problem. Therefore, the actual SD model can be seen as laboratories for analysis to solve social, economic, nonlinear complex systems. The method that SD uses to deal with complex problems is the combination of quantitative and qualitative, and its process of model establishment is a process of study, investigation and research. The main function of the model is to provide a policy analysis tool, and gradually make decision group or the whole group to a learning organization. Since the 1990s, SD has gradually been introduced to the power system and it has brought great benefits to the research of pricing policy. SD was first put forward by Professor Forrester in the 1950s. It runs by analysing the feedback loop structure behind behaviour, creating an SD model changing the stated value of related variables in the structure and then understanding the different behaviour of different strategies to accomplish the

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optimization strategy. Ref. [4] indicated that SD was fit for policy analysis and decision studies.

In the analysis and study of the electricity price with the use of SD, Ref. [5] built an SD simulation evaluation model and set simulation scenarios including different feed-in tariffs, subsidies, annual investment and so on to help decision-makers analyse the promotion of cost-effectiveness under the goal of reducing carbon dioxide emissions and budgets. Ref. [6] simulated a service node pricing mechanism by constructing an SD simulation platform and predicted the application of node pricing in the Chinese power market. Ref. [7] used a system dynamics approach to analyse the behaviour of ancillary service market in the long term. Based on customers' price response functions, a tripartite interest balance of the power producer, the power grid and power users was shown. Ref. [8] constructed a brief SD model for electricity market to analyse the fluctuation of energy demand and supply. However, the research only analysed the condition of spot market and was not related to real-time electricity pricing. Ref. [9] divided the system into different modules and established the connection between them through a cycle dynamic system model, but its research focused on the connection of different modules and did not involve in a specific tariff mechanism. Ref. [10] described the complexity and dynamic of the electricity system and approved the effectiveness of SD models in its application of complex systems such as energy systems. In general, the use of SD for pricing research, especially the real-time pricing mechanism, is relatively fragmented and a system of real-time electricity pricing has not been put forward.

In the analysis and research of real-time pricing, Ref. [11] studied various kinds of factors which influenced the electricity price and its volatility and made a reasonable price based on the neural network input featured by DCT to maximize the profits of power producers and consumers. Ref. [12] analysed user response to real-time electricity price and the promotion and application of real-time electricity pricing. Based on the smart grids and the perspective of demand-side management, Ref. [13] described the more detailed period division and the more effective load response of real-time price compared with peak pricing and time of use pricing. Ref. [14] proposed a security-constrained self-scheduling framework for generation companies in day-ahead electricity markets which considered the uncertainty of the predicted market prices and the risk of the models. Moreover, through the comparison with the current electricity price, it showed that the real-time electricity price policy brought greater benefits to both supply and demand. Ref. [15] put forward that the day-ahead electricity market is closely associated with other commodity markets such as the fuel market and emissions market and forecasted the real-time price based on the above factors. Ref. [16] predicted the market behaviours with some intelligent algorithm based on the historical prices and load so as to provide a basis for the forecast of the future prices and loads. Ref. [17] divided a day into 24 h and used the local day-ahead electricity market to study real-time energy management. Ref. [18] designed different real-time electricity price through the simulation and analysis of demand response behaviour. Ref. [19] proposed a new day-ahead direct time series forecasting method for competitive electricity markets based on clustering and next symbol prediction and showed that the proposed method outperforms the traditional methods obviously. Ref. [20] used a new feature selection algorithm and cascaded neural network technique to forecast the day-ahead price of electricity markets. Ref. [21] proposed a new method to forecast day-ahead electricity price which involved wavelet transform, Auto-Regressive Integrated Moving Average models and Radial Basis Function Neural Networks. Ref. [22] used a real time pricing approach in order to match the supply with demand in smart grid. Ref. [23] used the goal of maximizing the total social surplus to design and analyse the electricity pricing mechanism and made the establishment of the price mechanism more reasonable. However, most research is based on the mature power market, it is difficult to implement the findings in this electricity market stage in China and there is a lack of the design and analysis of the corresponding transition mechanism of real-time electricity pricing.

In this paper, the SD method is used to study the optimization of the Chinese real-time electricity pricing system. It establishes tariff modules, power market modules, user satisfaction and social surplus modules to study the real-time pricing system. Meanwhile, among the tariff modules, this paper proposes a different real-time pricing mode under four scenarios and studies the customer satisfaction and social benefits for each scenario. With an example of an industrial district, we study the changes of tariff, power, user satisfaction and social benefits in these four scenarios and design the initial development path of the dynamic real-time electricity pricing mechanism in China to provide guidance on China's future real-time pricing system optimization.

2. The overview of the real-time electricity pricing system

At present, the research on the real-time electricity pricing system is mainly concentrated on the tariff structure, the user response, the user load characteristic, power supply, power generation, interests of tripartite users and user satisfaction. It is thus necessary to analyse the several aspects above and explore their interrelationships. The general idea of this research on real-time electricity pricing is shown in Fig. 1.

In Fig. 1, the real-time electricity price system is divided into five parts which include electricity price, power, user response, user satisfaction and social benefit. Among them, the electricity price can be determined by specific pricing mechanism and different pricing mechanism will produce a different price. What is more, the adjustment of electricity price will affect the user response and feed back into power demand in each period quantitatively through the user response function, thus the new power structure of the user can be obtained. Meanwhile, power consumption and the electricity price will affect the use mode of electricity and electricity expenses, which further affect the user satisfaction of power consumption. Additionally, through the analysis of the power consumption and the electricity price, producer surplus and consumer surplus can be calculated and the total social surplus can be obtained. It is worth noting that real-time electricity price is a demand-side management measure needed to explore the situation of the total consumer surplus and producer surplus under a specific price and quantity demand. From the results of the user satisfaction and the total social surplus, we can further evaluate this kind of real-time electricity pricing mechanism.

3. The design of the real-time pricing model

The entire model is made by four modules (tariff, power, user satisfaction and social benefits), which form a mutual feedback system mode and describe the relationship between each part quantitatively. In the tariff modules, from the perspective of cost, load structure and so on, this paper simulates each scenario of real-time electricity pricing and analyses different pricing mechanisms of real-time electricity price. In the total social surplus modules, this paper analyses the influence of different pricing mechanisms on producers and consumers. Because of the small benefit of power suppliers and because the purchasing price remains a benchmark price in China, this research associates the producer surplus and the consumer surplus with the sales price to a greater degree and establishes the total social surplus system module with the power grid company as the producer and power