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Research on Real-time Pricing Strategy of Smart Grid Based on Behavioral Economics

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Abstract. With the rapid development of economy and the acceleration of the construction of smart grid, great changes have taken place in China's electricity market. New pricing mechanism has emerged in the electricity market. Real-time pricing (RTP) demand side management has been applied to smart grid, which improves the operation mode of power market, dynamically reflects the process of power resources being absorbed and improves the stability and security of power system. The article obtains from the power companies and users, compares several common pricing mechanisms, reasonably analyses the users' responses under real-time pricing, formulates a more efficient real-time pricing mechanism, presents a modeling method for generating companies directly to users and maximizes their utility, establishes a mufti-layer interactive model of real-time pricing, improves the transparency of electricity prices in the power market, and encourages users to choose their own electricity and actively participate in the regulation of power market. According to elastic price lever, it can give rise to adjust the balance between supply and demand of power market, optimize the daily load curve of users, reduce the peak-valley difference of power supply of power grid companies and improve the stability of power system.

1. Introduction

Nowadays, electricity is the most widely used and the most important energy in the world. Electricity is closely related to people's lives and is the basic industry of the national economy. The reason why human beings enter the modern social civilization is because of the emergence and use of electricity. Since the 21st century, with the rapid development of the global economy, so the management and operation mode of the traditional power grid has been greatly impacted and people need to find new solutions to improve the economic efficiency of power grid operation. At present, the interconnection of large power grids and the emergence of smart grids have become the key to solve the problem. The price modes of smart grid mainly include peak load price, step price, time-sharing price and real-time price. In the reform of power market, Britain is the first country to put forward the real-time price mechanism. More and more researches about the real-time price of smart grid have been done.

Compared with several common motor mechanisms in the market, this paper mainly discusses the problem of real-time electricity price when power suppliers supply power to users, and proposes a new algorithm for real-time electricity price, so that users can obtain the optimal electricity price benefits and the benefits of electricity suppliers. A mufti-layer interactive model of real-time electricity price is established directly between generators and users, encourages users to make their own choices. During the period of power consumption, we can actively participate in the regulation and control of the power market and adjust the balance between supply and demand in the power market through price

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elastic lever, improve the utility of users and reduce the peak-valley difference of power supply.

2. The main bodies of smart grid electricity market

2.1 Power suppliers

The cost items of electric power products include material fee, water fee, fuel fee, maintenance fee, other expenses and so on. In China's current power generation situation, it is still mainly thermal power. In general, the price of coal is relatively stable in the market. Power producers and coal mining companies also buy coal under contract system. Therefore, the price of coal is considered stable relative to the price of electricity. The price of coal is not shown in the cost function of power generation, but hidden in the coefficient of cost function. In this paper, the cost function of e-commerce defined in reference [1] is adjusted as follows:

$$Y_t(Q_k) = a_1(Q_k)^3 + a_2(Q_k)^2 + a_3(Q_k) + a_4 \qquad (1)$$

In the above formula: a_1, a_2, a_3, and a_4 are the cost coefficient of the generator, and the Q_k is the contract's capacity. According to the cost of raw materials, the loss of machines and the market bidding situations, the electricity generator divided the risk quotation of electricity price into two stages. According to the supply and demand relationship in the market electricity, the quoted price by the generator at every moment is:

$$P_k^{\ t} = \begin{cases} P_1^t & Q_{\min} < Q_k < Q_0 \\ P_2^{\ t} & Q_0 < Q_k < Q_{\max} \end{cases} \qquad (2)$$

The K in the above formula indicates the number of the generator, P_1^t and P_2^t are the electricity price under the different risks; the generation of high and low risk's Q_0, $Q_{\min}$, and $Q_{\max}$ represents the critical power generation, minimizes power generation, and maximizes power generation.

2.2 Contract system of power generators

Power suppliers sell electricity contracts with users to implement contract power consumption through centralized bidding and listing, and sign purchase. The power grid company is connected with the upper generators and the lower consumers, and plays the role of transportation hub. It maintains the information exchange and shares between generators and users. Its main purpose is to provide convenient services for users. According to the development and construction of the power grid company itself, the power generation company pays the certain cost of passing by the network to the power grid company. The transaction function of the generator is [2]:

$$L_k^{\ t} = \begin{cases} L_{k1}^{\ \ t} = P_1^t Q_k & Q_\lambda \le Q_k \\ L_{k2}^{\ \ t} = P_2^{\ t}(Q_\lambda - Q_k) & Q_\lambda > Q_k \end{cases} \qquad P_2^{\ t} = P_1^{\ t} + r(Q_\lambda - Q_k) \qquad (3)$$

L_k^t in the above formula represents the revenue of the power producer at time t, the P_1^t and P_2^t respectively represent the contract price and the outside contract price, and Q_λ and r respectively represent the actual electricity and the electricity coefficient. The benefit function of the power producer at time t is:

$$L_m(t) = \begin{cases} L_{k1}^{\ \ t} - Y_t(Q_k) - \beta Q_k & Q_\lambda \le Q_k \\ L_{k1}^{\ \ t} + L_{k2}^{\ \ t} - Y_t(Q_\lambda) - \beta Q_\lambda & Q_\lambda > Q_k \end{cases} \qquad (4)$$

$L_m(t)$ in the above formula is the benefit of the generator at time t, the $Y_t(Q_k)$ and $Y_t(Q_\lambda)$ respectively represent the cost function of the generator in the contracted electricity, and the cost function of the actual electricity of the generator. β, βQ_k, and βQ_λ respectively indicate the over-network coefficient, the over-network fee in the contracted power, and the over-net cost of the actual power.

2.3 Power user

In order to obtain normal living needs, users consume certain power products in daily life . The user's willingness to purchase electric energy is different in every period. The user's power consumption is generally reflected by the utility function. Here, $W(\varepsilon, X_t^c)$ is used to calculate the user's power utility, where ε , δ and ξ is the user's willingness to purchase electric energy, the user's psychological account, the electricity price elasticity coefficient, and X_t^c indicates the electricity load. Each person's psychological account, fairness theory, self-control, inter-temporal choice and saving behavior, lifestyle, personal anxiety and satisfaction, etc. It makes people produce different electricity consumption theories and choose different consumption periods. User's consumption of electric energy is a psychologically satisfying process. At the beginning, the utility gains will increase rapidly, but with time going by, the rate of increase will slow down until the utility reaches the maximum to match the user's psychological will. Therefore, three utility functions are used here to quantify the benefits of electricity use, $W(\varepsilon, X_t^c)$as follows:

$$W(\varepsilon, X_t^c) = \varepsilon (X_t^c)^2 - \delta (X_t^c)^3 \qquad 0 < X_t^c < \frac{2\varepsilon}{3\delta} \tag{5}$$

The total load of electricity used at the t moment is:

$$D = \sum_{t=0}^{24} X_t^c \tag{6}$$

The economic cost of electricity during this time is:

$$H_t^c = \xi P_\eta^t X_t^c \tag{7}$$

3. Mufti-layer interactive mechanism of real-time electricity price in smart grid

3.1 Generator model

Through feedback from power grid companies, intelligent interactive customer service platform, so that they make the electricity prices open and transparent. Its electricity price in the formulation, many aspects of influence are taken into account. The user receives the information of the real-time electricity price through the server, acquires the information of the electricity price in time, participates in the real-time electricity price interaction, selects a reasonable time period of electricity, increases the user undefined self-selection will, and improves the environment-friendly consciousness of the user. Due to the different power requirements of the users for each period, the real-time electricity price level for each time period of the next day is calculated through the balance of supply and demand and the cost of generating electricity, The real-time price for the next day is announced by the generator association at 5:00 p.m. every day. As a result, the benefit of the generator is a time-varying benefit function $S_m(t)$:

$$S_m(t) = \sum_{t=0}^{24} L_m(t) \tag{8}$$

3.2 User model of electricity

The smart grid provides users with real-time electricity price information through the server that helps to understand the power usage of each time period. You can get the total utility value $F_c^v(t)$ of the user at time by substituting all the parameters into the user utility function $W(\varepsilon, X_t^c)$.

$$F_c^v(t) = \sum_{t=0}^{24} \left(\varepsilon (X_t^c)^2 - \delta (X_t^c)^3 - \xi P_\eta^t X_t^c \right) \qquad 0 < X_t^c < \frac{2\varepsilon}{3\delta} \tag{9}$$

Therefore, the obtained model is a piece-wise function. We can use the computer to optimize and solve the model. The particle swarm algorithm is fast and efficient, and its operation is relatively simple and suitable for solving the model in this paper. The particle swarm algorithm is used to solve the model. During 24 hours in a day, we can find the time when the user is the most profitable by

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analyzing the value that was obtained. At this point, the model analysis of the power producer shows that the electricity price (that was obtained) is substituted into the power producer, and the profit of the power producer can be known.

4. Data analysis

According to the model proposed in this paper, we used MATLAB to carry out numerical simulation experiments on the model to verify the feasibility and effectiveness of the model. In the process of experimental simulation, the feasibility of verifying the model is carried out by observing the change of its value and the convergence efficiency. It is assumed here that n=10000 users, the purchase power of the bidding online contract is that $Q_0 = 10$ MW, the purchase price is that $P_1^t = 0.55$ yuan/kWh, the buying price is that $P_2^t = 0.64$ yuan/kWh, and the user's willingness ε to purchases randomly distributed within [4, 10]. The price elasticity coefficient is a uniform random distribution within [0, 1].

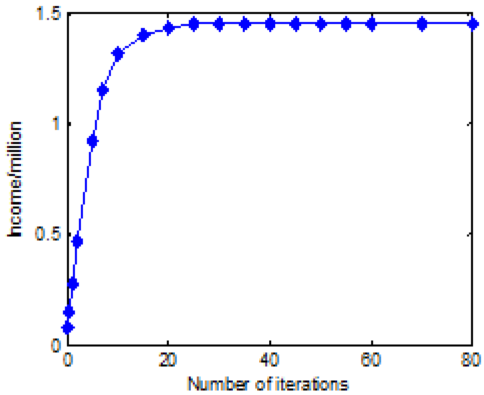

Fig.1.Iterative changes in the revenue of power producers

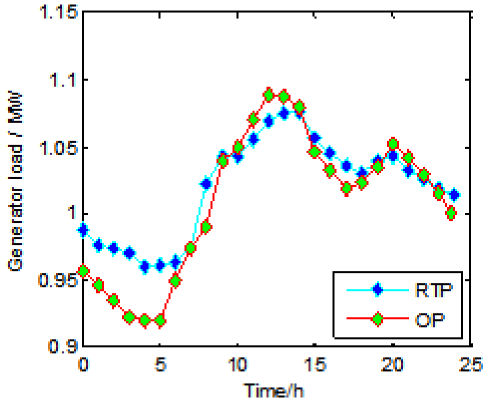

Fig.2.Power generator load change

As shown in Figure 1, It can be seen from the figure that the convergence speed of the particle swarm algorithm is still relatively fast, and it enters the convergence state during the 10th iteration. Therefore, the particle swarm optimization algorithm is effective and feasible for solving the model.

In Figure 2, according to the real-time electricity price model, it can be found that the real-time electricity price is relatively stable compared with the original electricity price. According to the change of the generator's daily load curve, the maximum load reduction and the minimum load increase can be found, and the load fluctuation is small, which reduces the daily load peak-to-valley difference.

The entire time period is set to 24 hours a day, and the situation in which the user uses electricity in one day and the change in the power supply load curve under the condition of different electricity prices are observed in T from (0, 24).

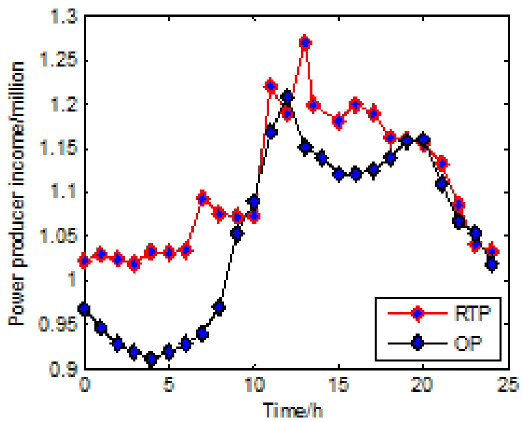

Fig.3.Changes in the income of power producers

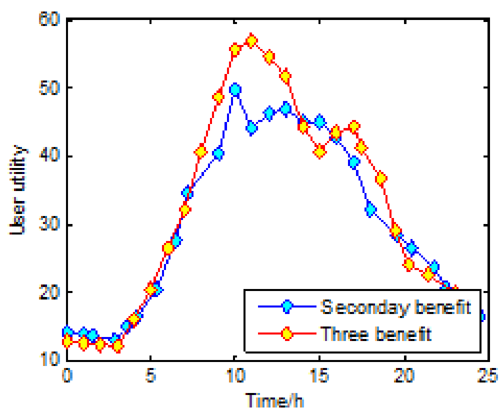

Fig.4.Changes in user power usage

As shown in Figure 3, due to the implementation of real-time electricity prices, there are different price elasticity of electricity in one day. According to the daily life arrangement, users can reasonably choose the period for electricity consumption. The dynamic adjustment of power resources by generators has enabled the rational use of electrical energy. Compared with the original electricity price, the generators' income is much higher than before.

Figure 4 shows that from the user's perspective, the improved model after the implementation of real-time electricity price policy, the power market price transparency was opened t o encourage users to actively participate in the regulation of the power market, increase the willingnes s of users to make their own choices, and improve users' awareness of savingand environmental protec tion. Under the real-time electricity price mechanism, users can timely purchase electricity and avoid the risk of power failure by timely understanding the electricity price and remaining electricity through smart meters and smart phones. In the meanwhile, by means of price elasticity lever, the peak period of electricity consumption is staggered, the supply and demand balance of the power market is adjusted, emission reduction and energy structure optimization, and the electricity benefits of users are improved.

5. Conclusion

In this paper, we combined with the direction of China's power market reform, studied the pricing mechanism of real-time electricity price in the future power market, and gave full play to the role of the power market under the economic lever of price. A good price mechanism can effectively alleviate the tension between power supply and demand, achieved energy conservation and emission reduction, improved production efficiency, and promoted economic growth. Under the real-time electricity price mechanism, the price of electricity fluctuates with time in a day, which can dynamically adjust the power in each region, play a role in cutting peak and filling valley, and reasonably optimize the source configuration. Through smart meters and smart phones, users can independently choose the time when they use electricity, and actively participated in the construction of smart grid so as to save energy and improve the benefits of users' electricity. Real-time electricity price can reflect the consumption situation of power resources dynamically, optimize the daily load curve of power, reduce the peak and valley difference of load, make the change of load curve more stable, reflect the demand response of users through the price mechanism, improve the stability and security of power system, and solve the power demand of each region dynamically. At the same time, we should make the electricity market price transparent, encourage users to save electricity and use electricity reasonably, and make the dividend of real-time electricity price benefit every power user.

Acknowledgments

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