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RESEARCH ARTICLE

Optimal Strategies of Power Generation Companies and Electricity Customers Participating in Electricity Retailing Trading

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ABSTRACT To reform the electricity selling trading and standardize the electricity retail market, the optimal participating strategies of power generation companies and electricity customers in an electricity retail market under the spot electricity market mode are investigated. First, the influence of the external environment on power generation companies is considered, the dispatching sequence of power generation companies is optimized, and the profit models of power generation companies and power retailers, as well as the utility model of electricity customers are built. Second, an improved genetic algorithm (IGA) is applied to solve the formulated optimal participating strategies model for power generation companies and electricity customers, and the effect of IGA is compared with that of traditional genetic algorithm (GA), simulated annealing (SA) algorithm and particle swarm optimization (PSO) algorithm. The simulation results show that the IGA algorithm has the advantages of fast convergence and saving electricity consumption in this paper. Finally, two examples are employed to demonstrate the feasibility and efficiency of the developed strategies. Both example 1 for presented method in this paper and example 2 for multiple retailers competing, the simulation results show that the interests of market competing entities (participants) can be well balanced. Furthermore, the advantages of power retailers acted as a guider in electricity retail market are revealed, and the credibility and security of the electricity market management system are maintained.

INDEX TERMS Electricity retail market, real-time pricing, electricity transaction, improved genetic algorithm, optimal strategies.

I. INTRODUCTION

An electricity retailer, referred to as a ‘‘market mediator’’, is the intermediary that purchases electricity from power generators and sells it to customers. Given the dynamic reform of the spot electricity market, electricity retailers' purchase and sales business are facing new challenges and opportunities. Thus, power generation companies and electricity customers should develop optimal participating strategies in electricity markets to maximize the profit and utility. Given this background, the electricity retail market, in which power generation companies and electricity customers, including renewable energy participate, is discussed, resource allocation is optimized by the corresponding policy of electricity supply and demand feedback [1].

Electricity retailers play an important role in the power market reforming, and their operational efficiency directly determines the success or failure of the market reform. However, electricity retailers face market risks owing to the uncertainty of electricity demand and prices, thus, they need to optimize market behavior to protect their own interests [2]. In short, electricity retailers represent the electricity cus-

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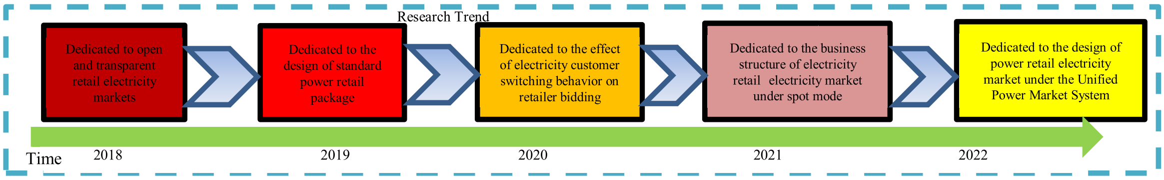


FIGURE 1. Research based on the electricity retail market in recent years.

tomers, who participate in the market according to a certain trading mode and reap profits from the price difference [3]. Based on the characteristics of electricity customers and the multi-attribute utility of the price package, a hybrid retail price package is proposed [4]. TABLE 1 shows some of the retail package models currently being implemented in Shanxi, China.

TABLE 1. Electricity retail packages currently being implemented in Shanxi, China [5].

Serial number	Type of retail package	Formula
1	Fixed electricity price	Retail electricity price = Fixed electricity price
2	Time-of-use pricing	Time-of-use price = Fixed electricity price
3	The price difference	Retail electricity price = Benchmark coal price-(Benchmark coal price-The average transaction price of the corresponding transaction type of the power selling company in the wholesale market)×Prorated retailing electricity customers
4	Fixed electricity price+ The price difference	Retail electricity price = Fixed electricity price-(Fixed electricity price-The average transaction price of the corresponding transaction type of the power selling company in the wholesale market)×Prorated retailing electricity customers

Electricity retailers are the link that connects the end electricity customer directly to the power consumption channel. Under the condition that the price of electricity is liberalized, electricity retailers purchase electricity directly from the generation end and resell it to the consumer, therefore, retailers should make reasonable power purchase and price decisions. Electricity pricing refers to the process of charging consumers for electricity. Further, electricity prices play a crucial role in the electricity retail market, and there are a major factor influencing consumer decision making [6]. Real-time pricing is an important method of demand-side control [7], which can effectively realize demand-side control and guide consumers to use electricity more correctly and effectively [8]. The real-time electricity price can successfully adjust the supply and demand of electricity through the price mechanism and avoid the waste of electricity resources as much as possible. Meanwhile, the generation side can adjust the electricity price to encourage electricity customers to avoid excessive electricity consumption during peak periods and implement electricity storage during low periods, which can play the role of cutting down the peak and filling the valley [9]. In [10], a real-time pricing mechanism based on a bilevel programming model is presented for load stability. By examining the above literature, we summarized the main details of the studies in TABLE 2.

In addition, social welfare maximization should also be considered in this study. In [11], the alternative use of photovoltaic (PV) and thermal power is introduced in the real-time pricing model of social welfare maximization, but the trading entity does not involve the power generation company.

In [12], they established a social welfare maximization model for real-time pricing in a smart grid, which is a convex design with consumer power consumption as a decision variable and can be solved using a dual method, but the trading entity does not involve the electricity retailers. For electricity customer utility analysis, an online algorithm is described in [13], in which the customer's utility function is not disclosed. The electricity customer only needs to report their planned electricity consumption in real time according to different prices, then, the wholesale side provides the improved price according to the planned electricity consumption reported by the customer, and the price that both the customer and the wholesale side can agree on can be obtained by repeating this process, but the trading entity does not involve the electricity retailers.

TABLE 2. Real-time pricing research model.

Variables Used	Method	Results Achieved
Retailers' real-time electricity prices during peak and low hours[6]	Real-time pricing Stackelberg game decision	Retailers have the best returns
Virtual resistor [7]	Adaptive differential evolution algorithm	To minimize the total operating cost of DC micro-grid under real-time pricing
Electrical characteristics of electricity customers [8]	Real-time grid pricing model	Increasing total social welfare effectively

Owing to the uncertainty of PV power output, the power system operation has a certain fluctuation; according to the traditional deterministic analysis, it will also have a certain error. Therefore, a study [14] presented a short-term decision-making model based on bilevel stochastic programming for power retailers that ensures optimal decision-making for power retailers under different levels of risk aversion. In [15], the authors analyzed the price strategies of power retailers under different scenarios, which provided useful information for this study. But neither of the two above literature mentions the spot trading model.

The research focus of the electricity retail market in recent years is shown in Figure 1 [16], [17].

The latest literature research focuses on the following: in [18], a two-stage retail pricing strategy based on personalized demand response incentives is proposed for different electricity consumers, but the trading entity does not involve the power generation company. A recent study [20] proposed an incentive mechanism considering the government, retailers and residents. And monetary incentive and price incentive are discussed under the management of government and retailers, but the trading entity does not involve the power generation company, too. In [21], strategic market bidding analysis and resource bidding allocation technique are proposed in the spot market to maximize overall benefits. The difference from this paper is that our trading bodies and strategies are different. In [22], a new contract-based trading mechanism of power flexibility (FlexCon) between variable renewable energy producer and an electricity retailer is presented when considering uncertainties. The proposed mechanism is managed by FlexCon operator (a new entity), and coordinate the transactions with the system operator. The difference from this article is that the competition among retailers is not taken into account.

The major differences between this study and the existing publications are as follows: During the process of electricity retailing trading, the power generation company participating in the wholesale market is considered in this study. However, in the existing electricity retail market, the main trading parties are electricity retailers and electricity consumers. According to quotations from the retailers, the revenue models of PV units and thermal power generators are built, and the modeling process is described. Then, the revenue model of electricity retailers under spot transactions is established, and the utility model of electricity customers is established using an improved genetic algorithm to determine the optimal level of customer consumption and provide feedback to the power generation enterprise. The novelty of this study is that the spot transaction model is integrated into the retailer transaction, and the improved genetic algorithm is adopted to obtain the electricity customer's optimal electricity consumption plan. The model solving method proposed in this study is applicable to the scenarios discussed in this study as well as to demand response and dynamic pricing, peer-to-peer electricity trading, electricity market including electricity storage, local market, distributed energy market, etc.

The contributions of this paper is that providing a new trading model for the existing electricity retail market, which can give retailers more decision-making power, while also allowing power generation enterprises to participate in electricity retail transactions and increasing their enthusiasm by getting their profits. For consumers, they can have more options for choosing packages and increase their engagement. Figure 2 is the diagram of general scheme. The relationship of power generation enterprises, electricity retailers and electricity consumers is as shown. The advantage of this study fully demonstrates the effectiveness of including power generators in the trading strategies of electricity retailer market under the spot environment, which try to balance the interests of all participants as possible as and contributes to the development of the retail electricity mark. It provides a certain basis for studying the new electricity retail market.

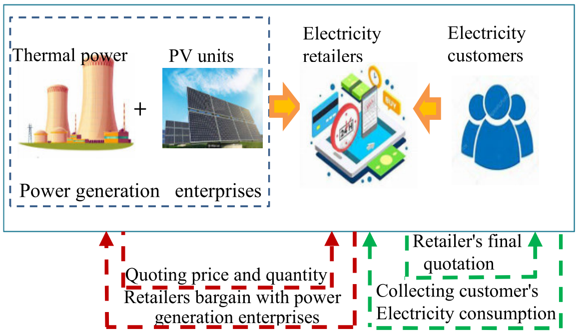


FIGURE 2. The diagram of general scheme.

II. MODELING OF TRADING SYSTEM

At present, the domestic electricity retail market mainly adopts the retail package model, and the market operation mechanism is not perfect. The operating mechanisms of foreign electricity retail markets mainly include setting up price comparison websites, setting up retail packages of fixed and variable rate, and consumers can choose different electricity selling companies. Market supervision is relatively complete, but no model has been proposed to allow power generation enterprises to participate in retail market transactions. The electricity retail market proposed in this study considers the participation of power generation enterprises of the wholesale market and coordinates the interests of multiple parties in the electricity retail market.

This paper mainly discusses the trading strategies of electricity retailers when power generation companies and electricity customers participate in the electricity retailing market. As a power generation company, it can take part in different market transactions, such as spot trading, ancillary service market trading, electricity retail market trading, etc. In this study, power generation enterprises mainly participate in electricity retail market transactions. Both thermal power generators and PV units are considered. Thus, in this section, to protect the interests of all parties involved in the transaction, the profit models of each transaction entity are developed.

A. THE OBJECTIVE FUNCTION

1) REVENUE MODEL OF PV UNITS

The revenue maximization problem of PV units is formulated as

$$\max Y_m = \sum_{t=1}^{T} (p_{t,m} q_{t,m} \Delta t - C_{t,m}) \tag{1}$$

where $p_{t,m}$ and $q_{t,m}$ are the quotations for the time period and the declared power plan, respectively, in the spot energy market made by the m PV enterprise according to the market information of the time period $t$provided by the retailer; $p_{t,m}$ can be calculated as shown in (2) and $q_{t,m}$ can be calculated as shown in (4); Δt represents the interval between t and (t-1) periods; $C_{t,m}$ is the power generation cost of the PV units during the t period and it can be calculated as shown in (5).

$$p_{t,m} = -k\hat{Q}^t + b \tag{2}$$

where k and b are the coefficients of the demand side curve, and $\hat{Q}^t$ is the power demand of the demand side, which can be calculated by (3) for time period t.

$$\hat{Q}^t = \tilde{\theta} Q^{t-1} + (1-\tilde{\theta})\bar{Q}^t \tag{3}$$

where $\tilde{\theta}$ is the weight distribution coefficient, Q^{t-1} is the power consumption of electricity customers during the (t-1) period and $\bar{Q}^t$ is the average power consumption of customers during the t period.

$$q_{t,m} = \tilde{q}_{t,m} + \delta_{t,m} \tag{4}$$

where $\tilde{q}_{t,m}$ is the expected output of the generator set m in time period t, and $\delta_{t,m}$ is the difference between the real output of the generator m and the expected output of the generator m in time period t.

$$C_{t,m} = a_{t,m}(q_{t,m}\Delta t)^2 + b_{t,m} q_{t,m} \Delta t + d_{t,m} + c_\varepsilon \rho_{t,m} \varepsilon_{t,m} \tag{5}$$

where $a_{t,m}$, $b_{t,m}$ and $d_{t,m}$ are the coefficients of power generation cost function when the values of PV units are greater than zero, and $c_\varepsilon \rho_{t,m} \varepsilon_{t,m}$ is the penalty cost when PV output is lower than expected.

2) REVENUE MODEL OF THERMAL POWER GENERATORS

The revenue maximization problem of a thermal power generator can be formulated as

$$\max Y_h = \sum_{t=1}^{T} (p_{t,h} q_{t,h} \Delta t - C_{t,h}) \tag{6}$$

where $p_{t,h}$ and $q_{t,h}$ are the quotation and generation output plan of the thermal power generator, respectively, for the time period based on the market information of the time period t provided by the retailer, and it can be calculated by (7); $C_{t,h}$ is the cost of the thermal power generator of producing electricity $q_{t,h}$ during the t period, and can be calculated by (8).

$$\begin{cases} p_{t,h} = -k\hat{Q}^t + b \\ q_{t,h} = \tilde{q}_{t,h} + \delta_{t,h} \end{cases} \tag{7}$$

The definition and calculation of variables in (7) are similar to those of PV units.

$$C_{t,h} = a_{t,h}(q_{t,h}\Delta t)^2 + b_{t,h} q_{t,h} \Delta t + d_{t,h} \tag{8}$$

where, $a_{t,h}$, $b_{t,h}$ and $d_{t,h}$ are the coefficients of power generation cost function when the values of thermal power generators are greater than zero.

3) REVENUE MODEL OF ELECTRICITY RETAILERS

When negotiating with power generation companies, electricity retailers need to determine the supply, demand, and income status. When the electricity supply exceeds the demand, the electricity price tends to decrease, and vice versa. During the period of T, the negotiated price difference between the electricity retailer and the power producer is shown in (9):

$$\begin{aligned} Bar(\sigma_1, \sigma_2) = {} & (Q_{t-1} - q_{t-1,m}\Delta t - q_{t-1,h}\Delta t)/\sigma_1 \\ & + (p_{t-1} q_{t-1,m}\Delta t + p_{t-1} q_{q-1,h}\Delta t - X_{t-1})/\sigma_2 \end{aligned} \tag{9}$$

where Q_{t-1} refers to the (T-1) time consumption of the total power consumption and total power purchase difference; X_{t-1} is the difference between the electricity sales revenue of the electricity retailer and the cost of purchasing electricity during the (t-1) period; and σ_1, σ_2 are the iteration step sizes.

At the base of Equation (9), the final electricity price of PV and thermal power companies are:

$$\tilde{p}_{t,m} = p_{t,m} + Bar(\sigma_1, \sigma_2) \tag{10}$$

$$\tilde{p}_{t,h} = p_{t,h} + Bar(\sigma_1, \sigma_2) \tag{11}$$

where $\tilde{p}_{t,m}$ and $\tilde{p}_{t,h}$ are the final prices of the PV and thermal power generators, respectively.

As an intermediate regulator, the electricity retailer buys electricity from the power generation enterprise by collecting the customer's electricity demand to maintain the balance of power generation and consumption. Under the condition of guaranteeing its own income, it maintains the balance of power supply and demand as well as the stable operation of the enterprise. The revenue is calculated as follows:

$$\max Y_L = \sum_{t=1}^{T} Y_L^t \tag{12}$$

$$Y_L^t(P^t) = P^t Q^t - (\tilde{p}_{t.m} q_{t,m} + \tilde{p}_{t.h} q_{t,h})\Delta t \tag{13}$$

where P^t and Q^t are the electricity price for electricity customers in the t-period and total electricity consumption, respectively; $Y_L^t(P^t)$ represents the retailer's revenue at time t, when the retailer's operating expenses are ignored and when the retailer offers a price for P^t to the electricity customers.

4) BENEFIT MODEL OF POWER ELECTRICITY CUSTOMERS

When an electricity retailer quotes a price, the electricity customers will determine how to maximize their own revenue (welfare) and ensure that the total electricity consumption is less than the total electricity purchase of the electricity retailer. Electricity consumption and social benefits for each electricity customer per day are calculated as shown in (14):

$$\max M = \sum_{t}^{T} (R(e_n^t, \alpha_n^t) - P^t Q^t) \tag{14}$$

where $R(e_n^t, \alpha_n^t)$ is the customer's benefit function for the t period.

The function can accurately express the variation in the customer's satisfaction with the consumption of electricity. In fact, there are many types of electricity customers; thus, to simplify the model, the power consumption scale of the electricity customer selected in this study is usually small:

$$R(e, \alpha) = \begin{cases} de - \frac{\alpha}{2}e^2, 0 \le e \le \frac{d}{\alpha} \\ \frac{d^2}{2\alpha}, e > \frac{d}{\alpha} \end{cases} \tag{15}$$

where e is the amount of electricity consumed, and $d$is the customer's satisfaction with the electricity consumption. The parameter α is a coefficient of the electricity customer benefit function. The smaller the value, the more benefits can be obtained when the customer increases electricity consumption. It can be set according to the satisfaction degree of the electricity customer.

B. CONSTRAINTS

1) The constraint of the difference between the actual and expected output of PV modules:

$$-a \le \delta_{t,m} \le a \tag{16}$$

2) Power supply and demand balance constraints in any time period t:

$$(q_{t,m} + q_{t,h})\Delta t = Q^t \tag{17}$$

3) The restriction of the electricity consumption cost paid by the electricity customer:

$$0 \le P^t Q^t \le E^t \tag{18}$$

where E^t is electricity customers in the t-time electricity cost forecast value, in case the electricity cost is considerable high and destroys the order of the electricity market. It can be expressed as shown in (19).

$$E^t = [\tilde{\theta} Q^{t-1} + (1 - \tilde{\theta})\bar{Q}^t]\bar{p} \tag{19}$$

where $\bar{p}$ is the base price, $\tilde{\theta} \in [0, 1]$ is the weight, Q^{t-1} is the total power consumption of all electricity customers during the (t-1) period and $\bar{Q}^t$ is the average power consumption of all electricity customers during the t period in history.

4) The electricity customer's power consumption constraint in any time period t:

$$(1 + B\%)Q^t \le (q_{t,m} + q_{t,h}^{\max})\Delta t \tag{20}$$

where $B\%$ is the required rotation or standby power at peak load, and $q_{t,h}^{\max}$ is the maximum output power for the PV unit in t period [18].

III. MODEL SOLVING

A. SYSTEM POLICY

A simple trading system is composed of power generation companies, power retailers and customers, with the trading procedure shown in Figure 3.

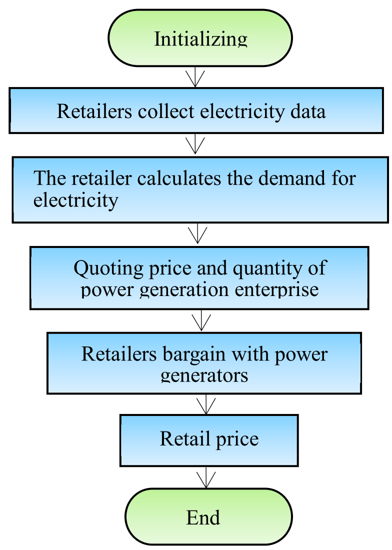


FIGURE 3. Flow chart of system operation strategy.

The operation strategy is as follows:

1) Electricity retailers calculate the demand value Q^t of electricity according to the consumption of electricity Q^{t-1} at time (t-1) and the average consumption of electricity $\bar{Q}^t$ at time t. During the period of PV working hours, PV power generation is prioritized, using thermal power enterprises for supplementary power generation. Thermal power is the main source of power generation in the off-duty period of PV, that is, PV enterprises report electricity prices and quantities to electricity retailers first, and then thermal power companies quote according to the demand value of electricity consumption.

2) The electricity retailer and the power generation enterprise negotiate the price and obtain the power generation enterprise's final quotation.

3) Power retailers determine the price of electricity.

4) Calculate the benefit of power generation enterprises, power retailers and customers.

The demand side algorithm chooses the improved genetic algorithm, which can converge rapidly, and use the selection operator in the genetic algorithm based on the optimal preservation strategy; therefore, the damage to the population diversity is reduced when the optimal solution is sought to achieve multi-objective optimization.

B. ELECTRICITY CUSTOMER OPTIMAL POWER CONSUMPTION PLAN BASED ON IMPROVED GENETIC ALGORITHM

The genetic algorithm is used to identify the optimal solution by simulating the natural development process [22]. The approximate process includes population initialization, coding, computing fitness and genetic operation.

To reduce the complexity of the algorithm time, the genetic algorithm is improved in this study. The flow of the electricity customers' optimal power consumption plan based on the improved genetic algorithm (IGA) is shown in Figure 4.

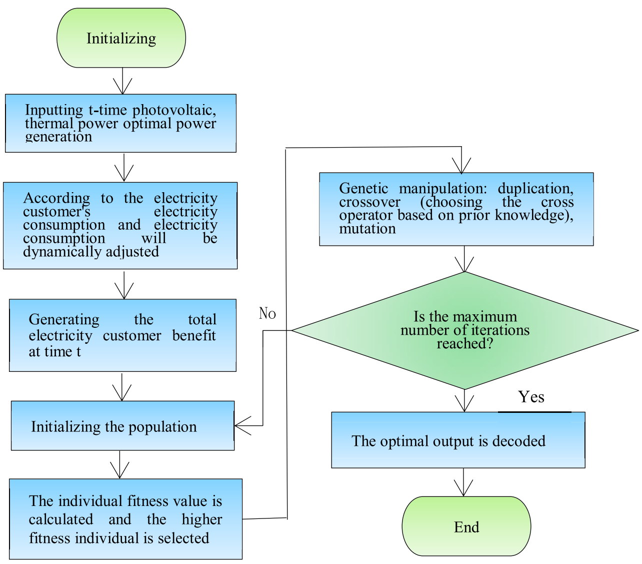


FIGURE 4. Flow chart of electricity customer optimal power consumption plan based on improved genetic algorithm.

Operations to improve genetic algorithms include:

1) Initialization. First, the maximum number of iterations I, population size S, mutation probability p_{m} and crossover probability p_{c} are defined.

2) Choosing. In this process, individuals with higher fitness will be selected, while the remaining individuals will be cross-bred and mutated to produce the next generation. Therefore, the new individuals selected by the improved genetic algorithm will have the highest fitness. The algorithm completes the individual selection by roulette, and the probability of selecting individuals to recombine is closely related to their fitness.

3) Crossover operator. The improved genetic algorithm uses the crossover operator based on prior knowledge to realize the crossover operation. The individuals selected from their parents in the selection stage are more adaptive.

4) Variation. The mutation operation can enhance its overall search ability as well as its gene mutation ability. The application of mutation operation based on the idea of population segmentation can improve the goal and direction during mutation, while ensuring the authenticity of chromosome mutation.

When the fitness of the optimal individual in a continuous group is constant or the maximum number of iterations reaches the desired value, the optimal result will be output, that is, the optimal electricity consumption plan of the electricity customer under the social welfare maximization [24].

IV. NUMERICAL RESULTS

In this section, first, we assume that all retailers in the retail electricity market adopt the strategy proposed in this study; retailers act as market guiders and power generators and customers as participants in designing the price setting for these electricity retailers. Second, considering that there are also electricity retailers with different pricing strategies in the actual electricity market, this section adds retailers with different pricing strategies and analyzes the revenue in this state. The following two sets of electricity market simulation examples are designed in this section:

Example 1: Considering power generators and electricity customers, only one retailer using the strategy presented in this paper is considered.

Example 2: Adding four retailers at the base of Example 1, where Retailer 2 uses the strategy proposed in this paper for pricing.

A. PARAMETER SETTINGS

The electricity retail market adopted in this paper includes retailers, generators and customers, where generators mainly include PV and thermal power.

In Experiment 1, the number of customers is 40, and all customers are supplied by the retailers described in this paper. In Experiment 2, the number of customers is set to 120, the reason is that the retailers with other pricing strategies are added to compete. The initial number of customers for each retailer is 24 and all customers change their electricity retailers quarterly based on quantified customer benefits. The benefits of each body in the retail market are counted for one year.

The operation period of the simulation system is divided into T time periods, setting $t = 1,2,\ldots,T$, $t \in T$, $T$is the set of all time periods, and each time period is set to one hour.

1) PV forecast power generation

In this calculation example, the power generation of PV is forecasted by historical electricity customer electricity consumption, and the PV power generation is shown in Figure 5.

Figure 5 illustrates that the predicted output of PV is relatively close to the actual one and can meet the required accuracy of the simulation.

2) Relevant parameters in mathematical model

In this paper, the following assumptions are made: the generation function coefficient is constant within 24 h, and the cost of PV power generation is higher than that of thermal power generation. The parameters are set as shown in TABLE 3 [14].

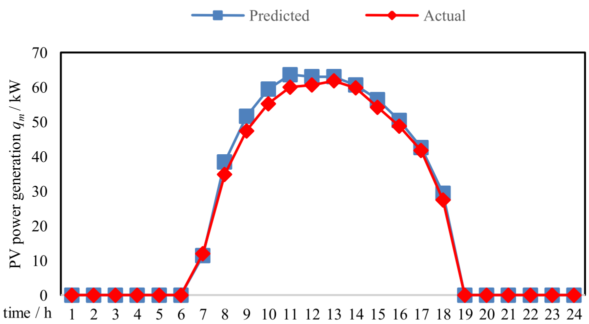


FIGURE 5. Predicted power generation on PV.

TABLE 3. System parameters.

Parameter	The Values
solar energy conversion efficiency μ	0.01
PV panel area SPV/m^2	60
coefficient of thermal power generation α_{th}	0.01
PV power generation coefficient α_{tm}	0.004
step length σ_1、σ_2	1000 1000
demand curve coefficient k	0.001
price compensation coefficient b	0.5
weight θ、$\tilde{\theta}$	0.5 0.5
deviation between actual output and predicted output	±20%
PV penalty coefficient C	12
rotational reserve rate $B\%$	12%
electricity customer satisfaction α	0.5
electricity customer will d	[5,6]
maximum number of iterations	100
population size	50

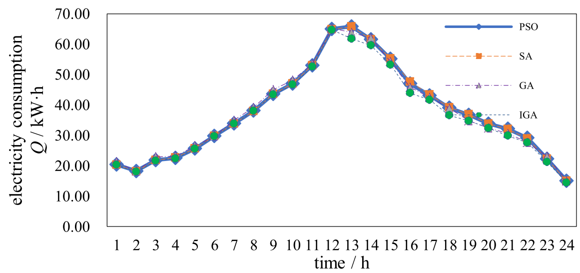
B. EXAMPLE SIMULATION

1) THE RESULTS OF THE ELECTRICITY REPORTING

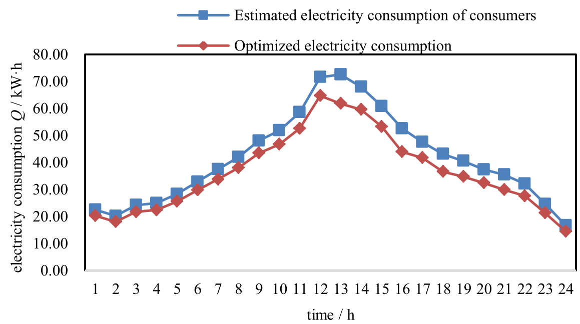
ARMA model is used to capture the linear trend of electricity customers in [25], while adopting the SVM model to predict its nonlinear law, and forecasts the power consumption of electricity customers. In this paper, IGA is mainly used to find the optimal electricity consumption of users, and in order to verify the effectiveness of IGA, simulated annealing algorithm (SA) and particle swarm optimization (PSO) are also used in this section as a comparison. The result of three optimal algorithms is shown in Figure 6(a). Through the comparison of multiple optimization algorithms, the convergence speed of IGA is the fast one and electricity consumption is relatively lesser. The predicted value of the user's electricity consumption and the optimal electricity consumption obtained by IGA optimization are shown in Figure 6(b), its optimal electricity consumption is generally smaller than the predicted value and which makes the user's own welfare is maximized. A PV power prediction algorithm is proposed in [26] based on the PSO-Soft attention bidirectional LSTM algorithm, the 24 h output of the PV and thermal power plants are shown in Figure 6(c). The graph shows that PV generation has time-sensitive, while thermal companies have a more stable and controllable power generation. When the conditions for PV power generation are met, the power output of the PV unit tends to increase, while coal-fired power generation companies reduce the power outputs. When the conditions for PV power generation are not met, the PV will not produce power outputs, while thermal power generators immediately increase power outputs to ensure the balance between power supply and demand.

2) SIMULATION RESULTS OF EXAMPLE 1

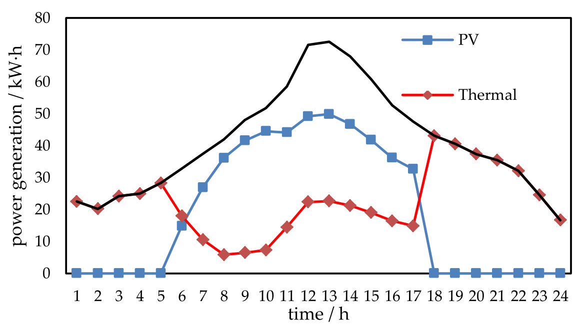
Figure 7 depicts the price of electricity sold by a power producer to a retailer and the price of electricity sold by a retailer to a consumer. Thus, the retail price is higher than the wholesale price, satisfying the retailer's revenue, to maintain a balance between the supply and demand of electricity, thus ensuring the stable operation of the market.



(a). Optimal consumer electricity consumption solved by different algorithm



(b). Estimated and optimal values of electricity consumption of consumers.



(c). PV and thermal power generation.

FIGURE 6. Results of power supply and demand.

At the price of electricity shown in Figure 7, the revenue of each member in the retail electricity market are shown in Figure 8. Figure 8(a) shows the day-to-day earnings of power generation companies, demonstrating a negative correlation

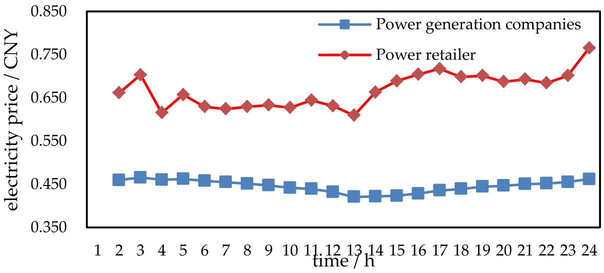


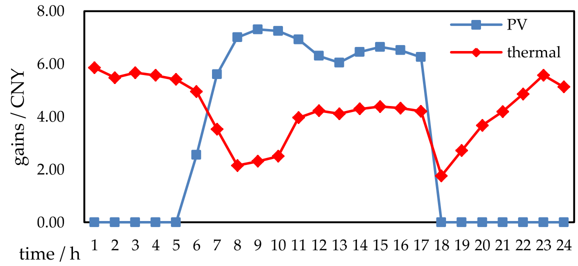
FIGURE 7. Wholesale electricity price of power generation companies and power retailers.

between the two types of power generation companies. Between 7:00 and 17:00 when solar power is booming, electricity retailers prioritize buying electricity from PV companies. Currently, solar revenues are higher than those of coal-fired power plants. In the remaining period, there is less or no solar power, which allows coal-fired power generation companies to increase sales, this time gaining more revenue. Figure 8(b) shows a positive correlation between generators' and retailers' earnings as electricity consumption increases. However, in the early stage of the income of power generation companies and retailers, when there is PV power, retailers' income reaches the highest, in line with the priority of the renewable energy demand. Figure 8(c) shows the relationship between the profits of PV companies, thermal power companies and retailers. The graph shows that thermal power companies have lower profits during the period when PV power is available. When PV power is not available, thermal power companies' profits increase. At this time, the revenue of electricity retailers increases first and then decreases. In the right-hand chart, the color band area represents the bottom-up, and the revenue increases as the color changes from dark blue to red. Figure 8(d) shows a graph of total benefits for retailers, power generators, and consumers. Furthermore, the graph shows that as the retailer's revenue increases, so does the power generator's revenue and the electricity customer's total benefit. The color band on the right side of the chart shows that as the color changes from deep blue to deep red, the benefits of retailers, consumers, and power generation companies will all increase.

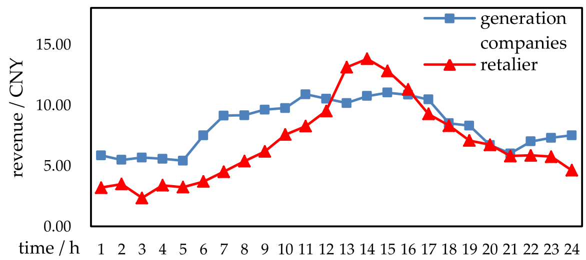
3) SIMULATION RESULTS OF EXAMPLE 2

After adding competing retailers 1, 3, 4 and 5, the average daily electricity prices of the power generation companies and each retailer over a year are shown in Figure 9.

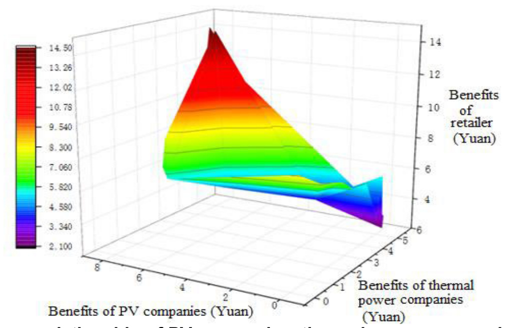
Among of them, retailer 1 adopts a fixed-margin pricing strategy, retailer 2 adopts the pricing strategy proposed in this study, and the price of retailer 3 is at the base of historical electricity consumption. Retailer 4, 5 adopt an electricity retailing model of multi-package, and they all have two available packages. Package 1 of Retailer 4 and 5 both use a fixed-margin pricing strategy which is similar to the retailer 1, but the price is slightly different from retailer 1. Package 2 of Retailer 4 is similar to the retailer 2, but the price is



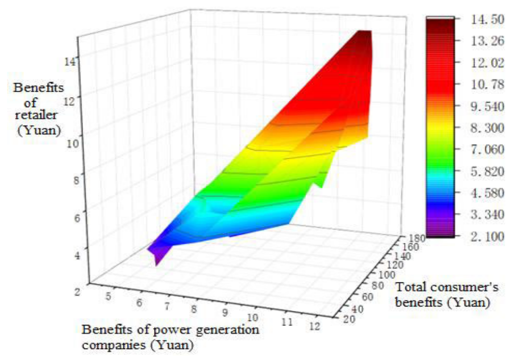
(a). Income of power generation companies.



(b). Revenue of power generation companies and retailers.



(c). Income relationship of PV companies, thermal power companies and retailers.



(d). Relationship diagram among total benefits of retailers, profit of power generation companies and total benefits customers.

FIGURE 8. Revenue of each member in the retail electricity market.

slightly different from retailer 2. Package 2 of Retailer 5 is similar to the retailer 3, but the price is slightly different from retailer 3. Overall, all the retailers are priced higher than the price of electricity purchased from the power generation companies.

At the end of each quarter, electricity customer's benefits are calculated under each retailer according to formula (14). Retailers who got higher electricity customer's benefits will be able to capture more customers in the next quarter. The

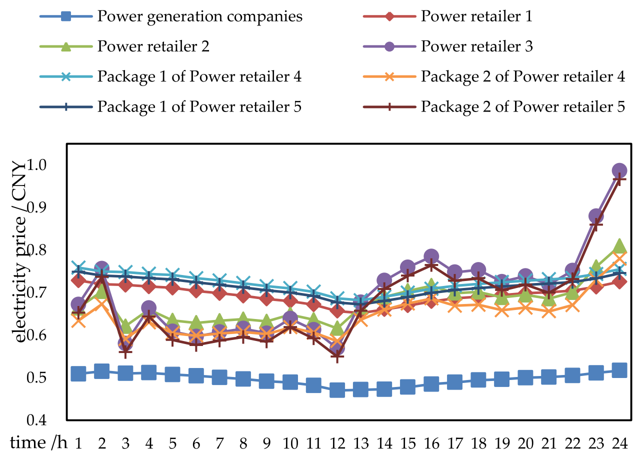


FIGURE 9. Prices of power generation companies and retailers in each period.

total electricity customers' benefits for each retailer over a year are shown in TABLE 4:

TABLE 4. Total benefits for electricity customers with different retailers in two quarters.

User benefits of different retailers	The 1st quarter (CNY)	The 2nd quarter (CNY)	The 3rd quarter (CNY)	The 4th quarter (CNY)
Retailer 1	45428	43525	39743	32208
Retailer 2	45799	49576	57105	74138
Retailer 3	45464	43590	39844	32220
Retailer 4	45683	47542	51281	57043
Retailer 5	45570	43711	39973	32336

Table 4 illustrates that the strategies proposed in this paper lead to more benefits for electricity customers. According to the total electricity customer's benefits in the previous quarter, the electricity customer's changing at the beginning of each quarter for each retailer are shown in Figure 10.

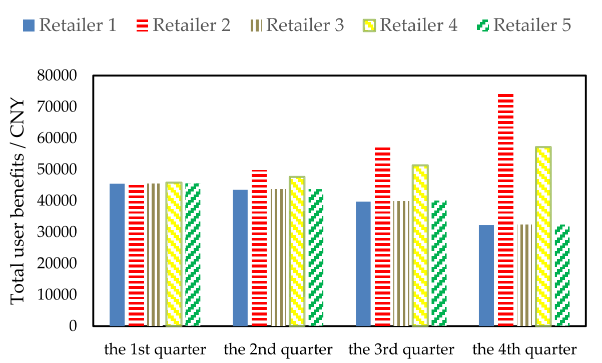


FIGURE 10. Changes in the number of customers for retailers at the beginning of the quarter.

In Figure 10, at the beginning of the second quarter, the customer's number of retailers 1, 3 and 5 decreased by one respectively, while the customers number of retailer 2 increased by two and that of retailer 4 increased by one. The third and fourth quarters were similar to the second quarter, but the customer numbers of retailers were different. By the end of the year, retail 2 had a total increase of 15 customers compared with the beginning of this year, while retailer 4 had an increase of 10 customers, and the customer's number of other retailers had decreased by 7. Figure 10 illustrates that the strategy adopted in this study can generate more revenue and get an advantage in the competitive market.

To further analyze the revenue of each retailer, Figure 11 represents the monthly revenue of each retailer.

In Figure 11, in the first and second quarters, the income gap between retailers is not large, but after the retailers adopted the strategy in this paper, which makes retailers 2 and 4 have an advantage in the future competition, so as to get more customers and bring more revenue.

This helped to obtain the research results shared in this paper. In [16], MSF is introduced to reflect the switching behavior of power electricity customers. With the increase in switching degree, the equilibrium retail price of retailer decreases, along with the abuse of market power, and the retail price is easier to determine. The retail price should be maintained a stable range: not too high or too low. The study in [3] established a robust pricing model to maximize the revenue of the retailer, guiding the electricity customers to use electricity in an orderly manner through price signals. In this study, the revenue of the retailer also considers the benefit function of the electricity customer to provide the customer with a reasonable electricity price and to ensure that they can make the most beneficial decision.

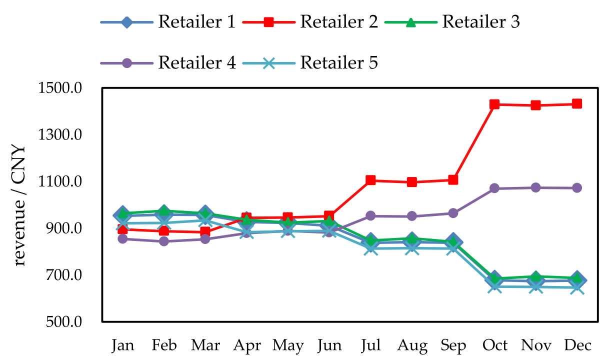


FIGURE 11. Monthly revenue of retailers.

V. CONCLUSION

A. CONCLUSION

This study discusses the strategy of power generation companies and consumers participating in retail trade in the spot market. In this study, the electricity retailers act as the guider in the retail market. On the premise of ensuring the maximum return, the electricity price is provided by the generation quantity and electricity consumption to guide the power generation companies to generate electricity rationally and the customers to use energy scientifically. Through the analysis of this study, the following conclusions are obtained:

1) This study selected two types of power generation companies. The PV power generation enterprise is affected by illumination, and thus its income is the highest when the power generation quantity is high between 7:00 and 17:00. Currently, the coal-fired power generation enterprise, as a supplement, has a lower income, but in the remaining period, the coal-fired power enterprise gains more when the PV power output is not generated.

2) When the PV and thermal power generation companies are considered as power generation companies, the revenue curve of the retailers aligns with that of the power generation companies, indicating that the retailers play a key role in market guidance.

3) When the income of the retailers increases, the income of the generation companies and the total welfare of the electricity customers also increase, and vice versa, which shows a certain proportional relationship between the three.

4) Using the improved genetic algorithm, the optimal value can be obtained to realize the electricity customer's optimal electricity consumption plan under the maximization of social welfare.

5) In a market with a competitive relationship, the strategy proposed in this study can gain more customers and bring more revenue because the retailer can coordinate both power generation companies and electricity customers.

Based on the above analysis, the optimal bidding mechanism and research strategy can be chosen by power generation companies, electricity customers, and retailers to ensure the balanced development of the interests of all parties in the spot market.

B. PROSPECTS

This is a retailer-led study that considers power generation companies and customers, and which does not contradict the current retail packages between retailers and customers. In the future, the revenue of retailers can be further refined based on the consideration of electricity customer's flexibility. Moreover, electricity customers should consider the corresponding strategy based on the cost of electricity customer's flexibility, and power generation companies can design suitable load flexibility products.

In a later market analysis, we will also examine the effect of the joint game behavior between electricity retailers on the competitive outcome. In addition, we will consider more electricity customer characteristics and the participation of power generation and energy storage enterprises to improve the trading competition mechanisms and strategies of all parties.

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