

Regional Power Market Impact in Competitive Power Market: A Case Study in Zhejiang

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Abstract. Along with the progress of the electricity market reform, the formulation of electricity prices and the bidding in the electricity market have become hot issues. Given that electricity price contains a variety of information in the electricity market and reflects market changes, insufficient understanding of electricity prices or improper response will not only affect the revenue of power supply companies, but also have adverse effects on consumers in the downstream of the electricity market. Taking Zhejiang Province as an example, this paper uses a Multi-objective optimization based on genetic algorithm to calculate the optimal power structure of Zhejiang Province under a competitive electricity market environment and evaluate the impact of the market. The results show that as the market reduces the transaction cost of purchased power, the purchased power to Zhejiang Province has a significant positive role in power cost, stability and cleanliness. The electricity cost could be cut down by 18.3 billion yuan, which is 0.04 yuan/kWh. In terms of cleanliness and stability of electricity consumption, the competitive electricity market will also bring about benefits by 2.43% and 1.64% respectively.

1 Introduction

Exploring the correlation between price and consumption in the electricity market is helpful to reveal the changing law of electricity price, which is an important signal of the market and a contributor to the formulation of bidding strategies for power plants[1, 2]. Establishing a competitive electricity market is also one of the goals of the new round of electricity system reform, while the wholesale power market is to further open up transmission services on the basis of the power generation competition, and is a method that allows big consumers and distribution utilities to participate in market competition. This transaction mode allows power generation companies to directly conduct transactions with distribution utilities and big consumer, greatly increasing the degree of competition in the power market[3, 4].

This paper uses a Multi-objective optimization based on genetic algorithm to calculate the optimal power structure of Zhejiang Province in a competitive electricity

market. On this basis, this paper further measures the impact of the competitive market on the power system.

1.1 Capacity and power generation status in Zhejiang province

From the 13th Five-Year Plan for Zhejiang's power development, by 2020, the power generation capacity is expected to reach about 94 million kilowatts, of which the thermal power, non-hydro renewable power, nuclear power, gas power, pumped storage, conventional hydropower and by-product heat and pressure power generation are 46.35, 13.10, 9.07, 12.50, 4.93, 7.04 and 1 million kilowatts respectively. According to the latest public data (Figure 1), thermal power still dominates, accounting for 74.4% in 2019, higher than the national average (69.6%), followed by nuclear power, accounting for 18.8%.

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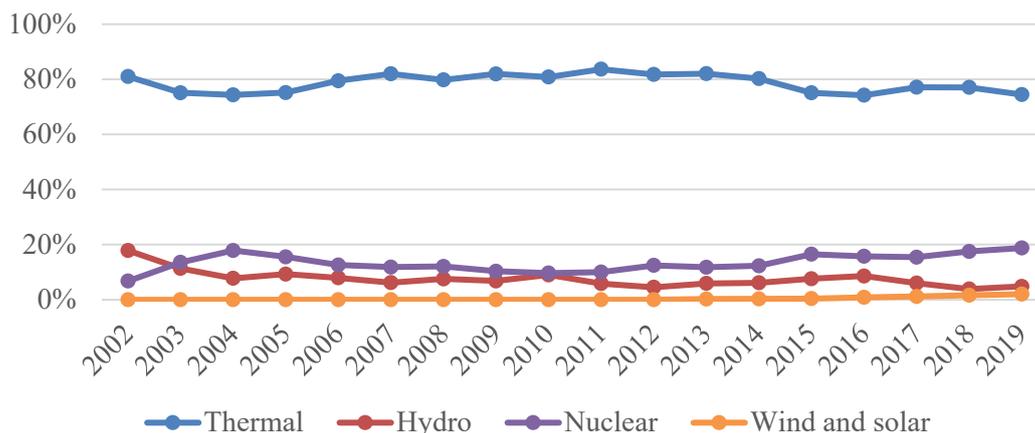


Figure 1. Power generation structure in Zhejiang Province (calculated by power generation).

According to the power balance plan of Zhejiang Province, in 2020, the province will arrange for 231.7 billion kWh of electricity generation, among which coal-fired, natural gas, nuclear power and hydropower is planned as 191.1, 15-20, 22.6 and 3 billion kWh respectively, wind power, photovoltaic and local power plants are arranged to generate electricity as 63.7 billion kWh.

1.2 The purchased electricity in Zhejiang

Zhejiang Province plans to purchase 160.5 billion kWh of electricity from other provinces in 2020, of which 32.6 billion kWh is from the Sanxia and Xiluodu hydropower station, 35.7 billion kWh is from East China Nuclear Power Plant, and these are arranged by the central government. The inter-governmental agreement arranged for 89.1 billion kWh, arranging Eastern Ningxia coal-fired

power units by 35-40 billion kWh, Anhui by 31.5 billion kWh, Sichuan hydropower by 6.6 billion kWh, Fujian by 3 billion kWh and Jiquan Direct current by 11.1 billion kWh.

From the perspective of supply structure, the power purchased from Sanxia, Xiluodu and Sichuan are hydropower; the power purchased from Eastern Ningxia and Anhui is mostly thermal power; the power from Qinshan and Fujian is nuclear power; the power from Xinjiang is a bundle of multiple resources. According to the generation capacity of Xinjiang announced in April this year (the ratio of thermal: wind:solar power is approximately 6:2:1), the power structure of Xinjiang’s power supply to Zhejiang can be roughly estimated, and the power structure of Zhejiang Province planned for 2020 is shown in Table 1. The main transmission lines are shown in Table 2, and the upper limit of the purchased power generation/transmission capacity is shown in Table 3.

Table 1 Power structure (billion kWh, 2020).

| | Coal-fired | Natural gas | Nuclear | Hydro | Wind, solar, et al. | Total |
|-----------|------------|-------------|---------|-------|---------------------|-------------|
| Generated | 191.1 | 15.0-20.0 | 22.6 | 3.0 | 63.7 | 295.4-300.4 |
| Purchased | 78.9 | | 38.7 | 39.2 | 37.0 | 160.5 |
| Total | 270.0 | 15.0-20.0 | 61.3 | 42.2 | 67.4 | 455.9-460.9 |

Table 2 Main transmission lines of purchased power.

| Source | Transmission Line |
|----------------------------|--|
| Sanxia and Xiluodu | ±800 KV Binjin Direct current |
| Qinshan Nuclear (Fangshan) | 500 KV high voltage transmission lines |
| Eastern Ningxia | ±800 KV Lingshao Direct current |
| Anhui | 1000 KV high voltage transmission lines |
| Sichuan Hydro | ±800 KV Yangzhong Direct current |
| Xinjiang | ±1100 KV high voltage transmission lines |
| Fujian | 1000 KV high voltage transmission lines |

Table 3 Upper limit of the purchased power generation/transmission capacity (billion kWh).

| Source | Upper limit | Method |
|----------------------------|-----------------------------------|---|
| Sanxia and Xiluodu | 28.5 (Planned Volume to Zhejiang) | Xiluodu has an annual generation of 57.1 billion kWh, of which 50% is transmitted to Guangdong and 50% to Zhejiang. |
| Qinshan Nuclear (Fangshan) | 51.7 (Total generation) | In 2019, the 9 units of Qinshan Nuclear Power generated a total of 51.778 billion kWh. |

| | | |
|-----------------|--------------------------------------|---|
| Eastern Ningxia | 50.0 (Transmission line restriction) | Lingshao ±800 kV DC allows for 50 billion kWh of annual electricity transmission. |
| Anhui | 50.0 (Transmission line restriction) | The power transmission from Anhui to Zhejiang allows for an annual transmission of 50 billion kWh. |
| Sichuan Hydro | 16.2 (Surplus hydropower) | In 2019, Sichuan “abandoned water” power was 9.2 billion kWh, and power transmitted to Zhejiang was 7 billion kWh |
| Xinjiang | 71.2 (Total delivery) | Power Transmission from Xinjiang was of 71.2 billion kWh in 2019 |
| Fujian | 43.5 (Total generation of nuclear) | The capacity is 8.71 million kW, with an average annual operating hours of 5000 hours. |

2 Electricity Cost Accounting in Zhejiang Province

2.1 Generating side electricity price accounting

The generating side electricity prices calculated from the power supply provinces reflect the generation cost of power sources, and then play a guiding role in the formation of future electricity market-oriented transaction prices. According to the latest electricity price supervision report "2018 National Electricity Price Regulatory Bulletin", the generating side prices are sorted out in Table 4 by various sources.

Table 4 Generating side prices sorted by sources (yuan/kWh).

| Type | Source | Price in 2018 |
|-----------|-------------|---------------|
| Generated | Coal | 0.4163 |
| | Nuclear | 0.9321 |
| | Natural gas | 0.4250 |
| | Hydro | 0.5668 |
| | Wind | 0.7334 |
| | Solar | 1.1336 |

| | | |
|-----------|---|--------|
| Purchased | Hydro (Sanxia and Xiluodu) ^a | 0.2783 |
| | Qinshan (Fangshan) | 0.3005 |
| | Anhui | 0.3828 |
| | Eastern Ningxia | 0.2487 |
| | Sichuan hydro | 0.2800 |
| | Xinjiang ^b | 0.3424 |
| | Fujian | 0.3725 |

a. As Xiluodu and Qinshan are national unified dispatching power plants, the prices are determined according to the tax-included generating side electricity price sent to Zhejiang in 2019

b. The price for electricity purchased from Xinjiang is calculated according to the weight of thermal, wind, and solar capacity, which is 6:2:1

2.2 Electricity demand forecast

According to the data in recent years, the electricity consumption in Zhejiang Province has been increasing year by year, but the power generation is relatively stable, and there is a trend of increasing gap between consumption and generation, as is shown in Figure 2.

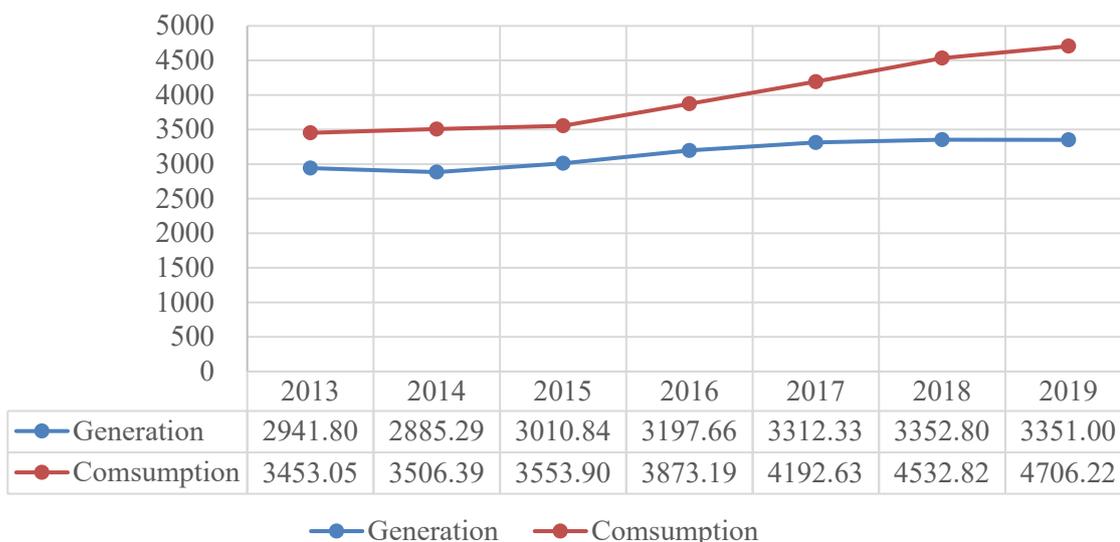


Figure 2. The power generation and consumption in Zhejiang Province.

From the perspective of electricity consumption structure (see Figure 3), in 2019, the proportions of electricity consumption by the primary, secondary and tertiary industries and residents were 0.44%, 70.71%, 15.23% and 13.62%, respectively, and the growth of electricity consumption was respectively -1.53%, 2.59%,

7.75% and 6.33%. Among them, industrial electricity consumption was 324.35 billion kWh, with an increase of 2.11%, accounting for 68.92%, among which the manufacturing industry consumed 271.74 billion kWh, with an increase of 2.62%.

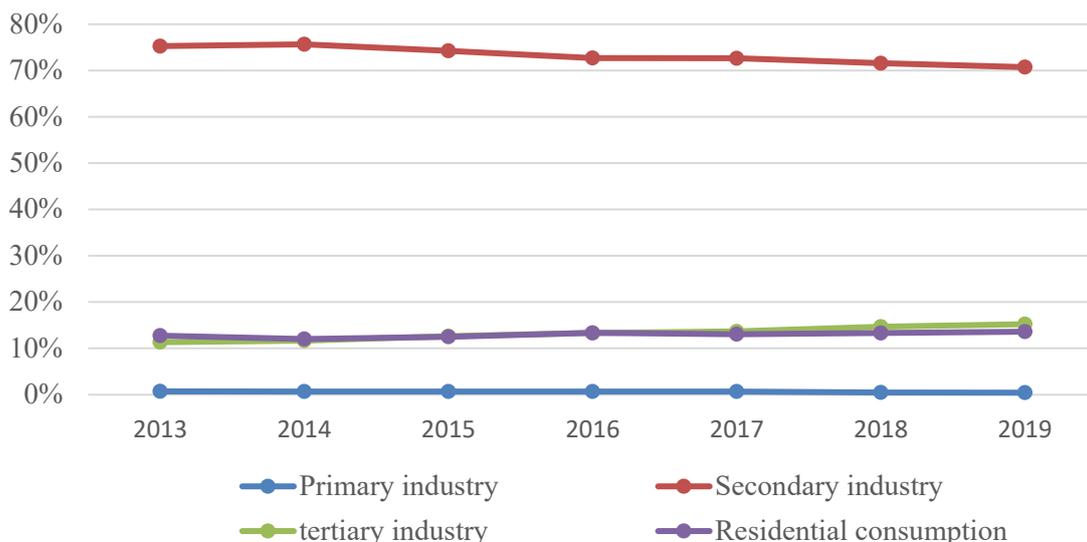


Figure 3. Electricity consumption structure in Zhejiang Province.

In 2019, GDP in Zhejiang actually increased by about 6.8%, and electricity consumption increased by 3.82%. With the GDP growth target of 6%-6.5%, in accordance with the electricity supply and consumption situation in the first quarter, it is estimated that the electricity consumption of the whole society will increase by 0%-1.5% for the year 2020 under normal climatic conditions, and the electricity consumption of will be 470.6- 477.7 billion kWh, the maximum load is about 91 million kW, with an increase of 6.9%.

From the perspective of power supply, the implementation of purchased power resources this year is relatively good, but the province's new installed capacity is insufficient, and the controlled coal constraints will affect the power generation of coal-fired units in the province and the Yangtze River Delta. In general, the power balance in peak season will be tightened this

summer, and there will still be a certain gap. In the event of extreme weather, there may be a gap in power supply and demand.

3 Optimal power structure model of Zhejiang province considering extraneous electricity shock

3.1 Multi-objective optimization model

In this part, we try to use the multi-objective optimization model to analyze the optimal power structure of Zhejiang province in the case of a perfect competition power market in the future. The core issues to be addressed in this paper are shown in figure 4.

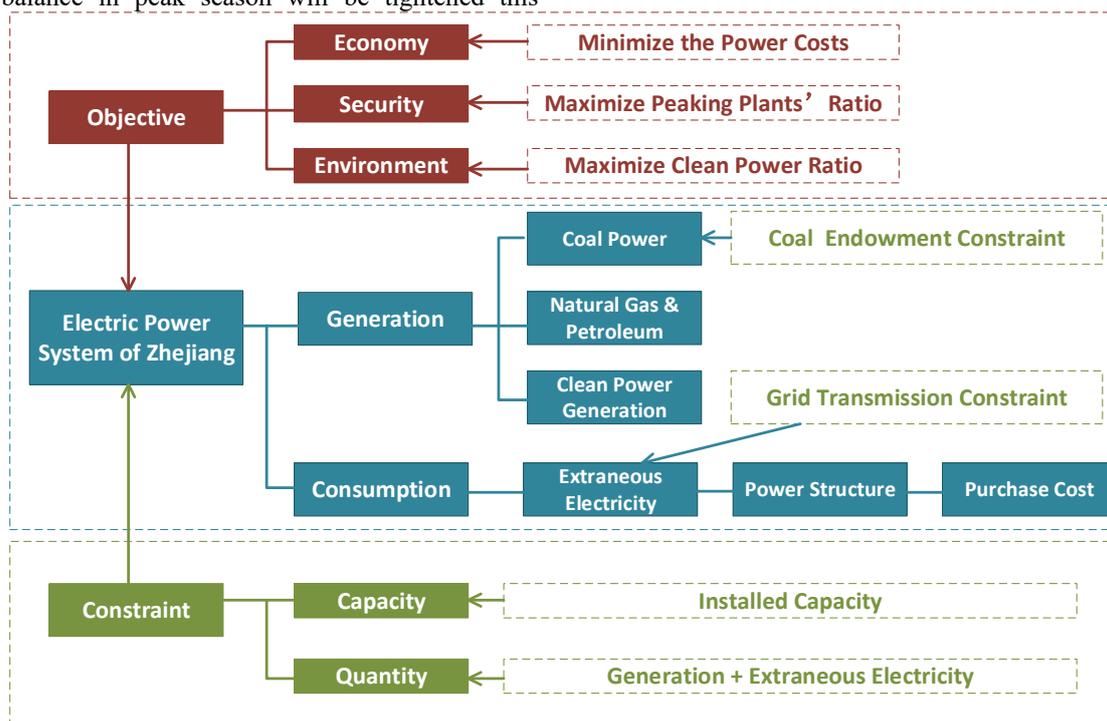


Figure 4. Multi-objective optimization problem.

A multi-objective optimization problem refers to the problem with two or more objectives. For Zhejiang province's power system, the goal to be achieved could be described from three dimensions. The first is economy, that is, under the condition of the entire competition power market, the power source can choose to produce within the province and purchase power externally. The primary goal is to minimize the cost of electricity consumption, and the competitive power market also provides a foundation for the realization of this goal. The purpose of the second dimension is safety. Thermal power units have a strong peak regulating capacity, stable supply, and high-power quality (Anuj et al, 2017; Usama et al, 2016). To maintain the safety and stability of Zhejiang's electric power system, it is necessary to maximize the proportion of adjustable peak thermal power produced in Zhejiang province. The third-dimension target is the environment, which becomes increasingly polluted as the economy improves. Zhejiang has always been the province with the most emphasis on environmental protection, the strictest environmental protection standards, and the complete ecological monitoring. Therefore, the goal of the third dimension requires that the proportion of clean energy electricity be as high as possible.

From the perspective of constraints, the most important limitation is the electricity constraint, that is, the sum of the generated and extraneous electricity should meet the primary electricity demand of Zhejiang province. In terms of other restrictions, self-generated thermal power within the province should meet the constraints of coal resource endowment (including transportation conditions), and the extraneous electricity quantity should meet the limit constraint of network planning channel capacity.

The optimal power structure model of Zhejiang province adopted in this paper can be expressed in the following formula.

Object:

$$\min \sum_{i=1}^{10} P_i * X_i \quad (1)$$

$$\max (X_1 + X_2) / \sum_{i=1}^{10} X_i \quad (2)$$

$$\max (X_3 + X_4 + X_5 + X_8 + X_9/3 + X_{10}) / \sum_{i=1}^{10} X_i \quad (3)$$

Subject to:

$$a * X_1 \leq b \quad (4)$$

$$X_i \leq c_i, i = 4,5, \dots, 10 \quad (5)$$

$$\sum_{i=1}^{10} X_i \geq d \quad (6)$$

$$X_i \leq e_i, i = 1,2,3 \quad (7)$$

Among them, X_1 , X_2 and X_3 respectively represent the generation of coal power, natural gas and clean energy in Zhejiang province. X_4 , X_5 , X_6 , X_7 , X_8 , X_9 and X_{10} are the purchased electricity quantities from different sources, which respectively represent the three Gorges Project, Xiluodu trans-regional hydropower Station, East

China Unified nuclear Power Station, Anhui Power Station, Ningdong Power Station, Zhejiang Coal Power Station, Sichuan Hydropower Station, Jiquan Direct Current power Station, and Fujian Nuclear Power Station summarized above. And P_i corresponds to the price of each power source. a is Zhejiang province's average coal power generation efficiency, and b represents for coal resources endowment. Formula (5) is to express the electricity transmission constraints, and c_i is the corresponding measure of the power grid. Formula (6) expresses the electric quantity constraint, and the sum of production and purchased electric quantity is not less than the electricity demand. Formula (7) represents the installed constraint of self-generated electricity, that is, the power generation within the province cannot exceed the installed power generation at full load. By solving this problem, the optimal power structure of Zhejiang province can be estimated under the condition of perfect power market competition.

3.2 Multi-objective optimization based on genetic algorithm

The essence of the traditional multi-objective optimization method is to transform each sub-objective function into a single objective function after processing or mathematical transformation. And then solve the problem by using single-objective optimization technology[5]. A multi-objective optimization algorithm can find the most reasonable and reliable solution from all possible solutions. Traditional multi-objective optimization methods include the evaluation function method, interactive programming method, and hierarchical solution method.

Genetic algorithm (GA) can simultaneously search a large number of feasible solutions in the whole space in parallel, overcoming the dilemma that traditional methods may converge to local optimal[6]. Using GA to solve the practical solution set of the multi-objective optimization problem is an effective means[7].

According to Knowles & Corne[8], the main steps of the underlying genetic algorithm adopted in this paper are shown in figure 5. Firstly, an initial population with a certain length is randomly generated. Secondly, the iteration of the string population is performed to calculate the adaptive value, and chromosome replication, crossover, and mutation are performed to produce the next generation population. Next, the best individual string that occurs in any generation is specified as the result of the algorithm's execution. Finally, after a given genetic algebra, all the execution results are compared to obtain the optimal one as the solution to the optimization process.

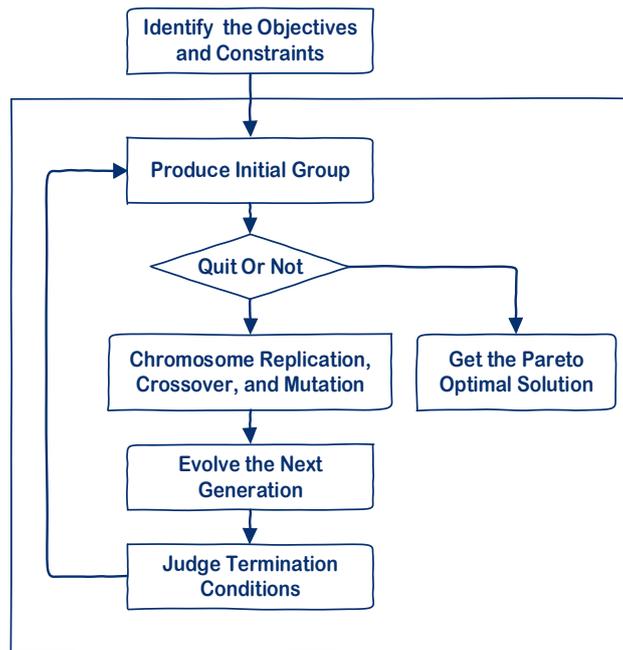


Figure 5. A genetic algorithm for optimizing multi-objective problem

As mentioned above, the specific set of model parameters in this paper is shown in table 5.

3.3 Multi-objective optimization model

Table 5. Model parameter setting

| Symbol | Implication | Value | Symbol | Implication | Value |
|----------|---------------------------|------------------|----------|---------------------------|----------|
| P_1 | Coal | 0.4163 yuan/ KWh | d | Power demand | 480 GWh |
| P_2 | Gas | 0.4250 yuan/ KWh | c_4 | Trans-regional hydropower | 28.5 GWh |
| P_3 | Clean enery | 0.8636 yuan/ KWh | c_5 | East China nuclear power | 51.7 GWh |
| P_4 | Trans-regional hydropower | 0.2783 yuan/ KWh | c_6 | Anhui electricity | 50 GWh |
| P_5 | East China nuclear power | 0.3005 yuan/ KWh | c_7 | Ningdong Power | 50 GWh |
| P_6 | Anhui electricity | 0.3828 yuan/ KWh | c_8 | Sichuan Hydropower | 16.2 GWh |
| P_7 | Ningdong Power | 0.2487 yuan/ KWh | c_9 | Jiquan power | 71.2 GWh |
| P_8 | Sichuan Hydropower | 0.2800 yuan/ KWh | c_{10} | Fujian Nuclear Power | 43.5 GWh |
| P_9 | Jiquan power | 0.3424 yuan/ KWh | e_1 | Coal capacity | 46.35 MW |
| P_{10} | Fujian Nuclear Power | 0.3725 yuan/ KWh | e_2 | Gas capacity | 12.5 MW |
| a | Coal power efficiency | 296.50 Gram/ KWh | e_3 | Clean capacity | 29.64 MW |
| b | Coal consumption | 74 million tons | | | |

The multi-objective optimization model based on genetic algorithm was calculated by R 4.0.2 software. The optimal power structure of Zhejiang province under the

competitive power market environment is shown in table 6.

Table 6. Optimal power structure in Zhejiang province under competitive power market environment (GWh)

| | Power Source | Optimal Power | proportion of electricity | Planning power | proportion of electricity |
|------------------------|---------------------------|---------------|---------------------------|----------------|---------------------------|
| Internal generation | Coal | 221.9 | 46.21% | 191.1 | 41.92% |
| | Gas | 5.6 | 1.17% | 17.5 | 3.84% |
| | Clean enery | 48.3 | 10.06% | 89.3 | 19.59% |
| Extraneous electricity | Trans-regional hydropower | 12.8 | 2.67% | 32.6 | 7.15% |
| | East China nuclear power | 55.8 | 11.62% | 35.7 | 7.83% |
| | Anhui electricity | 49.5 | 10.31% | 31.5 | 6.91% |
| | Ningdong Power | 3.8 | 0.79% | 37.5 | 8.23% |
| | Sichuan Hydropower | 11.5 | 2.39% | 6.6 | 1.45% |
| | Jiquan power | 46 | 9.58% | 11.1 | 2.43% |

| | | | | | |
|-------|----------------------|-----|-------|-------|-------|
| | Fujian Nuclear Power | 25 | 5.21% | 3 | 0.66% |
| Total | | 480 | | 455.9 | |

As can be seen from the calculation results, under the competitive power market environment, the proportion of coal power in Zhejiang province will increase slightly, and the percentage of clean energy generation will decrease, and external power will be purchased. In particular, external clean energy electricity, which is also a major change after extraneous electricity entered the market competition. In terms of the proportion of extraneous electricity, planning purchased electricity of Zhejiang province only accounts for 34.66%. In contrast, in the optimal power structure under perfect competition, the ratio reaches 42.57%, an increase of nearly eight percentage points. The purchased clean electricity increased significantly. Under the original plan, the total

purchased clean electricity was 89 GWh, while in the optimal structure, the purchased clean electricity exceeded 150 GWh. This is mainly because of the clean power generation in Zhejiang province comes mostly from nuclear power, and the cost is relatively high. Low-cost hydropower accounts for a relatively high proportion of outsourced clean electricity, so the enhancement of electricity market competitiveness provides a basis for cost-saving and electricity cleaning.

Furthermore, we investigate the changes in electricity cost of Zhejiang province under the competitive power market environment, and the calculation results are shown in table 7.

Table 7. Evaluation of the competitive power market impact

| Indicator | Optimal Power | Planning power | Adjusted planning power | Impact 1 | Impact 2 |
|---------------------|---------------|----------------|-------------------------|----------|----------|
| Cost (billion yuan) | 204.99 | 212.067 | 223.30 | -7.09 | -18.32 |
| Clean (%) | 41.54% | 39.11% | 39.11% | 2.43% | 2.43% |
| Stability (%) | 47.40% | 45.76% | 45.76% | 1.64% | 1.64% |

The second column in the table is the calculated optimal power structure, and the third column is the initially planned power quantity. The total amount of planned power initially is about 455.9 GWh, which cannot meet the 480 GWh primary power demand of Zhejiang province. Therefore, it is adjusted from the original structure, and the specific values are shown in the fourth column of table 7.

As can be seen from the results in the table, when the power market is in a perfect competition environment, it will bring three benefits to the power system of Zhejiang province. First, the cost of electricity is the most straightforward. Compared with the original plan, the electricity cost could be saved by about 18.3 billion yuan. Calculated according to per KWh, under the optimal structure, the cost is 0.4270 yuan/KWh, while under the planning, the cost is 0.4652 yuan/KWh. Therefore, the competitive power market will lead to a lower transaction cost of extraneous electricity, which will bring a reduction of 18.3 billion yuan of electricity cost in Zhejiang province and saving of 0.04 yuan per KWh. Moreover, in terms of electricity cleanliness and stability, the competitive electricity market will bring 2.43% and 1.64% improvement, respectively.

4 Conclusions and policy recommendations

Taking Zhejiang province as an example, this paper uses the multi-objective optimization model based on genetic algorithm to calculate the optimal power structure under the competitive power market environment. Compared with the original plan, the proportion of coal power

generation in the province has been slightly increased, while clean energy generation has been slightly decreased. However, the proportion of purchased electricity increased significantly. In the original plan, the proportion of purchased electricity was only 34.66%, while in the optimal power structure under perfect competition, the proportion of purchased electricity reached 42.57%, an increase of nearly eight percentage points. In particular, the proportion of extraneous clean electricity significantly increased.

However, the proportion of clean energy generation will decrease, and extraneous power will be purchased. In particular, external clean energy electricity, which is also a major change after extraneous electricity entered the market competition. In terms of the proportion of extraneous electricity, planning purchased electricity of Zhejiang province only accounts for 34.66%, while in the optimal power structure under perfect competition, the ratio reaches 42.57%, an increase of nearly eight percentage points. Under the original plan, the total purchased clean electricity was 89 GWh, while the purchased clean electricity in the optimal structure exceeded 150 GWh. This is mainly because of the clean power generation in Zhejiang province mainly comes from nuclear power, and the cost is relatively high. Furthermore, we investigate the changes of electricity cost of Zhejiang province under the competitive power market environment. From the results, we can see that the competitive power market environment directly reduces the transaction cost of purchased electricity [9, 10]. As a result, it has a significant positive effect to Zhejiang power system in terms of electricity cost, electricity stability, and cleanliness. Firstly, it will bring a reduction of 18.3 billion yuan of electricity cost in Zhejiang province and saving of

0.04 yuan per KWh. Moreover, in terms of electricity cleanliness and stability, the competitive electricity market will bring 2.43% and 1.64% improvement, respectively.

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