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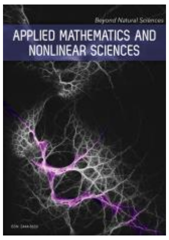

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Study on Optimization of Electricity Market Mechanism and Enhancement of New Energy Consumption Capacity

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Abstract

Under the background of "double carbon" goal and accelerating the construction of national unified power market system, new energy consumption and regional power market construction have become a research hotspot. Based on the trend of new energy development in China, this paper constructs a new energy consumption impact analysis model based on system dynamics. Based on the key factors affecting new energy consumption, we introduce the model of inter-regional contact line trend dispatchability to optimize the trading framework of the two-level power market, and finally put forward a two-layer optimization model of the market to promote new energy consumption. Based on the actual data, we investigate the changes of new energy consumption capacity after adopting the two-tier market optimization model. The final result is that the demand for purchased power decreases, the maximum load day decreases by 10.70%, the minimum load day decreases by 6.86%, and the new energy consumption increases from 81.79% to 95.39%, which proves that the two-tier optimization model is better than the traditional model to promote new energy consumption, and provides a reference for realizing the goal of "double carbon" and accelerating the construction of the nationwide unified power market system. It provides reference for realizing the goal of "double carbon" and accelerating the construction of national unified power market system.

Keywords: New energy consumption; Power market mechanism; Regional current dispatch; Power market design.
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1 Introduction

With the acceleration of industrialization and urbanization, the growing demand for energy has become a global problem. In order to meet the huge energy demand, many countries have implemented market-oriented reforms to integrate the power industry into the market system. Electricity market is a market system with the core of electric energy trading, through the trading behavior of the supply and demand sides to achieve the optimal allocation and rational operation of electric energy [1]. Electricity market mechanism is the system composed of the trading behavior and trading rules of the main participants in the electricity market [2-3]. It mainly includes the participating subjects of the power market, market structure, trading mechanism and market regulation. Grid power market needs to establish and implement a set of scientific and effective regulation mechanism to ensure the balance of power supply and demand, maintain the stability of market prices and improve the efficiency of electric energy resources [4-7].

Nowadays, countries around the world have increased the development and utilization of renewable energy. New energy generated by solar, wind, hydro and other renewable energy sources, with green, low-carbon, renewable and other characteristics, is widely used in the power system [8-9]. The consumption of new energy can reduce the dependence on traditional energy sources and promote the transformation and optimization of energy structure. It can also reduce the use of traditional energy sources such as coal and fuel oil, thus reducing air pollution and greenhouse gas emissions. It can also sustain the supply, which is conducive to promoting sustainable development [10-13]. However, the power system, as the main field of new energy consumption, faces new challenges. Firstly, the instability of renewable energy makes its power volatile, which conflicts with the stability of the traditional power system [14]. Secondly, the geographical characteristics of new energy lead to the increase of the difficulty of consumption, as new energy power generation is mainly concentrated in specific areas, far away from the power generation center, the transmission loss is larger, which brings challenges to the operation of the power grid [15-16]. Therefore, it is of great significance to study the new energy consumption technology and application, and promote its reliable, stable and efficient access in the power system, in order to realize the sustainable development of clean energy.

With the rapid growth of China’s new energy installed capacity, the task of new energy consumption is becoming more and more difficult. First of all, this paper constructs a system dynamics-based analytical model of the impact of new energy consumption to sort out the relationship between various types of power markets. It analyzes the impact of different quota ratios on the development of new energy from the mechanism, and explores the key factors affecting new energy consumption through the comparison of the impact of different variable investments on new energy consumption capacity. Secondly, based on the two-tier power market transaction clearing model, the inter-regional contact line trend dispatchable capacity model is introduced to optimize the two-tier power market transaction framework, and the two-tier optimization model of the market to promote new energy consumption is proposed. Finally, a simulation analysis is carried out using actual data to evaluate the performance of the two-tier market optimization model in the optimization of new energy consumption.

2 Analysis and modeling of the impact of new energy consumption based on system dynamics

2.1 Causal feedback loops

There are three types of power generation technologies in the new energy and system: traditional fossil energy power generation technology, hydro power generation technology and renewable energy power generation technology. Therefore, this paper will be the traditional fossil energy generation, hydroelectric power and renewable energy generation all 3 kinds of generation capacity to sum up, as the total installed capacity of the study.

After the new energy grid participation in power market trading, the factors that can affect the new energy consumption mainly involve power generation, power demand, electricity prices, power generation costs, installed capacity construction, demand growth, demand price elasticity and other factors. These factors interact with each other, mutual feedback, constituting a renewable energy grid-connected to the power market impact of causality ring, as shown in Figure 1.

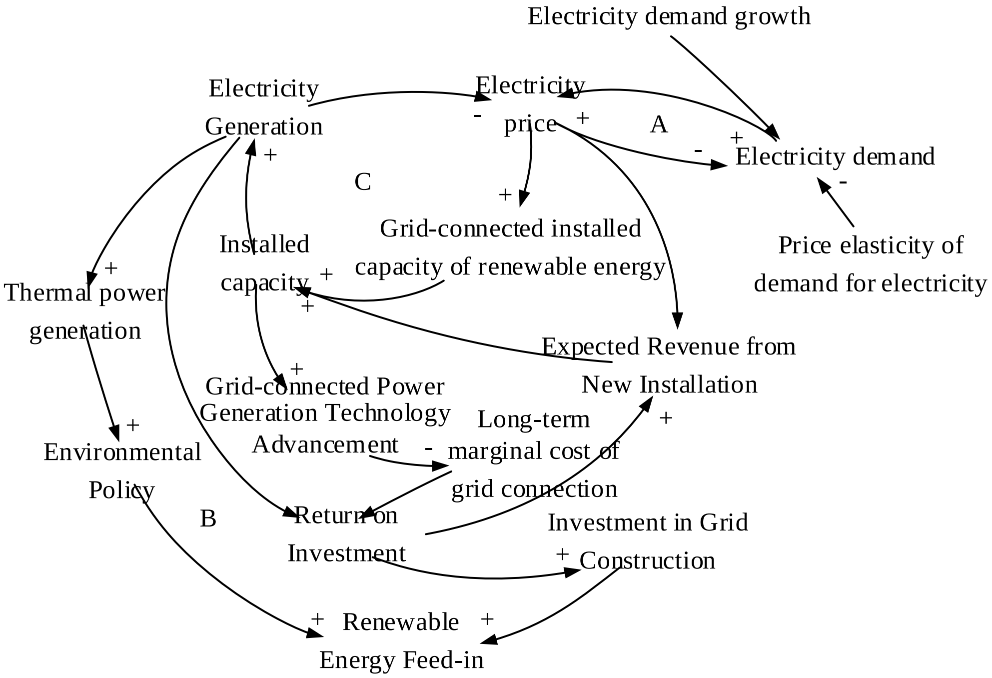

Figure 1. Renewable energy grid-connected causal cycle diagram

2.2 System flow diagram

In order to study the impact of grid-connected renewable energy on the operation of the electricity market, this paper utilizes system dynamics software to establish a system flow diagram model, which reflects the quantitative and qualitative relationships between various variables.

2.2.1 Power supply subsystem

The power supply subsystem calculates the power supply capacity of various power sources based on annual power supply planning. Each energy source is in a fair and equal competitive environment and does not follow the principle of giving priority to clean energy sources for feed-in, and the maximum power generation capacity (maximum supply of electricity) of wind power, solar power, hydropower and thermal power are all determined by the product of installed capacity and effective utilization hours. Among them, thermal power units are divided into two categories: conventional thermal power units and heating units, and the thermal power supply capacity is the sum of the installed capacity of both minus the outgoing capacity after deducting the maintenance, standby and obstructed capacity. Based on the capacity of a single unit, conventional thermal power units are divided into four classes of single unit capacity of 100,000kW, 300,000kW, 600,000kW, 900,000kW and above, and the generating capacity of the four classes of thermal power units is the product of their supply capacity after deduction of maintenance, standby and hindered capacity and the maximum number of hours of utilization of power generation.

2.2.2 Electricity demand forecasting subsystems

Electricity demand forecasting subsystem, through the rate of change of electricity price and the elasticity of demand of electricity price to determine the incremental amount of electricity consumption of each industry, and the sum of the incremental amount of electricity consumption of each industry and the initial amount of electricity consumption of each industry to form the prediction of each industry and the amount of electricity. Facing the power demand forecast of emerging energy users is through the prediction of electric vehicle ownership and the number of energy storage equipment (excluding pumped storage power stations), multiplied by a certain power consumption factor to get the initial demand for electricity, and then through the rate of change in electricity prices and power price demand elasticity to determine the incremental power consumption, the sum of the initial power consumption of the emerging energy users and the incremental power consumption, that is, the predicted power consumption. Generally speaking, emerging energy users can increase the load in the low valley time by storing energy in the low valley time, which is of some significance for load shifting and reducing the peak-valley difference. In this way, a feedback system is formed that takes into account the economy of production values, changes in electricity prices, and changes in electricity demand.

The main equations of this subsystem are listed as follows:

$$Q_{si,0} = OV_{si,0} \times e_{si} \tag{1}$$

$$OV_{si,0} = FT_{si,1}(Time) \tag{2}$$

$$e_{si} = FT_{ee,1}(Time) \tag{3}$$

$$\Delta Q_{si} = Q_{si,0} \times \Delta P_{si}\% \times \varepsilon_{si} \tag{4}$$

$$Q_{si,1} = Q_{si,0} + \Delta Q_{ds} \tag{5}$$

$$Q_{D,r,0} = FT_{demand,r}(Time) \tag{6}$$

$$\Delta Q_{D,r} = Q_{D_{r,r}} \times \Delta P_r\% \times \varepsilon_r \tag{7}$$

$$Q_{D,r,1} = Q_{D,r,0} + \Delta Q_{D,r} \tag{8}$$

$$N_c = FT_{N_c}(Time) \tag{9}$$

$$Q_c = N_c \times q_c \times \left(1 + \Delta P_c\% \times \varepsilon_c\right) \tag{10}$$

$$N_s = FT_{N_s}(Time) \tag{11}$$

$$Q_s = N_s \times q_s \times \left(1 + \Delta P_s\% \times \varepsilon_s\right) \tag{12}$$

$$Q_{h,x} = h_{h,x} \times IC_{h,x} \tag{13}$$

$$Q_x = Q_c + Q_s + Q_{h,x} \tag{14}$$

$$Q_{demand1} = Q_{p,1,1} + Q_{s,1} + Q_{i,1} + Q_{r,1} + Q_s \tag{15}$$

2.2.3 Social benefits subsystem

The social benefit subsystem consists of two components: producer surplus and consumer surplus. Since it is assumed that the price consumers are willing to pay for electricity is the same as the price they actually pay, the amount of change in consumer surplus is zero, which has no incremental effect on the social benefit subsystem and is not considered here.

The main equations of this subsystem are listed below:

$$S_{water} = \left(P_{water} - C_{water}\right) \times Q_{fard} \tag{16}$$

$$S_{wind} = \left(P_{wind} - C_{wind}\right) \times Q_{p,wind} \tag{17}$$

$$S_e = \left(P_e - C_e\right) \times Q_{praike,e} \tag{18}$$

$$S_{grnd} = \left(\overline{P_{Ske}} - \overline{P_S}\right) \times Q_{ckurnd} \tag{19}$$

$$S_p = S_{water} + S_{pine} + S_{wird} + S_e + S_{gnd} \tag{20}$$

Similarly, solar energy, as a renewable energy source, has the same formula as wind power and will not be repeated here.

2.3 Model Simulation and Analysis

2.3.1 Analysis of the impact of the quota system on new energy development

The model is based on the new energy installed capacity of a northeastern province from 2022 to 2032, and the initial values of wind power and photovoltaic installed capacity are 9.21GW and 4.02GW, respectively; the initial value of electricity consumption of the whole society is 236.5TWh, and the growth rate of electricity consumption in the simulation period is 6%. The average annual utilization hours of wind power and photovoltaic are taken as 2910 and 1310 hours respectively. New energy power generation is determined by the installed capacity of new energy and the annual average utilization hours, and new energy power producers can obtain 1 green power certificate for each MWh of electricity issued. Referring to the historical data of the National Green Power Certificate Voluntary Subscription Platform, the initial price of Green Power Certificate is RMB 67 per certificate, the price fluctuation range is from 0 to RMB 350 per certificate, and the penalty is RMB 300 per certificate. Combined with the growth of new energy installation in recent years, the equilibrium investment rate is taken as 18%.

For the impact of the quota system on the new energy development situation, this paper sets up a total of five scenarios with different allocation ratios, of which Scenarios 1-3 are the simulation period the quota ratio stays unchanged, respectively 10%, 15% and 20%, to study the impact of different quota ratios on the price of green certificates and new energy installations. Scenarios 4 and 5 are based on an initial quota ratio of 10%, with annual incremental increases of 0.4% and 0.8%, respectively, to study the impact of the incremental rate of quota ratio on the price of green certificates and new energy installations under the scenario of incremental increase in quota ratio.

The impacts of different quota scenarios on the price of green certificates are shown in Figure 2. Under different quota ratios, in order to fulfill the quota obligation, the demand for green certificates from electricity sellers changes, which in turn affects the price of green certificates. Compared with Scenarios 1-3, where the quota ratio remains constant, the larger the quota ratio, the higher the price of green certificates. Analyzing from the perspective of the trend of change, the quota ratio in Scenarios 2 and 3 is higher than the 2022 non-water renewable energy consumption (14%), and the price of green certificates in the early period is affected by the shortage of supply to a certain extent; in the late period of Scenarios 1-3, affected by the decline in the cost of new energy power generation kWh and the rise in the comprehensive income, the growth rate of new energy installation is faster than the growth rate of electricity consumption, resulting in the supply of green certificates being in excess, and the price of green certificates is in a slow downward trend. In Scenarios 4 and 5, due to the increasing quota ratio, the price of green certificates is on the rise, providing new energy power producers with better revenue expectations, which is more conducive to incentivizing new energy installations to scale up.

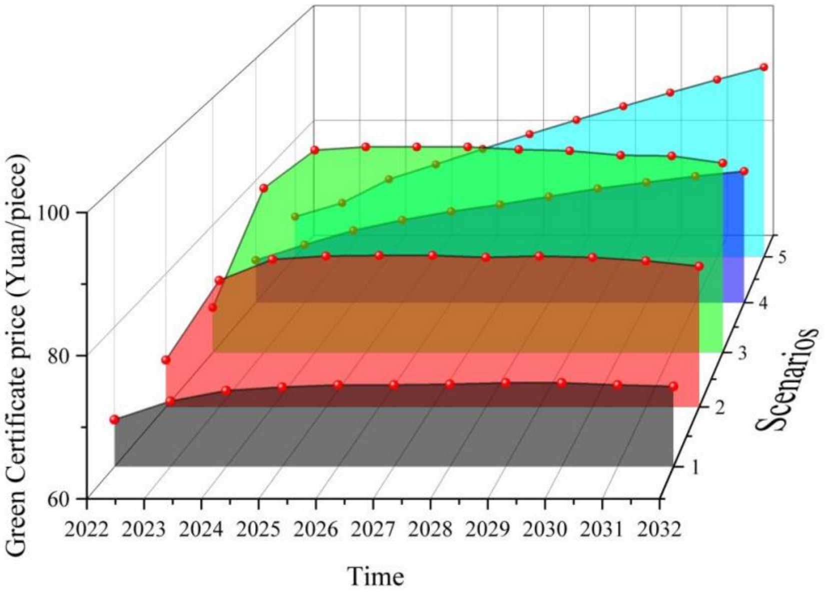

Figure 2. Price changes of green certificates under different quotas

Based on the above model and simulation results, it can be seen that in the process of supply and demand to form the price of green certificates, the demand for green certificates is related to the quota ratio set by the government, and the supply of green certificates is influenced by the amount of new energy generation. For this reason, the government can adjust the quota ratio to ensure that the price of green certificates fluctuates within a reasonable range, which in turn affects the revenue of new energy power generators and incentivizes investment in new energy installations.

The revenue of power generators is an important basis for their offer in the power market, and the environmental benefits of the green certificate market create conditions for new energy to participate in the power market. New energy in the green certificate market to obtain additional revenue to enhance its competitiveness in the power market, can compete with the lower cost of conventional energy on the same stage. At the same time, the green certificate revenue will affect the new energy generator's offer strategy in the power market to a certain extent, which should be taken into account in the optimization design of the mechanism later.

2.3.2 Analysis of key factors for new energy consumption

According to CEC's "China Electric Power Industry Annual Development Report 2021", in 2020, China's power grid engineering and construction completed investment of 489.6 billion yuan, of which about 30% is the investment in inter-area transmission lines, thermal power completed investment of 56.8 billion yuan, of which 50% is assumed to be used for unit flexibility transformation, and the State Grid centralized procurement of a total of 52.07 million smart meters, with a total value of about 15 billion yuan, which sets the investment ratio of inter-area transmission channel construction, conventional unit flexibility transformation and smart meter installation at 9:3:1. Transmission channel construction, conventional unit flexibility transformation and smart meter installation investment ratio of 9:3:1. Inter-regional transmission channel in accordance with the average transmission distance of 900 kilometers, AC 1200 kV construction, the cost of the unit transmission power of 5,000 yuan / kW, the cost of conventional unit flexibility transformation of 1,400 yuan / kW, the cost of the smart meter and the cost of installing 300 yuan / a. Still take a new energy province in the northeast as an example to analyze the cost of the new energy, the cost of the smart meter and installation of the smart meter. Still take a northeastern province as an example to analyze the key factors of new energy consumption, in 2022, the average load power of the province is 25.6GW, the maximum load power of 36.4GW, the average power of inter-regional transmission corridor plan to send out 32.5GW, the average load rate of 70.3%, the standby capacity of the system for the 15% of the total power; regulated power installed 78.4GW, the average depth of peaking take 0.35; Assuming a total of 22 million power users, the peak power consumption of users will drop by 7% after installing smart meters. The total initial investment is taken as 5 billion dollars, the average annual growth rate is 5%, and the time period of new energy consumption power space is 1 year.

The simulation results are shown in Table 1, with the increase of investment in inter-area transmission channel, flexibility transformation of conventional units and smart meter installation, the inter-area transmission capacity is improved, the peaking depth and the average load rate are gradually increased, and the system space for new energy consumption is obviously increased. Compared to 2022, in 2032, the cross-area transmission capacity is increased by 46%, the peak shifting depth is increased by 13.9 percentage points, and the average load rate is increased by 3.2 percentage points.

Table 1. Simulation results of key factors of new energy consumption

Year	Transmission capacity of trans-regional transmission lines/GW	Peak load depth/%	Average load rate/%	System new energy consumption capacity space/TWh
2024	36.4	0.418	0.701	60.9
2028	40.6	0.442	0.722	105.4
2032	47.5	0.489	0.735	165.7

Next, investment sensitivity analysis is conducted for the construction of inter-regional transmission channels, flexibility transformation of thermal power units and smart meter installation in the model to analyze the impact of investment in different variables on new energy consumption capacity. In order to facilitate the comparison of the magnitude of changes between different variables, the influencing factors and the overall consumption capacity are standardized, and the value corresponding to 2032 when the total investment growth rate is 0% is taken as the base value, and the total investment growth rate changes range from -20% to 20%. The results of the sensitivity analysis are shown in Figure 3, which shows that the investment has a similar effect on the enhancement of inter-area transmission capacity and unit peaking depth, and a smaller effect on the average load factor.

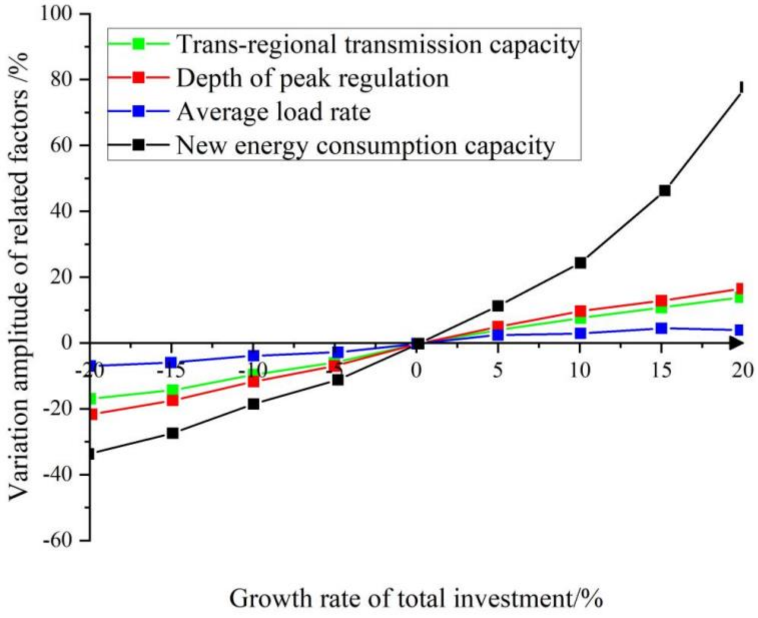

Figure 3. Sensitivity analysis of the impact of investment growth rate

The above results show that it is possible to optimize the intra-provincial and inter-provincial power markets to achieve the balance between supply and demand in the power market, thereby minimizing the operating costs and dispatch costs of power generation in the whole region, and solving the problem of new energy development and consumption.

3 Optimization of electricity market mechanisms to promote new energy consumption

3.1 Two-tier electricity market trading framework

In general, the design of two-level power market transactions should follow the following steps:

1) Each provincial power market carries out preliminary clearing based on the supply and demand of electricity in the province, and uploads its market information including grid operation to the inter-provincial power market for unified and coordinated clearing.

2) The inter-provincial power market coordinates and optimizes the market information uploaded by the intra-provincial power market and sends the optimization results, including information on the trend of inter-provincial liaison lines, to the intra-provincial power market.

3) The inter-provincial power market will use the optimization results issued by the inter-provincial power market as the boundary conditions to carry out the provincial market operation security verification and check whether the boundary conditions meet the provincial security operation constraints. If the operational security check is correct, the results given by the boundary conditions will guide the clearing of each intra-provincial market.

4) Boundary conditions do not meet the conditions of safe and stable operation within the province, modify the preliminary clearing results of the intra-provincial market, and repeat

steps (1) to (3) until the inter-provincial market issued boundary conditions to meet the conditions of safe and stable operation in each province.

It can be found that the traditional two-level electricity market trading process, due to the risk of boundary conditions not meeting the safe operation of the intra-provincial market, leads to the possibility of repeated iterations of modifying and confirming the boundary conditions between the two levels of the electricity market, which will reduce the coordination efficiency of the market. Usually the boundary conditions contain very complex information and contain sensitive information such as the operating conditions of the provincial grid, which needs to be kept secret from all other provincial electricity markets except the inter-provincial electricity market. This will put high demands on the markets within each province to guarantee the accuracy, privacy, and convenience of the uploaded information.

For this reason, this paper introduces the inter-regional liaison line trend dispatchability capability model, which transforms the regional static security constraints to a regional trend dispatchable set with only regional trend transmission variables by projection method. While the sensitive information of the provincial grid is hidden, the most important parameters of the inter-regional contact line trend dispatchable capacity are also retained, so that the privacy of the uploaded information and the amount of information can be well taken into account to optimize the two-tier power market trading framework. The two-level power market trading framework is shown in Fig. 4.

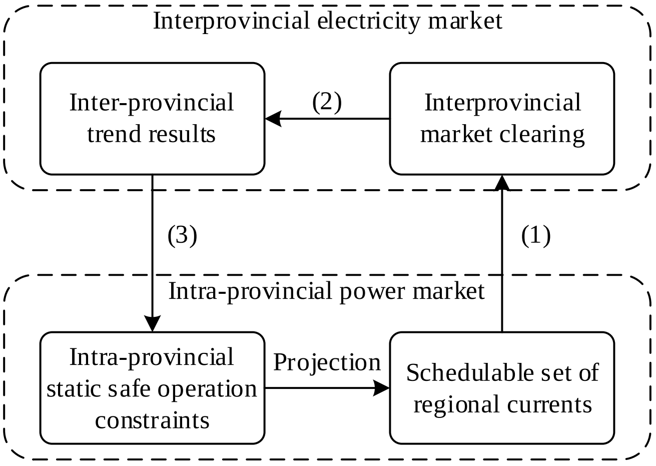

Figure 4. Two-level electricity market trading frame

3.2 Modeling of two-tier market bi-level optimization

In order to explore the impact of considering the tidal current dispatchability capacity of inter-regional liaison lines on the trading of two-tier power market, this section establishes a two-tier power market economic optimization model with the regional tidal current dispatchable set as the decision variable. The two-tier model refers to the inter-provincial power market day-ahead optimization model and the intra-provincial power market day-ahead optimization model. The purpose of the intra-provincial optimization is to optimize the generator output and branch circuit currents within each province to achieve the balance of supply and demand in the intra-provincial power market, and based on this, the above information is downscaled and projected into the regional trend dispatchable set. The purpose of the inter-provincial optimization model is to coordinate the regional trend dispatchable set uploaded by each provincial power market, optimize the distribution of the regional power contact line trend, and take into account the supply and demand of each sub-region in each period of time, so as to ultimately achieve the minimization of the operation cost of power generation and dispatch cost of the entire region, and then disseminate the dispatch result to the intra-provincial market. Each intra-provincial market uses the dispatch result as the boundary condition for intra-provincial dispatch to determine the final transaction data. The regional power market information transfer schematic is shown in Figure 5.

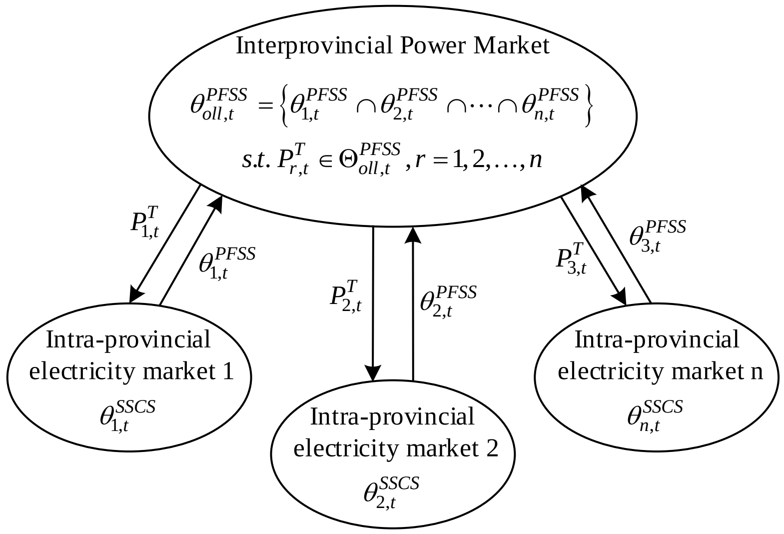

Figure 5. Schematic diagram of regional power market information transmission

For the two-level electricity market clearing model, this paper makes reasonable assumptions and settings. First, in the calculation of the regional grid trend model, each subregional grid ignores the internal branching situation and equates it to a virtual node. This is because the internal branch situation is often unimportant when calculating elements such as tidal currents between regional grids, and what needs to be concerned is the overall tidal currents injected into that grid. Similar assumptions are used in simulation calculations using the FB model for the European grid, for example. In this way, the regional grid current calculation model can be compared to the relationship between nodes and branches in an electric circuit, and some basic network theorems and calculation methods in electric circuits are also applicable in regional grid current calculation. For example, the current $P_{r,t}^{mj}$ of virtual node r in time period t is equal to the sum of the power of the generating units in the subregion minus the sum of the power of all the loads in the subregion.

The regional power market model established in this paper is an AC-DC contact line hybrid model: the DC contact line current can be optimized as a separate decision variable because the output power of the DC contact line is mainly controlled and adjusted by the power electronic converter and other equipment at both ends of the contact line. The AC contact line currents, on the other hand, are determined by the currents of the nodes at both ends and need to be solved by optimization. The specific model of the two-level power market is as follows.

3.2.1 Inter-provincial electricity market clearing models

1) Objective function

The objective function is to maximize the social welfare of the two-tier electricity market, including maximizing the welfare of the trading surplus of the market within each province minus the transmission cost of the inter-provincial power liaison line:

$$\max_{r_z} \sum_{a,b} \left(B_{s,t} - O_{b,t} - \lambda_{a,b} \right) P^{tr}_{pb,t}, \forall t \tag{21}$$

Where $B_{a,t}$ - Offer bids for region a in time slot t;

$O_{b,t}$ - the offer bid for region h in time period r;

λ_{ab} - Transmission price for the power liaison line between region a and region b;

$P^{tr}_{ab,t}$ - transmission power between region a and region b in time period t.

2) Constraints

$$\sum_{b} P^{tr}_{ab,t} \le P^{offer}_{a,t}, \sum_{a} P^{tr}_{ab,t} \le P^{bid}_{b,t} \forall a,b,t \tag{22}$$

Where P^{offer}_{a} - Power offer submitted by region a;

P^{bid}_{b} - power offer submitted by region b.

Constraint (22) represents the inter-provincial liaison line tidal flow transmission trading limit.

$$P^{tr}_{ab,t} \ge 0, \forall t \tag{23}$$

Constraint (23) tables interprovincial trading power limits.

$$\underline{P^{G}_{r,t}} \le P^{G}_{r,t} \le \overline{P^{G}_{r,t}}, \forall t \tag{24}$$

Constraint (24) indicates the power limit of the interprovincial generating units.

$$\underline{P^{tl}_{DC}} \le P^{tl}_{DC,t} \le \overline{P^{tl}_{DC}}, \underline{P^{tl}_{AC}} \le P^{tl}_{AC,t} \le \overline{P^{tl}_{AC}}, \forall t \tag{25}$$

Constraint (25) denotes the transmission limits of DC contact line and AC contact line power in the subregional grid.

$$-M_r P^{tl}_{r,t} \in \theta^{TLSS}_{r,t}, \forall t \tag{26}$$

where M_r - region-contact line correlation matrix.

Constraint (26) indicates that the contact line currents calculated for each region r in the inter-provincial market are required to satisfy the regional current dispatchable set constraints for each regional contact line in that time period.

In the regional grid, for the AC contact line currents are calculated as shown below.

Y^{AC} is the conductance matrix for the AC part of the regional grid, θ is the phase angle of the virtual nodes at both ends of the AC contact line, and M^{DC} is the area-contact line correlation matrix for the DC part of the regional grid.

$$Y^{AC}\theta = P_{r,i}^{inj} - M^{DC}P_{DC}^{tl} \tag{27}$$

Y^{AC} is calculated by the following equation:

$$Y^{AC} = M^{AC}diag(y)\left(M^{AC}\right)^T \tag{28}$$

Where y - the conductivity matrix of the AC contact line.

According to the results of solving Eq. (27) and Eq. (28), the value of the AC contact line current P_{AC}^{ti} at any time can be obtained from the DC current calculation formula as:

$$P_{AC}^{ti} = diag(y)\left(M^{AC}\right)^T \theta \tag{29}$$

3.2.2 Provincial electricity market optimization model

After the completion of the optimization of the inter-provincial power market clearing, the results of the regional tidal current transmission will be sent to the power municipalities within each province.

1) Objective function

   The objective function is to minimize the generation cost and regional trend transmission reduction cost in the intra-provincial market:

$$\min \sum_{r,u} c_{r,u} P_{r,t,u}^{G} + G\left(\left|P_{t,i}^{T}\right| - \left|P_{t,i}^{T1}\right|\right) \tag{30}$$

Where $c_{r,u}$ - Generating unit generation cost function;

G - Penalty cost coefficient:

$P_{t,i}^{T1}$ - Regional tidal current transmission results for self-optimization of the provincial electricity market.

2) Constraints

   The constraints are mainly regional static security operation constraints and regional tidal current transmission reduction constraints:

$$0 \le \mathrm{sgn}\left(P_{r,t,i}^{T}\right) \cdot P_{t,i}^{T1} \le \left|P_{r,t,i}^{T}\right| \tag{31}$$

Where $\mathrm{sgn}(\cdot)$ - the sign function.

3.3 Effectiveness of two-tier market optimization models

3.3.1 Analysis of the results of the two-tier market optimization model

Due to the limited data sources, this paper is mainly based on the load data of a certain month in a certain province to simulate the changes in the revenue results of each subject after adopting the market two-tier optimization model under different typical days in that month. The typical days were selected as the maximum load day and the minimum load day of the month, and the results of new energy manufacturers and grid companies are shown in Table 2.

Table 2. Income results of each subject after optimization

Time	category	New energy manufacturer	Power grid company
Maximum load day	Pre-optimization power (MW.h)	14564.88	26477.12
	Optimized power (MW.h)	16836.36(+15.60%)	23590.49(+10.90%)
	New income (ten thousand yuan)	80.35	98.39
Minimum load day	Pre-optimization power (MW.h)	11408.39	18293.74
	Optimized power (MW.h)	12849.03(+12.63%)	17309.38(5.38%)
	New income (ten thousand yuan)	48.03	38.23

From the above results, it can be seen that after adopting the market two-layer optimization model, the revenue of new energy manufacturers and the grid company is significantly improved. The maximum load daily power of new energy manufacturers increases by 15.60%, and the new revenue is 803,500 yuan. The minimum load daily power quantity increases by 12.63%, and the new revenue is 480,300 yuan. The demand for purchased power from grid companies decreased, the maximum load day decreased by 10.70%, and the new revenue was 983.9 thousand yuan. The minimum load day decreased by 6.86%, with an additional gain of 38.23 yuan, effectively reducing the power purchase cost of the grid company.

3.3.2 Analysis of the effect of market two-layer optimization model in promoting new energy consumption

In order to further analyze the enhancement effect of this paper's model on new energy consumption, the new energy consumption results of the market two-tier optimization model and the traditional two-tier power market trading model under the minimum load day are compared and analyzed with the minimum load day as a typical day, and the results are shown in Figure 6.

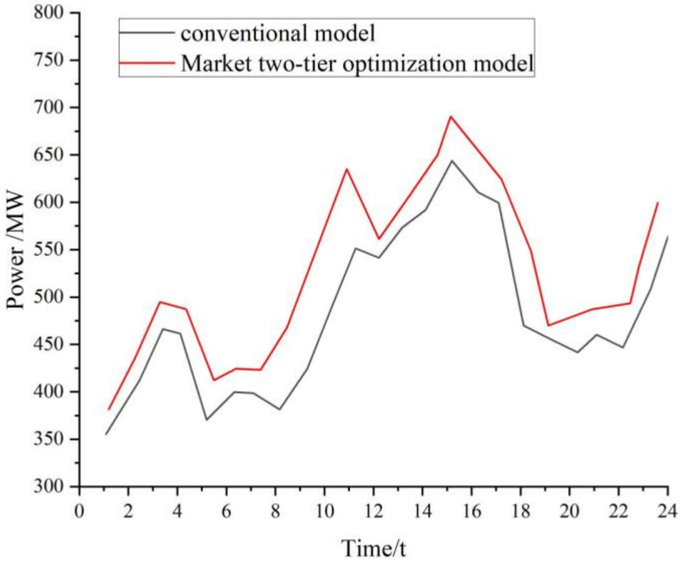

Figure 6. New energy consumption results comparison chart

It can be seen that the two models have roughly the same trend of consumption, but with the market two-layer optimization model, the new energy consumption is increased from 81.79% to 95.39%, i.e., the market two-layer optimization model is able to further consume new energy and alleviate the problem of new energy abandonment.

4 Conclusion

Based on the trend of new energy development in China, this paper constructs a system dynamics-based impact analysis model of new energy consumption, and constructs a market two-layer optimization model to promote new energy consumption based on the results of the impact analysis.

With quota ratios of 10%, 15% and 20%, the larger the quota ratio, the higher the price of green certificates. On the basis of the initial quota ratio of 10%, the annual increment of 0.4% and 0.8% respectively, the price of green certificates has a rising trend, which shows that the demand for green certificates is related to the quota ratio set by the government, and the supply of green certificates is affected by the new energy power generation.

With the increase in investment in inter-regional transmission corridors, flexibility modification of conventional units and smart meter installation, compared to 2022, the inter-regional transmission capacity in 2032 is increased by 46%, the peaking depth is increased by 13.9 percentage points, and the average load factor is increased by 3.2 percentage points, with the investment having a similar effect on the increase in the inter-regional transmission capacity and the peaking depth of the units, and having a smaller effect on the average load factor.

After adopting the market optimization model, the demand for purchased power is reduced, the maximum load day is reduced by 10.70%, and the new revenue is 983,900 Yuan. The minimum load day was reduced by 6.86%, with an additional revenue of RMB 382,300, effectively reducing the power purchase cost of the grid company. The new energy consumption increased from 81.79% to 95.39%, which means that the market two-layer optimization model can promote new energy consumption better than the traditional model.

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References

[1] CRAMTON, P. (2017). Electricity market design. Oxford review of economic policy, 33, 589-612.

[2] Bublitz, A., Keles, D., Zimmermann, F., Fraunholz, C., & Fichtner, W. (2019). A survey on electricity market design: Insights from theory and real-world implementations of capacity remuneration mechanisms. Energy Economics, 80(C), 1059-1078.

[3] Zahraoui, Y., Korõtko, T., Rosin, A., & Agabus, H. (2023). Market Mechanisms and Trading in Microgrid Local Electricity Markets: A Comprehensive Review. Energies (19961073), 16(5).

[4] Tsaousoglou, G., Giraldo, J. S., & Paterakis, N. G. (2022). Market Mechanisms for Local Electricity Markets: A review of models, solution concepts and algorithmic techniques. Renewable and Sustainable Energy Reviews, 156(C).

[5] Lezama, F., Soares, J., Hernandez-Leal, P., Kaisers, M., Pinto, T., & Vale, Z. (2019). Local Energy Markets: Paving the Path Toward Fully Transactive Energy Systems. IEEE TRANSACTIONS ON POWER SYSTEMS, 34(5), 4081.

[6] Sunar, N., & Birge, J. R. (2019). Strategic Commitment to a Production Schedule with Uncertain Supply and Demand: Renewable Energy in Day-Ahead Electricity Markets. Management Science, 65(2).

[7] Amin, W., Ahmad, F., Umer, K., Khawaja, A. H., Afzal, M., Ahmad, S. A., & Chaitusaney, S. (2022). An Effective Pricing Mechanism for Electricity Trading Considering Customer Preference and Reserved Price in Direct P2P Electricity Market Under Uncertainty in Grid Supply. IEEE Access, 10, 96197-96211.

[8] Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply. Front. Energy Res, 9, 743114.

[9] Adefarati, T., & Bansal, R. C. (2019). Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources. Applied Energy, 236(C), 1089-1114.

[10] Nitsenko, V., Mardani, A., Streimikis, J., Shkrabak, I., Klopov, I., Novomlynets, O., & Podolska, O. (2018). Criteria for evaluation of efficiency of energy transformation based on renewable energy sources. Montenegrin Journal of Economics, 14(4), 253-263.

[11] Yang, X., Zhang, J., Ren, S., & Ran, Q. (2021). Can the new energy demonstration city policy reduce environmental pollution? Evidence from a quasi-natural experiment in China. Journal of Cleaner Production, 287, 125015.

[12] Leonard, M. D., Michaelides, E. E., & Michaelides, D. N. (2018). Substitution of coal power plants with renewable energy sources-Shift of the power demand and energy storage. Energy Conversion and Management, 164, 27-35.

[13] Al-Shetwi, A. Q. (2022). Sustainable development of renewable energy integrated power sector: Trends, environmental impacts, and recent challenges. The Science of the Total Environment, 822, 153645-153645.

[14] Schmietendorf, K., Peinke, J., & Kamps, O. (2017). The impact of turbulent renewable energy production on power grid stability and quality. European Physical Journal B, 90(11), 222.

[15] Scorza, F., Pilogallo, A., Saganeiti, L., Murgante, B., & Pontrandolfi, P. (2020). Comparing the territorial performances of renewable energy sources' plants with an integrated ecosystem services loss assessment: A case study from the Basilicata region (Italy). SUSTAINABLE CITIES AND SOCIETY, 56, 102082.

[16] Muruganantham, B., Gnanadass, R., & Padhy, N. P. (2017). Challenges with renewable energy sources and storage in practical distribution systems. Renewable and Sustainable Energy Reviews, 73(C), 125-134.

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