



Design and Simulation of Power Grid Energy Saving Control Model

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Abstract. Aimed at the problem of volatile energy consumption of the traditional grid energy-saving control model, design a less volatile energy consumption of the power grid energy-saving control model, by building a basic calculation model, to meet energy-saving targets and related constraints, using the priorities and time calendar solving basic measurement model, in order to realize the energy-saving power generation dispatching; according to the results of energy-saving power generation scheduling, a power load stratification probability prediction method based on empirical mode decomposition and sparse Bayesian learning is used to establish a load forecasting model for load sampling. Based on the sampling results, the emission control cost and the reserve capacity cost, the nominal purchase cost of the non-renewable energy unit and the nominal purchase cost of the renewable energy unit are respectively constructed, and then the energy-saving control model of the power grid is constructed. In order to prove that the energy consumption fluctuation model of the power-saving control model is small, the model is Compared with the traditional grid energy-saving control model, the experimental results show that the energy consumption volatility of the model is less than that of the traditional power grid energy-saving control model, which reduces the nominal power purchase cost of renewable energy units and is more suitable for power grid energy-saving control.

Keywords: Power grid · Energy-saving control model · Basic measurement model · Energy-saving power generation dispatch · Minimum specific consumption

1 Introduction

In recent years, environmental protection and climate change have become the primary concerns of all countries in the world. Energy conservation, energy efficiency and the development of renewable energy have also become the basic energy policies of countries [1]. China has also proposed an ambitious goal of accelerating the construction of a resource-conserving and environment-friendly society, and proposed the reduction of energy consumption per unit of GDP during the 11th Five-Year Plan period, and the discharge of major pollutants during the 11th Five-Year Plan. A binding indicator of total reduction. As a basic industry of national economy, electric power is not only the creator of high-quality clean energy, but also a major energy consumer and

a major emitter of pollution, and plays an important role in the completion of energy-saving emission reduction targets [2]. Energy saving and consumption reduction of power industry run through the whole industrial chain from power production to power utilization, and the energy saving and consumption reduction potential of the electric power production link is the most significant. According to statistics, power generation energy accounts for more than 30% of the total energy consumption of the whole society, and coal consumption accounts for 50% of the total social coal consumption. Therefore, the energy saving and consumption reduction in the process of power production is of great significance to the completion of the indicators [3].

In the power production process, the power dispatching mode plays an important role in the allocation of power resources. At present, power generation dispatching in most provinces in China is based on the average capacity of the unit to allocate electricity generation hours [4]. This practice has led to the failure of the power generation capacity of clean energy units such as large thermal power units, hydro-power and nuclear power to fully utilize their environmental benefits. The high-energy, high-energy small thermal power units can generate more power, resulting in waste of energy resources and environmental pollution. Therefore, the General Office of the State Council and the Development and Reform Commission and other departments have issued a notice on the “Trial Implementation of Energy-Saving Power Generation Dispatching Measures”: requiring energy-saving power generation dispatching, mandatory energy-saving emission reduction, and reduction of energy consumption and pollutant emissions [5]. Therefore, the General Office of the State Council and the Development and Reform Commission and other departments have issued a notice on the “Trial Implementation of Energy-Saving Power Generation Dispatching Measures”: requiring energy-saving power generation dispatching, mandatory energy-saving emission reduction, and reduction of energy consumption and pollutant emissions. However, the energy-saving power generation scheduling mode may also bring severe challenges to the safe and stable operation of the power grid. The current energy-saving control model of the power grid has a large fluctuation of energy consumption, resulting in poor energy-saving control effect of the power grid, reducing the nominal power purchase cost of renewable energy units. Therefore, this paper designs a new energy-saving control model of the power grid.

2 Design Power Grid Energy Saving Control Model

2.1 Energy Conservation Power Generation Dispatch

(1) Build basic measurement model

By building a basic calculation model, the priority order and traversal were used to solve the problem before meeting the goal of energy conservation and relevant constraints, so as to realize the scheduling of energy-saving power generation [6]. In energy-saving generation scheduling, energy saving is the primary goal. Therefore, according to the current situation of energy-saving power generation scheduling, taking

the total energy consumption of power grid as the objective function, and the basic calculation model is established as follows:

$$\min F = \sum_{t=1}^T \sum_{k=1}^M [s_{k,t} f_k(P_{k,t}) + Z_k s_{k,t} (1 - s_{k,t-1})] \quad (1)$$

Where, F is the mathematical function of energy consumption of the system; $\min F$ represents the minimum objective function of total energy consumption of the power grid. M is the number of generator sets; T is the number of time periods; $s_{k,t}$ is the operation status of generator sets, when the value is 0, it means shutdown; when the value is 1, it means operation; $P_{k,t}$ is the active output of generator group k in t period; $f_k(P_{k,t})$ is the energy consumption function of the generating unit, which means the coal consumption when the output of the t period of the k unit is $P_{k,t}$; Z_k is the starting coal consumption of unit k .

The constraints of the basic calculation model generally meet the following constraints [7].

1) Active power balance constraint:

$$\sum_{i=1}^t P_{Li,t} = \sum_{k=1}^M s_{k,t} P_{k,t} \quad (2)$$

Where, $P_{Li,t}$ is the active load of node i at time t .

2) Rotational reserve capacity constraint:

$$\sum_{k=1}^M s_{k,t} P_{k,t,\max} \geq \sum_{i=1}^t P_{Li,t} + R_t \quad (3)$$

Where, R_t is the reserve capacity of grid t at the moment; $P_{k,t,\max}$ is the maximum output value of generator unit k in period t .

3) Unit output constraint:

$$P_{k,t,\min} \leq P_{k,t} \leq P_{k,t,\max} \quad (4)$$

Where, $P_{k,t,\min}$ is the minimum value of the output of generator unit k in period t .

4) Unit minimum start stop time constraint:

$$\begin{cases} (b_{k,t-1} - T_k^{ON})(s_{k,t-1} - s_{k,t}) \geq 0 \\ (x_{k,t-1} - T_k^{OFF})(s_{k,t-1} - s_{k,t}) \geq 0 \end{cases} \quad (5)$$

Where, $b_{k,t-1}$ and $x_{k,t-1}$ are the continuous operation downtime in period t ; T_k^{ON} and T_k^{OFF} are the minimum start and stop time of generator set k .

5) Speed restriction of climbing and downhill of generator set:

$$\begin{cases} P_{k,t} - P_{k,t-1} \leq R_{Hi}\Delta t \\ P_{k,t-1} - P_{k,t} \leq R_{Li}\Delta t \end{cases} \quad (6)$$

Where, R_{Hi} and R_{Li} are the climbing and downhill rates of generator unit k respectively.

6) Same constraint of output change trend:

$$\left(\sum_{i=1}^t P_{Li,t} - \sum_{i=1}^t P_{Li,t-1} \right) (P_{k,t} - P_{k,t-1}) \geq 0 \quad (7)$$

(2) Basic calculation model solution

The priority method combined with ergodic algorithm is used to solve the basic calculation model, so as to achieve the goal of minimum total energy consumption.

The priority method refers to the start-up sequence of the units in the system according to certain indicators, and then the corresponding unit operation or shutdown according to the size of the load [8]. This method also conforms to the basic idea of energy-saving power generation scheduling method, and is implemented strictly according to the sequence table of units.

1) Sequencing of generator sets

The energy consumption level of the unit is an important index of the unit sequencing, which reflects the energy consumption of the generator unit under normal operation. According to the sequence table, the energy conservation and emission reduction of the maximum energy conservation scheme can be realized. Because the same type of thermal power generating units need to be ranked from low to high strictly according to the energy consumption of each generating unit, and when the energy consumption of each generating unit is the same, it needs to be ranked according to the pollutant emission level of each generating unit, so the minimum specific consumption of the generating unit is used for evaluation.

The minimum specific consumption of the unit can be obtained according to the following formula:

$$\begin{cases} \mu_{kmin} = a_k P_{k,m} + b_k + \frac{c_k}{P_{k,m}} \\ P_{k,m} = \begin{cases} P_{kmin}, P_{k,m} \leq P_{kmin} \\ \sqrt{\frac{c_k}{a_k}}, P_{kmin} \leq P_{k,m} \leq P_{kmax} \\ P_{kmax}, P_{k,m} \geq P_{kmax} \end{cases} \end{cases} \quad (8)$$

Among them, μ_{kmin} is the minimum specific consumption of the unit; a_k , b_k and c_k are the maximum, medium and minimum energy consumption of the unit respectively; P_{kmin} , $P_{k,m}$ and P_{kmax} are the lowest, medium and highest emission levels respectively.

In the actual power grid dispatching process, the unit maintenance plan and the minimum start-up and shutdown time constraints can directly determine the status of the unit in some time periods, and these units can not participate in the unit sequencing in those time periods.

2) Determination of the number of generator sets

In the case of basic constraints, in order to ensure the output balance of adjacent periods, the minimum number of generating units is determined. Take the unit climbing as an example, the load value of the system in period t is P_t , and the number of generating units in period $t - 1$ is N . According to the climbing output limit of the unit, the maximum output that each generating unit can allocate can be obtained. At least, only $N + 1$ generating unit is required to meet the output in period t , that is, $N + 1$ generating unit is the number of basic generating units [9]. When the unit goes downhill, the corresponding number of generator units can be obtained in the same way.

After the priority method is used to sequence the generating units, the units in the first order are generally put into operation, and the units in the second order are generally not involved in the operation and are in shutdown state. However, due to the proximity of the sort index, it is not possible to determine the intermediate unit manually. Therefore, it is necessary to evaluate and calculate the combination mode of marginal units by ergodic method, so as to obtain the system energy consumption of each combination mode and finally determine the optimal combination mode of units. For a large number of units, cloud computing should be considered and advanced computing methods should be used to improve the depth of optimization. The priority algorithm can get the optimal strategy based on the current situation when solving the optimization problem, that is, to find the local optimal solution. The basic model solution flow is shown in Fig. 1.

The priority method and ergodic method are combined to determine the stop or start unit by using the basic constraints of the unit and the unit sequence table obtained by the sequencing index, and then the step-by-step relaxation constraints are used to search the state of the marginal unit to obtain the optimal unit combination scheme. By using this method, we can simplify the calculation and improve the speed of operation under the condition of ensuring the optimization depth.

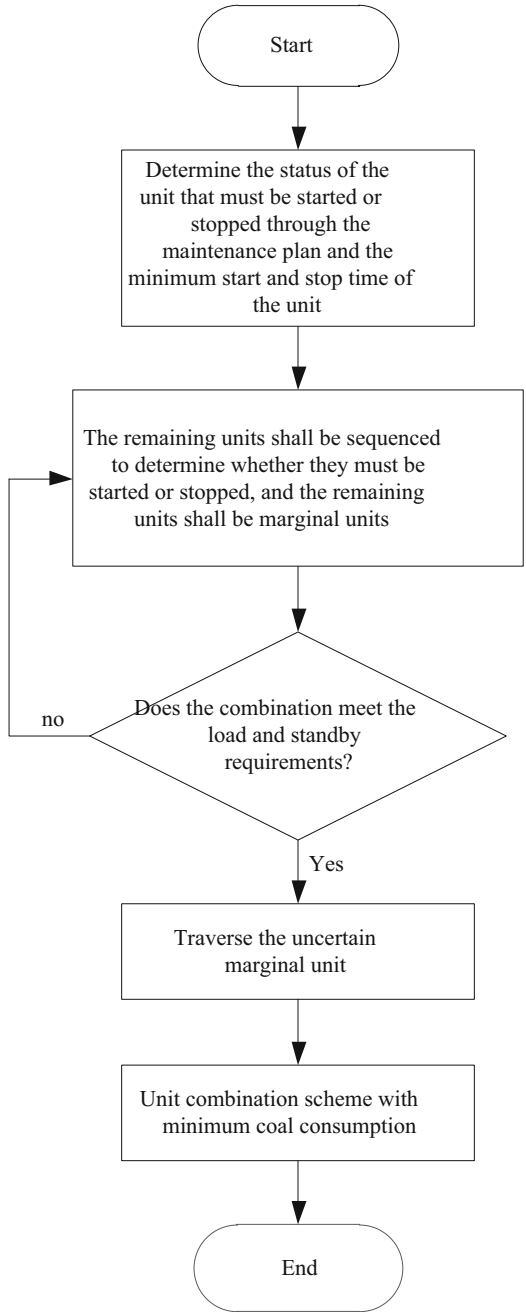


Fig. 1. Basic model solving process

2.2 Load Sampling

(1) Building load forecasting model

According to the results of energy-saving power generation scheduling, a hierarchical probability prediction method based on empirical mode decomposition and sparse Bayesian learning is adopted. Through the distributed collaborative network, a series of data such as the load size of each node in the power grid are analyzed, temperature and humidity, is extracted and eliminated by classification, and then the effective data is sent to Bayesian learning and training, so as to build Establish load forecasting model.

The specific prediction steps are as follows:

- 1) kernel principal component analysis (KPCA) is used to obtain the principal component characteristics of load samples.
- 2) using Mahalanobis distance weighting method to determine the similarity between the trained samples and the predicted samples, excluding the samples with low similarity;
- 3) empirical mode decomposition is used to process power load samples and extract high-frequency and low-frequency components from power signals.
- 4) SBL is used to predict the high frequency and low frequency load.
- 5) integrate the prediction results of different frequency bands to obtain the final power load prediction results.

Through the above steps, the user load demand can be predicted as a certain confidence interval “band”, as shown in Fig. 2.

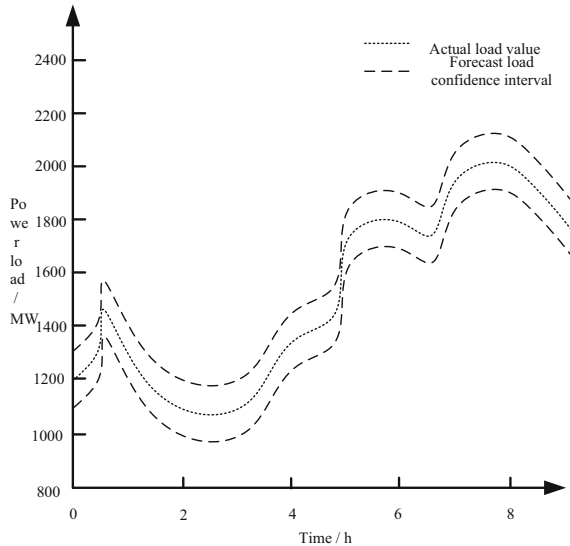


Fig. 2. Load forecast interval

(2) Load sampling

The load demand forecasting interval with confidence of ζ is divided into r cells with different confidence, and each sub interval obeys a certain fuzzy membership function.

Assuming that the first l load forecasting interval is $[P_{L/\min}, P_{L/\max}]$, the interval is divided into r sub intervals, which are respectively expressed as $a_1, \dots, a_{\vartheta}, \dots, a_r$, where:

$$a_{\vartheta} = \left[\begin{array}{c} P_{L/\min} + \frac{(\vartheta-1)([P_{L/\max}-P_{L/\min}])}{r} \\ P_{L/\min} + \frac{\vartheta([P_{L/\max}-P_{L/\min}])}{r} \end{array} \right] \tag{9}$$

The confidence of interval a_{ϑ} is set as ζ_{ϑ} , and the load distribution in a_{ϑ} obeys the membership function.

As the load forecasting interval contains r sub interval, the load sampling value is determined by the sampling value and reliability of r sub interval. That is, the sampling value $\delta_{j_{\vartheta}}$ ($j = 1, 2, \dots, r$) obtained by sampling j_{ϑ} times in the ϑ interval, then the sampling value of the uncertainty is:

$$\begin{aligned} \delta_j &= \frac{\zeta_1 \delta_{j_1} + \zeta_2 \delta_{j_2} + \dots + \zeta_r \delta_{j_r} + \dots + \zeta_r \delta_{j_r}}{\zeta_1 + \zeta_2 + \dots + \zeta_r} \\ &= \frac{\sum_{j=1}^r \zeta_{\vartheta} \delta_{j_r}}{\sum_{j=1}^r \zeta_{\vartheta}} \end{aligned} \tag{10}$$

In the actual sampling, the triangular membership function is used in the load distribution of each sub section.

2.3 Power Grid Energy Saving Control Model

(1) Nominal power purchase cost of non renewable energy unit

According to the results of load sampling, the emission control cost and reserve capacity cost are introduced to construct the nominal power purchase cost of non renewable energy units and the nominal power purchase cost of renewable energy units.

Considering energy saving factors based on unit environmental benefits, the nominal power purchase cost of the non renewable energy group is constructed as follows:

$$C_G = C_{GS} + \eta_{EPI} \times C_{EC} + C_{GT} \tag{11}$$

Where, C_G is the nominal power purchase cost of non renewable energy units; C_{GS} is the total fuel cost; η_{EPi} is the environmental penalty cost coefficient; C_{EC} is the total cost of emission control; C_{GT} is the operating cost of each unit at its maximum output.

(2) Nominal power purchase cost of renewable energy unit

Due to the randomness, intermittence and variability of renewable energy generation, in order to ensure the stability and safety of the grid, it is necessary to increase the reserve capacity of the grid. In order to reasonably reflect the power value of renewable energy, the loss to the grid caused by renewable energy should be reasonably reflected while considering its environmental benefits [10]. Therefore, reserve capacity penalty cost is introduced, and its expression is as follows:

$$C_{RPi} = \rho_{RPi} \cdot [\text{Min}(0, P_{wj} - P_{wja})] \tag{12}$$

Among them, C_{RPi} represents the penalty cost of reserve capacity; ρ_{RPi} represents the penalty cost coefficient of reserve capacity for grid connection of renewable energy; P_{wj} represents the actual generation capacity of renewable energy generating units; P_{wja} represents the planned generation capacity of renewable energy generating units.

The nominal power purchase cost of renewable energy units can be expressed as follows:

$$C_R = \sum_{i=1}^n C_{PRi} + C_{RT} \tag{13}$$

Among them, C_R is the nominal power purchase cost of renewable energy units; C_{RT} is the power purchase cost of renewable energy units; n represents the number of renewable energy generating units; i is the number of renewable energy generating units.

(3) Construction of power grid energy saving control model

Since the output of renewable energy units is a random variable, the output of non renewable energy units, generation cost and up and down rotating reserve capacity are also random variables. Therefore, the mathematical expectation minimization of the nominal power purchase cost of power grid enterprises is taken as the objective function, and the constraints with uncertainty are expressed in the form of probability, so that they can meet a certain confidence level interval. Therefore, the power grid energy-saving control model is constructed as follows;

$$\begin{cases}
 \text{Min}E \left[\sum_{t=1}^T \sum_{i=1}^N U_{it}C_{Gi} + \sum_{t=1}^T \sum_{i=1}^N U_{it}C_{Ri} \right] \\
 \sum_{i=1}^N P_{Git} + \sum_{i=1}^M P_{Wit} = P_{Dt}, t \in T \\
 p_{Git}^{\min} \leq P_{Git} \leq p_{Git}^{\max} \\
 P \left\{ \sum_{i=1}^N (p_{Git}^{\max} - P_{Git}) \geq SR_u \right\} \geq \theta_1 \\
 P \left\{ \sum_{i=1}^N (P_{Git} - p_{Git}^{\min}) \geq SR_d \right\} \geq \theta_2 \\
 P \left\{ S_{dGi} \leq P_{Git} - P_{Gi(t-1)} \leq S_{uGi} \right\} \geq \theta_3
 \end{cases} \tag{14}$$

Where, T is the number of cycle hours; N is the number of thermal power units; M is the number of renewable energy units; C_{Gi} is the nominal power purchase cost of thermal power unit i ; C_{Ri} is the nominal power purchase cost of renewable energy unit i ; P_{Dt} is the load demand of period; P_{Git} is the output of pyroelectric motor group i at time interval t , p_{Git}^{\min} and p_{Git}^{\max} are the upper and lower limits of its output respectively; SR_u and SR_d are the upper and lower rotation reserve requirements of power grid in period t respectively; S_{dGi} and S_{uGi} are the decline and rise rates of the active power output of thermal power unit i in period t ; θ_1 , θ_2 and θ_3 are confidence levels; P is thermal power unit; P_{Wit} is the power consumption of thermal power unit; $MinE$ is the minimum number of energy savings.

3 Simulation Experiment and Analysis

3.1 Experimental Process and Method

Taking the actual data of a certain region’s power system as experimental data, the grid energy-saving control model designed in this paper is used to conduct grid energy-saving control experiments. The power supply structure of the power system is: thermal power proportion is 70.18%, hydropower is 28.24%, and gas and wind power is only 1.57%. The proportion of each capacity class of the thermal power unit is shown in Table 1.

Table 1. Proportion of each capacity class of thermal power units

Unit capacity (MW)	Number of tables	Capacity	Proportion
600	6	3600	10.03%
300 and 320 and 330	44	13660	38.06%
200 and 220	8	1460	4.07%
135 and below	96	6470	18.03%
Total	154	25190	70.18%

According to the thermal power unit capacity bin, the electricity price of the power system in the region is measured. According to the characteristics of the power system power distribution, the thermal power unit capacity is divided into 600 MW, 300 MW, 200 MW, 135 MW and below. The electricity price is only determined according to the coal consumption level of power generation. The standard coal price corresponding to the capacity level of each gear and the average coal price corresponding to the different calorific values of the four regions of the system are used as the basis for calculating the electricity price, and the electricity price of the thermal power units in the four regions is obtained. The valuation is shown in Table 2.

Table 2. Valuation of electricity price of thermal power units in four regions

Capacity class (MW)	A area	B area	C area	D area
600	99.1–105.4	81.3–83.6	85.5–89.3	85.2–91.8
300	105.6–109.1	86.2–88.3	90.8–94.2	90.2–97.6
200	108.2–119.7	95.6–97.3	100.2–104.4	100.1–107.9
135	130.3–177.9	117.6–151.3	119.0–158.3	117.1–161.0

Select the typical daily load curve of the power system in this region to control the grid energy, as shown in Fig. 3.

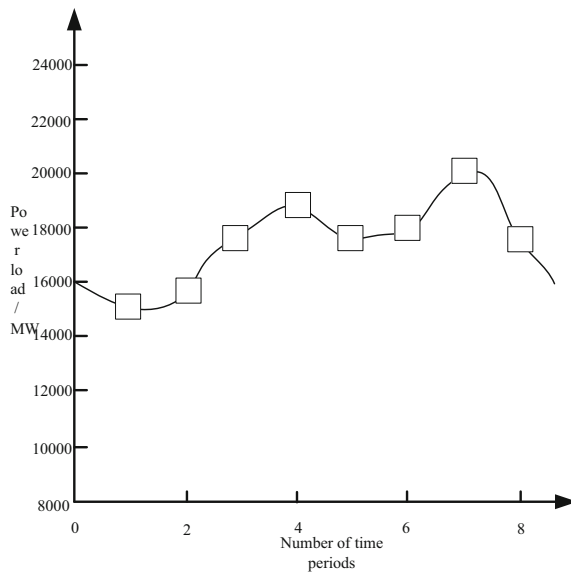


Fig. 3. Typical daily load curve of the power system in January

In order to ensure the effectiveness of the experiment, the traditional grid energy-saving control model is compared with the grid energy-saving control model designed

in this paper. The energy volatility of each grid energy-saving control model is compared, and the energy volatility is smaller, which proves its grid energy-saving control. The performance is even better. The judgment of energy consumption volatility is the stability of the energy consumption fluctuation curve, and the more stable the energy consumption fluctuation curve, the smaller the energy consumption volatility.

3.2 Analysis of Results

The experimental results of the energy consumption volatility comparison between the traditional grid energy-saving control model and the grid energy-saving control model designed in this paper are shown in Fig. 4.

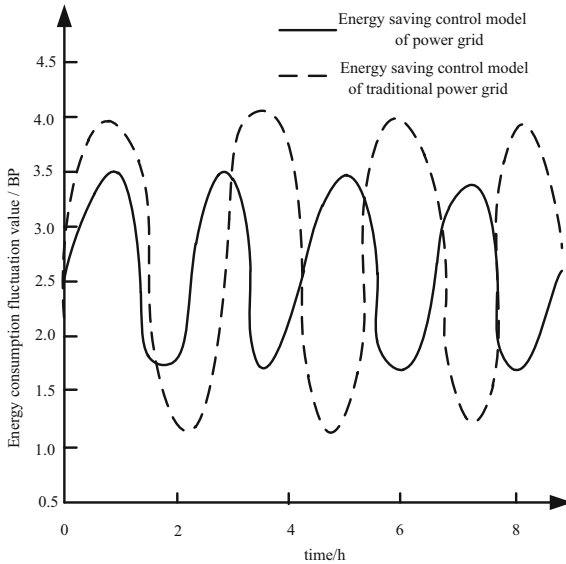


Fig. 4. Comparison of energy volatility experiment results

According to the energy consumption volatility comparison experiment results in Fig. 4, with the increasing cycle hours T , the energy consumption of both models is in a state of fluctuation. Compared with the traditional power grid energy-saving control model, the power grid energy-saving control model designed in this paper has a stronger stability of energy consumption fluctuation curve, that is, the energy consumption volatility is smaller and more stable, and it enhances the energy-saving control effect of the power grid.

In order to further verify the effectiveness of the model in this paper, taking the nominal power purchase cost C_R of the renewable energy unit as the experimental index, a comparative analysis is made on the nominal power purchase cost of the traditional power grid energy-saving control model and the renewable energy unit of the power grid energy-saving control model designed in this paper. The comparison results are shown in Fig. 5.

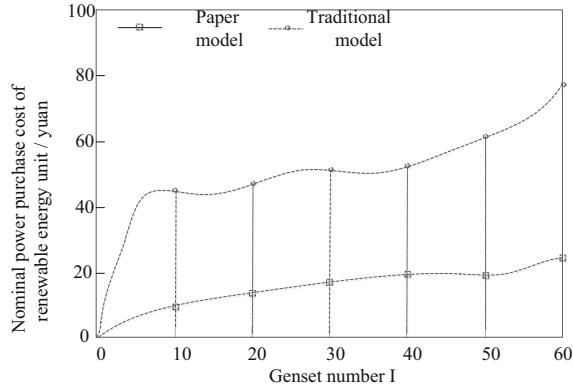


Fig. 5. Comparison of nominal purchase cost of the two models

According to Fig. 5, with the number of renewable energy generating unit I not increasing, the nominal power purchase cost of the renewable energy generating unit of the traditional power grid energy-saving control model and the power grid energy-saving control model designed in this paper is also increasing, but the nominal power purchase cost of the renewable energy generating unit of the power grid energy-saving control model designed in this paper is higher than that of the traditional power grid energy-saving control model. The nominal power purchase cost of generating units is low.

4 Conclusion

Due to the large fluctuation of energy consumption in the traditional power grid energy-saving control model, the effect of power grid energy-saving control is poor, which reduces the nominal power purchase cost of renewable energy units. Therefore, this paper designs a power grid energy-saving control model with small fluctuation of energy consumption, which realizes the reduction of energy consumption fluctuation, reduces the nominal power purchase cost of renewable energy units, and provides energy-saving control tools for power grid of great significance.

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