Study on optimal allocation of energy storage in multi-regional integrated energy system considering stepped carbon trading

Weimin Zheng[1,*], Bo Zou[1], Jiting Gu[1], Jiaqian Chen[2] and Jiansheng Hou[3]

[1]Economy Research Institute of State Grid Zhejiang Electric Power Company, Hangzhou 310020, China; [2]State Grid Huzhou Electric Power Supply Company, Huzhou 310020, China; [3]State Grid Jinhua Electric Power Supply Company, Jinhua 321000, China

Abstract

In this study, an energy storage configuration optimization model of multi regional integrated energy system based on integrated scheduling and stepped Carbon emission trading is proposed. By analyzing the steady-state, dynamic, and variable operating characteristics of multi regional integrated energy systems, a distributed energy planning modeling method was adopted to construct energy storage configuration constraint objects and optimization models. The target scheme of energy storage configuration is optimized by using the results of integrated scheduling scheme and dynamic distribution analysis of ladder Carbon emission trading, and the parameters are optimally estimated by using Monte Carlo method and quadratic fitting algorithm. The simulation results show that this method has a strong scheduling capability in the context of stepped Carbon emission trading, can accurately assess the load demand and supply demand relationship, reduce carbon emissions, and improve energy efficiency, with an average of 0.9121.

Keywords: Stepped carbon trading; Multi-regional integrated energy system; Energy storage configuration; Fusion scheduling

*Corresponding author.
lanhuan61658068@163.com

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1. INTRODUCTION

The energy consumption of 1.4 billion people is an important livelihood issue. The large population makes the energy consumption huge, but at the same time, the wide area can provide many different forms of energy sources. However, these energy sources have different properties. If we want to give full play to the advantages of different energy sources, we must improve the efficiency of energy utilization. Integrated energy system breaks the barrier of conventional physical isolation between various energy systems and easily integrates into the existing power market, which can not only reduce operating costs, but also improve energy efficiency [1]. Besides meeting the growing energy demand, it plays a vital role in reducing carbon emissions and coping with the climate crisis. Adding carbon emission-related research into the integrated energy system can give priority to the use of energy types with less carbon emissions in optimal dispatching, and reduce the possibility of carbon emissions before they occur. At the same time, the combination of CCUS technology and integrated energy system makes the concept of carbon emission reduction run through the whole flow process of energy in the system, from the beginning of energy entering the system to the use of load terminals. In recent years, Integrated Energy Styles TMS (IES) has broken the barrier of conventional physical isolation between various energy systems and conformed to the development trend of renewable energy [2]. In addition to meeting the growing energy demand, IES plays a crucial role in reducing carbon emissions in response to the climate crisis, and is therefore a current research hotspot [3, 4].

At present, there have been a lot of researches on IES optimal scheduling. Reference [5] proposed a multi time scale optimal scheduling model for regional integrated energy system with high proportion of photovoltaic permeability, realized the day ahead scheduling and real-time scheduling of the electricity gas system, and considered the interaction between CVaR risk assessment model and energy flow. Reference [6] proposes a capacity

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optimization configuration model for shared energy storage systems under the interconnection of multiple RIES. Through a two-layer optimization configuration model, the collaborative operation between the shared energy storage system and multiple RIES is achieved, and genetic algorithm, CPLEX solver, and Nash bargaining method are used for capacity optimization, equipment output planning, and benefit allocation. Reference [7] established an economic operation model of a regional integrated energy system containing multiple energy storage equipment by introducing batteries, thermal storage electric boilers and Power-to-gas equipment, and considering the response to electricity, heat and gas demand. The results show that comprehensive consideration of multiple demand responses can improve energy utilization and achieve environmental protection. The PSO algorithm, spatial grid area planning method, and PID algorithm in traditional methods are common methods used for planning energy storage configuration schemes in multi regional integrated energy systems. However, these methods have limited optimization capabilities, are prone to falling into local optima, and have relatively weak adaptive control capabilities. To overcome these shortcomings, multi-objective evolutionary methods combined with intelligent control algorithms can be used to optimize the energy storage configuration of multi region integrated energy systems. Multi objective evolutionary method can consider multiple optimization objectives at the same time, and find the optimal solution through Evolutionary algorithm. Combined with intelligent control algorithm, it can improve the intelligent planning and control ability of energy storage configuration to adapt to the complex and changeable energy system requirements [8–10].

In order to solve the above problems, this paper proposes a multi-regional integrated energy system energy storage configuration model based on integrated scheduling under the background of stepped carbon trading. The overall model of energy storage operation planning of multi-regional comprehensive energy system is analyzed under the characteristics of steady state, dynamic state and variable working conditions. By establishing the operation scheduling model including energy conversion and energy storage model, the target scheme of energy storage configuration of multi-regional comprehensive energy system is optimized and analyzed by using the fusion scheduling scheme and the dynamic distribution analysis result of stepped carbon trading, and the optimal estimation of energy configuration parameters is realized by using Monte Carlo method and quadratic fitting algorithm for uncertain load or other uncertain influencing factors. Finally, the simulation test analysis shows the superior performance of this method in improving the optimal allocation capacity of energy storage in multi-regional integrated energy systems under the background of stepped carbon trading. In order to deal with the impact of uncertain load or other uncertain factors on energy allocation, the method uses Monte Carlo method and quadratic fitting algorithm to achieve the optimal estimation of energy allocation parameters. This can improve the reliability and robustness of the energy storage configuration scheme.

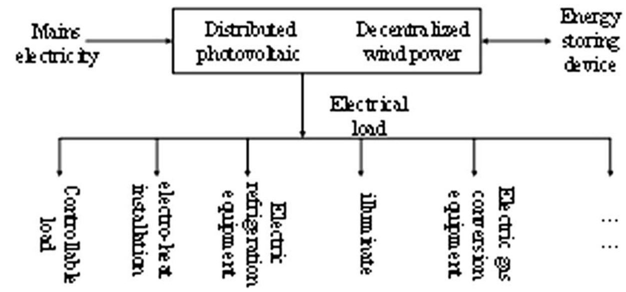

Figure 1. *Multi-regional integrated energy system.*

2. OVERALL MODEL AND PARAMETER FUSION PROCESSING OF ENERGY STORAGE OPERATION PLANNING FOR MULTI-REGIONAL COMPREHENSIVE ENERGY SYSTEM

2.1. Overall model of energy storage operation planning for multi-regional comprehensive energy system

This article focuses on the study of integrated energy systems and introduces a dual-agent stepped carbon trading mechanism. A two-layer optimization model is established, and a fitness-related algorithm is used to solve the problem. The combination of carbon trading and integrated energy systems, as well as the multi-energy scheduling optimization problem of integrated energy systems, are investigated. Figure 1 illustrates a multi-regional integrated energy system.

Integrated energy system scheduling optimization model with carbon emission measurement. The proposal of dual-carbon target requires actions from all walks of life, and the energy industry bears the brunt. In order to reduce the carbon emission of the system, carbon measurement is introduced into the system economy to guide the system to operate in a low-carbon economy. To do this, we must first be able to measure the carbon emissions in the system, and then calculate the carbon emission cost according to the carbon emissions. In addition, CCUS technology is considered, and carbon capture and utilization are added, so that the system itself consumes part of carbon emissions, while ensuring the energy consumption of the load and reducing the operating cost of the system. Energy storage battery device is an important part of comprehensive energy system, which has the advantages of improving power quality and reliability, cutting peaks and filling valleys, reducing fluctuations and so on [11]. However, if the battery is frequently charged and discharged, the life of the battery will be greatly shortened, which will lead to a great increase in the investment and maintenance costs of the distribution network. For power supply, the energy storage device has the advantages of improving power quality and reliability, cutting peaks and filling valleys, and reducing fluctuations. Similarly, if energy storage devices are added for cold energy and heat energy, on the one hand, energy can be stored when redundant cold energy and heat energy are generated, and the energy utilization rate can be increased; on the other hand, the toughness of the system can be enhanced, the flexibility of optimal scheduling can be improved, and the comfort of users can be guaranteed. The leading rule function for constructing energy storage configuration of multi-regional comprehensive energy system is:

$$\phi(i,t) = \prod_{j=1,\cdots,n} \left\{P\left(j,t-1\right)(1-\beta) + \left[1 - P\left(j,t-1\right)\right]\right\} = \prod_{j=1,\cdots,n} \left[1 - \beta P\left(j,t-1\right)\right] \tag{1}$$

In the formula, P represents energy storage capacity, and β represents energy storage efficiency. Because the number of adjacent nodes J of node I is n, energy storage configuration scheme planning and adaptive control are carried out under the pheromone guiding rules of energy storage configuration scheme distribution of multi-regional integrated energy system, and the global optimization problem of energy storage distribution dynamics of multi-regional integrated energy system is obtained, so that carbon emission reduction is no longer just the carbon emission reduction of a certain integrated energy system. When the internal emission reduction of the system reaches a certain amount, its own carbon emission rights can be sold to reduce its own operating cost. Therefore, min $\left\{f(x)\right\}$, sets a stage carbon trading mechanism for the system to promote further energy saving and emission reduction of system operators [12]. On the other hand, in order to actively guide users in the system to participate in carbon trading, the energy consumption side is also set in a ladder shape, and the carbon trading mechanism obtains the evolutionary algebra of the distribution of energy storage configuration schemes of multi-regional integrated energy systems. In the D-dimensional space, the distribution vector fusion parameters of energy storage control in the dual-agent stage carbon trading are as follows:

During the operation of the regional power system mentioned in this paper, the electric energy is mainly provided by photovoltaic and wind power, and the energy storage device can support the consumption of some renewable energy. Only when photovoltaic and wind power generation are insufficient, the energy storage device will supplement it. If it is still unable to supplement it, the commercial power will be introduced to relieve the pressure of the power system. In case of emergency, certain load regulation measures will be taken for the controllable load to ensure the safe operation of the power system. Randomly select a random number, if $0 \leq q \leq 1$, carry out the position analysis and node control of the energy storage configuration scheme of the multi-regional comprehensive energy system, and get that the node distribution position is $q \geq q_0$, and the distributed photovoltaic power generation device can absorb the solar radiation energy, and then convert it into electric energy, and then turn it into alternating current that can be used by the system through the inverter, and then access the power grid system. In order to facilitate regulation, the photovoltaic power generation equipment connected to the system is actively controlled. Its output power is related to solar radiation intensity, as follows:

$$\inf\left\{E\left[c_1, c_2, \phi | u_0\right]\right\} = \lambda_1 \int_{\Omega} (u_0 - c_1)^2 H(\phi)\, dxdy + \lambda_2 \int_{\Omega} (u_0 - c_2)^2 \left(1 - H(\phi)\right) dxdy \tag{3}$$

According to the above vector model, the overall energy storage model of multi-regional comprehensive energy system under the background of stepped carbon trading is constructed. Decentralized wind power is a distributed power generation system that converts wind energy into electric energy. Because it is close to the load center and has the characteristics of small scale and preferential access to the local power grid, it can be used for its own use, and the surplus electricity is connected to the internet, which is safe, reliable, energy-saving and economical, and can cooperate with other power sources to make output, and the load adjustment is flexible. For wind power generation equipment, the stronger the wind power of natural wind, the greater its output power, and the natural wind itself has obvious random characteristics, which leads to the same output power of wind power [13].

2.2. Configuration information fusion

Decentralized wind power is a distributed power generation system that converts wind energy into electric energy. Because it is close to the load center, the scale is small, and it is preferentially connected to the local power grid for consumption, it can be used for its own use, and the surplus electricity is connected to the Internet, which is safe, reliable, energy-saving and economical [14]. It can also cooperate with other power sources and adjust the load flexibly. For wind power generation equipment, the stronger the wind power of natural wind, the greater its output power, and the natural wind itself has obvious random characteristics, which leads to the same output power of wind power. In order to make the output power of wind power clearer and better model it, this study uses Raleigh distribution function to realize this model, and the optimal location set is:

$$p_{ij}^k(t) = \begin{cases} \dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]^{\beta}}{\sum\limits_{s \in allowed_k} \left[\tau_{is}(t)\right]^{\alpha}\left[\eta_{is}(t)\right]^{\beta}}, & if\, j \in allowed_k \\ 0, & else \end{cases} \tag{4}$$

Wherein, $\tau_{ij}(t+n) = (1-\rho)\,\tau_{ij}(t) + \Delta\tau_{ij}(t)$ represents the pheromone feature distribution vector set of energy storage search of multi-regional comprehensive energy system under the background of stepped carbon trading, and represents the distribution set of energy storage configuration information fusion parameters of multi-regional comprehensive energy system under the background of stepped carbon trading within the kth perceptual range. Constrained objects and optimization models of energy storage configuration of multi-regional comprehensive energy system are constructed. By establishing operation scheduling models including energy conversion and energy storage models, it is assumed that the pheromone intensity distribution set of energy storage optimal configuration nodes of multi-regional comprehensive energy system is $\left\{x_{k-1}^{i}, w_{k-1}^{i}\right\}$ under the background of step-by-step carbon trading at all times. Energy storage is an important flexible resource in new energy power system. Energy storage equipment can stabilize the fluctuation of photovoltaic devices and wind power devices, contribute to the power smoothing of power system, and effectively reduce the impact of distributed generation on power grid. Due to the limited service life of energy storage devices, when using distributed energy storage devices, the fuzzy weights are:

$$\tilde{w}_{k}^{i}=\tilde{w}_{k-1}^{i}\frac{p\left(z_{k}/\tilde{x}_{k}^{i}\right)p\left(\tilde{x}_{k}^{i}/x_{k-1}^{i}\right)}{q\left(\tilde{x}_{k}^{i}/x_{k-1}^{i}\right)} \tag{5}$$

Controllable load can be divided into three levels according to system response time: second level, minute level and hour level. In the system described in this paper, due to the adoption of the day-ahead scheduling strategy, given the estimated prior probability $p\left(x_{0}\right)$ of energy storage optimal allocation of multi-regional integrated energy system under the background of stepped carbon trading, the energy storage optimal allocation and path planning of multi-regional integrated energy system under the background of stepped carbon trading are carried out in the intelligent mixed quantum group, and the adaptive weight is initialized to 1/N, and the normalized weight of energy storage allocation space planning of multi-regional integrated energy system under the background of stepped carbon trading is:

$$\tilde{\tilde{w}}_{k}^{i}=\tilde{w}_{k}^{i}/\sum_{i=1}^{N}w_{k}^{i} \tag{6}$$

Global optimal control needs accurate data, including photovoltaic prediction, wind power prediction and load prediction. Then, an optimal scheduling model is established, and then the scheduling scheme is obtained by using the optimization algorithm to meet the load demand of users and deal with the consumption of renewable energy. Because of the integral nature of the energy storage device, we can't seek the best solution at a certain time. Instead, we need to start from the overall situation, consider the output situation of the whole period, get the linear planning parameter $N_{eff} \approx 1/\sum_{i=1}^{N}\left(\tilde{w}_{k}^{i}\right)^{2}$, adopt the multi-objective Pareto mapping method to configure the energy storage of the multi-regional integrated energy system, adopt the fuzzy detection method, get the node space regional distribution set of the energy storage configuration of the multi-regional integrated energy system under the background of stepped carbon trading as $\left\{W_{final}\right\}=\{\{W_{H}\},\{W_{C}\},\{W_{O}\}\}$, find the population position of the target point, and get the fuzzy constraint of the energy storage configuration of the multi-regional integrated energy system under the background of stepped carbon trading.

$$\hat{x}_{k}=\sum_{i=1}^{N}w_{k}^{i}x_{k}^{i} \tag{7}$$

At the initial stage of operation, the positions of i quantum group individuals in the energy storage configuration of multi-regional comprehensive energy system under the background of stepped carbon trading are calculated, and the iterative formula of path fusion is obtained:

$$x_{i}\left(k+1\right)=x_{i}(k)+s\left(\frac{x_{j}(k)-x_{i}(k)}{\left\|x_{j}(k)-x_{i}(k)\right\|}\right) \tag{8}$$

Where: $\left\|\overrightarrow{x}\right\|$ represents the Euler function of $\overrightarrow{x}$. Under the background of stepped carbon trading, the spatial distribution weight coefficient of energy storage configuration of multi-regional comprehensive energy system is:

$$r_{d}^{i}\left(k+1\right)=\min\left\{r_{S},\max\left\{0,r_{d}^{i}(k)+\beta\left(n_{i}-\left|N_{i}(k)\right|\right)\right\}\right\} \tag{9}$$

To sum up, the pheromone distribution in the environment is optimized by hybrid quantum genetic control, and the communication model of energy storage configuration pheromone transmission in multi-regional comprehensive energy system under the background of stepped carbon trading is established, and the path planning and design are carried out.

3. OPTIMIZATION OF ENERGY STORAGE CONFIGURATION IN MULTI-REGIONAL COMPREHENSIVE ENERGY SYSTEM

3.1. Integrated energy system energy storage integration scheduling

The first consideration is the cost of the system, which mainly includes the operating cost. Because the life of photovoltaic equipment and fan device is 20 years, compared with the short life of energy storage device, the loss rate is faster, so besides the operating cost, the life loss of energy storage device needs to be considered additionally. The operating cost of the system mainly includes the purchase cost of commercial power and the penalty cost of load shedding and wind abandonment, so it is obtained that the target state function of optimal allocation of energy storage in the energy system is:

$$\begin{aligned} x_F^i &= \frac{1}{N}\left\{\sum_{i=1}^{m} x_H^i + \sum_{i=1}^{N-m-a} x_O^i + \sum_{i=1}^{a} x_C^i\right\} = \frac{1}{N}\sum_{i=1}^{m+a} x_H^i \\ &\quad + \frac{1}{N}\sum_{i=1}^{N-m-a} x_O^i \\ &= \frac{1}{N}\sum_{i=1}^{m+a} x_H^i + \frac{1}{N}\sum_{i=1}^{N-m-a} x_S^i\left(1-Kd_i^{\max}\right) + \frac{1}{N}\sum_{i=1}^{N-m-a} Kd_i^{\max} x_L^i \end{aligned} \tag{10}$$

According to the above settings, the constraints of the whole global optimal control include: system constraints (power balance constraints) and physical constraints of controllable resources themselves. Initialize the parameters of mixed rule model for optimal allocation of energy storage in multi-regional comprehensive energy system under the background of n stepped carbon trading, and get that the characteristic distribution individual of population is $(X_1(0), X_2(0), \ldots, X_N(0))$, and the physical constraint S of controllable resources itself is inequality constraint. The photovoltaic control variables mainly consider the reactive power output of each inverter as follows:

$$\begin{aligned} \mathbf{V}_{t+1,i} = &\underbrace{\omega \times \mathbf{V}_{t,i}}_{(mementum)} + \underbrace{C_1 \times \text{rand}\,() \times \left(p_{t,i} - \mathbf{X}_{t,i}\right)}_{(Cognitive\ Component)} \\ &+ \underbrace{C_2 \times \text{rand}\,() \times \left(p_{gt} - \mathbf{X}_{t,i}\right)}_{(Social\ Component)} \end{aligned} \tag{11}$$

Wherein, $\mathbf{X}_{t+1,i} = \mathbf{X}_{t,i} + \mathbf{V}_{t+1,i}$. The background monitoring thread of the configuration system is established, and the initial thread parameters of energy storage distribution and configuration of multi-regional comprehensive energy system are set to $\tau_s = \tau_c + \tau_{CSA}$, and the population array fusion parameter set of energy storage optimal configuration of multi-regional comprehensive energy system under the background of stepped carbon trading is established. The global optimal path control of energy storage distribution and configuration of multi-regional comprehensive energy system is carried out, the individual optimal position pi and the global optimal parameter set pg of mixed quantum group distribution for energy storage optimal configuration of multi-regional comprehensive energy system under the background of stepped carbon trading are set, and the statistical characteristics of energy storage optimal configuration of multi-regional comprehensive energy system under the background of stepped carbon trading are solved. By establishing operation scheduling models including energy conversion and energy storage models, a fusion scheduling scheme is adopted. Combined with the dynamic distribution analysis results of stepped carbon trading, the optimization analysis of the target scheme of energy storage configuration of multi-regional integrated energy system is realized, and the integrated scheduling of energy storage of integrated energy system is realized [15].

3.2. Realization of regional comprehensive energy system configuration

Energy storage device can store energy, as an important flexible resource in IES, an indispensable element to realize complementary advantages and collaborative planning of various energy systems, and an important support and key technical equipment for comprehensive energy systems. With the fuzzy boundary of different energy forms and the strengthening of coupling relationship, the information concentration of energy storage in multi-regional comprehensive energy system is optimized under the background of stepped carbon trading. The transferable load is not constrained by continuity, its working time and working period are adjustable, and its operation flexibility is high, but the total electricity consumption needs to be kept unchanged during the dispatching period. It can reduce the power consumption load of users during the peak period of power consumption and transmit it to the low period of power consumption. It can reduce the peak-valley difference of power demand, smooth the characteristics of net load and reduce the demand for energy storage regulation capacity. Its mathematical model is expressed as follows:

$$\tau_{ij} = \frac{k_{ij}}{m} \tag{12}$$

Carry out feature separation and information reconstruction on the above formula, and get the power load of T period after the user responds. The iterative function of optimal configuration modeling is:

$$v_{id}^t = v_{id}^{t-1} + \left(x_{id}^t - x_d^*\right).f_i \tag{13}$$

In the formula, v_{id}^t and v_{id}^{t-1} are the optimal characteristic solutions of the upper discharge limit of the energy storage battery at the sum time, respectively. The iterative equation of global extremum or individual extremum seeking for the path planning of energy storage distribution of the multi-regional integrated energy system is expressed as follows:

$$\begin{aligned} v_{i,d}^{k+1} = \omega \cdot v_{i,d}^k + c_1 \cdot \text{rand}\,() \cdot \\ \left(c_3 \cdot \text{rand}\,() \cdot pbest_{i,d}^k - x_{i,d}^k\right) + \\ c_2 \cdot \text{rand}\,() \cdot \left(c_4 \cdot \text{rand}\,() \cdot gbest_d^k - x_{i,d}^k\right) \end{aligned} \tag{14}$$

Wherein, $c_3 \cdot \text{rand}\,()$ and $c_4 \cdot \text{rand}\,()$ are called the random distribution operator of energy storage planning of multi-regional comprehensive energy system under the background of stepped carbon trading, and its expression is:

$$c_3 \cdot \text{rand}\,() = \begin{cases} 1, & e_p > e_{0p} \\ c_3 \cdot \text{rand}\,(), & e_p \le e_{0p} \end{cases} \tag{15}$$

$$c_4 \cdot \text{rand}\,() = \begin{cases} 1, & e_g > e_{0g} \\ c_4 \cdot \text{rand}\,(), & e_g \le e_{0g} \end{cases} \tag{16}$$

Based on the above analysis, combined with the dynamic distribution analysis results of stepped carbon trading, the target scheme of energy storage configuration of multi-regional comprehensive energy system is optimized and analyzed, and the optimal estimation of energy configuration parameters is realized by Monte Carlo method and quadratic fitting algorithm for uncertain load or other uncertain influencing factors.

Because of its detailed calculation process, the obtained results have high accuracy, which makes it more suitable for micro-level. However, there are some shortcomings in the use of this method, and it is difficult to determine the stages and boundaries of the life cycle. If it is not handled properly, it will have a certain impact on the integrity of the system. Moreover, the validity of the data ensures the accuracy of the algorithm, so it takes a lot of manpower and material resources to collect data, and the time period is long. In the related application of carbon emission statistics, this method has not been widely used, but only has a preliminary attempt, such as diagnosing the current situation of carbon emission of some enterprises and controlling the governance cost to a minimum.

4. SIMULATION TEST ANALYSIS

There are many different forms of energy in the comprehensive energy system, and these different heterogeneous energies can be coupled with each other, and their use time is not the same, so the consumption of renewable energy can be improved. Because the renewable energy in the system is influenced by the external environment and the fluctuation of demand load, it is necessary to fully consider the wind power consumption on the supply side and the fluctuation of demand side, design the optimization goal as the minimum system operating cost, and combine the constraints of power, natural gas and thermal network system to construct the optimization model of cold-heat-gas-electricity comprehensive energy system. There are two main differences in the comprehensive energy system used in the experiment: one is to consider the carbon emission factor when calculating the system cost, and to add the carbon emission cost when calculating the system operation cost; Secondly, P2G equipment is added to the system to absorb part of CO_2 generated by the system. The following system is designed for simulation experiment, which includes distributed photovoltaic, energy storage battery, electric refrigeration device, electric heating device, gas boiler and cogeneration equipment, among which the cogeneration equipment includes gas turbine and absorption refrigerator. The solution method adopts fitness dependent optimizer (FDO), and the natural gas price is recorded as 3.694yuan/kg, the valley-time electricity price is 0.35 yuan/kwh, the peak-time electricity price is 0.55 yuan/kwh, and the waste light price is 1.04 yuan/kwh according to twice the electricity price. The scale of energy storage of multi-regional integrated energy system is 120, the global optimal value of energy storage path distribution of multi-regional integrated energy system is $\min(f_6) = f_6(0, 0, \ldots, 0) = 0$, the fuzzy matching parameter is $c_{1ini} = 3$, the iterative step of energy storage control of integrated energy system is $c_{2fin} = 5.4$, the maximum detection threshold is $\mu_{\max} = 0.67$, and the minimum detection threshold is $\mu_{\min} = 0.23$, and the energy storage load of multi-regional integrated energy system is obtained as shown in Figure 2.

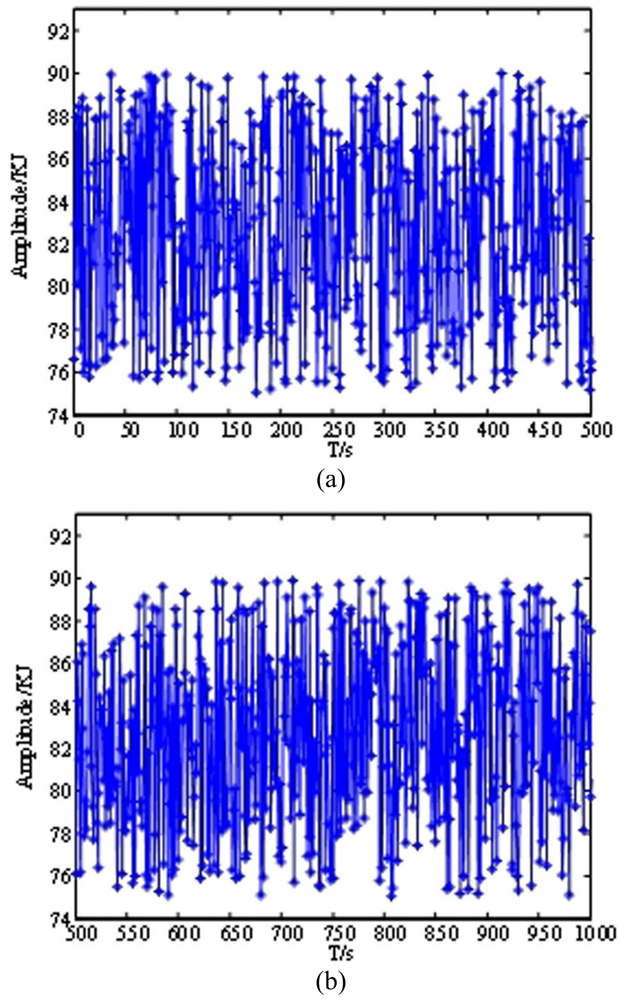

Figure 2. *Energy storage load of multi-regional comprehensive energy system. (a) Test object 1. (b) Test object 2.*

In this series of curves, the portion above zero scale represents the corresponding energy generated or provided, while the portion below zero scale represents the corresponding energy consumed, and the dashed line in the graph represents the energy consumed by the corresponding load. Therefore, the corresponding energy relationship should be that the energy above the zero scale can meet the corresponding load and the energy consumed below the zero scale, and the predicted result of energy storage configuration is shown in Figure 3.

As can be seen in the electric load diagram, the peak period of the electric load is concentrated in noon and evening, and the noon period benefits from the greater intensity of the sun's light, at which time photovoltaic can meet the load demand, while at other periods, it is necessary to introduce commercial

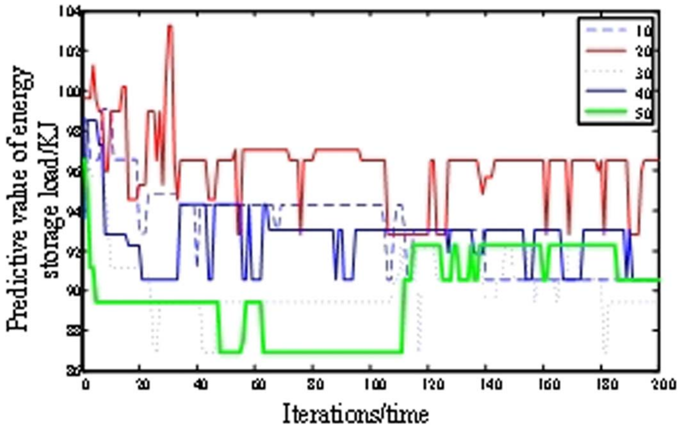

Figure 3. *Prediction results of energy storage configuration of multi-regional comprehensive energy system.*

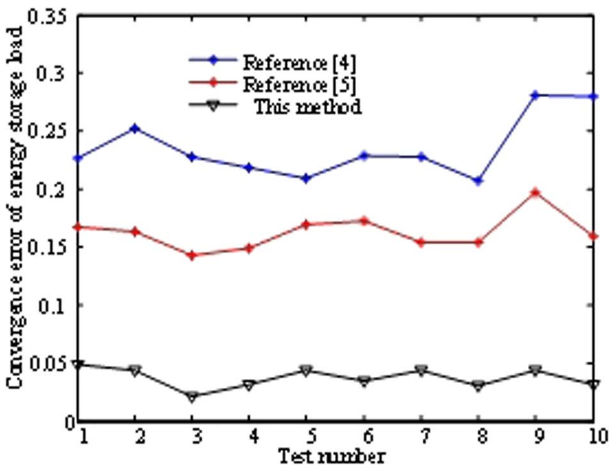

Figure 4. *Convergence of energy storage configuration of multi-regional integrated energy system.*

power and use other equipment to provide electric energy. In addition, in addition to the electric load, there are also devices inside the system, such as electric refrigerators and electric heating equipment, which consume electric energy. From the point of view of electric energy, this behavior increases the demand for electric energy, but from the overall point of view, using such devices to provide other forms of energy just saves energy. Finally, the convergence of the energy storage configuration algorithm is tested, and the convergence curve is shown in Figure 4. See Table 1 for the comparison results of energy utilization efficiency.

The analysis shows that this method has strong scheduling ability of energy storage allocation in multi-regional integrated energy system under the background of stepped carbon trading, and can accurately evaluate the dynamic supply-demand relationship between load demand and model, reduce carbon emissions, improve system operation system and improve energy utilization efficiency. Using the above scheduling scheme, the operating cost of the system is 20,223.55 yuan, which is mainly used for purchasing electricity and gas, while if the corresponding equipment

Table 1. *Comparison of energy utilization efficiency.*

Test times	This method	Reference [4]	Reference [5]
10	0.805	0.592	0.525
20	0.947	0.524	0.586
30	0.861	0.614	0.590
40	0.867	0.630	0.528
50	0.924	0.555	0.529
60	0.969	0.652	0.515
70	0.906	0.684	0.586
80	0.850	0.678	0.521
90	1.000	0.522	0.504
100	0.992	0.640	0.546

is selected for separate supply without energy coupling, the cost is 42,955 yuan. Among them, the purchase cost of natural gas is 0.5 yuan/L. Without coupling, in order to meet different kinds of load requirements, such as cooling load, electric refrigeration equipment must be used for refrigeration, and the waste heat of gas turbine at this time will be wasted; In addition, the cost generated in the system is not only the purchase of gas and electricity, but also the penalty cost caused by the system's failure to absorb excess photoelectric in time. Therefore, using single energy for supply can't effectively use the by-product energy in the process of capacity production, resulting in energy waste. In addition, considering the environment, the energy input of the system, whether it is commercial power or natural gas, will emit CO_2, and the waste of energy will inevitably lead to an increase in carbon emissions. Therefore, the use of comprehensive energy system can significantly reduce the waste of energy, and then reduce CO2 emissions.

5. CONCLUSIONS

With the development of clean energy application technology, energy conversion technology, physical information transmission technology and distributed energy system technology, comprehensive energy system has made great progress. The cold-heat-gas-electricity comprehensive energy system with carbon trading not only integrates various types of energy resources such as electricity, gas, cold energy, heat, wind energy and solar energy, but also achieves the coordinated and effective optimization and interactive reaction of various heterogeneous energies, which promotes the complementary and common development of various energies, improves the utilization ratio of clean energy, and also reduces the carbon emissions of the system and absorbs some carbon emissions with the help of the carbon trading market, enriching the ways and means of energy conservation and emission reduction, and helping peak carbon dioxide emissions. In this paper, a multi-regional integrated energy system energy storage configuration model based on integrated scheduling is proposed under the background of stepped carbon trading. The overall model of energy storage operation planning of multi-regional comprehensive energy system is analyzed under the characteristics of steady state, dynamic state and variable working conditions. The planning modeling method of distributed energy is adopted to realize the fusion of multi-regional comprehensive energy distribution parameters under the background of stepped carbon trading, and the constrained object and optimization model of energy storage configuration of multi-regional comprehensive energy system are constructed. By establishing operation scheduling models including energy conversion and energy storage models, a fusion scheduling scheme is adopted. Combined with the dynamic distribution analysis results of stepped carbon trading, the target scheme of energy storage configuration of multi-regional comprehensive energy system is optimized and analyzed, and the optimal estimation of energy configuration parameters is realized by Monte Carlo method and quadratic fitting algorithm for uncertain load or other uncertain influencing factors. The simulation results show that this method has strong scheduling ability for energy storage configuration of multi-regional integrated energy system under the background of stepped carbon trading, and can accurately evaluate the dynamic supply-demand relationship between load demand and model, reduce carbon emissions, improve system operation system and improve energy utilization efficiency. At the same time, in order to fully mobilize the enthusiasm of energy users to participate in energy conservation and emission reduction, a double-agent ladder carbon trading mechanism is formulated, and the calculation method of carbon trading cost is refined. Then, the double-layer optimization model is used to solve the problem, which can better and fully utilize the carbon trading market, enhance the environmental awareness of all users, and obtain better economic and environmental benefits.

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Author Contributions

Weimin Zheng (Conceptualization [Equal], Writing – review & editing [Equal]), Bo Zou (Data curation [Equal]), Jiting Gu (Formal analysis [Equal]), Jiaqian Chen (Methodology [Equal]), and Jiansheng Hou (Writing – original draft [Equal])

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