Energy Storage Optimization of Wind Solar Hybrid Power Generation System Based on Improved Grasshopper Algorithm

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Abstract

During the heating period, the solid thermal storage electric boiler is added to use the waste electricity for local heating, and the corresponding energy storage optimization model of wind solar hybrid power generation system is constructed with the maximum waste electricity contotalityption and the minimum power purchase cost as the objective function, and the contotalityption and waste electricity constraint, system power balance constraint, electric boiler power constraint, heat storage constraint, and regulation times constraint as constraint conditions. Improved moth algorithm is constructed to solve the optimization model, and a Pareto solution set with both economy and reliability is obtained. Optimal compromise solution is screened out from the Pareto solution set, and optimal configuration capacity of the thermal storage electric boiler and annual amount of electricity discarded in the

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system can be obtained. Thus, the power rejection in the system can be reduced, promoting widespread use of independent renewable energy power generation systems.

Keywords: Energy storage optimization, wind solar hybrid power generation system, amended grasshopper algorithm.

1 Introduction

At present, world energy requirement is growing greatly, competition for oil or gas is very heated, pressure on environment is very large, and global climate change is attracting much concern; Green, low-carbon and durable development has been reasonable selection for sustainable prosperity of civilization. Energy sector has development rule of heavy investment, long period, and strong inertia. The country attaches great importance to the issue of energy security. Renewable energies such as wind and solar will grow rapidly.

At present, solar photovoltaic power generation and wind power generation technologies have been ripe, and cost drops quickly. In future, technology and economy of solar photovoltaic power generation and wind power generation can achieve same level as that of fossil energy, promoting advancement of energy reform. China has rich solar energy, and solar radiation power of land surface in China reaches about 1.68×10^3 TW, average horizontal irradiance reaches about 175 W/m^2. Moreover, solar radiation resources are extensively spread. Wind energy is kinetic energy generated by the movement of air. Technical exploitable amount of wind energy in China with an annual average wind power density of over 298 W/m^2 at 70 m level is 2.6 TW, and the technical exploitable amount of wind energy resources with an annual average wind power density of more than 200 W/m^2 at 70 m level is 3.6 TW. Vigorously developing renewable energy has become an important strategic measure for all countries in the world to cope with global climate change. Renewable energy is gradually developing from scattered and small-scale energy to an important form of energy that can partially replace fossil fuels, relieve the pressure on the ecological environment and realize large-scale utilization.

Solar wind hybrid power generation can realize the complementary characteristics of solar photovoltaic power generation and wind power generation, to achieve stable output of power generation day and night and electricity in all seasons. This system can make full use of resources more than separate solar and wind power generation, improve reliability and stability of power generation, and greatly improve continuous power supply performance of system. Solar wind hybrid power generation can also reduce investment and operating costs. The complementary advantages of the two power generation forms reduce the requirements for battery capacity and reduce costs. The best state of solar wind hybrid power generation system is to realize stable power output for 24 hours to the load without starting the external power supply, at this time, the system can maximize the economic and social benefits. The disadvantage of solar wind hybrid power generation is that its system is more complex than wind energy or solar energy alone, which makes the requirements for system control and management become higher, and the maintenance of the system will be more difficult. The operation process of the optical hybrid power generation system is: using natural wind power to generate electricity, the wind wheel absorbs the wind energy when it rotates, thus driving the wind turbine to convert the wind energy into electrical energy, the solar photovoltaic cell converts the absorbed sunlight into electrical energy, and the generated current can be directly connected to the DC load after rectification, voltage stabilization and controller, or the AC load can be connected after completing the AC DC conversion through the inverter, Generated electric energy is stored in the battery [1].

With the widespread application of wind power generation technology, the development prospect of wind solar complementary power generation system is unlimited. Its reasonable configuration is crucial to ensure the reliability of power generation system. A reasonable allocation of unit capacity of hybrid energy storage of the battery and supercapacitor in power generation system can significantly enhance the continuity and reliability of the power generation system. However, with increasing popularity of wind power generation in China, how to improve the energy storage capacity of wind power generation system is a key issue that should be concerned. For energy storage of wind solar hybrid power generation system, the cost has been optimized in previous articles, and the method adopted is to improve the grasshopper algorithm. Taking the minimum life cycle cost as the objective function, energy balance, energy storage capacity and power of storage battery, energy storage capacity and power of supercapacitor as constraints, energy loss rate and energy loss rate as reliability indicators, a model is established, and an improved grasshopper algorithm is constructed to solve model, to achieve optimal configuration of energy storage capacity of wind solar hybrid power generation system. Thus, energy loss rate and energy loss rate of optimized energy storage system are lower, and cost is also lower [2].

Previous studies on optimization problem of wind solar hybrid power generation has been coped with many optimization algorithms, however optimal precision and efficiency is relative low, these the novel optimization algorithm should be developed. The grasshopper algorithm is improved in this research, and the better optimization ability can be obtained. This research proposed improved grasshopper algorithm for optimizing wind solar hybrid power generation, and the optimization efficiency and precision of wind solar hybrid power generation can be improved.

2 Basic Theory of Wind Solar Complementary Power Generation System

The wind solar complementary power generation system generally uses photovoltaic power generation when the solar intensity is high, and the wind power supply branch is disconnected. On the contrary, the wind turbine generator is used to supply power, and the photovoltaic cell branch is disconnected. At present, there is a solar wind hybrid power generation system that can supply power from two lines simultaneously. As long as output voltage of two power supply branches is greater than the battery voltage, the diode can be connected to realize the simultaneous power supply of the two branches [3].

Wind power generation equipment, photovoltaic power generation device, energy storage device, control device and inverter device form a wind solar complementary power generation system. Wind solar system is illustrate in Figure 1. Wind solar system concludes wind turbine, solar panels, wind/solar inverter, and battery, the output of system is 220 Vac/50 Hz.

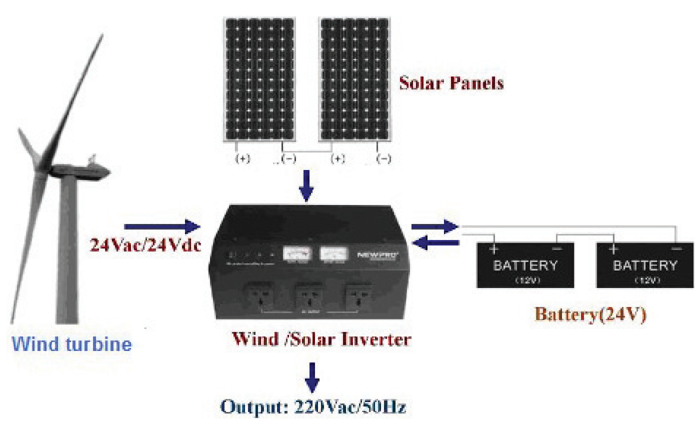


Figure 1 Diagram of wind solar system.

The power generation principle of the wind power generation device is to transform wind energy to mechanical energy of wind turbine through application of wind energy by wind turbine, and then transform it to electrical energy, and then use control device to store the generated electrical energy into the energy storage device. So far, the energy storage device is used for external power supply, and its power supply objects include both DC load and AC load. The power generation principle of photovoltaic power generation equipment is to convert the light energy into electric energy through use of solar photovoltaic panels, and then use the control device to store the generated electric energy into the energy storage device. So far, the energy storage device provides external power, and its power supply objects include both DC load and AC load. The working principle of the inverter device is to convert DC power into AC power. The existence of inverter is due to the mismatch between the energy storage device and the voltage and current of many electrical loads. Wind solar hybrid power generation system requires inverter device to convert current, at the same time, the inverter device can also stabilize the voltage, which has important function on improving stability of entire power supply system [4].

Solar wind hybrid power generation can be applied to domestic power contotalityption in rural areas without electricity, such as semiconductor outdoor lighting, navigation aids, power supply for surveillance cameras, communication base stations, desalination devices and pumped storage power plants. With the continuous development of green energy, solar wind hybrid power generation may become the main source of electricity for people in the future. In these aspects, the solar wind hybrid power generation has many advantages over the power supply of the ordinary grid. Take the communication base station as an example. Because of its geographical location, the communication base station in the plateau and mountain areas faces high costs, difficult maintenance and other problems when erecting power lines. The construction of solar wind hybrid power generation can effectively solve these difficulties, save costs, and make the communication base station operate normally [5].

3 Multi-Objective Optimization Model of Solid Heat Storage Electric Boiler

Within the scope of system power rejection, the way of electric heating with solid thermal storage electric boiler can improve phenomenon of excessive power rejection of renewable energy, but as the purchase of electricity will increase part of the operating costs, the grid electricity price is divided into peak, valley and flat values every day. Therefore, the key to optimal operation of thermal storage electric boiler is how to contotalitye the most discarded power at the lowest cost of power purchase. In this paper, taking the maximum waste power contotalityption and the minimum operating cost as objective function, optimal dispatching scheme of wind power thermal storage electric boiler system is obtained by using improved grasshopper algorithm, taking into account the constraints such as waste power, thermal storage tank capacity, equipment power, boiler regulation times, thermal power, etc [6].

The output thermal power Q_{eb} and input electric power P_{eb} of electric boiler in period *t* are linear, and the mathematical model is

$$Q_{eb} = \eta_{eb} P_{eb} \tag{1}$$

where η_{eb} represents the heat conversion efficiency of electric boiler.

Objective function is listed by:

(1) Objective function is to maximize amount of electricity discarded, which is expressed by [7]

$$\max F_1 = \sum_{t=0}^{T} P_{eb,t} \tag{2}$$

where: $P_{eb,t}$ is the waste electricity contotalityed by the electric boiler during *t*.

(2) The operation cost refers to the cost corresponding to the electricity contotalityption of the thermal storage electric boiler during the heating period, with the lowest total cost as the objective function [8]:

$$\min F_2 = C_1 + C_2 \tag{3}$$

where: C_1 is total price of electricity purchased from grid; C_2 is total price of heat storage using discarded electricity.

Constraint conditions conclude abandoned power restriction, system power balance restriction, electric boiler power restriction, heat storage restriction.

(1) Abandoned power constraint

In this paper, the research of thermal storage electric boiler is based on aim of maximizing amount of waste electricity, so it should meet the constraints of waste electricity [9]:

$$P_{b,t} = P_{e,t} \tag{4}$$

where $P_{e,t}$ is the discarded power,

(2) Power constraint of electric boiler

$$P_{\min} \le P_{b,t} \le P_{\max} \tag{5}$$

where $P_{\min}$ is minimum operating power of boiler; $P_{\max}$ is maximum operating power of boiler.

(3) Heat storage capacity constraint

Heat stored in heat tank shall be within its limits, which is expressed by [10]

$$Q_{\min} \le Q_{\tan\mathrm{k}} \le Q_{\max} \tag{6}$$

where $Q_{\min}$ is the minimum heat storage capacity of heat storage tank; $Q_{\max}$ is maximum heat storage capacity of heat tank.

(4) Regulation constraint of regenerative electric boiler

Considering the actual conditions, power regulation times of regenerative electric boiler should be not greater than 18, that is

$$L \le 18 \tag{7}$$

where, L is the number of boiler regulation.

(5) Heating load constraint

To adapt to heat load requirement of a certain area, it is critical to provide real-time heat supply required by heating users every day, so it is necessary to meet the constraints:

$$\sum_{t=0}^{T} P_{b,t} \cdot t \ge h_t \tag{8}$$

where h_t is real time heat supply.

4 Construction of Improved Grasshopper Algorithm

The core idea of grasshopper optimization algorithm is that grasshoppers jump and move according to the position of food and the position of other individuals in the grasshopper group. There are exclusion areas, comfort areas and attraction areas between grasshoppers. The grasshoppers update their positions according to the location update formula provided by the mathematical model. After all grasshoppers move, update the fitness value of all grasshoppers. The food position is determined by the optimal fitness value. When all grasshoppers move to the comfort zone, the grasshoppers will not move [11].

The location update model of each grasshopper in grasshopper population is formulated by

$$X_i = S_i + G_i + A_i \tag{9}$$

where X_i represents location of ith grasshopper, S_i represents social affecting factor, G_i represents gravity affecting factor, A_i represents affecting factors of wind direction, S_i is expressed by [12]

$$S_i = \sum_{j=1,j\neq i}^{T} [S(d_{ij}) \ \widehat{d}_{ij}] \tag{10}$$

where d_{ij} represents distance between *i*th individual and *j*th individual, T represents total number of individuals of population, $\widehat{d}_{ij}$ represents the unit direction vector from *i*th grasshopper and *j*th grasshopper. $S(\cdot)$ represents function defining the strength of social forces, which is expressed by

$$S(r) = f \cdot \overline{\overline{e^{l}}}^{r} - \bar{e}^{r} \tag{11}$$

where f represents attractive strength, which is always set as 0.6, l represents attractive length scale parameter, which is always set as 1.6. r represents distance between two individuals, when $S(r) > 0$, two grasshoppers are attracted; when $S(r) = 0$, two grasshoppers are in a comfortable state; when $S(r) < 0$, two grasshoppers are in a state of rejection [13].

G_i is expressed by

$$G_i = -g\hat{e}_g \tag{12}$$

where g represents gravitational constant, $\hat{e}_g$ represents unit vector pointing vertically to the geocenter.

A_i is calculated by

$$A_i = u\hat{e}_w \tag{13}$$

where u represents drift constant, $\hat{e}_w$ represents unit vector of wind speed.

The above formulas after integrating is expressed by

$$X_{i+1} = \sum_{j=1,j\neq i}^{T} \left[S(|X_j - X_i|) \frac{X_j - X_i}{d_{ij}} \right] A_i - g\hat{e}_g - u\hat{e}_w \tag{14}$$

However, this model can not be directly applied to solve the problem, so it is improved as follows [14]

$$X_i^d = c_2 \left[\sum_{j=1, j \neq i}^{T} c_1 \frac{ub_d - lb_d}{2} S(|X_j - X_i|) \frac{X_j - X_i}{d_{ij}} + \hat{T}_d \right] \tag{15}$$

where ub_d represents upper limit of decision variable X_i^d of dimension *d*, lb_d represents bottom limit, $\hat{T}_d$ represents *d*th dimensional value of current optimization solution, $d \in [1, N]$, c_1 and c_2 are adaptive parameters, which decreases during iteration, c_1 reduces the scope of exclusion zone, comfort zone and attraction zone, c_2 is similar to inertia weight.

The grasshopper algorithm is improved based on the following methods [15]:

(1) Reverse learning mechanism

In order to better learn the reverse learning mechanism, first explain the concept of reverse point. Taking one-dimensional scalar as an example, the reverse point of *a* is *z*, which is illustrated Figure 2.

Upper and lower limits are *lower* and *upper*, and *lower* + *upper* − *a* is reverse point of *a*. After each position update, calculate the reverse point of each solution, and compare the objective function values of current solution and reverse point. If reverse point has a optimal objective value, use reverse point to replace the current solution, otherwise it does not change. Reverse learning mechanism is applied to population initialization strategy and iterative updating process [16].

(2) Gaussian mutation operator

To deal with problem that multi-objective algorithm falls into local optimal solution, a Gaussian mutation operator is added to the position update. Contrasted with other mutation operators, Gaussian mutation operator has highest possibility of mutation near average value, and the mutation is the mutation centered on the previous generation, which makes local advancement of algorithm more available.

Figure 2 Diagram of reverse point.

During the operation of the algorithm, each dimension of each individual decision variable has a certain probability of having a standard deviation of σ, and the mathematical model of Gaussian variation is shown in expression (16) to expression (18) [17].

$$X_i^{k'} \sim N(X_i^k, \sigma^2) \tag{16}$$

$$N(X_i^k, \sigma^2) = X_i^k + [\sigma \cdot N(0,1)] \tag{17}$$

$$\sigma = \frac{ub_k - lb_k}{6} \tag{18}$$

where $X_i^{k'}$ is variation results of the *i*th individual in the *k*th dimension, X_i^k denotes value before the *k*th dimension of the *i*th individual changes.

(3) Population guidance

The locust optimization algorithm needs the optimal solution as a guidance to guide other locusts to move towards the optimal solution, so the selection of the optimal solution is crucial. However, due to the existence of contingency, sometimes the optimal solution is not reasonable. And the global optimal solution should not be limited to a fixed solution, but should be a set of better solutions.

(4) Pareto ranking

The population with n population is classified as graded Pareto front by non dominated sorting. Firstly, calculate whole Pareto fronts in population, and mark the Pareto fronts as 1. Then ignore the individuals with Pareto rating of 1, find the Pareto front among the remaining individuals, record the Pareto rating of 2, and then cycle until all solutions are classified. By introducing the calculation of Pareto grade and crowding degree, all solutions can be sorted, so that better top *N* solutions can be selected when the population is mixed [18].

(5) Crowding distance

Crowding distance is used to describe distribution characteristics of non dominated solutions, so as to select 10% high-quality solutions in Pareto optimal collection. In Pareto solution set, every non dominated solution corresponds to a crowding distance, which is used to denote totality of the distances of the nearest non dominated solution in each objective function dimension. The larger the crowding distance is, the farther the nearest solution is from the current solution, that is, the Pareto solution is sparse. On the contrary, the smaller the crowding distance is, the closer the nearest solution to the current solution is, that is, the denser the Pareto solutions are. The purpose of introducing crowding distance is to select the optimal Pareto solution according to the distribution of the current Pareto optimal solution, so as to guide the population to find solutions that make the Pareto front more uniform. In the boundary solution of Pareto front, crowding distance is defined by *inf*, and the calculation formula of crowding distance of other solutions is calculated by [19]

$$I[i]_{distance} = \sum_{m=1}^{M} \frac{I[i+1] \cdot m - I[i-1] \cdot m}{f_m^{\max} - f_m^{\min}} \tag{19}$$

where M represents dimensional degree of objective function, $I[i-1] \cdot m$ represents *m*th objective function value that is only next to *i*th solution after ranking *m*th objective function value in collection *I*, $I[i+1] \cdot m$ represents value *m*th objective function that is only better than *i*th solution. $f_m^{\max}$ and $f_m^{\min}$ represent maximum and minimum values of *m*th objective function [20].

5 Case Study

January in the middle period of heating is selected as research object, and according to data of abandoned electricity in January, the contotalityption of abandoned electricity is analyzed. Daily total quantity of discarded electricity in one month is listed in Table 1.

It can be seen from the statistics of abandoned power data in January that the daily abandoned power level is about 0–520000 kWh. Figure 3 shows the

Table 1 Daily total quantity of discarded electricity in one month

Date	Abandoned Electricity	Date	Abandoned Electricity	Date	Abandoned Electricity
1.1	0	1.11	32546.2	1.21	44567.5
1.2	0	1.12	26869.4	1.22	17535.3
1.3	17445.3	1.13	31658.2	1.23	4387.3
1.4	32445.4	1.14	29678.7	1.24	27654.8
1.5	0	1.15	40654.6	1.25	34337.1
1.6	8468	1.16	1154.5	1.26	27884.6
1.7	31784.26	1.17	37854.4	1.27	39975.4
1.8	50642.51	1.18	12655.8	1.28	24768.2
1.9	38769.34	1.19	34768.5	1.29	31558.4
1.10	24879.26	1.20	22854.4	1.30	17545.9
				1.31	21774.5

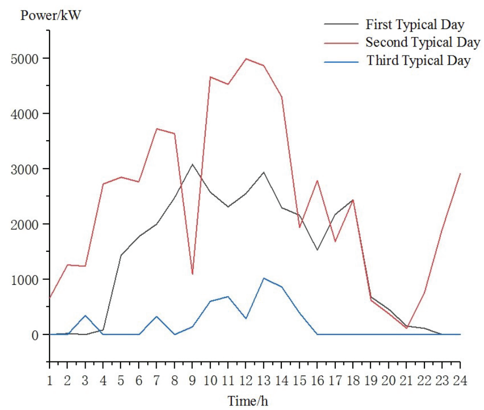


Figure 3 Diagram of three typical daily power rejection.

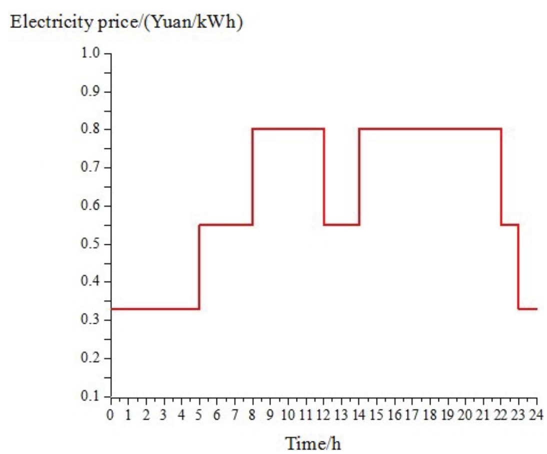
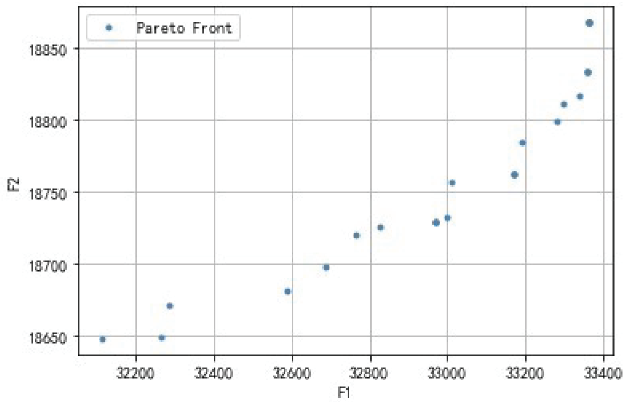


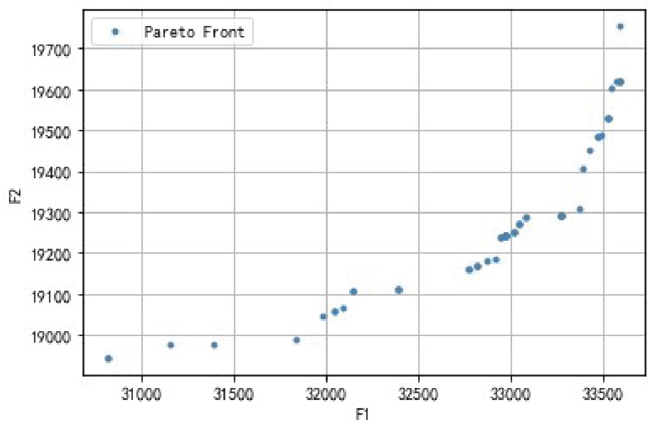
Figure 4 Real time electricity price of power grid.

abandoned power data of three typical days selected in the heating period. First typical day is a day with more abandoned power, second typical day is a day with moderate abandoned power, and third typical day is a day with less abandoned power.

Under the multi-objective optimization operation, the discarded electricity and the power grid are used as the power source of the boiler. When the discarded electricity is not enough to meet the heating demand, the heat is supplemented by purchasing electricity from the power grid. Power grid price is divided into peak, average and valley according to the time period, as shown in Figure 4.



(a) Eight boilers



(b) Nine boilers

Figure 5 Pareto solution set under different number of boilers.

To obtain optimal capacity of boiler, under different number of boilers the improved grasshopper algorithm is used to get final non inferior solutions distributed in the objective function space. The Pareto solution set on first typical day is shown in Figure 5 and Figure 4.

It can be seen from Figure 5 that if only the economy is considered to be optimal, the electricity contotalityption is the lowest; If only the most discarded power contotalityption is considered, the operation cost will be greatly increased. Therefore, it is necessary to comprehensively consider various factors and fully tap the information contained in the Pareto optimal

Table 2 Pareto optimal compromise solution under different number of boilers on first critical day

Number of Boilers	Abandoned Electricity Contotalityption/kWh	Power Purchase Cost/Yuan
7	32043	23043
8	33954	21954
9	34560	20456
10	34995	21054
11	35845	22009

Table 3 Optimal results of second typical day and third typical day

	Number of Boilers	Abandoned Electricity Contotalityption/kWh	Power Purchase Cost/Yuan
Second typical day	7	32049	19485
Third typical day	6	30483	20129

solution to find optimal compromise solution. As shown in Table 2, optimal compromise solution is obtained for different number of boilers.

From the perspective of sensitivity analysis, it can be seen that on a typical day, when 7 boilers are installed, the low rated power of the boiler results in the least amount of electricity contotalityed and discarded, so more electricity is purchased from the grid, which leads to highest total cost. Therefore, the effect of installing 7 boilers is poor; By comparing the situation of 8, 9, 10 and 11 boilers, it can be seen that when 9 boilers are installed, the power purchase cost is the lowest and the contotalityption effect is the best. Therefore, the optimal solution of 9 boilers is taken as the optimization result of typical day, and discarded electricity of a day is 34560 kWh.

The optimal results of second typical day and third typical day are listed in Table 3.

In order to better improve the capacity of thermal storage electric boiler system to absorb electricity discarded, and enhance use significance, the solid thermal storage electric boiler system is taken as research object, and a multiple objective optimization scheme is proposed that gives consideration to both the electricity discarded and the electricity contotalityed and the stable heating capacity. The mathematical model of the electricity contotalityption and operation cost of the regenerative electric boiler is established, and the improved locust algorithm is used to solve the problem. The optimization effect is significant, which verifies effectiveness of proposed means.

6 Conclusions

In this research, a multi-objective optimization operation strategy for thermal storage electric boiler is presented. With the maximum power contotalityption and the minimum power purchase cost as the objective function, the multi-objective optimization modeling of thermal storage electric boiler is carried out through the constraints of boiler and heating power, thermal storage capacity and boiler regulation times. The improved grasshopper optimization algorithm is used to obtain Pareto solution set under different number of boilers, and the optimal number of boilers for different typical day is obtained. Analysis results show that the proposed method can obtain best energy storage effect of wind solar hybrid power generation system. In future, the optimization model of wind solar hybrid power generation system should be improved for approaching real situation, and novel optimization algorithm should be established for improving optimal effectiveness.

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Biographies

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