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# Artificial Intelligence Assisted Energy Optimization and Control Method for Microgrids

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**Abstract.** As the future direction of power development, microgrids are particularly important for rational and efficient energy management. This article establishes an optimization model with multiple uncertainties as parameters for the microgrid energy system, with the objective function of minimizing operating costs. Then, an improved harmony algorithm was used to solve for the optimal solution of the model parameters. Finally, a microgrid system consisting of wind and thermal power units established in a certain area of Hebei Province was used for solution analysis. After experimental verification, the proposed method in this paper achieved significant improvements in both operational cost reduction and microgrid efficiency.

**Keywords:** Microgrids, energy optimization, harmony search algorithm

## 1 Introduction

Sustainable development, green and low-carbon has become a global problem and common concern facing the development of human society today. China is committed to making its own contribution to tackling climate change. Carbon dioxide emissions will peak before 2030 and become carbon neutrality by 2060. The utilization efficiency and power generation capacity of new distributed energy sources, mainly wind power and photovoltaic power generation, have been widely developed, promoting the diversification of power system structures and providing important means for energy conservation and emission reduction.

Microgrid is a small power system composed of a variety of distributed generation units, energy storage systems and local loads. It is the development direction of the future power system. Therefore, how to achieve reasonable energy management, intelligence, and efficient operation of microgrids is an important prerequisite for exerting their functions. However, there are currently the following problems in the operation process of microgrids:

(1) Microgrids lack the inertia of large generator sets and have drawbacks such as low inertia, time-varying, and parameter uncertainty, which increases the requirements for the control end.

(2) The microgrid has multiple flexible and controllable distributed generation units, each of which can integrate advanced communication, computing and control technologies, and has the prerequisite for AI intervention control, but the current control is not intelligent and efficient enough.

(3) Some scholars have established models that are not perfect enough, and the solving speed is slow in the algorithm search process.

Therefore, this article focuses on the problems existing in the current operation of microgrids and does the following work:

(1) Considering the multiple uncertainties of microgrids, establish an objective function with the goal of minimizing the operating cost of microgrids, and improve the constraint conditions;

(2) In the process of solving the objective function, the harmony algorithm was used. In order to improve search efficiency and avoid local optima, the harmony algorithm was improved.

(3) Taking a real microgrid in a certain area of Hebei as the experimental object, the algorithm in this paper is

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used to provide guidance for the operation of the microgrid in that area.

In order to comprehensively describe the work done in the article, it is divided into the following chapters. Chapter 2 mainly searched for the relevant achievements of relevant scholars and found that there is not much research at home and abroad. Chapter 3 established and improved the microgrid optimization model, Chapter 4 improved the harmony algorithm, and used the algorithm to solve the optimal solution of the objective function. Chapter 5 verified the proposed method using real cases, and Chapter 6 is the conclusion section, Summarized the shortcomings and explored further research directions.

## 2 Related Work

Gugulothu proposed a centralized energy management strategy for an independent DC microgrid, aimed at improving the lifespan and reliability of battery energy storage systems, and reducing hydrogen consumption. Simulation experiments have verified the effectiveness of the method [1]. Pokharel mainly solves the problems of intermittent and slow dynamic response in microgrids, and proposes a vertical control strategy based on DC bus signal. The effectiveness of the method has been verified through simulation [2]. Singh proposed a new power management strategy for power sharing between batteries and supercapacitors in energy storage systems, which is used to improve the efficiency of microgrid operation and has reference significance for the control of DC microgrids. Finally, simulation has proven the feasibility of this strategy and can improve battery life [3]. Haoyun Sheng has established a micro energy network architecture model that includes multiple distributed devices to address the common problems of local optima and slow convergence in algorithms, and an optimization configuration model that takes into account reliability and contains multiple constraints. Finally, the improved particle swarm optimization algorithm is applied to the actual operation model to obtain the configuration scheme and optimal annual economic cost of each distributed device [4]. Yongjun Lin proposed a scheduling optimization plan based on artificial intelligence control strategy to address the issue of operational efficiency of microgrids. He built an automatic scheduling optimization model for microgrids, with operational economic benefits as the optimization goal, ultimately achieving the maximization of economic and environmental benefits of microgrids [5]. Yang Song, taking a typical airport microgrid as the research object, established an optimization scheduling model for the airport microgrid, and proposed an improved sparrow search algorithm for solving the optimization scheduling of the airport microgrid. The algorithm has the characteristic of fast convergence speed, and the improvement method of the algorithm has reference significance for this article [6].

## 3 Optimization Model for Energy Regulation of Microgrid

During the operation of microgrids, there are multiple uncertainties. An optimization model is established with multiple uncertainties as parameters, and through the intelligent optimization process of the model, the regulation of microgrids under multidimensional uncertainty conditions is achieved. This article regards a single microgrid as an intelligent agent, and establishes a scientific optimization model to achieve regulation of the microgrid with the optimization goals of maximizing operational benefits and minimizing operating costs.

### 3.1 Microgrid Structure

Combined with the actual situation, the micro grid, diesel generator set and renewable green energy discussed in this paper. Therefore, the schematic diagram of the network structure of the microgrid is shown in Fig. 1.

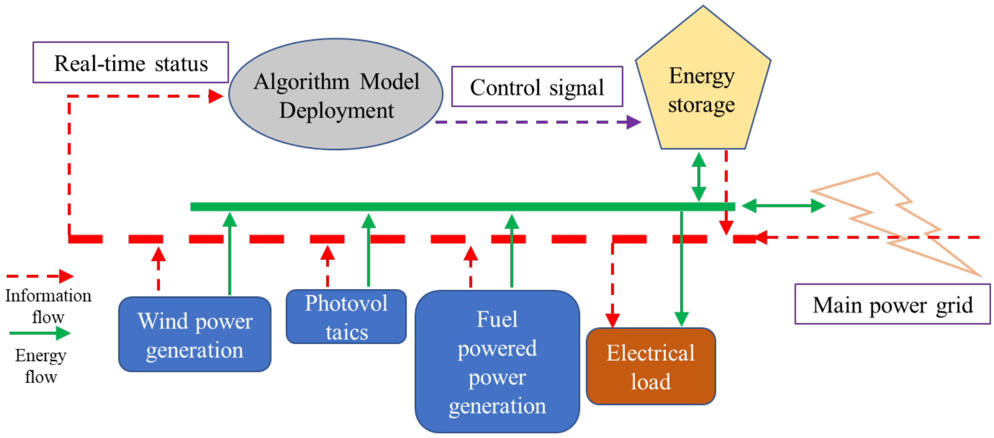

**Fig. 1.** Schematic diagram of microgrid network structure

### 3.2 Establishment of Microgrid Operation Model

The microgrid operation model consists of operating costs, objective functions, and constraints [7]. The microgrid operation model is established as follows:

(1) Operating costs

The operating cost is an important parameter for the operation status of microgrids, with microgrids in island mode as the main research object. The operating cost includes the generation cost A of thermal units represented by fuel generators, the renewable energy generation cost B, the system operation cost C, and the environmental protection cost D. The optimization cycle is daily optimization, i.e. cycle E [8]. Therefore, the operating cost F can be expressed as:

$$C = \sum_{t\ T}\left[C_r + C_k + C_y + C_h\right]. \tag{1}$$

For the power generation cost of a thermal unit, including the construction cost of the unit and the fuel cost of the calorific value unit, it is expressed as:

$$C_r = \sum_{t=1}^{T}\left(\left(\sum_{i=1}^{N}\frac{T}{T_i^{\max}}C_i^{build}\right)+f_{DE}(t)\right). \tag{2}$$

In the formula, $T_i^{\max}$ is the service life of unit $i$, $C_i^{build}$ is the installation and debugging cost of unit $i$, $f_{DE}(t)$ is the combustion cost of the thermal unit at time $t$, and the combustion cost $f_{DE}(t)$ is expressed as:

$$f_{DE}(t) = \alpha + \beta P(t) + \gamma P^2(t) + Q\frac{1}{C}\frac{P(t)}{\eta}. \tag{3}$$

In the formula, $P(t)$ is the output power of the thermal unit at time $t$, $\alpha$, $\beta$, and $\gamma$ are the combustion cost coefficients, $Q$ is the fuel cost, and $C$ is the low calorific value of the fuel. Different thermal units use different fuel with different H values.

Specifically, the cost of renewable energy generation takes into account the underestimated costs of wasting available wind and solar power, as well as the overestimated costs that require additional reserves. The main costs are energy storage components such as battery charging and discharging losses and the cost of power generation equipment losses. The comprehensive expression method is as follows:

$$C_k = n_w \cdot C_w \cdot P_w + n_g \cdot C_g \cdot P_g + C_c. \tag{4}$$

In the formula, $n_w$ represents the number of wind power units, $C_w$ represents the direct cost of wind power generation, $P_w$ represents the expected processing value of wind power generation, $n_g$ represents the number of photovoltaic power units, $C_g$ represents the direct cost of photovoltaic power generation, $P_g$ represents the expected cost of photovoltaic power generation, and $C_c$ represents the loss cost. The table method is as follows:

$$C_c = \sum_{i=1}^{n_l} G_s \left[ V_i^2 - V_j^2 \right]. \tag{5}$$

A represents the number of charges and discharges, B represents the loss coefficient, and C and D represent the voltage changes of line E and line F. The cost of environmental protection mainly includes the penalty cost of pollutants generated by the operation of thermal power units, expressed as follows:

$$C_h = \sum_{t=1}^{T} (\lambda_{DE} Q_{DE}(t)). \tag{6}$$

In the formula, $\lambda_{DE}$ is the processing coefficient of the diesel engine, and $Q_{DE}(t)$ is the amount of environmental pollutants generated by the thermal unit at time $t$.

(2) Objective function

This article takes the minimum operating cost of microgrid optimization scheduling as the objective function, therefore the objective function is expressed as:

$$f = \min \sum (C_r + C_k + C_y + C_h). \tag{7}$$

(3) Constraints

Under normal working conditions, the power provided by each power source in the microgrid is equal to the load power, so the power balance constraint conditions represent:

$$P_{load}(t) = \sum_{i=1}^{n} P_i(t) + P_{grid}(t). \tag{8}$$

In the formula, $P_{load}(t)$ is the load power, $P_i(t)$ is the output power of each distributed power source, $P_{grid}(t)$ is the interaction power between the microgrid and the main grid. When $P_{grid}(t) > 0$ is, the microgrid needs the main grid to supply power, that is, to purchase the main grid power. When $P_{grid}(t) < 0$ is, the microgrid can store or supply power to the main grid, that is, to sell power to the main grid. Due to the existence of power limits for equipment such as large power grids and transmission lines, the range of interactive power constraints is defined as:

$$P_{grid}^{\min} \le P_{grid}(t) \le P_{grid}^{\max}. \tag{9}$$

In the equation, $P_{grid}^{\min}$ and $P_{grid}^{\max}$ are the minimum and maximum constraint values of interaction power, respectively. As a distributed microgrid, its network output power is limited, so its own active power output constraint is defined as:

$$P_i^{\min} \le P_i(t) \le P_i^{\max}. \tag{10}$$

In the formula, $P_i(t)$ is the current power of the $i$ -th distributed power source, $P_i^{\min}$ is the minimum power constraint value, and $P_i^{\min}$ is the maximum power constraint value. To ensure the working life of the energy storage part, it is generally required that the energy storage part should not be charged to its full capacity and discharged to exhaustion. At the same time, it is necessary to limit the charging and discharging speed of the battery. Therefore, the energy storage constraint is defined as:

$$S_{OC-\min} \le S_{OC}(t) \le S_{OC-\max}. \tag{11}$$

$$0 \le P_{cha}(t) \le P_{cha}^{\max}. \tag{12}$$

$$0 \le P_{dis}(t) \le P_{dis}^{\max}. \tag{13}$$

In the formula, $S_{OC-\min}$ is the lower limit of the energy storage system capacity, $S_{OC-\max}$ is the upper limit of the battery capacity, $P_{cha}^{\max}$ is the maximum charging power, and $P_{dis}^{\max}$ is the maximum discharge power. The change rate of output consolidation rate of thermal units is limited. To ensure stable operation of thermal units, the ramp rate constraint of thermal units is defined as:

$$r_{DE}^{down} \le P_{DE}(t+1) - P_{DE}(t) \le r_{DE}^{up}. \tag{14}$$

In the formula, $P_{DE}(t+1) - P_{DE}(t)$ is the climbing rate of the thermal unit from period $t$ to $t+1$ , $r_{DE}^{down}$ is the minimum climbing rate, and $r_{DE}^{up}$ is the maximum climbing rate.

## 4 Improved Algorithm for Solving the Optimal Solution of the Objective Function

In order to obtain the optimal solution of the objective function, this article uses an improved harmony search algorithm. The harmony search algorithm is a new intelligent algorithm generated by simulating the creator's process of repeatedly adjusting the melody to obtain harmony. By treating the melodies of various different instruments as multiple parameter variables that need to be optimized, the resulting most beautiful harmony is considered the optimal solution to the problem to be solved [9].

### 4.1 Calculation Steps of Harmony Search Algorithm

(1) Set parameters: Harmony search memory capacity $M$ , value probability $P_{HMCR}$ , adjustment probability $P_{AR}$, adjustment bandwidth $B_W$ , and number of cycles $T_{\max}$ ;

(2) Random generation: use the stacking function to generate $X_1, X_2, ..., X_M$, a total of $M$ harmony, and call it the solution space of $X$ , then calculate and record the corresponding fitness value $f(X)$ , and call the matrix containing the solution space and the fitness value $H$ , the expression of $H$ is:

$$H = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_M \end{bmatrix} = \begin{bmatrix} x_1 \\ x_{1,2} \\ \vdots \\ x_{1,M} \end{bmatrix}. \tag{15}$$

(3) Comparison loop: The first step is to generate random numbers $P_1$ and $P_2$ between [0, 1]. If $P_1 \ge P_{HMCR}$, a new harmonic variable is randomly generated from the solution space in $X$. If $P_1 < P_{HMCR}$ , a harmonic solution vector is randomly extracted from the harmonic memory library $H$ ; Step 2: If the harmony is a randomly extracted harmony variable $P_2 < P_{AR}$ from the harmony memory, update the harmony vector according to the update

formula containing the adjusted bandwidth $B_W$ . Other situations remain unchanged to obtain a new harmony $X_{new}$ $(i + 1)$. The specific update formula is:

$$X_{new}(i+1) = X_{new}(i) + B_w(2rand - 1). \tag{16}$$

Among them, $i$ is the number of iterations.

(4) Update the harmony memory, and evaluate $X_{new}$ $(i + 1)$, that is, calculate $f(X_{new}(i + 1))$. If its fitness value is smaller than the worst fitness value in the memory, that is, $f(X_{new}(i + 1)) < f(X_{worst})$ replaces $X_{worst}$ with $X_{new}$ $(i + 1)$, otherwise it will not be modified.

### 4.2 Algorithm Improvement

The classic harmony algorithm heavily relies on the value of $P_{HMCR}$ to adjust the solution. When the value of $P_{HMCR}$ is unreasonable, it reduces the convergence speed and optimization ability of the algorithm. However, using the dynamic $P_{HMCR}$ value method can achieve the improvement effect of the algorithm. The improvement formula is as follows:

$$P_{HMCR}(i) = P_{HMCR\min} + \frac{P_{HMCR\max} - P_{HMCR\min}}{T_{\max}} i. \tag{17}$$

In the formula, $i$ represents the current number of iterations and $P_{HMCR}$ represents the probability of taking a value. Considering that the micro grid model established in this paper is multi parameter, the concept of virtual fitness is introduced on the basis of harmony algorithm. Therefore, the solution flow of the entire algorithm is shown in Fig. 2.

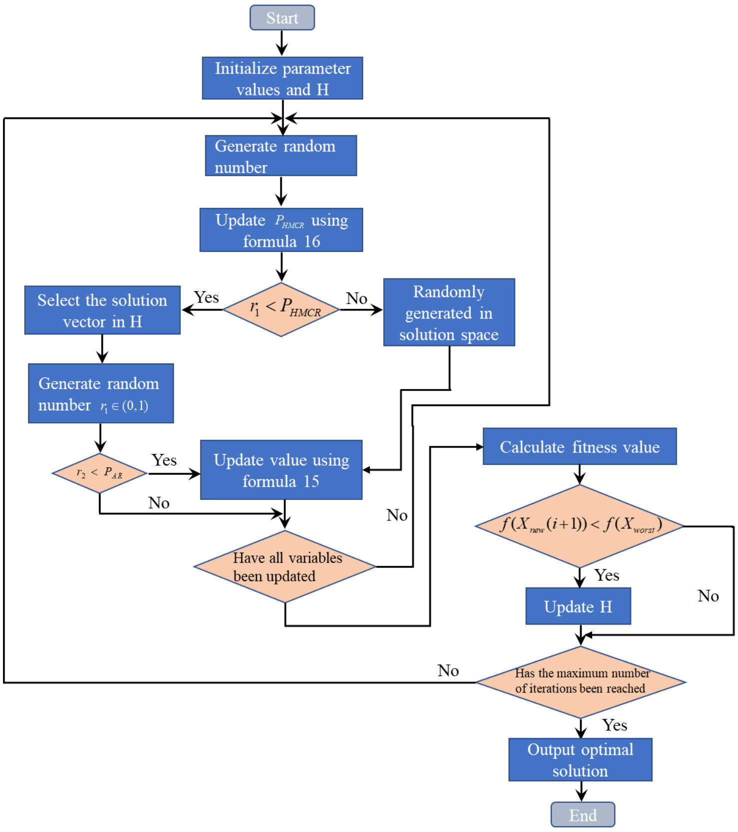

**Fig. 2.** Algorithm solving flowchart

## 5 Simulation Experiment and Result Analysis

This article takes the actual microgrid project in a rural area of Hebei as the research object, and its network topology is shown in Fig. 3. The upper limit of the power of the interconnection line between the distribution network and the superior power grid is $3300kW$ , and the upper and lower limits of the auxiliary service electricity prices are $0.8yuan / kW \cdot h$ and $0.1yuan / kW \cdot h$ , respectively.

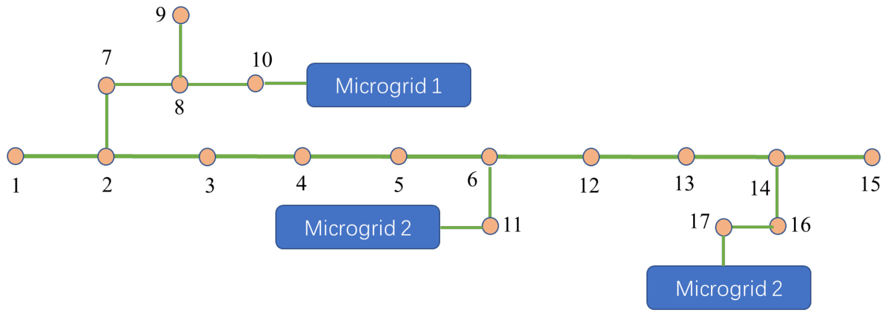

**Fig. 3.** Microgrid network topology diagram

The operating parameters of the microgrid are shown in Table 1, Table 2 shows the parameters related to environmental pollution:

**Table 1.** Operating parameters of each Microgrid

| Microgrid type | Rated power (/kW) | Fuel cost (yuan/Kg) | Maintenance factor | Operating efficiency (/%) |
|---|---|---|---|---|
| Photovoltaic power generation (microgrid 1) | 200 | / | 0.009 | 90 |
| Wind power generation (microgrid 2) | 150 | / | 0.031 | 89 |
| Thermal unit power generation (microgrid 3) | 250 | 7.05 | 0.003 | 47 |

**Table 2.** Pollution-related emission coefficient

| Types of pollutants | Processing costs (yuan/g) | Emissions (g/(kW.h)) |
|---|---|---|
| CO | 0.011 | 0.08 |
| NO | 0.058 | 1.18 |
| SO2 | 0.017 | 1.53 |

This article sets the microgrid scheduling strategy as follows:

(1) Due to the pollution-free characteristics of photovoltaic and wind turbines, priority is given to using photovoltaic and wind turbines for power supply;

(2) The thermal unit is only used as a backup for power generation to avoid environmental pollution;

(3) If the distributed power generation cannot meet the load demand, the large power grid will timely transmit power to the airport microgrid. If the renewable energy generation exceeds the load demand, the microgrid will sell electricity to the large power grid, and comprehensively analyze the system operating costs and environmental costs to achieve maximum benefits.

According to the above parameters, Matlab software is used for data modeling. In order to prove that the improved harmony algorithm has better optimization ability and fast convergence ability, the particle swarm optimization (PSO) algorithm and sparrow search algorithm (SSA) are used as the comparison objects. Under the same conditions, the iterative process and search results are compared, and the number of iterations is set to 300 and the number of individuals is set to 100. The iterative curves of the three are shown in Fig. 4.

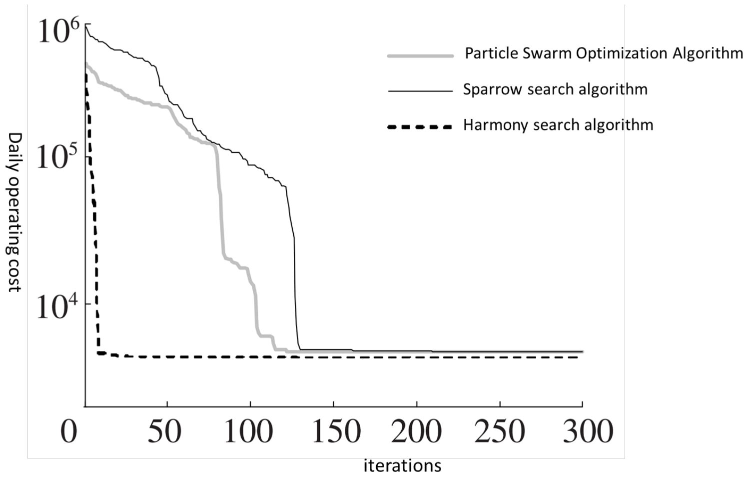

**Fig. 4.** Algorithm iteration curve

From Fig. 4, it can be seen that both particle swarm optimization algorithm and sparrow search algorithm fall into local optima in the early stages of algorithm operation, resulting in a decrease in convergence speed; In the mid-term of algorithm operation, the convergence speed of particle swarm optimization and sparrow search algorithm has increased; The harmony search algorithm proposed in this article has a faster convergence speed since the initial iteration, better global search ability, and higher accuracy of optimization results, with superior overall performance.

Compare the mean, standard deviation, and minimum values of each algorithm, and the results of each algorithm are shown in Table 3. According to the simulation results, the minimum daily running cost found by the Harmony algorithm of 3247.28 yuan is the optimal result of this article.

**Table 3.** Comparision of solution results

| Algorithm | Daily operating cost/yuan | | |
|---|---|---|---|
| | Mean value | Standard deviation | Minimum value |
| Particle Swarm Optimization | 3793.27 | 68.31 | 3678.52 |
| Sparrow search algorithm | 3683.42 | 54.92 | 3661.36 |
| Harmony search algorithm | 3278.69 | 25.17 | **3247.28** |

The output curves of each microgrid module are shown in Fig. 5. From the graph, it can be seen that within the period of 0-8 hours of a day, the renewable energy generation capacity of the microgrid cannot meet the load. At this time, the power generation of thermal units and battery power should be appropriately increased. During the 9-18 hour period, the light intensity is relatively high, and the energy generated can basically meet the load. At this time, the thermal unit does not generate electricity and is in a standby state. During the remaining period, the light intensity is weak, and the thermal power unit and battery start and discharge, while the battery is charged and discharged, which plays a role in peak shaving and valley filling, and suppressing wind and solar fluctuations in the microgrid.

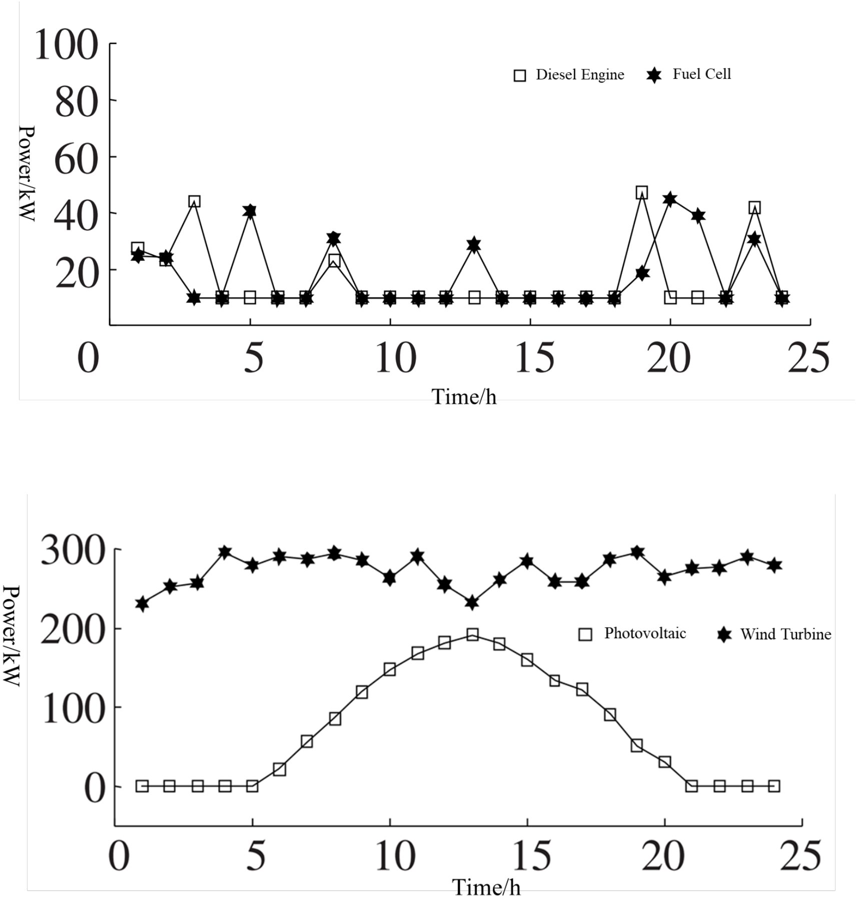

**Fig. 5.** Output status of each functional module

## 6 Conclusion

This article uses ResNet as the basic network structure, and proposes a model structure suitable for energy optimization of microgrids through structural improvements. Then, an objective function is established with the goal of minimizing operating costs of microgrids. Finally, the harmony search algorithm is used to solve the optimal solution of the objective function. Finally, an optimization method is proposed using the optimization strategy proposed in this article, taking a practical case as the object. Throughout the entire article, there are still the following shortcomings:

(1) The established model simplifies some parameters, which is suitable for most microgrids. Therefore, the universality of the method proposed in this article still needs to be improved;

(2) During the search process, although there is no local optimal solution for the objective function, there is a possibility of a local optimal solution. Therefore, further research is needed to improve the search method, completely avoiding the optimal solution and avoiding search divergence.

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