The Optimal Dispatching of Micro Grid Based on Improved Limit Learning Machine Under Source-Load Interactive Electric Market

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June 26, 2022

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Abstract

In order to improve the absorption rate of photovoltaic output power and realize the optimal configuration of renewable energy under source-load interactive electric market. Based on the SAE-ELM algorithm, the output of photovoltaic units and load demand of the micro-grid were predicted by the historical data of the source and load in this paper. On this basis, taking the minimum generation cost as the objective function, and considering the constraints of the micro-grid system, the source-load interactive optimal scheduling model of the micro-grid was established, and the ant lion optimizer (ALO) was used to solve the scheduling model. The preliminary scheme of unit commitment and output plan is obtained, then the scheduling scheme is fine-tuned according to the data of real-time scheduling stage. The simulation results show that the proposed optimal scheduling strategy can improve the photoelectric consumption rate, reduce the amount of abandoned solar power by about 41%, improve the economic benefit of micro grid, the cost can be saved about 33% compared with the conventional scheduling method. The micro grid optimal dispatching method proposed in this paper has certain reference value for guiding the power sales of micro grid in the open power market.
Keywords: micro-grid; SAE-ELM algorithm; source- load interactive; the ant lion optimizer -ALO; optimal scheduling.

1. Introduction

The energy sector is facing environmental pollution problems in China, the transformation of energy structure is imminent. For the electric power industry, it is the general trend to adjust the energy structure and energy development policy and to low-carbon economy. In order to achieve Chinese strategic goal of carbon neutrality by 2060, the important path of energy industry is to reduce coal consumption and vigorously develop renewable green energy. Over the past decade or so, renewable energy has been growing at an annual rate of about 10 percent, and the cost of wind and photovoltaic power has continued to fall, matching the average cost of coal fired power, and new energy applications have become commonplace [1].However, due to the fluctuation of wind energy and photovoltaic power generation, access to the power grid will affect the stability of the power grid, but also lead to the abandonment of light, wind and other issues. Large-scale renewable energy cannot rely on the adjustment ability of the distribution system and the traditional scheduling method of the system is limited, it is very important to explore a flexible scheduling method for new energy grid-connected [2].

There is a common understanding that micro-grid can effectively organize and manage the access of distributed renewable energy, and how to realize the coordination and optimal operation among the main power system of micro-grid has been widely concerned by scholars in related fields. Micro-grid can combine the renewable energy power generation system, load, energy storage and dispatch management system reasonably, and realize the optimal dispatch of interaction with grid, power output and demand response [3].The research on the optimal scheduling of micro-network is concerned at home and abroad. Reference [4] establishes a multi-objective optimal operation model with multiple constraints, aiming at minimizing the generation cost, pollutant emission cost, compensation cost of load shedding and network loss of micro grid.

To figure out the optimum operation of micro-sources for decreasing the electricity production cost by hourly day-ahead and real time scheduling, an algorithm for energy management system based on multi-layer ant colony optimization is presented to find energy scheduling in micro grid in reference [5]. Reference [6] proposes a new energy-saving dispatch problem while considering energy-saving and emission-reduction potentials of generation and demand sides, as well as the interaction between the two.. In reference [7], a simulation analysis method based on probability distribution is proposed, and a new energy optimal scheduling scheme is established, which can reduce the operating cost of micro grid and increase the consumption of distributed generation. Based on fuzzy theory and considering the distribution of operation cost and power flow, an optimal dispatch model of power system including wind power is established in [8]. In the optimization modeling, Liu Wen-ying and others take the renewable energy absorption maximization and the cost minimum as the optimization goal, has realized the regional power grid dispatch optimization [9]. Considering the temporal dependence of wind power fluctuation, the intra-day wind power scenario generation method is put forward, and both day-ahead and intra-day optimization-scheduling models based on the scenario method are established in [10].

Based on improving the safety, efficiency and economic benefit of micro-grid operation, and considering the characteristics of new energy generation and load, the optimal dispatch is carried out, but all of these depend on the accurate prediction of the power of the generation output and the load, and the accurate short-term prediction model is the basis of establishing the optimal dispatch under the source-load interaction. There are many kinds of short-term source-charge prediction algorithms, and choosing appropriate algorithms can improve the accuracy of source-charge side power prediction [11].Extreme Learning Machine (ELM) is widely used in prediction and large-sample Learning [12].However, because the hidden-layer parameters of ELM are generated randomly, it is necessary to optimize the parameters of limit learning machine to improve the accuracy of prediction [13].Based on the literature review, stacked auto encoder (SAE) is selected to optimize limit learning machine (ELM) in this paper, and uses SAE-ELM fusion algorithm to train and forecast historical source data. Based on the prediction results, an economic dispatch model of Micro grid is constructed, and the Ant Lion Optimizer (ALO) is used to correct the dispatch model in real time to reduce the error between the predicted short-term source load and the actual target load. Finally, an example is given to verify whether the method can reduce the operating cost of micro-grid and the abandonment of solar power.

2. The optimal scheduling of micro grid based on SAE-ELM algorithm

2.1. Framework for Optimal Dispatch of Micro Grid

The historical source data have influence on the prediction error and optimization model of source-load side power based on SAE-ELM fusion algorithm [14].The prediction uncertainty is one of the important factors that affect the in-situ dissipation level of Micro grid, and its accuracy is obviously different in different time scales, the maximum prediction error of PV output can reach 20 ~ 30% on the day-ahead time scale, and the prediction error will decrease gradually with the shortening of time scale. In the real-time scheduling time scale, the maximum error of PV is about 10%. In order to solve the above-mentioned contradiction, the short-term forecast data based on PV in the day-ahead time scale is established for the preliminary establishment of the system scheduling plan, and the ultra-short-term forecast data based on PV in the real-time scale is fine-tuned for system scheduling, to reduce the level of abandonment solar power in the micro grid [15].

The source-to-load Interactive micro grid optimization framework based on SAE-ELM Fusion Algorithm is shown in Fig.1. The principle of the framework is based on the SAE-ELM fusion algorithm, and the power supply layer scheduling constraint model, to determine the unit commitment and output planning of the preliminary scheme. Then, the on-line training and prediction are carried out with the data of real-time scheduling stage to reduce the prediction error so as to obtain the optimal scheduling method in line with the real-time working condition.

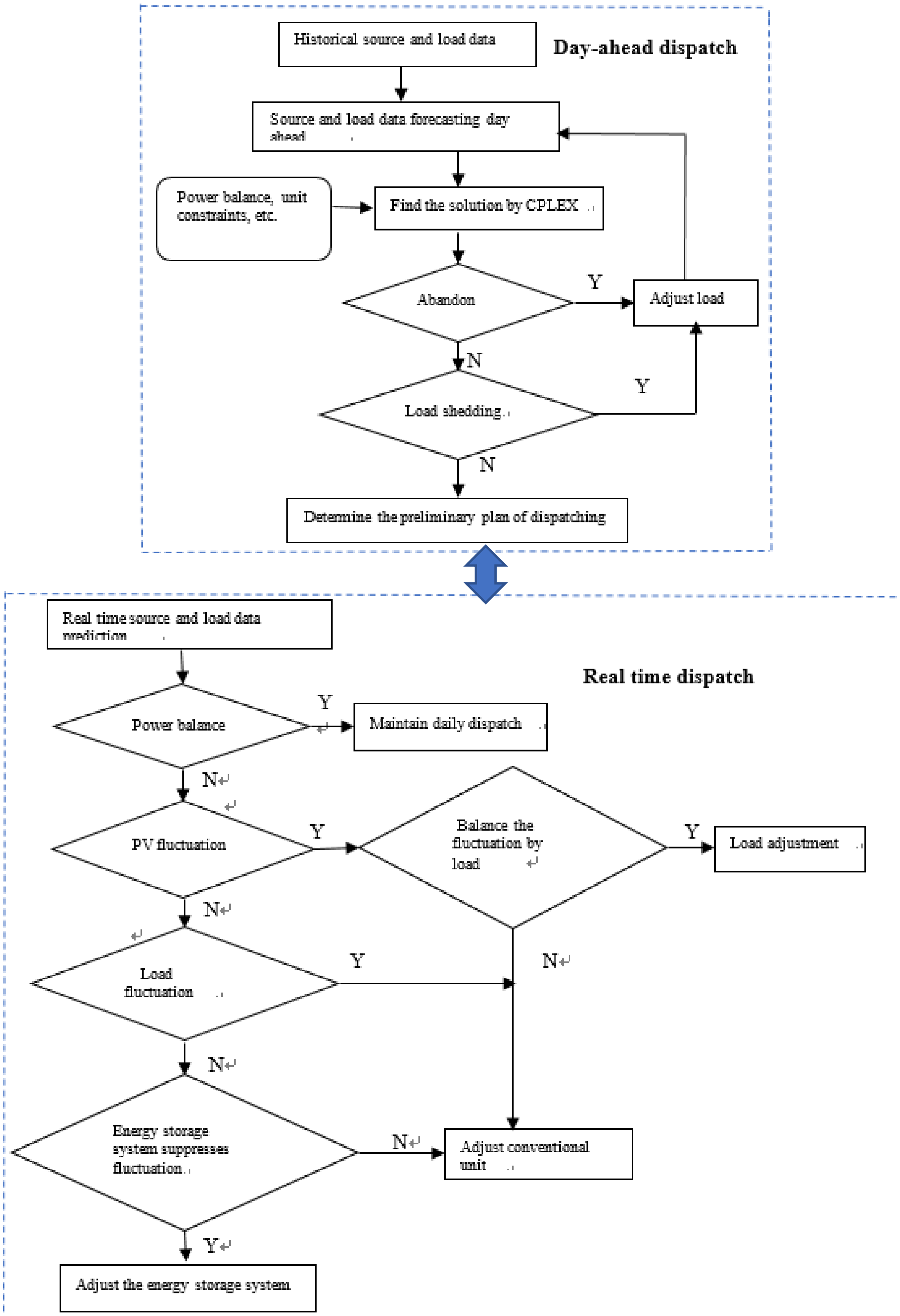


Fig.1 Optimal scheduling framework of micro-grid

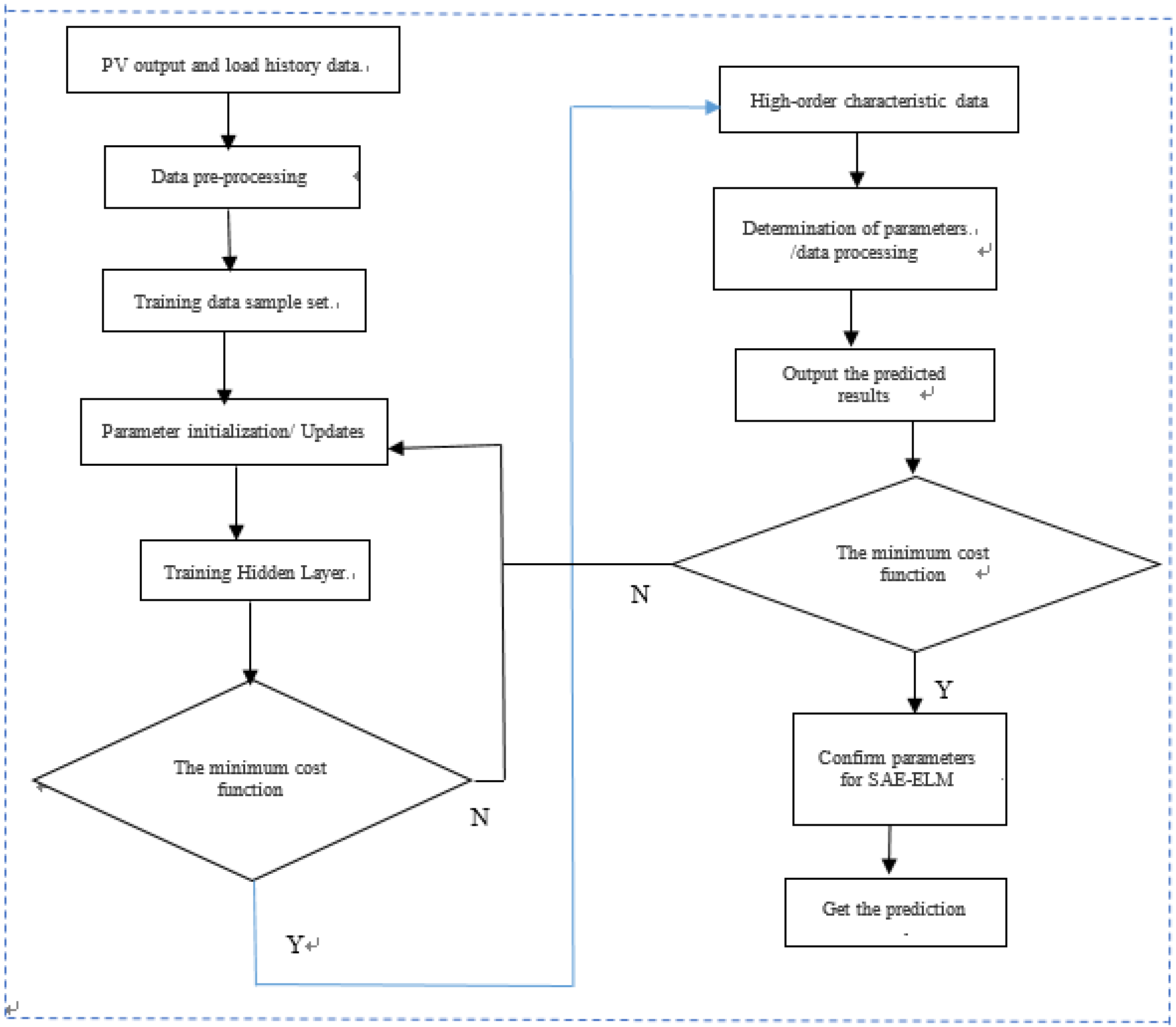


Fig.2 Flow chart of photovoltaic output and short term load forecasting

2.2. The prediction method based on SAE-ELM algorithm

Photovoltaic (PV) output and load forecasting algorithms determine the forecasting performance of the forecasting model, so we should build the forecasting framework first so as to follow-up work in an orderly manner. The prediction process is shown in Fig.2. First, the photoelectric output and load history are Data pre-processing, then the population is initialized, the output weight Matrix and root mean square error of the network are calculated, and the population is mutated and crossed, to determine whether the test vector obtained from the variation in the population can reach the next generation, and to optimize the parameters of the limit learning machine by repeating the above calculation until the constraint conditions are satisfied, the optimized input weights and the hidden layer deviation parameters are transmitted to ELM to determine the parameters of the SAE-ELM model.

2.3. The Optimal Dispatching Model of Micro Grid

2.3.1 Power layer scheduling model with photovoltaic new energy sources

The traditional electric power dispatching is balanced by regulating the output and load forecast of the generating unit. But the randomicity of pv power generation makes it difficult to control the PV power flexibly to realize regulation and control, even when the capacity of the system is out of control, we have to passively discard the light. The following for the Photovoltaic Energy micro-grid system, the establishment of the power layers scheduling model.

In the power supply layer, gas-fired units and photovoltaic units are used as conventional units and new energy units respectively. Photovoltaic energy is preferred, because the cost of photovoltaic operation is basically fixed, it is estimated that no need to optimize, but need to consider the penalty cost of discarding light [16].The objective function of power layer optimization is to minimize the scheduling cost, that is:

$$\begin{cases} \min C = C_r + C_{qg} + C_b \\ C_r = \sum_{i=1}^{M}\sum_{t=1}^{T} \alpha_i P_{i,t}^2 + \beta_i P_{i,t} + \gamma_i \\ C_{qg} = \sum_{i=1}^{T} \lambda_{qg}(P_{w,t}^y - P_{w,t}) \\ C_b = \sum_{i=1}^{M}\sum_{j=1}^{T} (\mu_{i,u} R_{i,j}^u + \mu_{i,d} R_{i,j}^{\mathrm{d}}) \end{cases} \quad (1)$$

Where C_r is the cost of gas unit;$P_{i,t}$ is the active output of unit i at time t;C_qg represents lighting penalty cost; λ_{qg} represents the light rejection penalty coefficient; $P_{w,t}^y$ and $P_{w,t}$ represent the predicted photoelectric power and the actual photoelectric output power at time t, respectively;C_b is the rotating reserve cost; $\mu_{\mathrm{i},u}$ and $\mu_{\mathrm{i},d}$ are the up and down rotation reserve prices respectively; $R_{i,j}^u$ and $R_{i,j}^d$ are Up and down rotating reserve capacity respectively.

The constraints of micro grid scheduling system are the follow.

1） Output constraint of solar unit

$$0 \le P_s^t \le P_{sy}^t \quad (2)$$

Where P_{sy}^t is the predicted value of photovoltaic output power in t period.

2） Output constraint of gas unit

$$P_i^{\min} \le P_i^t \le P_i^{\max} \quad (3)$$

Where $P_i^{\min}$ 、 P_i^t and $P_i^{\max}$ respectively represent the minimum output, actual output and maximum output of group i gas unit.

3）Reserve capacity constraints of gas units

$$\begin{cases} R_{d,t} \le P_{\max,t} \\ R_{u,t} \le P_{\max,t} \end{cases} \quad (4)$$

Where $R_{\mathrm{u,t}}$ and $R_{\mathrm{d,t}}$ are the upper and lower standby of the gas unit at time t respectively.

4）The standby of gas unit is restricted by the climbing limit

$$\begin{cases} 0 \le R_{d,t} \le \tau r_{c,d} u_t \\ 0 \le R_{u,t} \le \tau r_{c,u} u_t \end{cases} \quad (5)$$

Where $r_{\mathrm{c,u}}$ is the climbing speed of gas turbine; $r_{\mathrm{c,p}}$ is the descent rate; τ is standby response time,u_t refers to the operation state of the gas unit at time t.

5） System power balance constraint

$$P_{s,t} + P_{in,t} + P_{bat,t} + \sum_{i=1}^{N} P_{i,t} = P_{L,t} + P_{out,t} + P_{qg,t} \quad (6)$$

Where $P_{\mathrm{s,t}}$ and $P_{\mathrm{L,t}}$ are the solar energy output and load demand of the system at time t respectively; $P_{\mathrm{in,t}}$ and $P_{\mathrm{out,t}}$ are the power of the micro grid to buy electricity from and sell electricity to the distribution network at time t, respectively;$P_{\mathrm{qg,t}}$ is the amount of light discarded at time t;$P_{\mathrm{i,t}}$ 和 $P_{\mathrm{bat,t}}$ respectively refers to the output power of gas unit and energy storage equipment at time t .

6） The power limitation constraints to distribution network transmission.

$$\begin{cases} P_{out,t} \leq P_{out,\max} \\ P_{in,t} \leq P_{line,\max} \\ P_{out,t} \leq P_{line,\max} \end{cases} \quad (7)$$

Where $P_{\text{out, max}}$ and $P_{\text{line, max}}$ are the maximum value of reverse transmission power and the maximum value of exchange power on tie line respectively. The remaining photovoltaic output after micro grid consumption can be sold to the distribution network, but the power quality of the distribution network will be affected due to the instability of photovoltaic power generation.

2.3.2 Load scheduling

The controllable load is divided into translational load and interruptible load [16].The translatable load can be adjusted by the day ahead optimal dispatching based on the TOU price mechanism. The regulation of interruptible load belongs to real-time dispatching, and can be adjusted flexibly according to the real-time situation [17]. The main constraints of the load layer are as follows [16, 17].

1) Variation range of uncontrollable load:

$$Q_{\min} \leq Q_{ss} \leq Q_{\max} \quad (8)$$

Where $Q_{\min}$, $Q_{\max}$ and Q_{ss} are the minimum, maximum and actual values of uncontrollable load respectively.

2) Uncontrollable load fluctuation constraint

$$V_{qss} \leq V_{q\max} \quad (9)$$

Where V_{qss} and $V_{q\max}$ are uncontrollable load fluctuation rate and maximum fluctuation rate respectively.

3) Interruptible load constraint

$$\begin{cases} P_k^{\min} \leq P_{k,t} \leq P_k^{\max} & k \in n_f \\ 0 \leq N_j \leq n_{T,j}^{\max} & j \in n_T \\ T_{IL,i}^{total} \leq T_{IL,i}^{\max} \end{cases} \quad (10)$$

Where $P_k^{\min}$ and $P_k^{\max}$ are the minimum and maximum values of interruptible load *j* respectively; N_j is the actual number of calls for interruptible load *j*; $n_{T,j}^{\max}$ is the maximum number of calls for interruptible load *j*; $T_{IL,i}^{total}$ is the total interruption time in the cycle; $T_{IL,i}^{\max}$ is the maximum time that can be reduced in the cycle.

4) Scheduling cost of interruptible load

$$S_j(x_j, \beta_j) = K_1 x_j^2 + K_2 x_j - K_2 x_j \beta_j \quad (11)$$

Where $S_j(x_j, \beta_j)$ is cost of interruptible load scheduling for user *j*; $\beta_j \in [0,1]$ is load participation for interruptions; x_j Load interruption for user j; K_1 、 K_2 is constant and greater than 0.

5) Translatable load constraints

$$\begin{cases} P_{y,j}(t) - P_{y,j}(t-1) \leq P_{y,j}^{\max} \\ \sum_{t=1}^{T} P_{y,j}(t) \times \Delta t = \sum_{t=1}^{T} P_{y0,j}(t) \times \Delta t \end{cases} \quad (12)$$

Where $P_{y,j}(t)$ is the power after the response of translatable load *j* in *t* period; $P_{y,j}^{\max}$ is the maximum allowable variation power of the load; $P_{y0,j}(t)$ is the original power of the load *j* in *t* period.

6) Scheduling cost of translatable load

$$S_j = \sum_{t=1}^{T} \left[C_{y0}(t) P_{y0,j}(t) \Delta t - C_y(t) P_{y,j}(t) \Delta t \right] \quad (13)$$

Where $C_{y0}(t)$ the original electricity is price at time *t*; $C_y(t)$ is the price at time *t*; $P_{y,j}(t)$ is the actual power of the load *j* in *t* period; Δt is the sampling time.

3. Results and Analysis

The ant lion optimizer-ALO is used to solve the day before scheduling model, and the ALO algorithm is used to simulate the hunting behavior of the ant lion to get the best solution. The main body of the algorithm is ant and ant lion. First initialize their respective location and fitness values. The factors affecting ant walking include boundary limit and ant lion trap. When the ant explores a better location, the ant lion immediately preys on the ant to replace the ant location to realize the update operation. After the iteration, the optimal solution in the ant lion is elite ant lion. Finally, the global optimal solution elite ant lion is obtained after the iteration is completed [18, 19].The flow chart of the day ahead scheduling model is shown in Fig. 3. The real-time scheduling model is similar to the previous one.

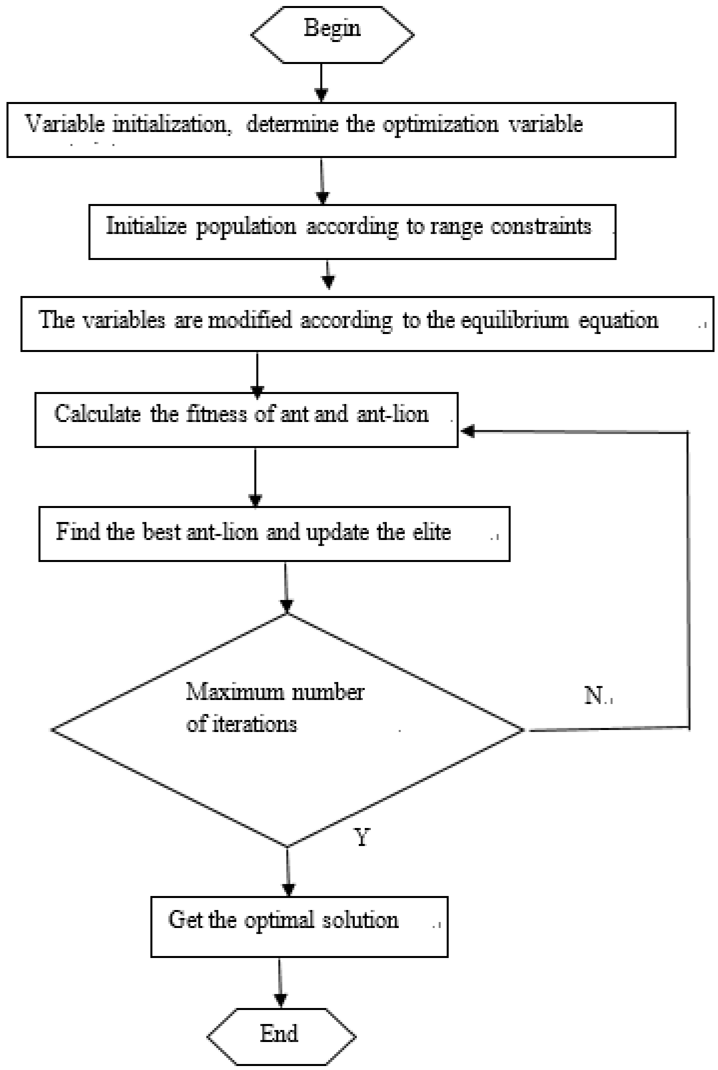


Fig.3. Solving process of day-before scheduling model

In order to verify the effectiveness of the source load interactive micro grid optimal dispatching based on SAE-ELM fusion algorithm proposed in this paper, 5, 5 and 2 gas units, solar units and energy storage equipment are selected, adjustable loads are introduced, and solved by CPLEX simulation with MATLAB. The parameters of micro grid system and gas unit are shown in Table 1. The rated power of the solar unit is 180kW. Parameters of energy storage equipment are shown in Table 2.

Table 1 Parameters of micro-grid system and gas turbine

parameters	value
Solar power selling price /yuan/kWh	0.873
Electricity purchase price from distribution network /yuan/kWh	0.487
Electricity selling price to distribution network /yuan/kWh	0.395
Solar power abandonment penalty coefficient /yuan/kWh	2.93
Efficiency of gas turbine	28%
Maximum output power of gas turbine unit /kW	60
Minimum output power of gas turbine unit /kW	0
Climbing rate of gas turbine unit /kW/min	12
Constraints on transmission power with distribution network /kW	68
Maximum power of reverse delivery /kW	58

Table 2. Parameters of energy storage equipment

parameters	value
Maximum unit capacity of battery（A.h）	60
The maximum SOC	0.9
The minimum SOC	0.2
Initial state-SOC	0.5
Charge and discharge efficiency	0.9
capacity /kWh	120

Under standard conditions, the maximum power of photovoltaic units in a region is 180kW. According to the light intensity data and historical output data of battery packs in the region, the photovoltaic output and load power are predicted according to the model, as shown in Figure 4.

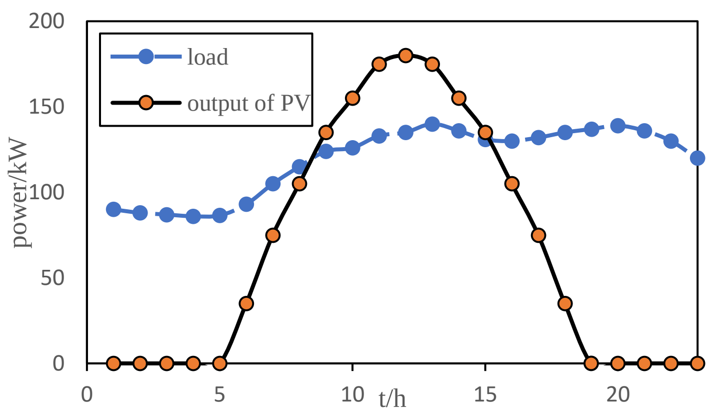
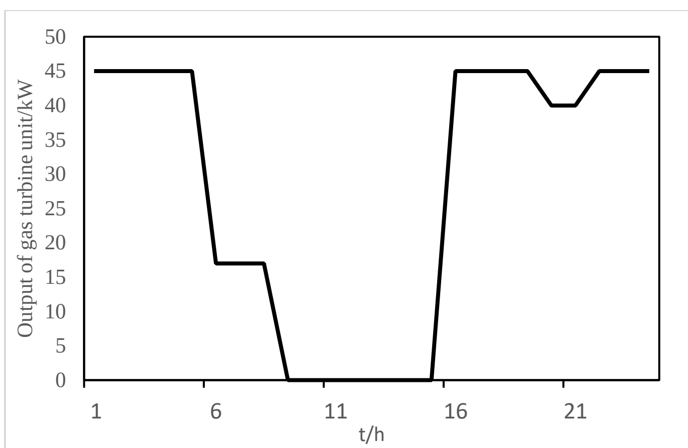


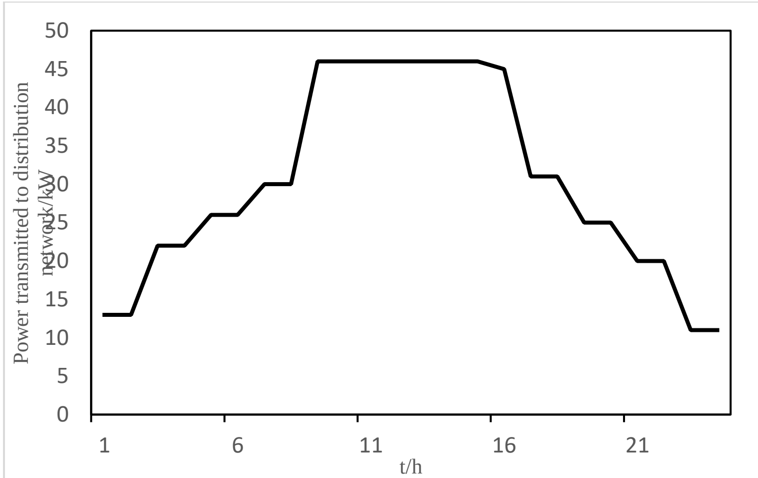
Fig.4 Photovoltaic output and load forecasting

The results of day ahead and real-time dispatching are shown in Figure 5 and Figure 6. It can be seen that the photovoltaic output is low in the morning and evening, and the load is mainly provided by the gas turbine unit; During the peak period of photovoltaic output at noon (10:00 ~ 15:00), the system load can be fully provided by photovoltaic output. In order to improve the photovoltaic consumption level, the energy storage device is in the charging state during this period, and the load level will be improved at this stage. As can be seen from Fig. 5 (b), during the strong illumination period, the energy required by the load in the micro grid is completely self-sufficient, and there is abundant electric energy transmitted to the distribution network. This is because in this example, the power generation cost of the distributed generation in the micro grid is lower than the cost of purchasing electricity from the distribution network. From Figure 5 (c), we can see that there is still a small amount of light abandoning in the dispatching stage. Comparing Fig. 5 and Fig. 6, it can be seen that the exchange power between micro grid and distribution network is generally consistent with the dispatching plan in the day ahead and real-time stage, but the fluctuation of dispatching power is very obvious due to the shorter unit time of real-time dispatching. The problem of discard light in the real-time scheduling phase is obviously improved, which is 41% of the total amount of discard light in the pre dispatch stage. This is mainly due to the error of PV and load forecasting in the real-time scheduling stage less than the forecast error in the pre dispatch stage. Therefore, the reserve capacity of the system can be significantly reduced, thus allowing more power generation capacity for PV.

The comparison of dispatching cost is shown in Table 3. The total cost calculated by the dispatching method proposed in this paper is lower than that of the traditional dispatching method, saving about 33%, indicating that the method proposed in this paper effectively improves the economic benefits of micro grid. It can be seen from table 3 that the traditional day ahead scheduling cost method fails to take into account the impact of the intermittency, volatility and other uncertainties of photovoltaic power generation when formulating the plan, and the adaptability of the scheduling plan is poor, resulting in frequent adjustment in the later day operation stage, increasing the operation cost of real-time regulation, resulting in a high final total operation cost. The optimal scheduling scheme proposed in this paper, The source load state of the micro grid is fully predicted, so that the optimal dispatching optimization results can be solved in a smaller and more accurate feasible region, the cost of real-time regulation is low, the photovoltaic output is fully predicted, the light rejection is reduced, and the economic benefit of the micro grid is improved.



(a)



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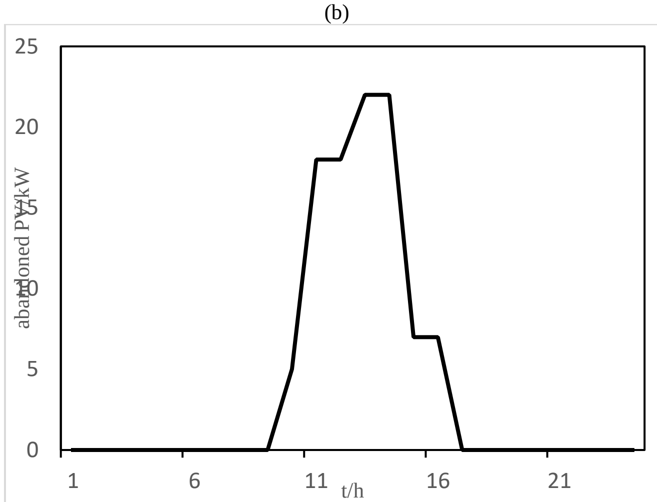
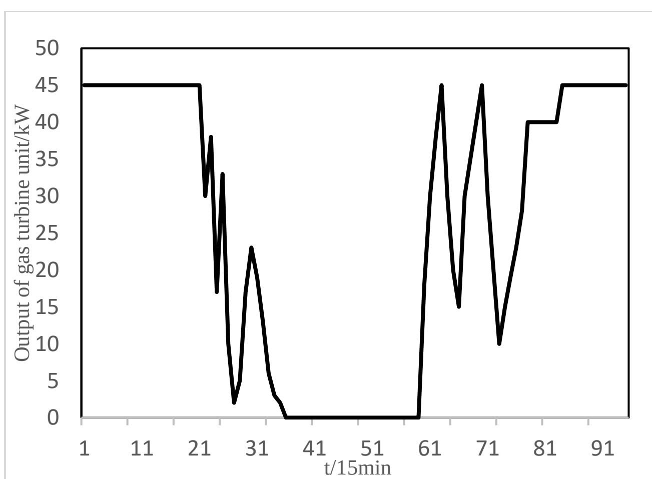


(c)

Fig.5 Day ahead scheduling results



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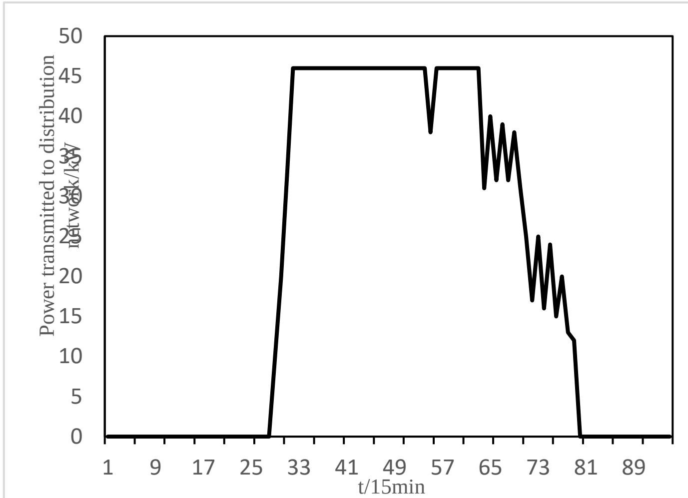

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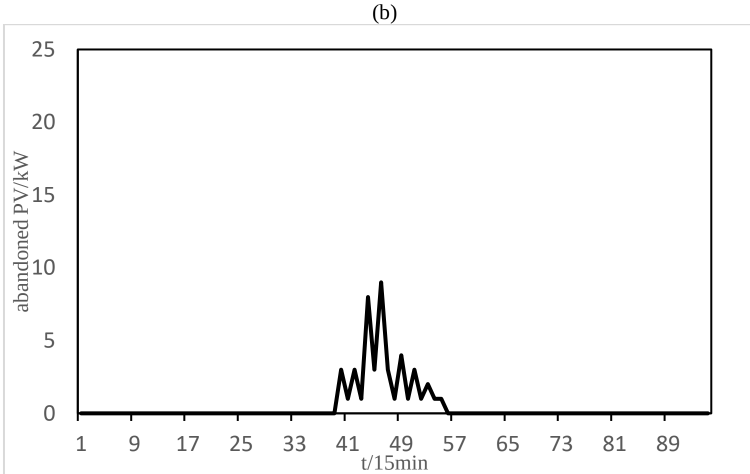

(c)

Fig.6 Real time scheduling results

Table 3 Scheduling method cost comparison table

running cost /yuan	dispatch cost day ahead/yuan				Real time dispatch cost /yuan					Total cost of two stages /yuan
	gas turbine	Transaction with distribution network plan	Energy storage	total cost	Gas turbine unit regulation	transaction regulation with distribution network	Energy storage regulation	Solar power abandonment punishment	total cost	
Traditional scheduling	4033	-2312	985	2706	1157	1274	515	1102	4048	5205
Scheduling in this paper	3769	-1742	-206	1821	1349	117	-78	244	1632	3453

4. Conclusion

Based on the analysis of source load characteristics, a double-layer interactive scheduling strategy was proposed in this paper. The micro grid scheduling optimization method was studied based on SAE-ELM, the micro grid scheduling optimization framework was designed based on the ecological relationship of micro grid source and load coordination and interaction response, which based on a power system with gas unit, photoelectric output, energy storage equipment and electric load. The prediction accuracy of micro grid source load power was improved through the fusion algorithm. Based on the prediction results, the real-time scheduling regulation was carried out through the ALO algorithm, which further reduces the error between the predicted value and the actual value. An example has shown that the scheduling method proposed in this paper can significantly improve the prediction accuracy in the real-time scheduling stage; the energy utilization rate was increased by 41% of the solar power in the dispatching stage. The total cost of dispatching is lower than that of traditional dispatching methods, saving about 33%, increasing the economic benefits of micro grid and ensuring the real-time and flexibility of micro grid dispatching.

The micro grid optimal dispatching method proposed in this paper has certain reference value for guiding the power sales of micro grid in the open power market. The micro grid takes advantage of the opportunity of retail transfer to sell electric energy and various auxiliary services to users. The biggest benefit of micro grid in retail transfer comes from the fact that distributed power generation can realize local load consumption, delay the investment life of power grid and reduce the investment cost of power grid.

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