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Economic and low-carbon island operation scheduling strategy for microgrid with renewable energy

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Abstract

With the advancement of supply-side reforms in the energy and power fields, a comprehensive energy system that integrates various energy sources such as electricity, heat, and natural gas has become the main development trend. Based on this, this paper proposes a combined heat and power(CHP) microgrid model with renewable energy. Based on the improved particle swarm algorithm, the optimal scheduling problem of the microgrid model is calculated, and a feasible optimal scheduling strategy considering both economy and low carbon is proposed. Finally, the economy and correctness of the optimal scheduling strategy proposed in this paper are verified by simulation.

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Keywords: Microgrid; Renewable energy; Optimal dispatch; Energy storage

1. Introduction

Microgrid is a system composed of distributed energy, energy storage systems, power conversion devices and other units [1–3]. With the gradual maturity of distributed energy power generation technology and the continuous reduction of construction difficulty, the cost of power generation and environmental cost will be reduced under certain constraints, and the power generation will be improved [4–6]. Therefore, the current research direction is to realize the optimal scheduling of microgrid [7–9].

Many scholars have studied the optimal scheduling method of microgrid and obtained some constructive results. In Ref. [10], an economic optimization scheduling model of active distribution network with CCHP microgrid has been proposed, and opportunity constrained programming has been used to deal with new energy and cooling and heating in CCHP microgrid cluster. For the randomness of electrical load, the distributed modeling method has been used to minimize the operating cost of each area, and the objective cascade method has been used to

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obtain the optimal economic dispatch results of each area in parallel. In Ref. [11], the power grid system has been combined with the heating system, the temperature of the water outlet and return water of the heating system has been monitored in real time, instructions have been issued through the grid dispatching, and the optimal dispatching has been carried out with the objective function of minimizing the curtailment rate. In Ref. [12], combined with the principle of robust optimization, the random factors in the traditional microgrid system economic dispatch model have been processed accordingly, and a robust optimal dispatch model for microgrid economic dispatch with distributed energy systems has been established. In Ref. [13], an optimal economic dispatch strategy for grid-connected microgrids based on demand response has been proposed. In Ref. [14], a system-wide optimal coordinated energy dispatch method was proposed for microgrid grid-connected mode and island mode. Microgrid technology and distributed power generation can better cope with the two major problems of energy crisis and environmental degradation facing the world today. However, none of the above-mentioned documents have considered the issue of carbon emissions, which is not conducive to environmental protection. Therefore, this paper proposes an optimal dispatch strategy considering both economical and environmental protection for the island operation mode of the co-generation microgrid.

The structure of the remaining sections is as follows: In Section 2, the characteristics and mathematical model of the microgrid power generation unit are introduced. In Section 3, an optimal dispatch model for microgrid system is proposed based on economy and environmental friendliness. In Section 4, the solution method of the microgrid system optimal dispatch model is introduced. In Sections 5 and 6, through the simulation to analyze a certain example, and the corresponding conclusions are presented.

2. Characteristics and mathematical model of microgrid power generation units

The CHP microgrid containing renewable energy studied in this paper includes co-generation units, wind turbines, photovoltaic units, fuel cells and electric energy storage devices, as shown in Fig. 1.

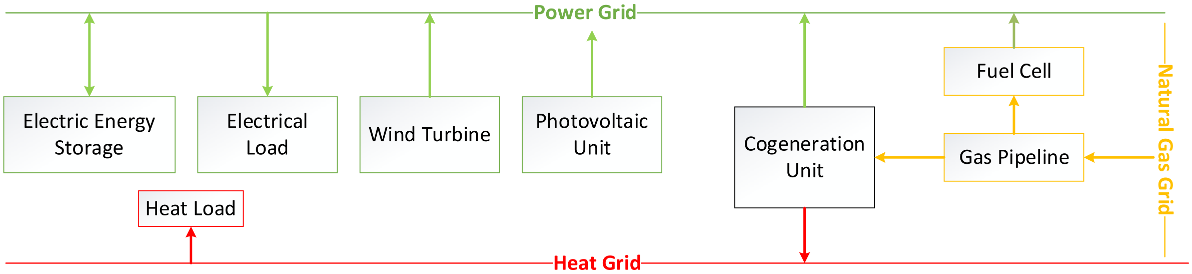

Fig. 1. CHP microgrid system.

The mathematical model of the output power of the wind turbine is

$$P_w = \begin{cases} 0, & v \le V_c \\ av^3 - bP_R, & V_c < v < V_R \\ P_R, & V_R < v < V_F \\ 0, & v > V_F \end{cases} \tag{1}$$

In the above equation, $a = P_R / \left(V_R^3 - V_C^3\right)$, v is the wind speed, $b = V_C^3 / \left(V_R^3 - V_C^3\right)$, P_R is the rated power, V_c is the cutting wind speed, V_F is the cutting out wind speed, and V_R is the rated wind speed.

Solar cell power output characteristics are related to their voltage–current characteristic. Light intensity, ambient temperature, weather and environmental conditions, stray resistance inside the material, and filling factor can all affect the conversion efficiency of solar cells. Its output characteristic is

$$P = GHI \cdot \eta_{pv} \cdot A_{pv} \tag{2}$$

where GHI (Wh/m^2) is the horizontal illuminance, η_{pv} is the photovoltaic power generation efficiency, A_{pv} is the irradiation area, and the photovoltaic power generation efficiency range is [0, 1].

The mathematical model of the output power of the co-generation unit is

$$\begin{cases} P_t^{CHP} = E_t^{CHP} \cdot \eta_t^{CHP} \\ Q_t^{CHP} = E_t^{CHP} \cdot \left(1 - \eta^{CHP} - \eta^{loss}\right) \end{cases} \tag{3}$$

Among them, E_t^{CHP} is the natural gas consumption, η^{CHP} is the power generation efficiency, η^{loss} is the heat dissipation rate, and P_t^{CHP} and Q_t^{CHP} are the electrical power and thermal power output during the t-period.

The mathematical expression of fuel costs at the point of departure of the co-generation unit is

$$C_{CHP} = C_l \frac{1}{LHV} \sum \frac{P_t}{\eta_t} \tag{4}$$

where C_l is the local natural gas price (yuan/m^3), LHV is the low calorific value of natural gas (kWh/m^3), P_t is the output of the co-generation unit in the interval t (kW), and η_t is the work efficiency of the co-generation unit in the interval t.

The mathematical model of fuel cell work efficiency is

$$\eta_{FC} = -0.0023 P_{FC} + 0.674 \tag{5}$$

The mathematical model of the cost of fuel cell power generation is

$$C_{FC} = C_l \frac{1}{LHV} \sum_{\alpha} \frac{P_\alpha}{\eta_\alpha} \tag{6}$$

The mathematical model of the energy storage device is

$$S_t^{es} = S_{t-1}^{es} \left(1 - \sigma^{es}\right) + \eta^{esc} \cdot P_t^{esc} - \frac{P_t^{esd}}{\eta^{esd}} \tag{7}$$

Among them, $\mathrm{S_t^{es}}$ is the t-period storage capacity, σ^{es} is the loss rate of the electric energy storage device, $\mathrm{P_t^{esc}}$ is the charging and discharging power of the t-period electric energy storage device. η^{esc} is the charging and discharging efficiency of the electric energy storage device.

3. Optimization dispatch model of microgrid system

The microgrid optimization dispatch model is an optimal dispatch model composed of wind, light, energy storage device, co-generation unit, fuel cell, etc. The operation and maintenance cost of each unit constitutes the system operating cost. At the same time, due to the increasingly serious problem of environmental pollution, this paper pays attention to the environmental pollution control cost of microgrid when building the model.

3.1. Objective functions

The operating cost of each distributed unit and the user's power outage loss cost constitute the operating cost of the microgrid. The power generation cost includes the raw material purchase cost and maintenance cost of each generator set, in which the raw material purchase cost is related to the actual power generation. During the operation of clean energy power generation, there is no need to consider power generation costs and environmental costs. Considering the economic costs as well as the environmental benefits, the objective function is described below.

(1) Optimal economic benefits

Considering the principle of economic optimality of microgrid operation, the first objective function is

$$min\ C_1 = \sum_{t=1}^{T} (C_f(t) + C_{OM}(t) + C_L(t)) \tag{8}$$

$C_f(t)$ is the cost of fuel consumption of each distributed power source at t-time, and its mathematical model is

$$C_f(t) = C_{CHP}(t) + C_{FC}(t) \tag{9}$$

where $C_{CHP}(t)$ is the fuel cost at the time of the co-generation unit at the t-time, and $C_{FC}(t)$ is the fuel cell power generation cost at the t-time.

$C_{OM}(t)$ is the maintenance cost of each unit at t-time, and its mathematical model is

$$C_{OM}(t) = \sum_{i=1}^{N} K_{OM,i} P_i(t) \tag{10}$$

where $K_{OM,i}$ is the maintenance fee of 1 kW h power consumption issued by the micro-power supply i.

$C_L(t)$ is the blackout compensation cost of the cut-out load type, and its mathematical model is

$$C_L = C_a Load(t) \tag{11}$$

where C_a represents the compensation cost (yuan/kW h) of the microgrid when cutting loads, and $Load(t)$ is the total amount of loads cut during the t period.

(2) Optimal environmental benefit

Considering environmental benefits is the most principled, the second objective function is

$$min\ C_2 = \sum_{t=1}^{T} (\sum_{m=1}^{M} 10^{-3} C_m (\sum_{i=1}^{N} \beta_{im} P_i(t))) \tag{12}$$

where C_2 is the environmental remediation cost during the operation of the microgrid, m indicates the type of released gas (such as CO_2, SO_2, NO_X, CO), C_m is the cost per kilogram of polluted exhaust gas, and β_{im} is the penalty cost rate (g/kW h) of the pollutant m generated by the output energy of the ith power generation unit.

(3) Total optimal benefit of microgrid operation

The optimal total benefit of microgrid operation is a reasonable distribution of objective functions 1 and 2, when the total benefit of microgrid operation is the largest, and the weighting coefficient method is adopted to calculate the total benefit, and the calculation expression is

$$min\ C_3 = \gamma_1 C_1 + \gamma_2 C_2 \tag{13}$$

where C_3 represents the total operating cost of the microgrid, γ_1 and γ_2 represent the weighting coefficients, usually $\gamma_1 \geq 0$, $\gamma_2 \geq 0$, $\gamma_1 + \gamma_2 = 1$.

3.2. Constraint equations

Aiming at the economical operation of the microgrid system, it is necessary to impose necessary constraints on the model of each unit in the microgrid to determine the optimal output of each unit in the system. Specific constraints are described below.

(1) Power balance constraints

$$P_d^t + P_{loss}^t = P_{Gi}^t \tag{14}$$

where P_d^t is the system load power in the t period, P_{loss}^t is the line loss power of the system transmission energy in the t period, and P_{Gi}^t provides active power for each distributed generation unit in the t period.

(2) Power constraints on the output of each distributed generation unit

$$P_i^{min} \leq P_{Gi} \leq P_i^{max} \tag{15}$$

where P_i^{min} and P_i^{max} represent the minimum and maximum values of the active power provided by the micro-power i at the t moment, respectively.

(3) Rotate the spare capacity constraint

The role of the rotating standby capacity is mainly to solve the fluctuation of the output of wind energy and solar power generation units in the system and the instability caused by the load prediction error.

$$\sum_{n=1}^{N} P_i^{max} \geq P_L(t) \cdot (1 + L\%) + P_{wp}(t) \cdot u_s\% \tag{16}$$

where $L\%$ represents the demand factor of the electricity load on the rotating standby capacity in the microgrid, $u_s\%$ is the demand coefficient of the wind energy and solar power generation units for the rotating standby capacity, and $P_{wp}(t)$ is the sum of the nominal capacity of the wind energy and solar power generation units in the t-time system.

(4) Power constraint of the energy storage unit

The termination capacity value of the energy storage device in the dispatching period is equal to the initial capacity.

$$P_{es}^{min} \leq P_{es}^{i} \leq P_{es}^{max} \tag{17}$$

$$\sum_{i=1}^{T} P_{es}^{i}\delta = 0 \tag{18}$$

where P_{es}^{min}, P_{es}^{max} is the boundary value of the operating power of the energy storage device, δ is the scheduling period.

4. Improved particle swarm optimization algorithm for optimal scheduling model of microgrid

In this paper, by changing the size of the weight and adjusting the value of the acceleration factor, the algorithm can obtain the solution of the multi-objective problem with a faster convergence speed. The microgrid optimization scheduling algorithm is as follows.

Among them, the initial position x_{id}^{0} of particle i is

$$x_{id}^{0} = r_1(x_d^M - x_d^m) + x_d^m \tag{19}$$

where r_1 represents a random number between (0, 1), and x_d^M and x_d^m represent the maximum and minimum values of the dth component of the particle.

The initial velocity v_{id}^{0} of particle i is

$$v_{id}^{0} = r_2 v_d^M \tag{20}$$

where r_2 represents a random number between (0, 1), v_d^M represents the velocity change of the dth component of the particle.

The inertia weight coefficient ω is

$$\omega = \omega_{start} - \frac{t(\omega_{start} - \omega_{end})}{T} \tag{21}$$

where $\omega_{start} = 0.9$, $\omega_{end} = 0.4$, t represents the iteration value of the particle swarm so far.

The acceleration factors c_q and c_2 are

$$\begin{cases} c_1 = \dfrac{(c_{1f} - c_{1e})t}{T} + c_{1e} \\ c_2 = \dfrac{(c_{2f} - c_{2e})t}{T} + c_{2e} \end{cases} \tag{22}$$

where c_{1e}, c_{1f}, c_{2e}, c_{2f} represent c_1, c_2 is the value at the beginning and end of the optimization process, usually 2.5, 0.5, 0.5, 2.5.

The improved particle swarm optimization algorithm is as follows:

5. Simulation analysis

5.1. Microgrid system model and parameters

The microgrid system considered in this paper includes a wind turbine with a rated power of 45 kW, a solar power unit with a rated power of 25 kW, a fuel cell group with a rated power of 50 kW, a co-generation unit with a rated power of 60 kW, and an energy storage device with a rated power of 45 kW. In addition, the load composition in the microgrid is divided into three levels according to its requirements for power supply reliability, and the rated capacity of each level of load is 50 kW.

The model parameters of distributed generation units and energy storage devices in microgrid systems are shown in Table 1.

The dispatch model of the microgrid in this paper is based on the parameters provided on a typical day in a certain area to simulate the output of each unit in the grid. The output power of the typical daily wind power generation and photovoltaic power generation units in this area is shown in Figs. 2 and 3.

Algorithm Improved Particle Swarm Optimization

Set the number of particle swarms, set the number of iterations k=1;
Randomly initialize particle velocity and position;
Alternate calculation of the velocity and position of each particle;
Substitute the calculation result and initial value into the fitness value of each particle in the objective function;
Find the individual and global optimal positions of particles;
Let k=k+1, update the particle velocity and position, and limit the out-of-limit variable;
Update the calculation again for each particle;
Substitute the calculation result and initial value into the objective function to find the fitness value of each particle;
Update particle velocities and positions, limit out-of-limit variables;
If $k=k_{max}$ stop, the result is output. Otherwise let k=k+1, Continue to update particle position and velocity

Table 1. Model parameters.

Micro-power type	PV	WT	MT	FC	ES
Installation cost (10,000 yuan/kW)	6.35	2.45	1.68	4.28	0.5
Upper output limit (kW)	40	20	65	50	20
Lower output limit (kW)	0	0	0	0	0
Operation and maintenance costs (yuan/kW)	0.02	0.3	0.03	0.09	0.001

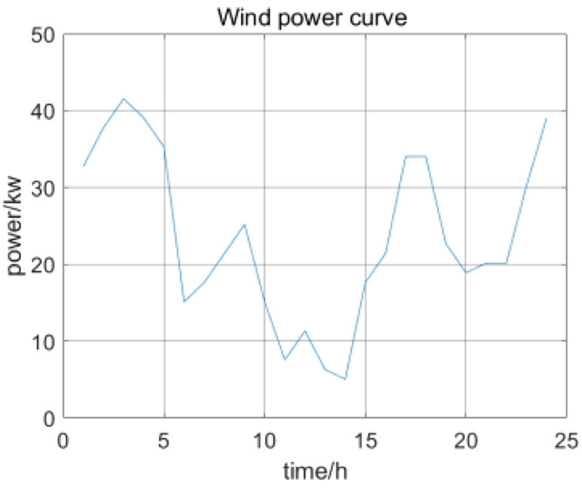

Fig. 2. Typical daily wind power generation curve.

5.2. Simulation and analysis of microgrid system operation

In this paper, the number of particles in the particle swarm is set to 50, the maximum number of iterations of the algorithm is set to 300 times, the acceleration factors c_1 and c_2 are set to 3.0, and the inertia weight coefficient is set to 0.9.

When the microgrid is island operating, the model is solved by the improved particle swarm algorithm based on the constraints of each model, and the output power of each power generation unit is determined. The specific output diagram is shown in Fig. 4.

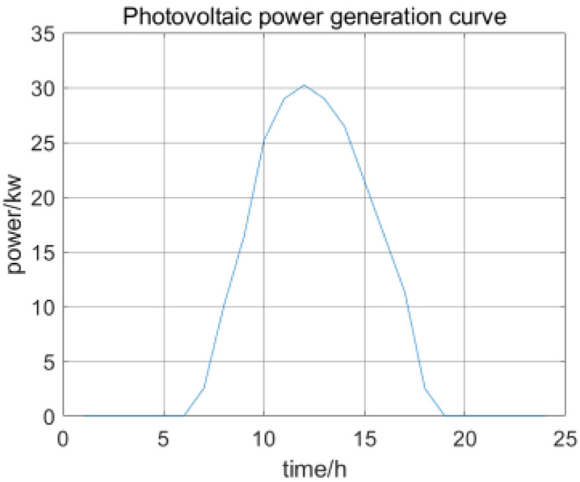

Fig. 3. Typical daily photovoltaic power generation curve.

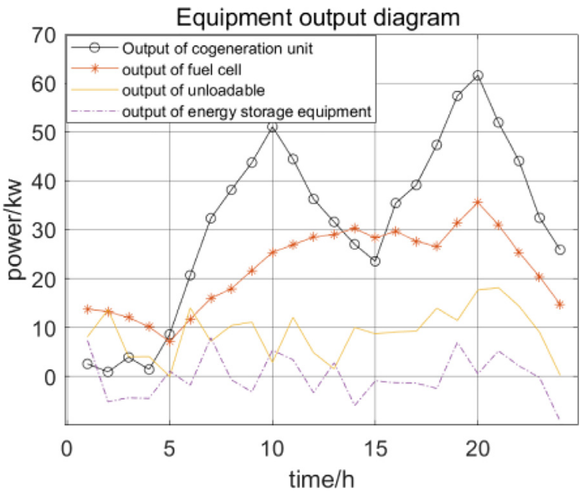

Fig. 4. Output of each equipment.

From the analysis of the curves in Fig. 4, the following conclusions can be drawn. During periods of low power consumption, the fuel cell is preferentially used to power the load. During peak power consumption periods, the fuel cells operate at full load, and the insufficient power is provided by co-generation units and energy storage devices. When the output of all generator sets in the grid reaches the maximum value, but still cannot meet the load demand, it is necessary to cut off the unimportant loads in the system to achieve power balance.

The operating costs of the microgrid using the conventional dispatching strategy and the scheduling strategy proposed in this paper are shown in Fig. 5. From the overall effect of Fig. 5, the total cost of the conventional dispatching method is much lower by using the microgrid dispatching strategy method proposed in this paper, which ensures the economy of the algorithm.

6. Conclusion

In this paper, considering the volatility and randomness of renewable energy power generation, an economical and environmentally friendly operation model of the CHP microgrid system is established, and the optimized solution is

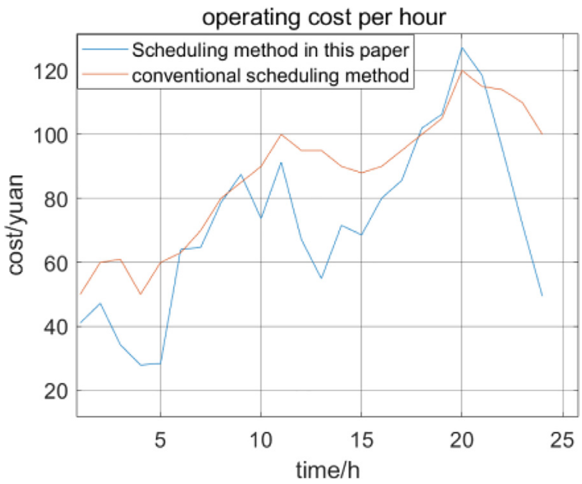

Fig. 5. Comparison of different dispatching strategies and costs of microgrid.

carried out through an improved particle swarm algorithm. The case analysis shows that the dispatching strategy in this paper is more economical than the traditional method, and the research results can provide a technical reference for the planning and design of the co-generation microgrid. The renewable energy co-generation microgrid system in this paper is relatively simplified, and its optimization model needs to be further improved.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

References

[1] Zhou Quan, Shahidehpour Mohammad, Li Zhiyi, et al. Compartmentalization strategy for the optimal economic operation of a hybrid AC/DC microgrid. IEEE Trans Power Syst 2019;35(2):1294–304.
[2] Abbas Muhammad, Zhang Duanjin. A smart fault detection approach for PV modules using adaptive neuro-fuzzy inference framework. Energy Rep 2021;7(1):2962–75.
[3] Song Kun, Wu Zhikai, Nan Zhe, et al. Optimization method of energy storage system scheduling strategy based on multi-step electricity price prediction. J Shenyang Univ Technol 2021;43(05):493–9.
[4] Liu Yang, Jiang Zhanpeng, Hao Lichao, et al. Data-driven robust value iteration control with application to wind turbine pitch control. Optim Control Appl Methods 2021;1–10. http://dx.doi.org/10.1002/oca.2834.
[5] Tan Zhukui, Zhang Xiaoshun, Xie Baiming, et al. Fast learning optimiser for real-time optimal energy management of a grid-connected microgrid. IET Gener Transm Distrib 2018;12(12):2977–87.
[6] Wang Guo, Wang Qinqin, Qiao Zhi, et al. Optimal planning of multi-micro grids based-on networks reliability. Energy Rep 2020;6:1233–49.
[7] Yang Liu, Zuoxia Xing, Lei Chen, et al. H∞ control for a class of discrete-time systems via data-based policy iteration with application to wind turbine control. IEEE Access 2020;(08):14565–72.
[8] Li Yang, Wang Ruinong, Yang Zhen. Optimal scheduling of isolated microgrids using automated reinforcement learning-based multi-period forecasting. IEEE Trans Sustain Energy 2022;13(1):159–69.
[9] Liu Yan, Deng Bin, Wang Jin, et al. Electric vehicle charging scheduling strategy based on multi-objective optimization model. J Shenyang Univ Technol 2022;44(02):127–32.
[10] Yang Xiaohui, Zhang Liufang, Wu Qinglong, et al. Economic optimal dispatch of active distribution network with combined cooling, heating and power microgrid considering IDR. Power Syst Prot Control 2022;50(03):19–28.
[11] Shang Qingxiao, Sun Ming. Research on grid optimization scheduling based on wind power and storage (heat) heating system. Chin J Solar Energy 2021;42(07):65–70.

[12] Zhou Youwei, Zhong Yuzhe, Yu Daihai, et al. Research on economic optimal scheduling of distributed microgrid system based on improved ECA algorithm. Electr Times 2022;(02):34–9.
[13] Nwulu Nnamdi, Xia Xiaohua. Optimal dispatch for a microgrid incorporating renewables and demand response. Renew Energy 2017;101:16–28.
[14] Li Zhengmao, Xu Yan. Optimal coordinated energy dispatch of a multi-energy microgrid in grid-connected and islanded modes. Appl Energy 2018;210:974–86.