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Capacity Optimization of Photovoltaic Storage Microgrid System Considering Carbon Trading Under Power Rationing Conditions

Xuesong Chang[1], Bolong Mao[1], Yingzi Xian[1], Lei Wang[1*]

1 College of Automation, Chongqing University, Chongqing, 400044, PR China

ABSTRACT

Since 2021, energy prices in the international market have risen sharply, and the contradiction between supply and demand of electricity and coal in China has continued to be tight, resulting in power cuts and power rationing, which has slowed down China's efforts to reduce carbon emissions. In order to improve the self-power supply capacity, stability and low carbon economy of microgrid, a capacity allocation method of optical storage microgrid system based on power limit conditions considering carbon trading profit is proposed. Firstly, an energy storage system is introduced to construct the topology structure of the integrated optical storage microgrid system. By setting the upper limit of the load demand power in the configuration model and considering the carbon trading profit, an economic capacity allocation model with the maximum net income of the system operation as the optimization objective is established. Combined with the operation control strategy of energy storage battery work priority and the optimal configuration algorithm based on grey Wolf optimization algorithm, the optical storage micro-grid capacity configuration scheme considering carbon trading profit under the condition of power restriction is solved.

Keywords: carbon trading， optimal configuration， power rationing conditions， photovoltaic storage microgrid

1. INTRODUCTION

In 2015, countries around the world signed the Paris Agreement on global climate change, requiring that greenhouse gases achieve the goal of "net zero emissions" in the agreement in this century, and the use of fossil fuels must be significantly reduced in the next few decades. The global energy system has put forward the demand for energy transformation, and renewable energy such as wind power and photovoltaic will see explosive growth. Renewable energy will gradually replace the traditional fossil energy to occupy the dominant position in the energy field [1].

Since 2021, China's power demand has grown faster than its power supply, leading to a widening gap between supply and demand. At the same time, some provinces have adopted measures of " energy dual control " for short-term regulation due to the failure to achieve the "dual energy control" targets. In view of this, there is an urgent need for the plant to adapt to the development of renewable energy power generation system under the condition of power rationing, in order to avoid the shutdown of plant facilities and equipment as much as possible and to increase additional revenue for the plant.

In the process of utilization of many renewable energy, especially photovoltaic power generation is the least restricted by environment and region and the most widely used. However, the independent photovoltaic power generation system has a serious day-night imbalance. Photovoltaic arrays can convert solar energy into electricity only when there is daylight in the day, but do not generate any electricity at night. Photovoltaic power generation is also affected by natural factors such as illumination and season, and the output power fluctuates sharply. If there is only independent photovoltaic power generation system in the power supply grid of a region, then the load power supply quality of the region is extremely poor, and there is the possibility of power failure at any time. Especially under the power limiting conditions targeted by the study, the independent photovoltaic power generation system cannot be applied [2].

In addition, the energy storage system can achieve the role of peak cutting and valley filling by absorbing abandoned light or compensating for the missing energy of photovoltaic on load, reduce the fluctuation of distributed energy so that it can be stable output, and can coordinate the photovoltaic power supply to the user load to meet the needs of different loads, improve the safety and reliability of the system, and reduce the waste of energy. Based on this, the capacity optimization configuration of low-carbon optical storage micro-grid system under the condition of power restriction is studied, which can not only maintain the stable operation of optical storage micro-grid, improve the power supply quality of micro-grid, but also effectively reduce the construction cost of micro-grid, and reduce the power supply burden of the grid, and help realize the national "energy dual control" and dual-carbon goals.

The second section introduces the system architecture of optical storage microgrid and the mathematical model of the system components. The third section studies the system operation strategy that prioritizes battery work, considers the carbon trading profit to solve the optical storage microgrid system capacity optimization configuration scheme with the goal of maximizing the net income of the system operation. In the fourth section, simulation analysis is carried out for the research conditions of the example.

2. SYSTEM DESCRIPTION AND METHODOLOGY

2.1 Overview of System Architecture

Fig.1 shows the structure of a typical grid-connected optical storage micro-grid system, which mainly includes four parts: photovoltaic power generation system, energy storage system, factory load under power limit conditions and large power grid [3]. All system units are connected to the public BUS through power electronic devices. Considering that the system is designed based on power limiting conditions, the upper limit of the power demand of the factory load is set at 50kw. The whole system is mainly maintained by photovoltaic + energy storage. When the optical storage is insufficient to support the system load, the large power grid is used to maintain the stability of the system operation. When the large power grid is disconnected, it is a typical independent microgrid.

2.2 System component model

2.2.1 Mathematical model of PV

The generating power of photovoltaic panels is mainly related to the surface light intensity of photovoltaic panels and the temperature of photovoltaic Fig.1 Solar storage microgrid system architecture panels. The mathematical relationship between the output power of photovoltaic panels and the temperature and light intensity is shown in Eq. (1).

$$P_{PV\_t} = P_{PV\_rated} \frac{G_t}{G_{STC}} \left[1 + k(T_{ct} - T_{STC})\right]$$

Where P_{PV_t} is the output power of the photovoltaic

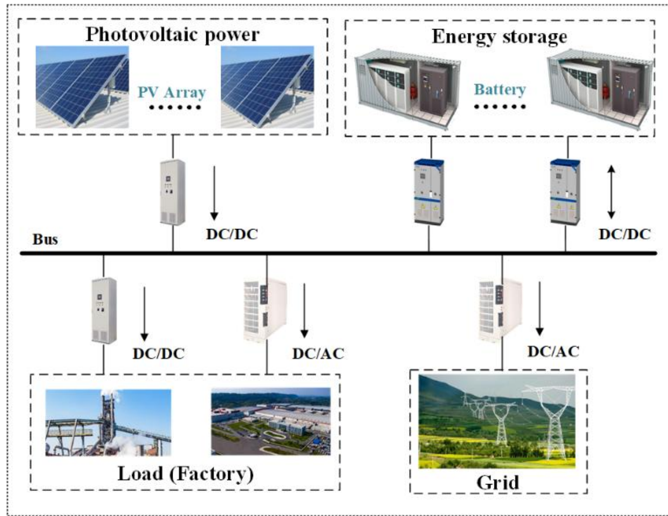

Fig1. Solar storage microgrid system architecture

panel at time t, P_{PV_rated} is the rated output power of the photovoltaic panel, G_t is the light intensity of the photovoltaic panel surface, G_{STC} is the standard test light intensity, 1000 W/m^2 , k is the maximum power temperature coefficient of the photovoltaic panel, T_{ct} is the temperature of the photovoltaic panel, T_{STC} is the standard test temperature, 25℃.

2.2.2 SOC mathematical model of energy storage battery

Energy storage batteries can provide a variety of services such as peak regulating, frequency regulating, reserve and demand response support for power grid operation. They have the characteristics of bidirectional charge and discharge, small size, fast reaction speed and easy installation. The model of energy storage battery is divided into Charge and discharge model and life model. This project adopts the State of Charge (SOC) model of battery.

The SOC model of energy storage battery charging process is shown in Eq. (2).

$$SOC(t+1) = SOC(t) - P_{BAT\_t} \cdot \Delta t \cdot \eta_c / C$$

Where $SOC(t)$ is the SOC of the energy storage battery at time t, P_{BAT_t} is the power of the energy storage battery, Δt is the charging time, η_c is the charging efficiency of the energy storage battery, C is the battery capacity, kWh.

Where P_{BAT_t} is the charge and discharge power of the battery at time t, the charge is negative and the discharge is positive. The terminal voltage of the battery is the bus voltage, so the input and output power of the battery can be controlled by controlling the input and output current of the battery. The SOC model of the discharge process of the energy storage battery is shown in Eq. (3).

$$SOC(t+1)=SOC(t)-\frac{P_{BAT\_t}\cdot\Delta t}{\eta_d\cdot C}$$

Where η_d is the battery discharge efficiency.

3. SYSTEM DESCRIPTION AND METHODOLOGY

3.1 System Operation Strategy

Based on the control operation strategy of the optical storage micro-grid system considering carbon quota trading under the condition of power limiting, the real-time photovoltaic power generated by the photovoltaic mathematical model is input with the light intensity data, and the maximum power demand of 50kw load set under the condition of power limiting is taken as the input. The objective function and constraint conditions are established. Combined with the capacity optimization configuration algorithm, the high efficiency and low cost energy storage capacity configuration can maximize the system benefits. When the system is running, only the large power grid can be connected to output surplus electric energy for sale. In addition, according to China's carbon emission trading system, the paper plans to carry out stepped-up carbon trading under the condition of power restriction in order to increase additional benefits of the system [4]. The system operation strategy is shown in Fig.2. The paper adopts the operation control strategy of energy storage battery priority. Under this operation strategy, the system operation scenarios can be divided into four types.

Case 1: The output power of the distributed generation device is surplus after meeting the load demand, and the surplus power is less than the maximum charging power of the battery. In this case, if the battery SOC reaches the upper limit after charging, all the remaining power will be connected to the grid and sold to obtain profits.

Case 2: After the output power of the distributed generation device meets the load demand, the remaining power is less than the maximum charging power of the battery. In this case, if the battery SOC after charging is lower than the upper limit, the remaining power is used to charge the battery; otherwise, the battery will not be charged.

Case 3: The output power of the distributed generation device is insufficient to meet the load demand, and the load deficit power is less than the maximum discharge power of the battery. In this case, if the battery SOC does not exceed the lower limit after discharge, the power deficit is provided by the battery, and the load is supported by the energy storage battery.

Case 4: The output power of the distributed generation device is insufficient to meet the load demand, and the load deficit power is less than the maximum discharge power of the battery. In this case, if the battery SOC exceeds the lower limit after discharge, the load will stop, triggering the punishment mechanism, and accumulating the system penalty cost.

3.2 Mathematical model of system size configuration

The capacity optimization allocation method in this study takes the maximization of the net operating income of the optical storage micro-grid system under the condition of power restriction as the objective function. Among them, the operating cost of the micro-grid includes the unit cost (including construction cost and operation and maintenance cost) of the distributed photovoltaic subsystem and the energy storage battery subsystem. At the same time, power balance constraint, energy storage battery operation constraint and energy storage real-time charge as constraints. In consideration of the blackout conditions, it is stipulated to sell electricity only to the large grid. For this study, the objective function is shown in Eq. (4).

$$\max PRO=R_{CT}+R_E-C_{BAT}-C_{PV}-C_{P\text{un}}$$

Where R_{CT} is the system carbon emission rights trading income, \$ (Chongqing factory carbon quota trading unit price 44 \$/ton), R_E is the revenue of system electricity sale, (unit price of electricity sale is 0.4 \$/kwh); C_{BAT} is the battery cost, \$, C_{PV} is photovoltaic cost, \$, $C_{P\text{un}}$ is start-stop penalty cost, \$.

The specific calculation formula of R_{CT} is as follows.

$$\begin{cases}R_{CT}=E_{IESt}\times\lambda\\ E_{IESa}=\chi_{ca}C_{unmet}\end{cases}$$

Where E_{IESt} is the transaction volume of carbon emission right, and χ_{ca} is the carbon emission generated by micro-grid purchasing unit electricity from power grid, which is set as 1.08kg /kWh in this paper.

The capacity configuration constraints are listed in Eq. (6)- Eq. (8).

Power balance constraint.

$$P_{PV\_t}+P_{BAT\_t}\geqslant P_{LOAD}$$

Energy storage battery power constraint.

$$|P_{BAT\_t}|<P_{BAT\_\max}$$

When battery works, its terminal voltage is the bus voltage of the system. Generally, the ground charging and discharging current of a battery cannot exceed 70%

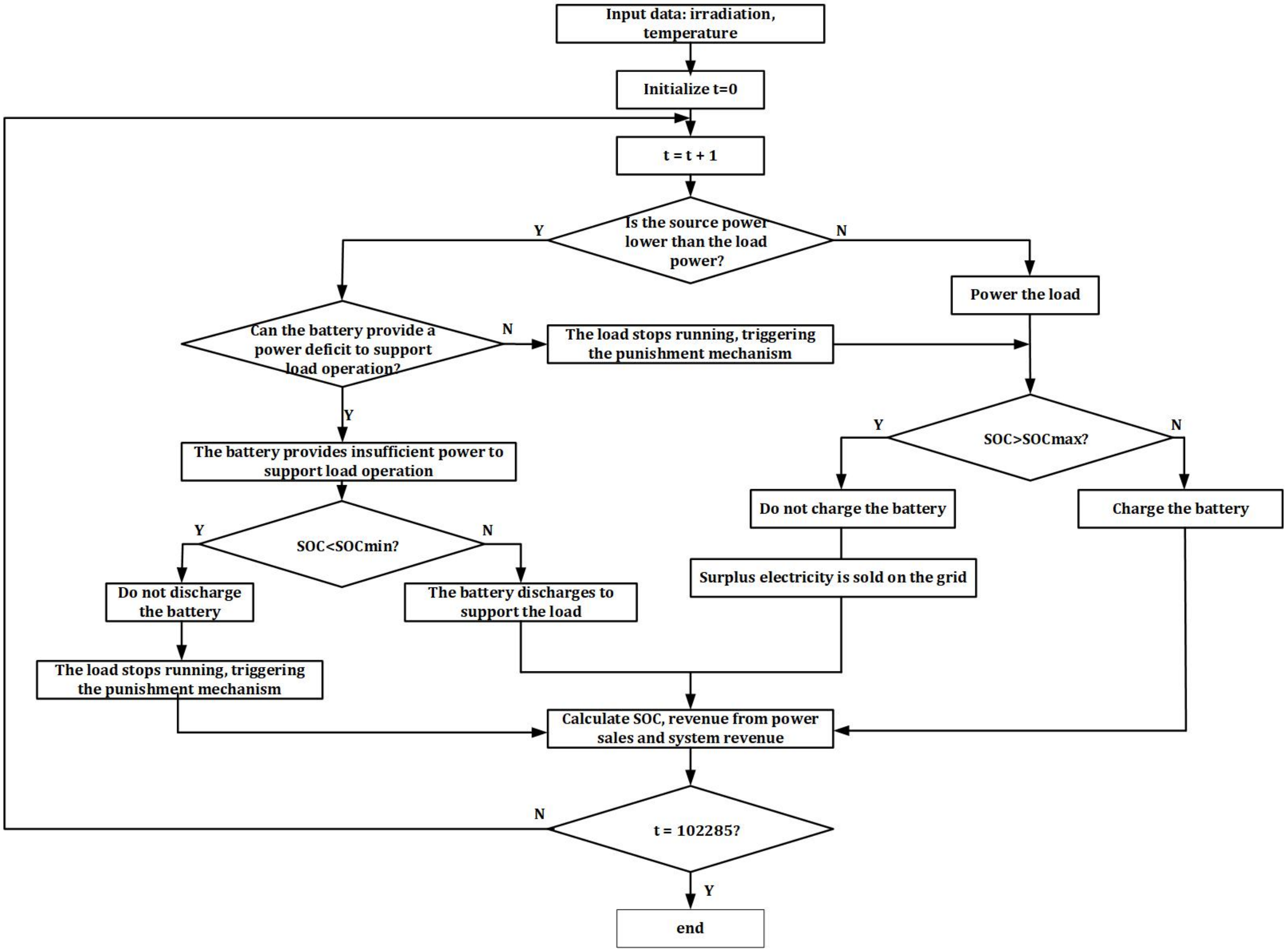

Fig.2 System operation policy flowchart

of its rated capacity. Therefore, the maximum charging and discharging power of a battery is limited.

Constraint on the number of load starts and stops. Considering that frequent start and stop reduces the service life of the device, set the number of load start and stop to 0.

Energy storage battery SOC constraint.

$$SOC_{\min} \leq SOC_t \leq SOC_{\max}$$

Deep battery charging and deep discharge reduce battery life. To maximize battery life, need to manage battery SOC. Maintaining the battery SOC in a healthy range during battery operation can effectively reduce the damage caused by overcharging and over-discharging. Where P_{PV_t} is the PV power at time t, P_{BAT_t} is the charging and discharging power of the energy storage battery at time t, and P_{LOAD} is the maximum power demand of the load. Set a fixed value of 50kw, $P_{BAT\_\max}$, $SOC_{\min}$ and $SOC_{\max}$ are the maximum power of the battery and the maximum and minimum charge of the battery respectively.

3.3 Size optimization configuration algorithm

The system optimization variables in this paper are the rated power of photovoltaic panels to be configured and the capacity of energy storage batteries, which are solved by grey Wolf optimization algorithm. The flow chart of grey Wolf optimization algorithm is shown in Fig.3.

4. SIMULATION AND RESULTS

The annual light intensity and temperature data of a factory in Chongqing are shown in Fig.4 and Fig.5, respectively. The data sampling frequency is 5min/ time. Based on this, the system optimization parameters are set as shown in Table 1.

The PV power and other parameters calculated by the PV mathematical model were input into the capacity configuration model, and the distributed PV power generation configuration capacity was 878kw and the energy storage system configuration capacity was 1356kwh based on the grey Wolf optimization algorithm. The optimization process results were shown in Fig.6 and Fig.7. It is concluded that the maximum operating profit value of the system within the service life cycle of the photovoltaic microgrid hardware is -816307 dollars, and the maximum operating profit value is -874813 dollars without carbon trading mechanism. Due to poor local lighting conditions and obvious temperature fluctuation, the photovoltaic configuration capacity is large, which increases the system construction cost, and with the continuous increase of the unit price of carbon quota trading in the factory, The cost of the system will also be reduced.

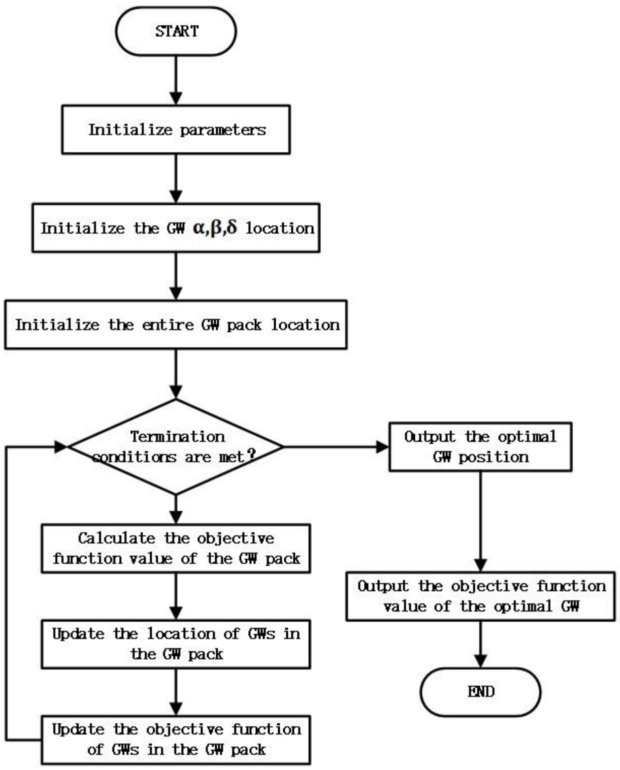

Fig.3 GWO algorithm flow chart

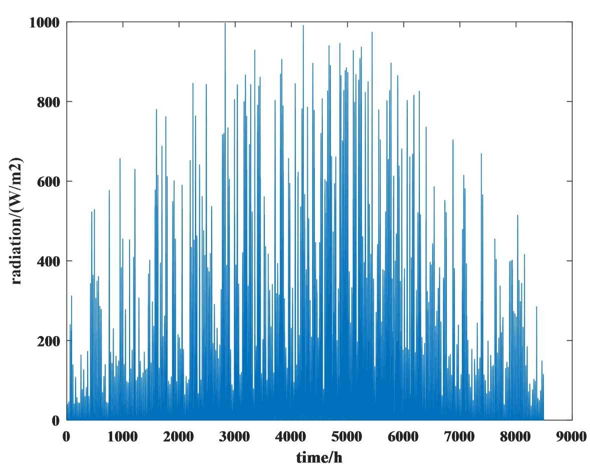

Fig.4 Annual radiation data (W/m2)

Table 1

Capacity optimization configuration parameters

		Value
C_{BAT}	*$/ kWh*	*281.10*
C_{pv}	*$/ kW*	*562.20*
r_E	*$/ kWh*	*0.056*
n_i	*Years*	*2.81*
C_{pun}	*$/times*	*702740.69*

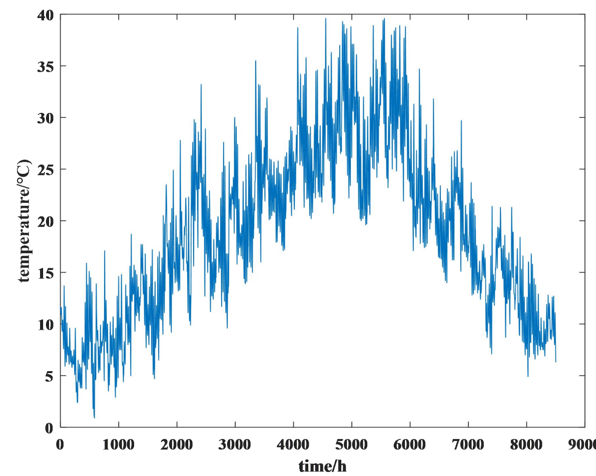

Fig.5 Annual temperature data

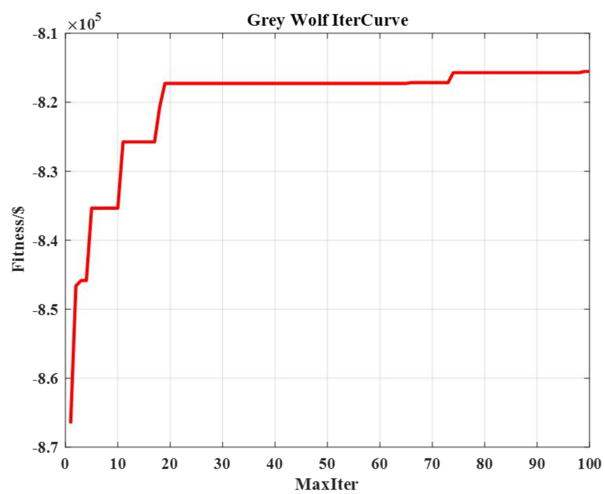

Fig.6 Iterative process of GWO

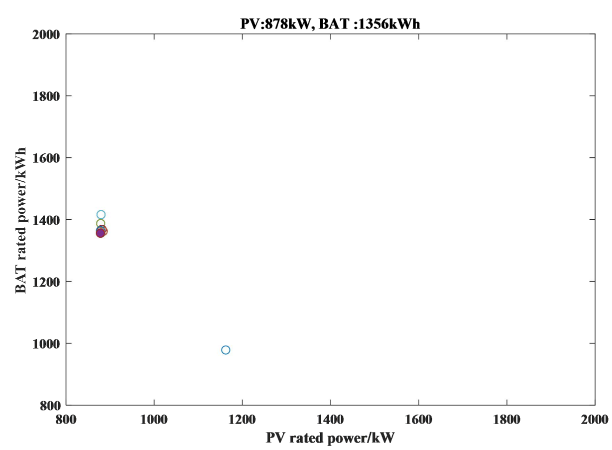

Fig.7 Sizing configuration optimization result

5. CONCLUSIONS

Based on the research of the system architecture and component mathematical model of optical storage microgrid, a mathematical model of capacity optimization configuration of optical storage microgrid system considering carbon trading under the condition of power limit is established. By solving the configuration model through the grey Wolf optimization algorithm, the optimal capacity allocation results under the condition of zero load start-stop were obtained, which alleviated the direct impact of power limiting measures on facilities and equipment, extended the service life of the load, and reduced the dependence of the microgrid on the large power grid. At the same time, this paper considers the carbon trading mode. Compared with the non-carbon trading mode, the system cost is reduced by 7%.

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