

# Research on Microgrid Operational Economy Based on Energy Storage Optimization

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**Abstract:** With the growing global energy demand and worsening environmental issues, microgrids have gained attention for integrating renewable energy. However, their economic operation is challenged by the volatility of renewable energy, making efficient operation a key research focus. This study collected and integrated microgrid data from three parks and established a microgrid energy storage optimization model using the NSWOA algorithm. Economic indices were calculated through methods like the composite rectangle formula and sensitivity analysis, focusing on key factors such as the price of the main power station and wind power costs. The study found that coordinated configuration of wind, solar, and storage systems improved economic efficiency by 1% to 4% across the three parks. Based on these findings, optimal operation strategies and power purchase plans were developed, with the recommendation that wind power and storage be prioritized during peak periods, supplemented by power purchases from the main grid. Excess power should be stored to reduce the abandonment of wind power generation. This study provides a framework for enhancing the stability and economic viability of renewable energy systems and offers decision support for coordinated wind and storage allocation and economic power purchase strategies.

**Keywords:** Optimization Model, NSWOA Algorithm, Coordinated Allocation of Wind Power and Energy Storage, Microgrid, Economy.

## 1. Introduction

As the world's largest energy producer and consumer, China's coal-based energy system structure has resulted in high carbon emissions from the power sector [1]. Under the guidance of the "dual-carbon" goal, China has begun to promote the upgrading of the energy consumption structure and energy saving, and the new energy field is developing rapidly [2]. As a new type of energy management model, microgrid has gained wide attention and application worldwide in recent years because of its ability to flexibly integrate renewable energy sources, improve energy utilization efficiency, and reduce dependence on traditional power grids. At present, China has built several microgrid engineering demonstration projects throughout the country. However, the volatility and intermittency of renewable energy access to the power system have an impact on the safe and stable operation of microgrids [3]. Along with the new energy scale access to the urban power grid, the power system gradually presents the supply-demand time-space mismatch situation, which will lead to a gradual decline in its static voltage stability margin, and even serious instability problems, greatly jeopardizing the reliability of power supply and security of electricity consumption [4-14]. How to realize the economic and efficient operation of microgrids in an unstable power generation environment has become an important direction of current research.

Park microgrids typically combine wind power generation with the main grid to supply power to loads. However, the volatility, randomness, and uncontrollability of wind power pose challenges, such as grid peaking limitations, frequency regulation constraints, and the abandonment of wind and

solar energy. While energy storage can mitigate these timing mismatch issues and reduce energy waste, its configuration must balance investment and revenue considerations. In this context, the coordinated and optimized configuration of wind power and energy storage in park microgrids is crucial. This study employs the Non-Dominated Sorting Whale Optimization Algorithm (NSWOA) to optimize energy storage capacity in microgrids with wind and solar components. The NSWOA enhances the traditional WOA by incorporating Logistic Chaos Mapping and Non-dominated Sorting, which increase population diversity and universality, effectively preventing the exclusion of superior individuals due to a limited search space.

This study first obtained and preprocessed electricity consumption and wind and photovoltaic power generation data for the parks. A microgrid energy storage optimization model was then established using the NSWOA algorithm, with calculation formulas defined for four economic indicators: purchased electricity, wind and photovoltaic power generation, total power supply cost, and average power supply cost per unit of electricity. These were combined with typical daily load data from the parks, and specific data results were produced using composite rectangle formulas. The study then analyzed key economic factors, conducting a sensitivity analysis on wind power price, photovoltaic power price, and main power station price, while excluding factors difficult to control, such as purchased power and abandoned wind and photovoltaic power. Given the park's energy storage system configuration of 50kW/100kWh, the economic indicators after energy storage configuration were calculated, and the study formulated an optimal operation strategy for energy storage and power purchase under this configuration.

## 2. Economic evaluation and sensitivity analysis of microgrids

The data for this study was obtained from <http://shumo.neepu.edu.cn/> and contains the electricity consumption and the time allocation of wind power and photovoltaic power generation in three parks, which are named here as Park A, Park B, and Park C. After pre-processing the obtained data, the following four economic indicators are defined in this study:

(1). Electricity purchase  $B_i$

The amount of power purchased,  $B_i$  is the amount of power that each park purchases from the main power site when there is a shortage of power.

$$\begin{cases} E_i^1(t) = \int_0^t P_{w,i,t} \cdot n_i^1(t) dt + \int_0^t P_{s,i,t} \cdot n_i^2(t) dt \\ E_i^2(t) = \int_0^t P_i^{cost}(t) dt \end{cases} \quad (1)$$

$$E_i(t) = E_i^1(t) - E_i^2(t)$$

$P_{w,i,t}$  in the equation denotes the installed wind power capacity of the  $i$ th park,  $P_{s,i,t}$  in the equation denotes the installed PV capacity of the  $i$ th park,  $n_i^1(t)$  and  $n_i^2(t)$  denote the efficiency of wind and photovoltaic power generation in the  $i$ th park at time  $t$ , respectively,  $P_i^{cost}(t)$  denotes the  $i$ th campus load power at time  $t$ ,  $E_i^1(t)$  denotes the amount of electricity generated in the  $i$ th park at time  $t$ ,  $E_i^2(t)$  denotes the  $i$ th campus load power at time  $t$ ,  $E_i(t)$  indicates the park's power deficit or power surplus.

So the amount of power purchased is:

$$B_i = \int_{E_i(t) < 0} -E_i(t) dt \quad (2)$$

(2). Amount of wind and solar power abandoned  $D_i$

The amount of wind and solar power abandoned  $D_i$  is the amount of wind and PV power issued but not used in each park. Combined with the power purchase derivation process, the formula for the amount of wind and photovoltaic power discarded can be calculated as follows:

$$D_i = \int_{E_i(t)>0} E_i(t) dt \quad (3)$$

(3). Total power supply cost  $W_i$

The total power supply cost,  $W_i$  is the sum of the typical day's main power plant power purchase cost, wind power purchase cost, and PV power purchase cost for each park. The specific formula is:

$$W_i = B_i \times price_{main} + \int_0^t P_{wind,i,t} \cdot n_i^1(t) dt \times price_{wind} + \int_0^t P_{solar,i,t} \cdot n_i^2(t) dt \times price_{solar} \quad (4)$$

Here,  $price_{main}$  are the main power plant tariff,  $price_{wind}$  the wind power tariff, and  $price_{solar}$  the photovoltaic tariff.

(4). Average cost of electricity supply per unit of electricity  $avgW_i$

The average cost of electricity supply per unit of electricity  $avgW_i$  is the average 24-hour cost of power supply for each park. Calculated by the formula: formula:

$$avgW_i = W_i / E_i(24) \quad (5)$$

Based on the above integral formula, the composite trapezoidal formula is used in this study to solve the problem: First, define the left-for integrals that will be used  $I = \int_a^b f(x) d(x)$ , by the integral median theorem, we know that:  $\exists$  one point  $\xi \in (a, b)$ , s.t:

$$\int_a^b f(x) d(x) = (b-a) f(\xi) \quad (6)$$

If we instead use the value of the function  $f(\frac{a+b}{2})$  at the midpoint  $c = \frac{a+b}{2}$  of the interval as the  $f(\xi)$ -approximation of the  $f(\xi)$ -approximation, we obtain the mid-rectangle formula as follows:

$$R = (b-a) f\left(\frac{a+b}{2}\right) \quad (7)$$

The remaining integral terms are:

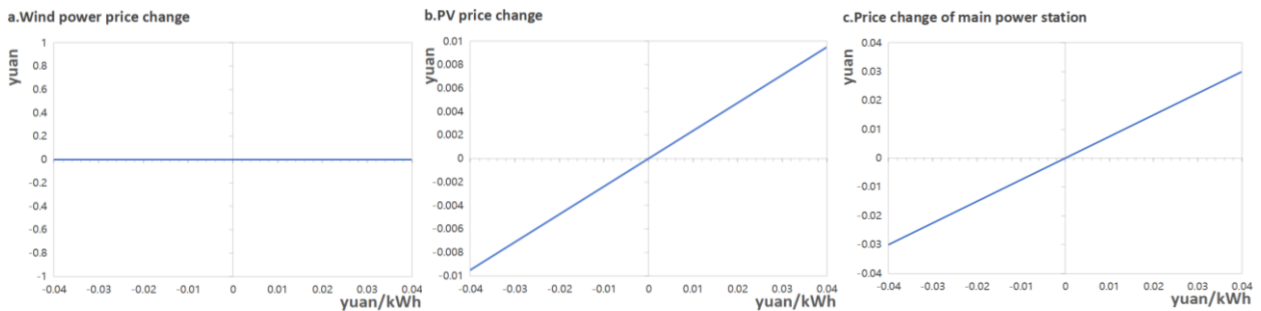
$$R_k = I - J = \frac{f^*(\eta)}{24} (b-a)^3 \quad (8)$$

The composite rectangular formula is to perform the rectangular formula calculation for each node separately. Based on the definition above, the calculation of the four indicators can be derived as in Table 1:

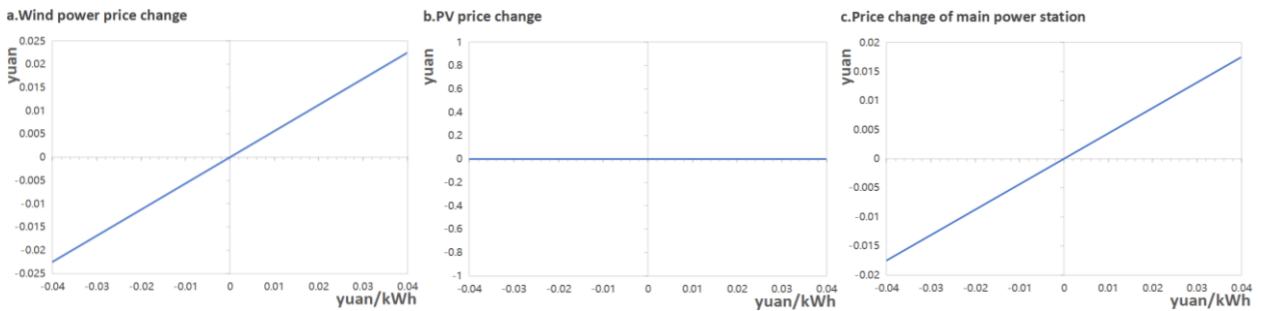
**Table 1.** Data on economic indicators for each park

Comparison	Park A	Park B	Park C
Quantity of electricity purchased	4874.13	2432.30	2699.39
Amount of wind and solar power abandoned	951.20	897.50	1128.02
Total cost of electricity supply	6465.35	5519.90	5472.08
Average power supply cost per unit of electricity	0.82	0.72	0.70

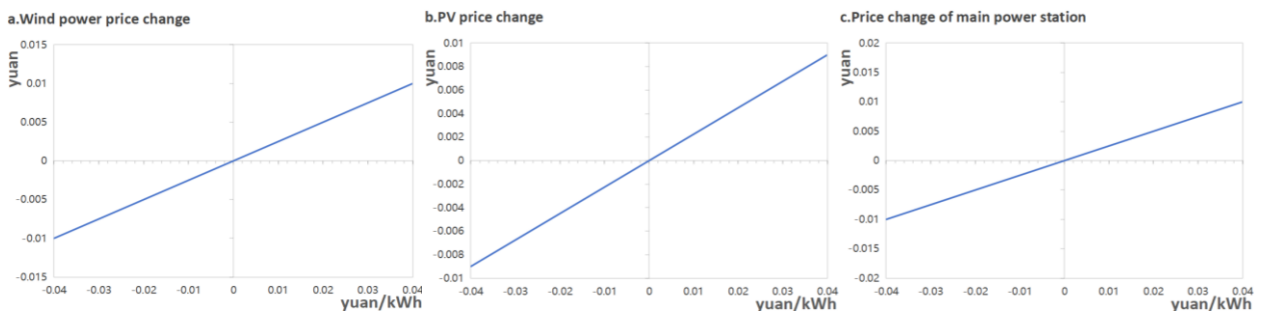
Based on this, this study conducts a sensitivity analysis of the key factors affecting the economy. As factors such as purchased power, abandoned wind, and photovoltaic power are naturally determined by the demand of the park and the stability of wind and light, which are more difficult to change, this paper carries out sensitivity analysis for the price of wind power, photovoltaic power, and the price of the main station, respectively, controlling the other variables to be consistent with the title conditions, and only one variable changes to explore the impact of different prices of each variable on different parks. The results of the sensitivity analysis of each park are shown in Figure 1~3 below:



**Figure 1.** Park A sensitivity analysis



**Figure 2.** Park B sensitivity analysis



**Figure 3.** Park C sensitivity analysis

From the above image, it can be seen that Park A is more sensitive to the price of the main power plant, Park B is more sensitive to the price of wind power and Park C is more sensitive to the price of the

main power plant. That is, the key factor affecting the economics of Park A and Park C is the price of the main power plant, and the key factor affecting the economics of Park B is the price of wind power.

### 3. Analysis of microgrid energy storage optimization operation

This study sets a 50kW/100kWh energy storage system to improve the overall economics of microgrid operation, focusing on the reasons behind these improvements. The paper details the impact on purchased power, wind and solar power abandonment, total power supply cost, and average power cost per unit after integrating energy storage. The formulas used are provided.

(9)

$$\begin{aligned}
 P_{batt\_charge,i,t} &= \min(P_{w,i,t} + P_{s,i,t} - P_{cost}^i, P_{batt\_max}) \\
 P_{batt\_discharge,i,t} &= \min(P_{cost}^i - (P_{s,i,t} + P_{w,i,t}), P_{batt\_max}) \\
 B_i &= P_{cost}^i - (P_{s,i,t} + P_{w,i,t} + P_{batt\_discharge}) \\
 D_i &= \max((P_{w,i,t} + P_{s,i,t} - P_{cost}^i - P_{batt\_charge}), 0) \\
 C_{average} &= \frac{800 \times 50 + 1800 \times 100}{3652} \\
 W_i &= 0.4P_{s,i,t} + 0.5P_{w,i,t} + P_b + C_{average} \\
 aveW_i &= \frac{W_i}{\sum_{i=1}^{24} P_i^{cost}(t)}
 \end{aligned}$$

$P_{batt\_charge,i,t}$  is the storage charging power of park I at time t,  $P_{batt\_discharge,i,t}$  is the storage discharging power of park I at time t,  $E_{batt,i,t}$  is the storage charging energy of park I at time t, and  $C_{average}$  is the average daily cost of the energy storage system.

Based on the definition above, the results of the four indicators after charging and discharging the energy storage can be calculated, as shown in Table 2:

**Table 2.** Operational economic indicators for energy storage conditions of 50kW/100kWh

Comparison	Park A	Park B	Park C
Quantity of electricity purchased	4798.13	2252.80	2588.80
Amount of wind and solar power abandoned	911.65	852.91	1098.45
Total cost of electricity supply	6389.36	5335.70	5348.58
Average power supply cost per unit of electricity	0.81	0.69	0.69

Comparison with the results in Table 1 shows that the operating economics of Parks A, B, and C are improved. The specific improvements are (measured here in terms of average cost of supply per unit of electricity): 1.14% for Park A, 3.34% for Park B, and 2.23% for Park C.

The reason for the improvement can be attributed to the fact that due to the use of energy storage systems, the time series regulation of wind power and photovoltaic power reduces the amount of wind and photovoltaic power discarded, which in turn greatly reduces the amount of power purchased from the main grid. Under the dual effect of the increase in the purchasing cost of the storage system and the reduction in the cost of purchasing power from the main grid, the operating economy of the parks has been improved.

To explore how to formulate the energy storage operation strategy and power purchase plan to make it have the best economy under this energy storage condition, this study establishes a multi-objective optimization model to solve the problem: firstly, the decision variable is determined to be the energy storage charging power of the park at the moment:  $P_{batt\_charge,i,t}$  The stored discharge power of the

moment t park I:  $P_{batt\_discharge,i,t}$  The stored charging energy of moment t park I:  $E_{batt,i,t}$  It is further required to minimize the total cost of purchased power and the cost of wind power generation in each park while considering the power and energy cost of the energy storage system, and the objective function of the model is determined as:

$$\min \sum_i \sum_t (price_{main} \cdot P_{grid,i,t} + price_{wind} \cdot P_{wind,i,t} + price_{solar} \cdot P_{solar,i,t}) + \sum_i \sum_t (C_{batt\_energy} \cdot P_{batt\_charge,i,t} + C_{batt\_energy} \cdot P_{batt\_discharge,i,t}) + C_{batt\_power} \cdot P_{batt\_max} \quad (10)$$

$C_{batt\_power}$  is the energy storage system power unit price..  $P_{grid,i,t}$ ,  $P_{wind,i,t}$ ,  $P_{solar,i,t}$  is the power purchased from the main grid, wind, and photovoltaic in the moment t park I.  $P_{batt\_max}$  is the maximum charging and discharging power of energy storage. Finally, the constraints of the model are made explicit:

①Energy balance constraints:

$$P_i^{cost}(t) + P_{batt\_charge,i,t} = P_{grid,i,t} + P_{wind,i,t} + P_{solar,i,t} + P_{batt\_discharge,i,t} \quad (11)$$

②Energy storage power change constraints:

$$E_{batt,i,t+1} = E_{batt,i,t} + \eta_{charge} \cdot P_{batt\_charge,i,t} - \frac{P_{batt\_discharge,i,t}}{\eta_{discharge}} \quad (12)$$

$\eta_{charge}$  and  $\eta_{discharge}$  denote the energy storage charging and discharging efficiency, respectively.

③Energy storage capacity constraints:

$$SOC_{min} \cdot E_{batt\_max} \leq E_{batt,i,t} \leq SOC_{max} \cdot E_{batt\_max} \quad (13)$$

$SOC_{min}$  and  $SOC_{max}$  indicate the minimum and maximum permissible states of energy storage, denoting maximum energy storage capacity.

④Energy storage power constraints:

$$\begin{aligned} 0 &\leq P_{batt\_charge,i,t} \leq P_{batt\_max} \\ 0 &\leq P_{batt\_discharge,i,t} \leq P_{batt\_max} \end{aligned} \quad (14)$$

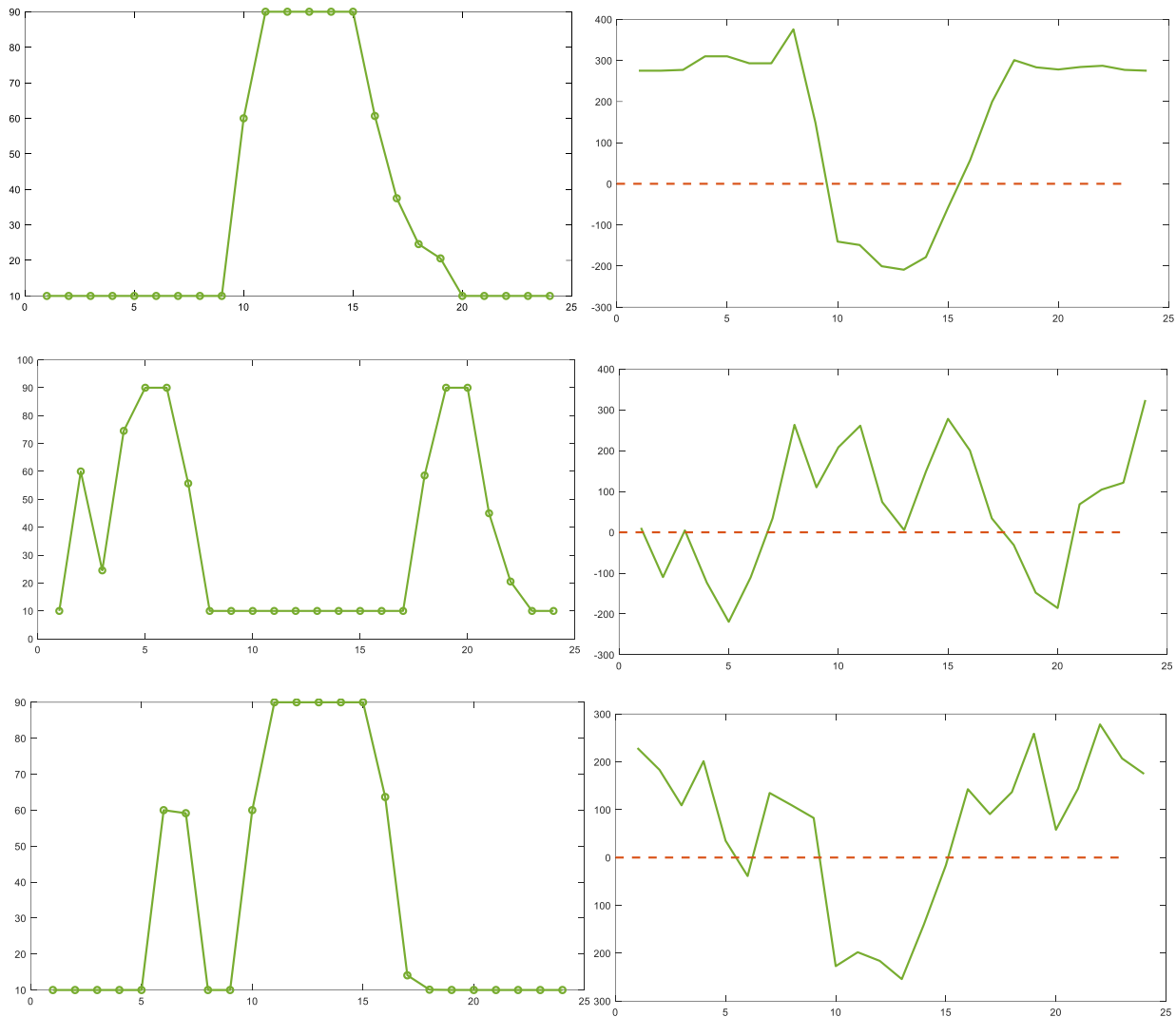
$P_{batt\_max}$  is the maximum charge/discharge power of the energy storage.

⑤Energy storage initial state constraints:

$$E_{batt,i,0} = E_{batt,i,T} \quad (15)$$

Based on the above-constructed model, the NSWOA algorithm is utilized for solving, and the optimal operation strategy and power purchase plan for energy storage in the three parks are obtained as shown in Figures 4 below:

From the comparison between prediction data and actual data, the BP neural network has better prediction performance and relatively small error, which can meet the demand completely, and has fast prediction speed and convenient operation.



**Figure 4.** Energy Storage Optimal Operation Strategy and Power Purchase Plan for Different Parks with a 50kW/100kWh Configuration. From top to bottom are Parks A, B, and C, respectively.

The above is the optimal operation strategy of energy storage and power purchase plan for each park: in the peak period of power consumption, the coordinated power generation by wind and solar storage is mainly used, supplemented by purchasing power from the main grid; in the surplus period of power consumption, the storage system is used to store power and reduce the abandoned power of wind and solar power generation.

#### 4. Results and discussion

This study firstly analyzes the economics of each park operation without energy storage configuration, and calculates four economic indexes (due to space reasons only one index result is listed here, see

Table 1 for details): purchased power: 4874.13kWh in Park A, 2432.30kWh in Park B, and 2699.39kWh in Park C. Then, using the sensitivity analysis, we determine the key factors affecting the economics of Parks A and C. The key factors affecting the economics of Parks A and C are the following the economy is the price of the main power station, and the key factor affecting the economy of B park is the price of wind power. Then, on this basis, the energy storage system with 50kW/100kWh storage condition is added to explore the improvement of the overall microgrid system operation economics and the reasons for it, and the results of the exploration are: in terms of the average cost of power supply per unit of electricity, the park A has improved by 1.14%, the park B has improved by 3.34%, and the park C has improved by 2.23%. Finally, this study establishes a multi-objective optimization model and uses the NSWOA algorithm to solve the optimal operation strategy and power purchase plan for energy storage in each park, and presents it visually in the form of images. (As shown in Figures 4-6)

## 5. Conclusion

The microgrid power system based on the coordinated configuration of wind power generation and energy storage is widely adapted and constructed flexibly, and the realization of the optimal configuration of wind power and storage is the key to solving the microgrid problem. This paper mainly focuses on the optimization problem of the coordinated configuration of wind power and storage, establishes a multi-objective planning model based on the NSWOA algorithm, solves the problem by using composite rectangular formula, sensitivity analysis, and intelligent algorithms, and finally analyzes the economy of the park operation and gives the optimal coordinated configuration scheme of wind power and storage.

This paper provides a research idea and framework applied to the related field of renewable energy generation, i.e., a microgrid energy storage optimization model based on the NSWOA algorithm. The model calculation results show that the coordinated operation plan of wind power and storage developed in this study has the effect of improving the phenomenon of temporal and spatial mismatch of power supply and demand caused by the instability of wind power generation, which can improve the stability of power supply, reduce the amount of abandoned power, improve the economy of power purchase, and at the same time, provide a new solution to the problem of energy shortage, which is of value and significance in the research.

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