Coordinated Optimization Configuration of Park Microgrid Wind-Solar-Storage

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Abstract: *The present paper proposes a novel methodology for the optimisation of energy storage allocation strategies within wind-solar storage microgrid systems. Firstly, a framework for the joint optimization and configuration of photovoltaic power generation, energy storage, and the power grid within the park has been developed. Secondly, the optimal energy storage allocation strategy for the wind-solar-storage microgrid system is determined based on the particle swarm algorithm (PSO). The potential of collaborative scheduling in joint parks is then verified by comparing the self-sufficiency of power supply in independent parks. The optimal energy storage configuration scheme for A park without energy storage configuration, B, C, and D parks with 153.81kW/400.13kWh, 54.74kW/68.42kWh, and 83.7kW/200kWh, was ultimately determined. It reveals the operation law of the joint operation mode to realize the optimal system operation through the energy sharing mechanism.*

Keywords: *Park Microgrids, Wind and Light Storage, PSO, Economics*

1. Introduction

Studies have shown that with the acceleration of the diversified upgrade of energy use in parks, the penetration rate of distributed energy continues to increase [1,2]. However, photovoltaic and wind power output and load demand timing mismatch problems, causing abandoned wind and light volume, low system economics and energy waste [3,4]. Therefore, the current use of energy storage configuration to achieve dynamic matching of power generation and load has become a core technology path to enhance the efficiency of distributed energy consumption.

Reference [5-7] studies the optimized operation of large-scale shared energy storage system deployed in new energy concentration area, proposes the model of shared energy storage system synchronously providing primary and secondary FM services, and verifies its significant economic benefits. Author proposed a coordinated allocation scheme and economic analysis of wind energy storage under two modes of independent operation and joint operation in a park with 50% load increase and constant load fluctuation characteristics by using the mixed integer linear programming (MLP) method in Reference [8].Reference [9,10] focuses on renewable energy uncertainty modeling and optimal allocation, using scenario generation and reduction techniques to deal with renewable energy uncertainty, and verifying the scenario method to improve system economics and planning accuracy.

Existing studies seldom study the optimal energy storage allocation problem in the joint operation of wind energy storage and grid, this paper proposes to construct the optimal energy storage allocation model of wind energy storage microgrid based on PSO, construct the park operation cost model and aim at economic optimization, and solve the optimal solution efficiently by relying on MATLAB simulation platform.

2. Park wind energy storage structure

The construction of three independent access points to the park's microgrid system is presented in Figure 1. This figure illustrates the installed capacity of wind power generation and the maximum load parameters of each system.

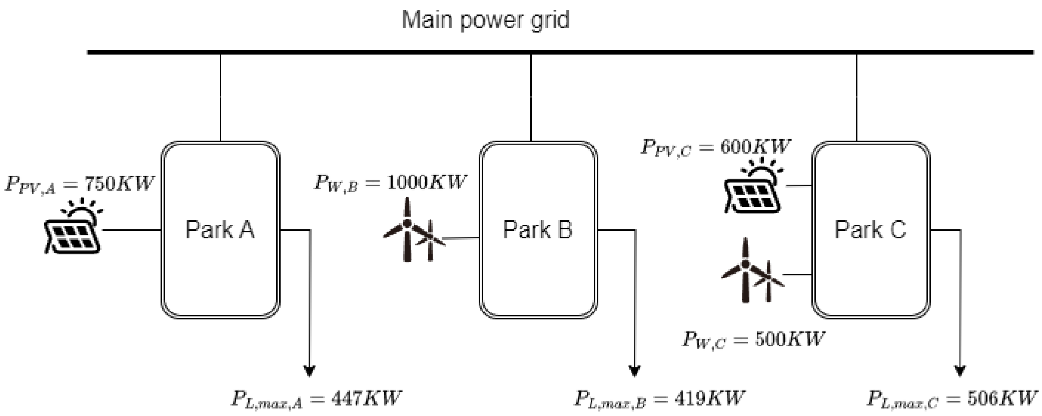

Figure 1 Independent Grid Architecture Map

Where, $P_{pv,A}$, $P_{pv,C}$ is the installed photovoltaic(PV) capacity of Parks A and C, $P_{w,B}$, $P_{w,C}$ is the installed wind power capacity of Parks B and C, $P_{L\max,A}$, $P_{L\max,B}$, $P_{L\max,C}$ is the maximum value of loads for parks A, B and C.

Joint System D is the A,B,C campus to realize energy sharing.

3. Co-configuration model of park microgrids for wind,solar and energy storage

3.1 Economic modelling of parks operating without storage

The economic analysis of a storage-less park can be based on four indicators: purchased power, wind and solar energy abandonment, total power supply cost and power supply cost per unit of power.

3.1.1 Electricity Purchase Modelling

In accordance with the established operational rules, in instances where wind and PV power generation falls short of meeting the demand, it becomes imperative to procure additional power from the primary grid:

$$P_{p,x,i} = \begin{cases} P_{L,x,i} - (P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i}) \ , & P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i} \le P_{L,x,i} \\ 0, & \text{else} \end{cases} \tag{1}$$

$$W_{p,x} = \sum_{i=0}^{23} P_{p,x,i} T \tag{2}$$

Where, x for Park, $P_{L,x,i}$ is the load power of the park for a given hour on a typical day, $P_{pv,x}$, $P_{w,x}$ is the installed capacity of the park's PV and wind power, $\partial_{pv,x,i}$, $\partial_{w,x,i}$ is the PV and wind power output of the park for a given hour on a typical day, $P_{p,x,i}$ is the purchased power of the park for a given hour on a typical day, $W_{p,x}$ is the purchased power of the park, T is the time, and is taken as a constant 1 .

3.1.2 Modelling of wind and photovoltaic emissions

Considering the Wind cost premium and with the objective of minimising the operating cost, the optimal scheduling strategy of abandoning wind and then abandoning light is adopted, and the model is as follows:

$$\begin{cases} P_{a,x,i} = \begin{cases} (P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i}) - P_{L,x,i}, P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i} \geq P_{L,x,i} \\ 0, \quad \text{else} \end{cases} \\ P_{a,x,i,w} = \begin{cases} P_{w,x}\partial_{w,x,i}, \quad P_{a,x,i} \geq P_{w,x}\partial_{w,x,i} \\ P_{a,x,i}, \quad \text{else} \end{cases} \\ P_{a,x,i,pv} = P_{a,x,i} - P_{a,x,i,w} \end{cases} \tag{3}$$

$$W_{a,x} = W_{a,x,w} + W_{a,x,pv} = \sum_{i=0}^{23} P_{a,x,i,w}T + \sum_{i=0}^{23} P_{a,x,i,pv}T \tag{4}$$

Where, $P_{a,x,i}$, $P_{a,x,i,w}$, $P_{a,x,i,pv}$ represent the total power, wind, and PV power losses in the park for a given hour on a typical day , respectively.

3.1.3 Total cost of supply modelling

When there is no energy storage, the cost of the park consists of the cost of supplying electricity from the new energy source and the cost of purchasing electricity from the grid.

$$\begin{cases} Y_{t,x} = \sum_{\text{i}=0}^{23} (P_{p,x,i}Y_p T + P_{pv,x,i}Y_{pv,x}T + P_{w,x,i}Y_{w,x}T) \\ P_{pv,x,i} = \min(P_{L,x,i}, P_{pv,x}\partial_{pv,x,i}) \\ P_{w,x,i} = \begin{cases} \min(P_{L,x,i} - P_{pv,x}\partial_{pv,x,i}, P_{w,x}\partial_{w,x,i}), P_{pv,x}\partial_{pv,x,i} \leq P_{L,x,i} \\ 0, \quad \text{else} \end{cases} \\ P_{p,x,i} = \begin{cases} P_{L,x,i} - (P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i}) \;,\; P_{pv,x}\partial_{pv,x,i} + P_{w,x}\partial_{w,x,i} \leq P_{L,x,i} \\ 0, \quad \text{else} \end{cases} \end{cases} \tag{5}$$

Where, $Y_{t,x}$, Y_p , $Y_{pv,x}$, $Y_{w,x}$ are the total cost of supplying electricity and purchasing electricity from the grid, pv and wind power, $P_{pv,x,i}$, $P_{w,x,i}$, $P_{p,x,i}$ are the PV, wind , and power purchased from the grid required for a given hour on a typical day in Park.

3.1.4 Cost of electricity supply per unit of electricity

The cost of supplying electricity per kWh is the ratio of the total cost to the amount of electricity supplied.

$$Y_{a,x} = Y_{t,x} \Big/ \sum_{i=0}^{23} P_{l,x,i} \tag{6}$$

3.1.5 Economics of joint parks without energy storage

The Joint Park is considered an expanded Park C (named Park D) with increased capacity and load demand, and is analyzed economically in the same manner as Park C.

$$\begin{cases} P_{pv,D,i} = P_{pv,A,i}\partial_{pv,A,i} + P_{pv,C,i}\partial_{pv,C,i} \\ P_{w,D,i} = P_{w,B,i}\partial_{w,B,i} + P_{w,C,i}\partial_{w,C,i} \end{cases} \tag{7}$$

The economic model for Park D is the same as in Sections 2.1.1 through 2.1.4.

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3.2 Operational economic modelling of energy storage allocation parks

The energy storage operation strategy is to prioritize PV > wind > storage > main grid based on power supply cost. With the goal of minimizing the cost of supplying electricity throughout the day, an optimization model is constructed by dynamically adjusting the power and capacity parameters of the energy storage system.

3.2.1 Power Purchase Model

In parks equipped with energy storage systems, power is purchased from the grid when the new energy and energy storage supply is insufficient.

$$P_{p,x,i}=\begin{cases}P_{L,x,i}-P_{pv,x}\partial_{pv,x,i}-P_{w,x}\partial_{w,x,i}-P_{s,x,i}, & P_{pv,x}\partial_{pv,x,i}+P_{w,x}\partial_{w,x,i}\le P_{L,x,i}\\ 0, & \text{else}\end{cases} \tag{8}$$

3.2.2 Charge and Discharge Power Modelling

Let the charging and discharging power be positive for discharging and negative for charging. Discharging is prohibited when the battery capacity is less than 10% and charging is prohibited when it is greater than 90%.

$$P_{g,x,i}=P_{pv,x}\partial_{pv,x,i}+P_{w,x}\partial_{w,x,i} \tag{9}$$

$$P_{s,x,i}=\begin{cases}\min(P_{L,x,i}-P_{g,x,i},\dfrac{P_{s,x,m}}{\eta},\dfrac{SOC_{s,x,i}E_{s,x}-0.9E_{s,x}}{\eta T}), & P_{g,x,i}\ge P_{L,x,i}\ \&\ SOC_{s,x,i}<90\%\\ 0 & ,P_{g,x,i}\ge P_{L,x,i}\ \&\ SOC_{s,x,i}=90\%\\ \min(P_{L,x,i}-P_{g,x,i},\dfrac{P_{s,x,m}}{\eta},\dfrac{SOC_{s,x,i}E_{s,x}-0.1E_{s,x}}{\eta T}), & P_{g,x,i}\le P_{L,x,i}\ \&\ SOC_{s,x,i}\ge 10\%\\ 0 & ,P_{g,x,i}\le P_{L,x,i}\ \&\ SOC_{s,x,i}=10\%\end{cases} \tag{10}$$

$$P_{s,x,in,i}=\begin{cases}-P_{s,x,i}, & P_{s,x,i}<0\\ 0 & , \text{ else}\end{cases} \tag{11}$$

Where, $P_{s,x,i}$, $P_{s,x,m}$ is the power of battery charging and discharging, and the maximum energy storage power, $SOC_{s,x,i}$ is the percentage of remaining capacity of the park's energy storage system at a given hour, $E_{s,x}$ is the energy storage capacity of the park, η is the charging/discharging efficiency ,we set η to be 95% .

The capacity of the battery $SOC_{s,x,i+1}E_{s,x}$ is determined by the capacity of the battery at the previous moment and the amount of charging and discharging at this moment.

$$SOC_{s,x,i+1}E_{s,x}=SOC_{s,x,i}E_{s,x}-P_{s,x,i}T\eta \tag{12}$$

3.2.3 Electricity supply cost modelling

Define the price per kWh of wind and PV power charging $Y_{av,x}$ as the ratio of the total new energy supply cost to the total electricity supply.

$$Y_{av,x}=\frac{\sum_{i=0}^{23}(P_{pv,x,i}Y_{pv,x}T\partial_{pv,x,i}+P_{w,x,i}Y_{w,x}T\partial_{w,x,i})}{\sum_{i=0}^{23}(P_{pv,x,i}T\partial_{pv,x,i}+P_{w,x,i}T\partial_{w,x,i})} \tag{13}$$

Energy storage park costs include new energy supply, grid power purchase, storage system and charging costs.

$$Y_{t,x}=\sum_{i=0}^{23}(P_{pv,x,i}Y_{pv,x}T+P_{w,x,i}Y_{w,x}T+\left|P_{s,x,i}\right|TY_{s,x}+P_{p,x,i}Y_{p}T+P_{s,x,in,i}Y_{av,x}T) \tag{14}$$

Battery-powered unit cost is the ratio of acquisition cost to full life-cycle active hours.

$$Y_{s,x}=\frac{C_P P_{s,x,m}+C_E E_{s,x}}{\eta E_{s,x}H_{s,x}T_{day}} \tag{15}$$

Where, $\eta E_{s,x}H_{s,x}$ is the sum of the charge and discharge capacity and T_{day} is the number of days of battery use in 10 years 365*10.

4. Optimisation of matching model based on particle swarm algorithm

Particle Swarm Algorithm (PSO) is a heuristic algorithm that searches for optimal solutions by particles iteratively in a solution space .The optimization process is shown in Figure 2.

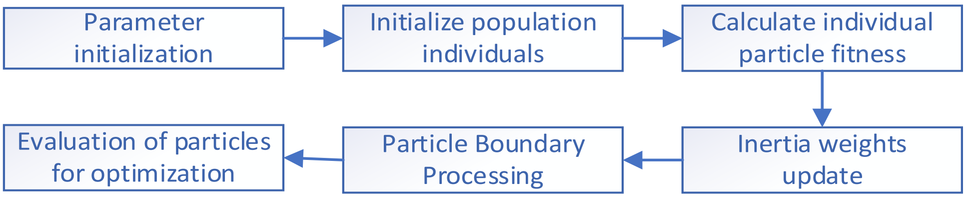

Figure 2 PSO optimization process

The PSO algorithm is used to optimize the power and capacity parameters of the energy storage, setting the two-dimensional variable (power/capacity), minimizing the park cost as the objective function, with the number of particles 3, and searching for the globally optimal solution by iterating 20 times.

5. Calculus Analysis

5.1 Basic Data

The original data for this article is taken from "Mathematical Modeling Problem A of the 16th National College Electrician Cup" .The cost of power purchase is 0.5 RMB/kWh (wind power), 0.4 RMB/kWh (PV), and 1RMB/kWh(Grid purchase), the remaining power cannot be sold. The energy storage is equipped with Li-FePO4 batteries, RMB 800/kW and RMB 1800/kWh, with SOC of 10%-90%, charging/discharging efficiency of 95%, and a life span of 10 years.

The 24h load fluctuations of the three parks are shown in the Figure 3 below:

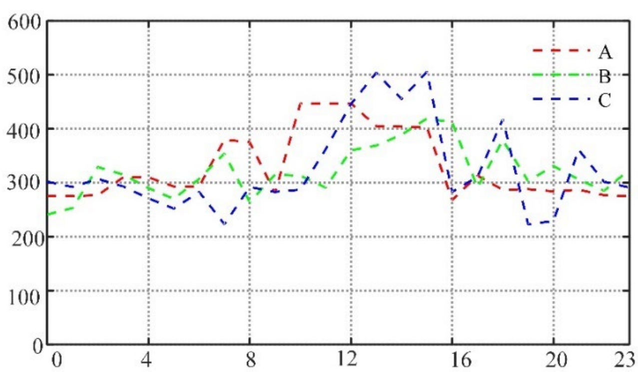

Figure 3 Daily load fluctuation curves for A, B, C parks

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5.2 Configuration results analysis

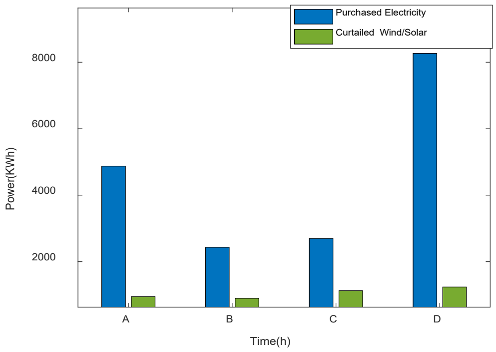
5.2.1 Economic analysis of the system without energy storage

Based on the model in section 2.1, the power purchase, wind and light abandonment, total power supply cost and average power supply cost indicators for parks A,B,C,D are calculated, and the results are shown in the following Table 1.

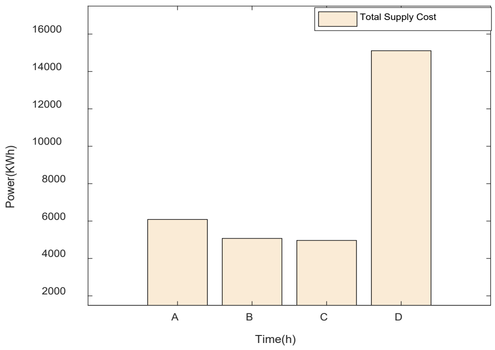
Table 1 Economy values for the four main parks

Park	Purchased Electricity (kWh)	Curtailed Wind/Solar (kWh)	Total Supply Cost (RMB)	Unit Supply Cost (RMB/kWh)
A	4874.13	951.2	6084.88	0.7701
B	2432.3	897.5	5071.15	0.6577
C	2699.39	1128.02	4963.31	0.6383
Sum	10005.82	2976.72	16083.34	2.0661
D	8266.3	1237.2	15108	0.646

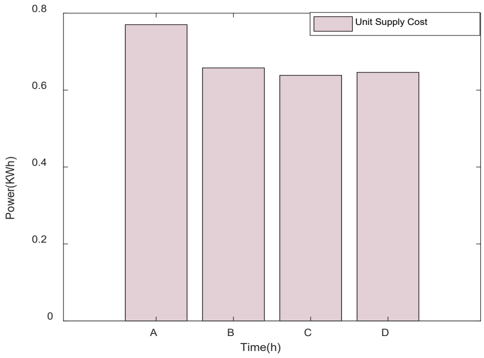
The data visualization is shown in Figure 4:



(a) Purchased Electricity and Curtailed Wind/Solar



(b) Total Supply Cost



(c) Unit Supply Cost

Figure 4 Economic indicators for the three A, B, C, D Parks

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In the single energy system, A (PV) has the highest purchased electricity/costs because of insufficient generation due to sunlight limitations, while B (wind) has moderate economics and no energy waste. In the multi-energy system, C (wind and PV) has the lowest total cost but the highest energy waste. After joint optimization, the purchased power/wasted energy is reduced by 1739.52 kWh and the cost is reduced by RMB975.34, which verifies the dual benefits of inter-area coordination in terms of energy efficiency and cost reduction.

5.2.2 PSO-based optimal energy storage configuration

The PSO algorithm is used to optimise the power and capacity allocation of the four parks with the objective of minimising the total cost, and the three-dimensional relationship between storage cost and power and the optimal allocation results are shown in Figure 5 and Table 2 respectively.

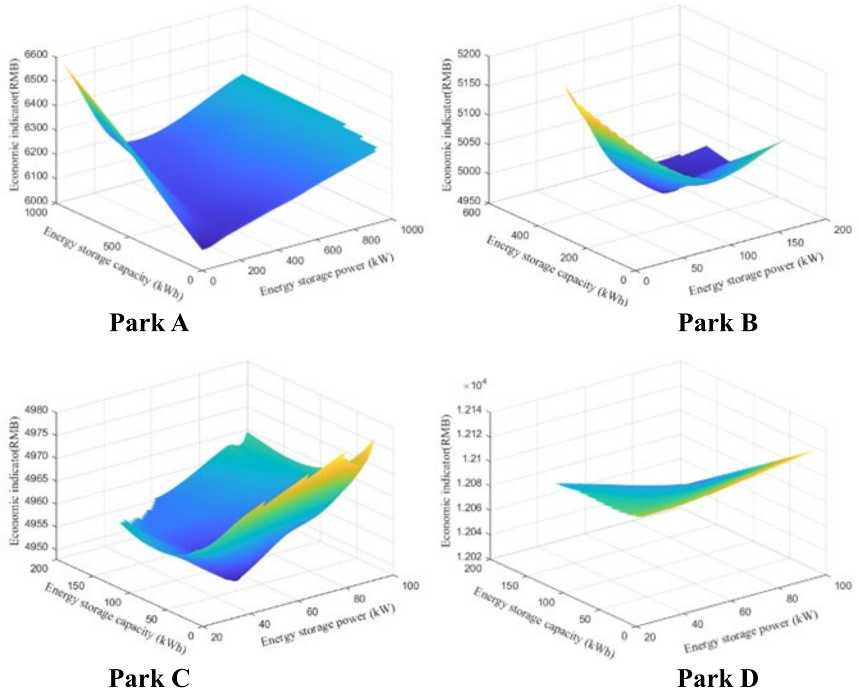

Figure 5 The optimal energy storage optimization 3D map of each park

The optimal energy storage power and capacity configuration values are as follows:

Table 2 Optimal energy storage configuration for the park

Park	energy storage power(KW)	Energy storage capacity (KWh)	Total cost (RMB)
A	0.1	0.1	6084.8
B	153.8131	400.1326	4961.8
C	54.7415	68.4219	4947.4
D	83.7009	200	12304

5.2.3 Data analysis

For Park A, The optimal energy storage allocation is close to 0, as PV generation is concentrated and insufficient in total, and energy storage is unable to bridge the supply-demand gap. For Park B, B is 71.6 RMB lower than the baseline configuration (50kW/100kWh), wind power output fluctuates greatly, energy storage can reduce power fluctuation. For Park C, The cost is reduced by only RMB 3.7 (baseline configuration 50kW/100kWh), and the sensitivity of the storage configuration is low, as the wind and solar hybrids have partially smoothed out the power fluctuations.

For Park D, Energy storage configuration is 83.7kW/200kWh, RMB3960 lower than standalone operation.

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6. Conclusions

The present paper puts forward a proposal for a PSO energy storage configuration model for wind energy storage and the power grid, with the objective of optimising costs. Through the validation of the A/B/C independent system and the joint park D example, it is demonstrated that the optimal configuration of D is 83.7kW/200kWh, and the configurations of B and C are 153.81kW/400.13kWh and 54.74kW/68.42kWh, respectively, and the configuration of A is not necessary due to the lack of economic efficiency. System A does not need to be equipped with energy storage due to insufficient economy. The findings indicate that the distributed energy synergistic sharing mechanism has the potential to reduce the total system cost by 6%, thereby substantiating the model's capacity to augment the rate of renewable energy consumption and contribute to the realisation of the "dual-carbon" objective. This study provides a significant technical avenue for the low-carbon transformation of the energy system.

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