Research on the Optimization of Park Microgrids Based on Renewable Energy Utilization and Storage Systems

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Abstract. In recent years, renewable energy has been widely used, meeting global energy demands and domestic challenges. However, its intermittency and instability remain debated. For this reason, to obtain the allocation of renewable energy scenarios for different scenarios, this study simulates the microgrid reserve optimization problem for three parks. Optimize the strategy and determine the total power supply cost for the purchased electricity. Use power consumption as the transmission medium to optimize electric capacity. In conclusion, the initial objective was to integrate an energy storage apparatus to optimize energy storage and reduce power consumption as a fundamental premise. Optimize the energy storage system by considering equipment layout cost and minimum power consumption. Build a math model for comprehensive optimization of wind and PV reserves. A genetic algorithm was employed to optimize the energy storage system, resulting in an optimal energy storage power of 146 kW. This methodology ensures the lowest average power consumption for the energy storage system. Compared to pre-optimized energy storage, the average electricity cost for the three parks is significantly lower. The marginal contribution of the three parks ABC is ¥4409, ¥5423, and ¥4853, respectively, and the total marginal contribution is $14685, which shows good economic efficiency.

Keywords: Optimal Allocation of Energy Storage, Multi-objective Optimization Model, Genetic Algorithm, Wind and Solar Energy Storage Synergy.

1. Introduction

With the increasing global demand for energy and the growing severity of environmental problems, the development and utilization of renewable energy have become one of the important ways for countries to achieve sustainable development. Wind energy and photovoltaic (PV), as major renewable energy sources, have received widespread attention due to their clean and renewable characteristics. However, their generation is intermittent and unstable, which poses a challenge to the stable operation of the grid. To effectively meet this challenge and realize the efficient utilization and management of renewable energy, it is of great practical significance to conduct relevant research. Park microgrids, as a new type of power system, are capable of organically integrating renewable energy sources such as wind and photovoltaic.

A genetic algorithm is a stochastic algorithm that simulates natural evolution and has unique advantages in solving optimization problems. In many fields, such as Wang et al.[1]applied it to the optimal allocation of energy in microgrids to improve the operational efficiency and economy of microgrids. Wang et al.[2]realized the economic optimization of wind-solar storage microgrid through genetic algorithm and reduced the operating cost of microgrid. Li et al.[3] Proposed a distributed power source siting and capacity determination decision model based on a multi-objective genetic algorithm to realize the matching between distributed power source allocation and demand relationship of electricity consumption load. Li et al.[4]A hybrid variable neighborhood search genetic algorithm is proposed to solve the large-scale problem of the parallel assembly line balancing problem. Yuan et al.[5]Aiming at the topology optimization problem of large-scale offshore wind power collection systems, an improved uniparental genetic algorithm is proposed, and Liu[6]A method of optimal allocation of wind power and storage microgrid power based on a genetic algorithm is proposed to obtain the optimal capacity allocation of wind power, photovoltaic and energy storage under the premise of ensuring the reliability of load power supply. The algorithm is widely applied in robot path planning, image segmentation, and logistics network optimization. Its effectiveness and reliability are proven. This study applies the genetic algorithm to solve energy allocation optimization in park microgrids, enhancing energy efficiency and cost reduction.

In this study, an in-depth analysis of the park microgrids was conducted to obtain the wind and PV power generation data for each park in each period. This was achieved through the inverse normalization of the data set. On this basis, an optimization mathematical model is constructed[7], and the economic performance without energy storage is investigated, including power purchase, wind and photovoltaic abandonment, total power supply cost, and power supply cost per unit of power, etc., and its main influencing factors are identified. Subsequently, the energy storage device is introduced, and a comprehensive optimization model of wind and light reserves is constructed to study whether the operational economic performance of the park is improved after the installation of the energy storage device and analyze the underlying causes.

2. Summary of Electricity Costs and Consumption

The entire dataset for this study was obtained from shumo.neepu.edu.co.uk. The park microgrid is supplied with power from a combination of wind power generation and the main grid, which is used to meet the energy demands of the loads. In this study, three distinct park microgrid configurations were created by controlling the overall system design. Each of the three park microgrids was connected to the main grid independently. Park A is powered by photovoltaic (PV) and the main grid (PV installed capacity of 750kw, load maximum of 447 kW). The installed capacity of park B is 1000 kW and the maximum load value is 419 kW), while park C is powered by PV and wind and the main grid (the installed capacity of PV is 600 kW, the installed capacity of wind is 500kw and the maximum load value is 506 kW).

In this study, the data in the dataset were first back-normalized to obtain the wind and PV power generation for each park during each period. The representative daily load power curves for the three parks show that the minimum load power per hour is above 200, so when back-normalizing set 0 as the lower limit of the power supply and the extreme value of the park capacity as the upper limit. From this, it was possible to construct an expression for obtaining the initial generation power data from the normalized data, the

$$\varepsilon = \frac{P_L}{W_L} \tag{1}$$

Where ε is the youngest value, P_L is the actual power generation and W_L is the installed capacity. Based on the above equations, repeated operations can be performed on the dataset to derive the specific power generation. The values after back-normalization are shown in Fig. 1.

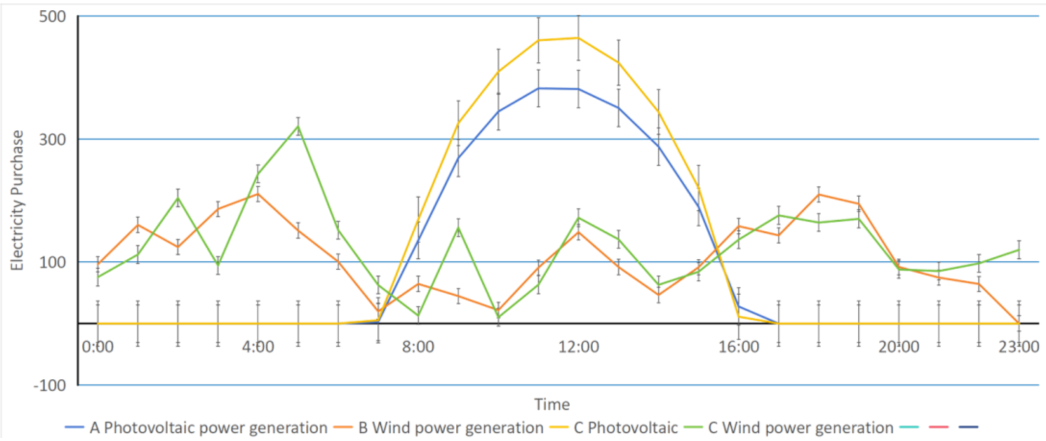

Figure 1. The data set has been denormalized.

In this study, the energy storage device is not set up first at the beginning, so it is assumed that each PV device is running at full load at the starting time. Each PV device is running at full load with 0 PV output, which does not cause any loss to the device and does not have any impact on the power grid.

$$p_i = \sum_{j=1}^{24} p_{ij} \tag{2}$$

The representative daily load data for period j of the ith park is statistically analyzed as the representative daily load data for the ith park. At each point in time, if there is not enough power and PV to support the parking load, then power has to be purchased from the main network, so at any given time (when used), the power from the main grid is, the

$$g = H - u_k - G_s \tag{3}$$

Here g is the demand on the primary power system at any given time, G_s is the spare generating capacity of the PV system, and u_k is the spare generating capacity of the PV system at any given time, and the power required by the load. At the end of the working day, the power left over at the PV cell unit is called wind and power rejections and it can be expressed as, the

$$c = f_i M_i + f_i \sum_{i,j}^{24} p_{ij} + g \tag{4}$$

Where f_i is the cost of wind or photovoltaic power generation and the cost is the cost of the wind or photovoltaic equipment.

$$f_i = \begin{cases} 0.5, \text{Wind power cost} \\ 0.4, \text{Photovoltaic costs} \end{cases} \tag{5}$$

Where c is the overall cost of electricity supply and 0.5 represents the price of electricity per unit of electricity from the PV cells in each area at the start time. The average cost per electricity can be considered as the cost of electricity consumed per time and can be expressed as

$$b = \frac{c}{24} \tag{6}$$

In this study, the above was numerically calculated using MATLAB software to obtain the power consumption in each area at each moment in time. The power purchased in different zones at various moments is shown in Fig. 2.

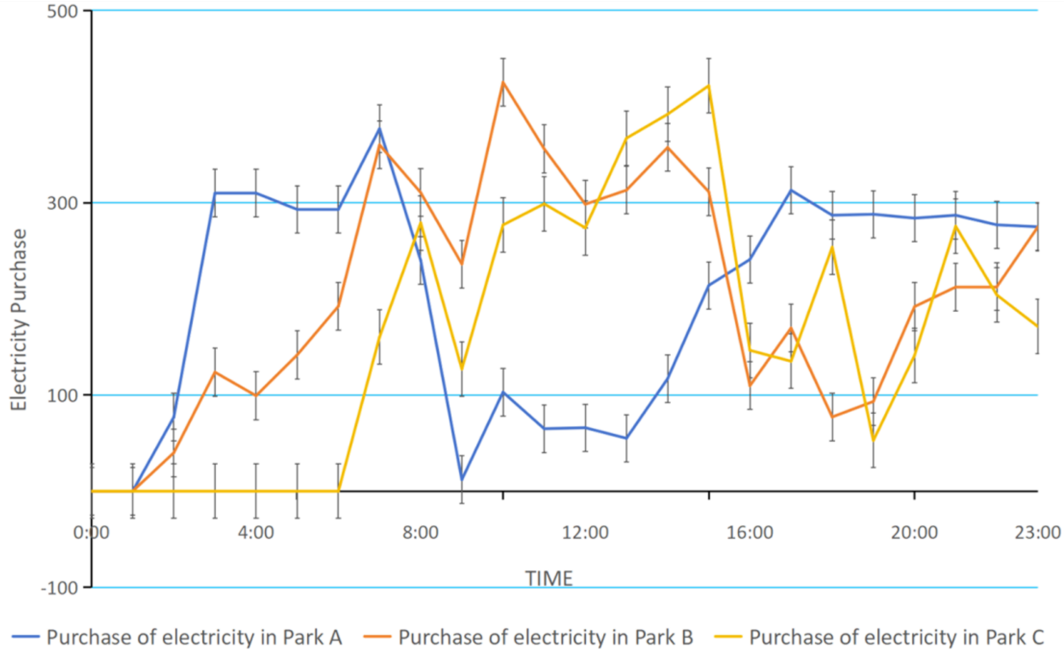

Figure 2. Trends in power purchases in the three parks.

The total power consumption, cost of power supply, power consumption, and the corresponding cost of power abandonment for each park are obtained by purchasing power at different times and the results are shown in Table 1.

Table 1. Total Electricity Consumption and Total Cost of Electricity Supplied and Cost per Unit of Electricity Supplied by Zone

Site developed for a group of related enterprises	*G (kW)*	*C(yuan)*	*b (yuan)*	*n*
A	3684	6465	269	0
B	3807	5519	230	0
C	3127	5543	231	0

Following the calculation and analysis of data about grid power purchase, PV power generation, wind power generation, load, and abandoned power generation at Park ABC, this study presents a visual representation of the results obtained from the optimization of the typical daily configurations of the three parks operated independently. The results of this visualization are presented in Fig. 3. The results denoted by a and b represent the visualization of the daily optimal modes of the independently operated Park A. The results denoted by c and d represent the visualization of the typical daily optimal configurations of the parks operated by Park B alone. The results represented by e and f represent the visualization of the typical daily optimal configurations of the parks operated by Park C alone.

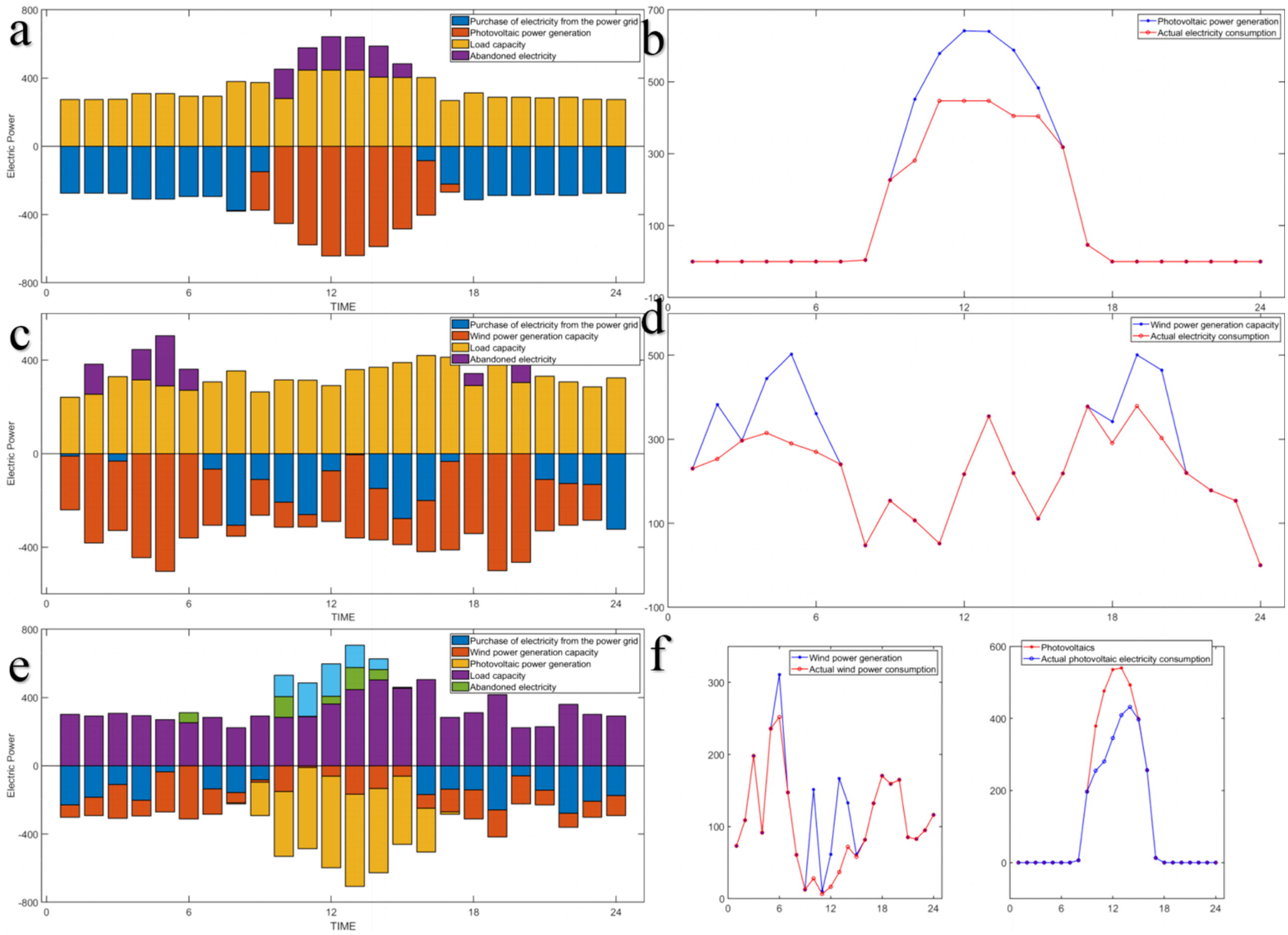

Figure 3. The optimal configuration for a typical day for each of the three ABC parks. a, b for Campus A; c, d for Campus B; e, f for Campus C.

The total amount of power required by each park and the total cost of power can be obtained by the power procurement carried out during the time in each park, which is further calculated by generating a comparatively small amount of power during each time. Therefore to procure more power from the main grid, it is necessary to enhance the power supply to the park microgrids for higher economic efficiency.

3. Integration of Energy Storage for Cost Minimization Energy Storage Introduction and Cost Minimization

This study investigates minimizing the cost of electricity, the configuration cost of equipment, and the cost of purchasing electricity in the park in one day, constructing a comprehensive optimization model for wind and light reserves, and introducing the energy storage problem[8]that explores whether it can improve the economic operation of the park. The lithium-ion battery is configured for the energy storage structure with the following specifications: power of 800/kW, unit of 1800/kWh, state of charge (SOC) tolerance of 10%—90%, charge/discharge efficiency of more than 95%, and service life of 10 years.

The cost of each unit of power and energy is significantly higher than the price of purchasing power from the network for each hour. Consequently, this research focuses on the analysis of 50 kW of power storage, and the limitations associated with battery life cycles are not included in the scope of the study of the one-day return problem. Consequently, the surplus capacity (including storage) of power generation and PV at each period is insufficient to meet the demands of the park's loads. Therefore, it is necessary to purchase power from the main grid, which was purchased from the main grid at the following hourly rates:

$$\mathrm{g} = H - u_k - G_s \tag{7}$$

Where *g* is the power demand of the main grid at any given time, G_s is the standby generating capacity of the PV cell system (value after battery storage), UK is the power installed by the PV system at any given time, and *H* is the power required by the load. The power remaining on the PV cells at the end of a day's work is called the power discard, *and d* is the discard rate, which can be expressed as:

$$d = G_s + g - H \tag{8}$$

The total amount of electricity supplied is the sum of the electricity procured by wind, photovoltaics (PV), and the main grid. In this context, *c* represents the total amount of electricity supplied and $f_i M_i$ denotes the price of PV electricity in each region at the initial time, which is expressed as.

$$\begin{gathered} \mathrm{c} = f_i M_i + f_i \sum_{i,j}^{24} q_{ij} + g + w_i \\ f_i = \begin{Bmatrix} 0.5, \text{Wind power cost} \\ 0.4, \text{Photovoltaic costs} \end{Bmatrix} \end{gathered} \tag{9}$$

Where w_i represents the energy storage structure (i.e., the storage capacity of each park) within each region, p_i represents the energy storage in the different parks, and the average cost of electricity is considered as the cost of electricity consumed at each moment in time, and the study is carried out to minimize the cost per day, the result can be obtained as.

$$\begin{gathered} w_i = 1800 + 800 p_i \\ p_i = (50,100) \end{gathered} \tag{10}$$

Where *c* is the total amount of electricity supplied, $0.5 f_i M_i$ it represents the price of electricity from PV cells in each zone at the initial time, and w_i represents the energy storage structure in each zone, where it represents the storage capacity in each park, respectively.

$$w_i = 1800 + 800 p_i$$
$$p_i = (50,100) \tag{11}$$

Where p_i denotes the energy storage in different parks, the average cost per power can be considered as the cost of power consumed per time, to facilitate the setting of targets to minimize the cost per day. The average cost per unit of electricity supplied can be considered as the cost of electricity consumed per hour and can be expressed as.

$$b = \frac{c}{24} \tag{12}$$

To sum up, this study finally establishes the objective optimization with the lowest one-day expense[8] model as follows.

$$\min\ c = f_i M_i + f_i \sum_{i,j}^{24} p_{ij} + g + w_i$$
$$s.t. \begin{cases} 0.1 < SOC < 0.9 \\ \eta = 0.95 \\ s = H - u_k - p_i \\ d = p_i + s - H \\ f_i = 0.4, 0.5 \\ w_i = 1800 + 800 q_i \\ q_i = (50,100) \end{cases} \tag{13}$$

Based on this optimization model, this study has numerically computed it using MATLAB software to obtain the power consumption of each region in each period and the detailed results are shown in Fig 4

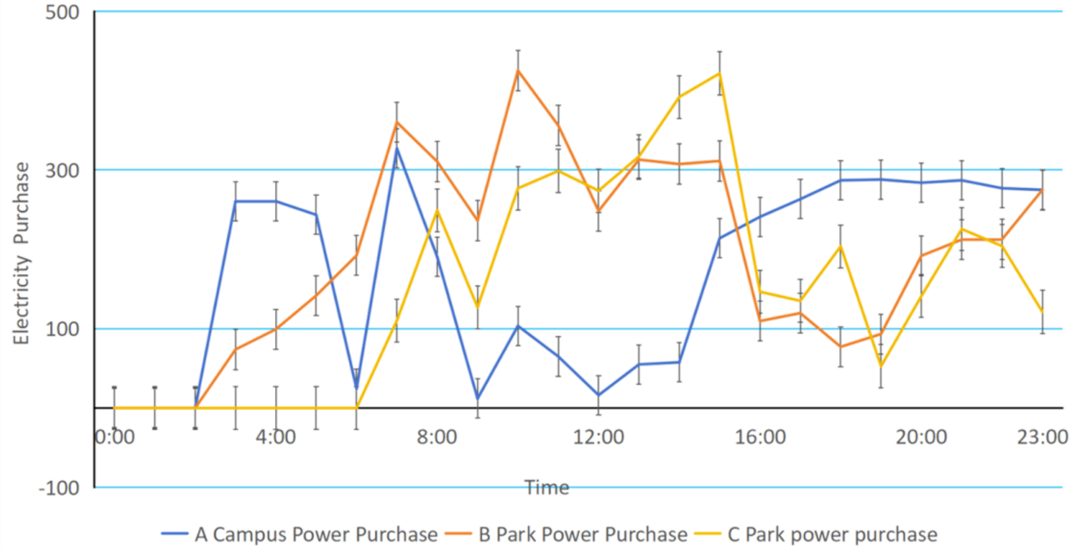

Figure 4. Purchased power in different parks at different moments after energy storage configuration

In the case of setting energy storage, the total amount of electricity purchased by each park at different times, along with the cost of electricity supply, can be obtained. Furthermore, the total amount of electricity purchased by each park and the cost of each type of electricity supply can be calculated. The results are presented in Table 2.

Table 2. Total Electricity Purchased, Total Electricity Cost, Unit Electricity Cost, and Abandoned Electricity Cost by Zone

Site developed for a group of related enterprises	*g (kW)*	*c (dollars)*	*b (dollars)*	*n*
A	3684	8359	348	0
B	3807	8507	354	0
C	3127	7963	320	0

By analyzing the results, this study found that the average level of minimum daily energy consumption for a given storage structure is higher than the average level when no storage is installed, thus making it difficult to improve the economic efficiency of the park in this case.

To improve the economic efficiency of the park, this study will continue to study the storage capacity allocation of different types of energy storage systems in different zones, and based on this, we will study the optimal storage capacity of different types of energy storage systems in different zones, to further study the optimal storage capacity allocation between different types of zones. In this study, it is known from the results of previous studies that it is not possible to achieve the optimum at 50-100 kW, so it is proposed to increase the stored power in each zone, and the average daily consumption is minimized when the stored power in each zone is p_i. Therefore, an optimization model with the objective of a minimum one-day cost is again developed for the study.

$$\min \ c = \frac{f_i M_i + f_i \sum_{i,j}^{24} p_{ij} + g + w_i}{24}$$

$$s.t \begin{cases} 0.1 < soc < 0.9 \\ \eta = 0.95 \\ g = H - \mathrm{u}_k - p_i \\ d = p_i + g - H \\ f_i = 0.4, 0.5 \\ w_i = 1800 + 800\mathrm{q}_i \\ q_i = n, n = 1,2,,,,1000 \end{cases} \tag{14}$$

Next, this study found that in this optimization model, the energy storage power p_i is an unknown quantity, so this study to find a way to get the energy storage power p_i, then a genetic algorithm-based[9]The minimum daily average power consumption is calculated by a genetic algorithm. The iteration curve of the genetic algorithm is shown in Fig. 5.

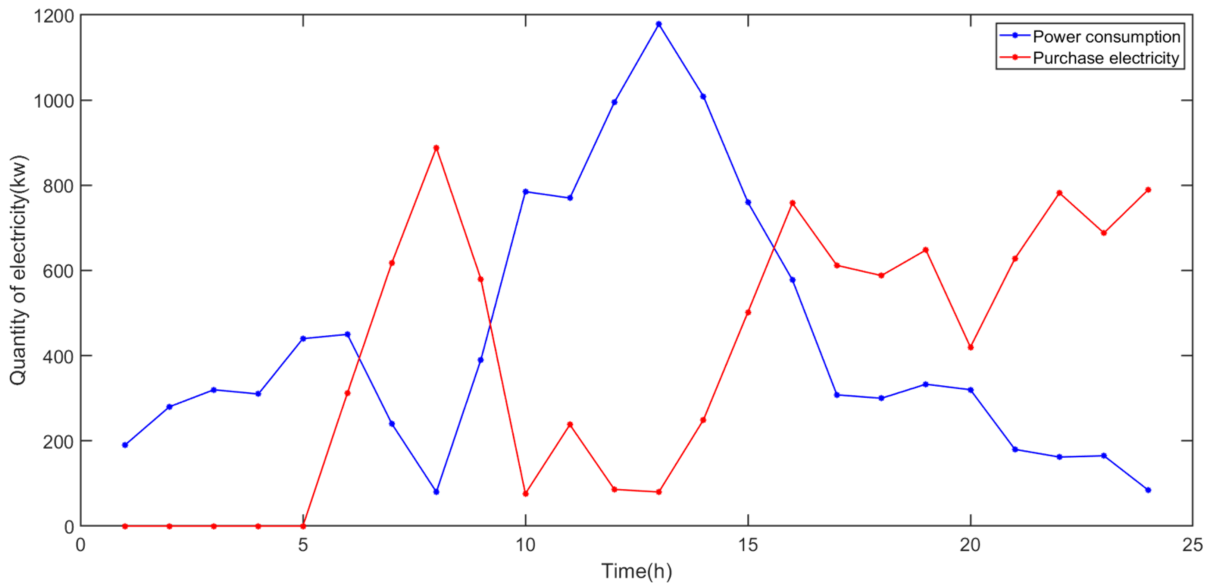

Figure 5. Genetic Algorithm Iteration Profile.

By iterating the model, a pi of 146 was obtained under this model. In this case, if energy storage is used, the total cost of one day for the three parks is much higher than the cost of purchasing electricity from the main power system and thus should be eliminated. However, the purchase cost of wind power and photovoltaic power is much lower than the cost of electricity storage, so the same amount of wind power can be used for the functional electricity demand. This will result in the total purchased electricity, the cost of total supply, unit supply, and discarded electricity for the set A, B, and C parks for the lowest cost scenario. p (kW) is the power of the motor, g (kW) is the electricity supplied from the main line, and h (kW) is the energy reserve set up, and the results are shown in Table3.

Table 3. Electricity Costs in Different Regions under the Lowest Cost Scenario

Site developed for a group of related enterprises	*p(kW)*	*c(yuan)*	*b(yuan)*	*g(kW)*	*h (kW)*
A	7901	3950	165	0	0
B	7710	3084	129	0	0
C	7776	3110	130	0	0

In this configuration, P (kW) represents the power generated by the engine, g (kW) denotes the power supplied from the trunk line, and h (kW) signifies the energy reserve set. A comparison of the no energy storage configuration with the optimized energy storage configuration reveals a notable reduction in the average daily electricity cost. The marginal contribution of the three parks, ABC, is ¥4409, ¥5423, and ¥4853, respectively, with a total marginal contribution of ¥14,685, indicative of economic efficiency. In this study, the last option was identified as the most feasible following the screening of the best economic efficiency under the storage condition of energy by successive studies. This method enables the optimization of the reserve problem for microgrid wind, thereby providing a feasible solution to the global energy demand and environmental problems.

4. Conclusions

In this study, the data obtained from the dataset were first back-normalized standardized, and simplified to obtain the wind and photovoltaic power generation for each park in each period. The typical daily load power curves of the three parks show that the minimum load power for each period is above 200. Therefore, when normalization was performed in this study, 0 was set as the lower limit of power and the maximum load of the parks was set as the upper limit. After calculating the capacity of PV cells at each point in time, the optimization mathematical model was constructed by taking the power consumption at each point in time as the output and the maximum power supply capacity of the unit as the limitation, immediately after this study, the power purchased, the total power consumption, the unit cost of power supplied, and the cost of power discarded were calculated for each park at different times in the absence of energy storage. In this study energy storage devices are introduced, the cost required to set up the device with the minimum cost of electricity in a day, while minimizing the amount of electricity purchased by considering the amount of electricity required to be arranged on the device. The construction of a comprehensive optimization mathematical model of wind and photovoltaic reserves as well as the use of genetic algorithms and through calculations, it is concluded that the average daily cost of electricity in this way is higher than the average daily cost of electricity when it is not set up, and it is not possible to improve the economic operation of the respective parks, based on which, this study will take into account the optimal allocation of energy storage and energy storage in the system with minimal cost of the system[10], the system can be maximized economically by increasing the storage of wind and photovoltaic.

This study provides a research idea and framework application of renewable energy-related fields, energy storage optimization through the introduction of energy storage devices, to minimize the cost of electricity cost, in consideration of the cost required for the layout of the equipment and the minimum electricity consumption, to build a comprehensive optimization mathematical model of wind and light reserves, and the use of genetic algorithms to study the optimization of the allocation configuration of the energy storage system.

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