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# Research on capacity allocation of optical storage system based on supply demand balance under the background of green power trading

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**Abstract**—As a medium - and long-term trading variety, green power is settled based on the actual annual or monthly electricity consumption, without the need to decompose its own load curve. However, with the continuous advancement of the construction process of China's spot market, medium - and long-term trading nature of green power trading cannot meet the trading requirements of the spot market on a time scale. Therefore, based on the existing capacity allocation model for optical storage joint systems, in order to achieve a high matching between the output curve, the declaration curve, and the load curve, this paper introduces the objective function of minimizing the net load variance to optimize the energy storage capacity, and verifies the scientificity of the model proposed in this paper through simulation.

## 1. Introduction

Green power transaction refers to the participation of green energy as a transaction type in medium and long-term power transactions, and the issuance of corresponding green energy consumption certificates [1]. For medium - and long-term green power trading, only the total amount of green power trading is considered, ignoring the coincidence between the green power output curve and the load curve. With its advantages of rapid response, energy storage batteries are considered the best tool for dynamically matching energy supply and demand [2]. The configuration objectives of energy storage systems are generally divided into two categories: economic efficiency and suppressing power fluctuations [3].

Literature [4-5] considers photovoltaic subsidies and two-part user time-of-use electricity pricing policies, and constructs a power planning model with the goal of maximizing net profit during the life cycle. Literature [6-8] has established a capacity improvement model for energy storage systems with the lowest system cost. Literature [9-10] proposed an economic energy storage capacity allocation plan considering the function of reducing wind abandonment for energy storage, while literature [11] designed an improved model for energy storage systems in wind power plants based on minimizing energy storage costs. Literature [12] studies the frequency spectrum of output power deviation and proposes an improved method for energy storage capacity configuration based on Fourier transform theory. Literature [13] proposed a method for suppressing voltage fluctuations that considers multi-period peak and valley loads. Literature [14] proposes a composite energy storage configuration plan that comprehensively considers wind power fluctuations and different energy storage technology characteristics. The existing research on energy storage configuration is based on stabilizing the safe operation of power systems and improving system economy. However, with the continuous development of electricity marketization, the balance of electricity supply and demand will further constrain the allocation of energy storage capacity.

Therefore, this article proposes to optimize the energy storage configuration based on the goal of supply and demand balance, comprehensively considering the economy of the optical storage joint system, by introducing the minimum net load variance of the system as the second goal, and verifies the rationality of the optimization model proposed in this article through case analysis.

## 2. Analysis of Combined Output and Load Matching Characteristics of Optical Storage System

### 2.1 Optical storage combined output characteristics

The components of the photovoltaic energy storage system include energy storage equipment, volt power generation equipment, and corresponding electrical and electronic equipment, and are connected to the external power grid through converters to ensure that the power supply and demand remain unchanged during grid operation. Figure 1 is a structural diagram of the system.

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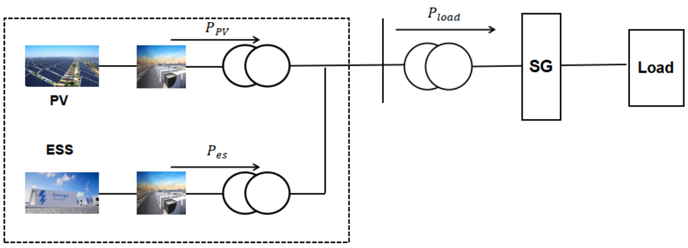


Fig.1 Typical Structure of Photovoltaic Energy Storage System

According to the power balance conditions, it can be obtained that:

$$P_{load} = P_{PV} + P_{ES} \quad (1)$$

Where, is the photovoltaic power generation power; Is the output power of the energy storage system; Is the grid-connected power of the optical storage power station.

## 2.2 Analysis of matching characteristics between combined output of optical storage and commercial daily load

Commercial loads refer to the air conditioning, lighting, and power consumption of the commercial sector. The consumption of these loads has steadily increased and their coverage is large, but their proportion in the total load is not as high as that of industrial and residential loads, and they are affected by seasonal fluctuations.

Figure 3 shows a typical photoelectric daily output curve. Due to changes in external light intensity and ambient temperature, the photovoltaic power curve presents a convex shape.

For commercial loads, there will be the first high peak during initial business hours, when the photovoltaic output is high. With the appropriate capacity configuration of photovoltaic power stations, it can provide all the energy consumption needs of the mall. In addition, with the help of energy storage devices, users' energy consumption needs in other periods can also be achieved to some extent by shifting the photovoltaic power generation volume from peak periods to nighttime periods.

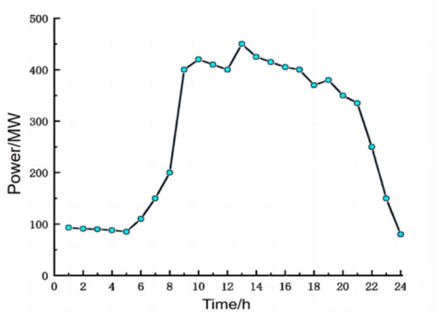


Fig.2 Commercial load curve

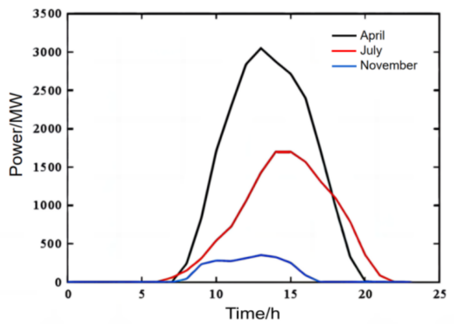


Fig.3 Output curve of a pv power station

# 3. Modeling Analysis

## 3.1 Objective function

Objective function 1: maximizing the benefits of a combined optical storage system

$$MAXF_{np} = \left( F_{grid} - M_{pv} - F_{pun} \right) \quad (2)$$

In the formula, $F_{np}$ refers to the income of the optical storage power station; $F_{grid}$ is the income from electricity sales; $M_{pv}$ is a deviation assessment fee; $F_{pun}$ is Punish for abandoning the light.

(1) Power generation income

$$F_{grid} = \sum_{t=1}^{96} F_g(t) \quad (3)$$

$$F_g(t) = \begin{cases} \gamma_{pv} \cdot P_{pv}(t) \cdot \Delta t + \gamma_{bess} \cdot P_{bess}(t) \cdot \Delta t \text{ , } P_{bess}(t) > 0 \\ \gamma_{pv} \cdot P_{pv}(t) \cdot \Delta t \text{ , } P_{bess}(t) \le 0 \end{cases} \quad (4)$$

Where, $F_g(t)$ is the electricity sales revenue at time t; $\gamma_{pv}$ is the photovoltaic grid price; $\gamma_{bess}$ is the electricity price for energy storage on the grid; $P_{pv}(t)$ is the photovoltaic power generation at time t; $P_{bess}(t)$ is the stored energy discharge power at time t.

(2) Deviation assessment cost

$$\Delta Q_m = Q_{load} - Q_{load,pre} \quad (5)$$

$$M_{pv} = \begin{cases} \left( |\Delta Q_m| - \alpha Q_{load,pre} \right) \cdot P^* \text{ , } & |\Delta Q_m| > \alpha Q_{load,pre} \\ 0 \text{ , } & |\Delta Q_m| \le \alpha Q_{load,pre} \end{cases} \quad (6)$$

In the formula, $Q_{load}$ is the actual power generation capacity of the optical storage power station; $Q_{load,pre}$ is the planned power generation capacity of the optical storage power station; $\alpha$ is the assessment exemption coefficient; $P^*$ is the price for unit deviation electricity.

(3) Abandonment punishment

$$F_{pun} = \sum_{t=1}^{96} \gamma_{pun} \cdot P_{pv,pun}(t) \cdot \Delta t \quad (7)$$

Where, $P_{pv,pun}$ is the abandoned light power at time t; $\gamma_{pun}$ is Penalty price for discarding all goods.

Objective function 2: Minimum variance of daily net load after energy storage

$$minf = \frac{1}{96} \sum_{t=1}^{96} \left[ P_{NL}(t) - P_{NL,ave}(t) \right]^2 \quad (8)$$

$$P_{NL}(t) = [\, p_{load}(t) - P_{PV}(t) - P_{ES}(t) \,] \quad (9)$$

$$P_{NL,ave}(t) = \frac{1}{96} \sum_{i=1}^{96} P_{NL}(t) \quad (10)$$

In the formula, $f$ is the daily net load variance value after the energy storage effect; $P_{NL}(t)$ is the net load value at time t; $P_{NL,ave}(t)$ is the average value of the net load at time t.

### 3.2 Constraint condition

(1) Power balance constraints

$$P_{load}(t) = P_{PV}(t) + P_{ES}(t) \quad (11)$$

Where, $P_{PV}(t)$ is the photovoltaic power generation power at time t; $P_{ES}(t)$ is the stored energy output power at time t.

(2) Energy storage power constraints

$$-P_{max} \le P_{ES}(t) \le P_{max} \quad (12)$$

Where, $P_{max}$ is the maximum discharge power of stored energy.

Where, $SOC(t)$ is the initial charge rate of the energy storage system

(3) Deviation constraint

In order to control the penalty cost of the deviation assessment mechanism, the deviation rate is limited to 10%.

$$|\, P_{load}(t) - P_{load,pre} \,| \le 10\% \quad (13)$$

Where, $P_{load}(t)$ is the grid-connected power of the optical storage power station at time t; $P_b(t)$ is he grid connection power for the optical storage power station at time t.

(3) Energy conservation constraints for charging and discharging during the daily cycle:

$$\sum_{t=1}^{96} \left[\, (1-\varepsilon) P_{e,c}(t) \alpha - P_{e,dis}(t) \times \beta \,\right] \Delta t = 0 \quad (14)$$

Where, $P_{e,c}(t)$ is the energy storage charging power at time t; $P_{e,dis}(t)$ is the energy storage discharge power at time t.

### 3.3 Improved particle swarm optimization algorithm

According to the process of particle swarm optimization algorithm, when the inertia value is at a large level, it promotes the global search for the optimal solution; If the inertia value is small, it will help to converge. Therefore, appropriate inertia should be selected to improve the approach speed of the algorithm. To achieve better algorithm results, consider adding ω Reduce from 0.9 to 0.4 for optimization.

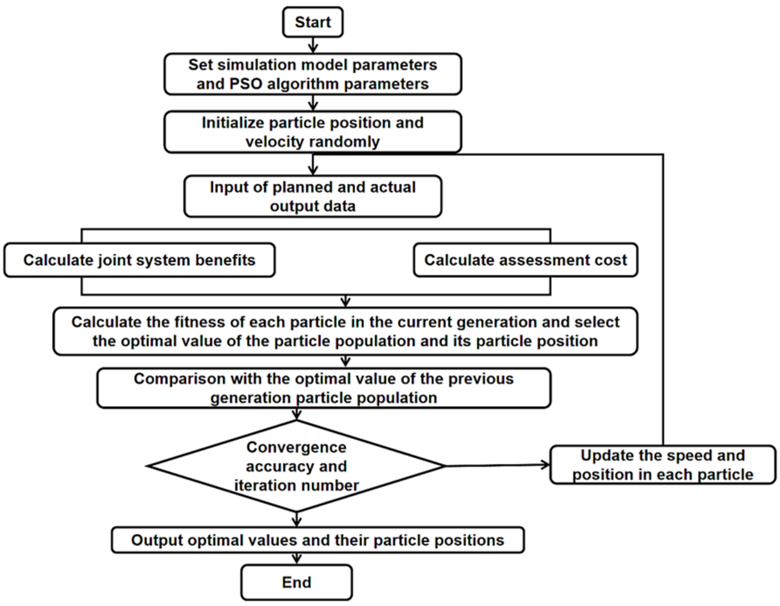


Fig.4 Solution flow of improved particle swarm optimization algorithm

## 4. Example analysis

### 4.1 Parameter settings

This calculation example uses a photovoltaic power station with an installed capacity of 30 MW. The basic parameters of the optical storage system are shown in Table 1, and the photovoltaic power data set of the system is obtained through HOMER simulation. The photovoltaic output and load curve is shown in Figure 5.

Tbl.1 Basic Parameters of Optical Storage System

| Parameter Name | unit | numerical value |
|---|---|---|
| Rated photovoltaic installed power $P_{PV}$ | MW | 30 |
| PV predicted output power $P_{PV,pre}$ | MW | 30 |
| PV power generation reliability E | % | 80% |
| Average annual illumination time $T_{Ir}$ | h | 1600 |
| Average annual light intensity $I_r$ | kWh/m$^2$ | 1578 |
| Average service life of PV $L_{PV}$ | Year | 25 |
| Average service life of ESS $L_{ESS}$ | Year | 20 |
| ESS charging and discharging efficiency η | % | 80 |
| Initial value of ESS SOC(0) | % | 50 |
| ESS charge rate SOC | % | 20-100 |
| PV grid price $\gamma_{pv}$ | Yuan/MWh | 1005 |
| Abandonment penalty price $\gamma_{pun}$ | Yuan/MWh | 500 |

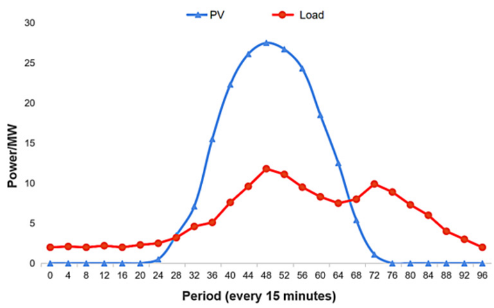


Fig.5 Pv station and commercial load forecasting curve

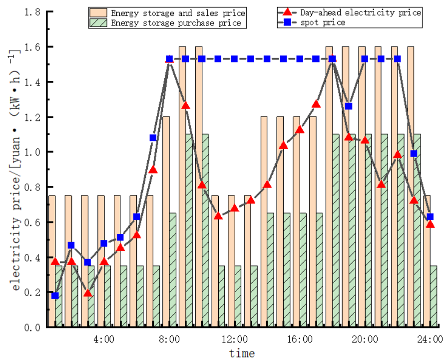


Fig.6 Electricity price parameters

In order to better demonstrate the advantages of the scheduling model proposed in this article, a control group is set up, as shown below:

Option 1: The optical storage power station adopts the maximum output mode, only considering economic objectives, and optimizing the energy storage configuration.

Option 2: The optical storage power station adopts the maximum output mode, comprehensively considering the dual objective function, and optimizing the energy storage configuration.

## 4.2 Analysis of calculation results

The simulation results of the optimal energy storage capacity, combined system total revenue, penalty cost, deviation rate, net load variance, and other indicators under the two schemes are shown in Table 2.

Tbl. 2 Analysis of Simulation Results of Two Schemes

| target | Option 1 | Option 2 |
|---|---|---|
| Total combined system revenue $F_{np}$ (ten-thousand-yua) | 83.1 | 99.5 |
| Revenue from electricity sales $F_{grid}$ (ten-thousand-yua) | 100.7 | 114.4 |
| Deviation assessment fee $M_{pv}$ (ten-thousand-yua) | 5.6 | 12.3 |
| Abandoned solar power $Q_{pun}$ (MWh) | 23.9 | 6.5 |
| Energy storage power capacity $P_{ES}$ (MW) | 3.6 | 5.8 |
| Energy storage capacity $E_{ES}$ (MWh) | 8.3 | 12.1 |
| Net load variance f | 211 | 47 |

As can be seen from Table 2, there are significant differences in various indicators obtained by the two configuration schemes. The optimal allocation capacity for energy storage is 3.6MW/8.32.6MWh and 5.8MW/12.12.6MWh, respectively. For photovoltaic power stations with an installed capacity of 30 MW, the energy storage ratio is respectively 12% and 19% of the installed capacity of photovoltaic power stations, which is within the current configuration requirements.

By comparing the total revenue of the combined system in Table 2, Scheme 2 is 164000 yuan higher than Scheme 1. The reason is that Scheme 2 considers the constraints on the net load variance after the energy storage effect when configuring the energy storage capacity, which not only enables the combined system's power generation curve to be consistent with the predicted power generation curve, but also ensures the matching degree between the power generation curve and the load curve, and controls the penalty for discarding light and the deviation cost of the assessment nature, To a certain extent, it improves the system's electricity sales revenue and increases the economy of the combined power generation system. At the same time, in view of the "arch shaped" characteristics of photovoltaic power generation output, part of the excess electricity generated is stored in the energy storage during the noon power generation period, and is discharged to supply power to the mall during the peak power consumption period in the evening, maximizing the realization of 100% green power supply demand. Therefore, the energy storage configuration capacity of Scheme 2 is higher than that of Scheme 1.

## 5. Conclusion

In order to solve the development defect of current green power trading that does not consider the fitting of green power generation curves and user load curves, this paper, based on the balance between green power supply and demand, introduces the system net load variance to optimize the allocation of energy storage capacity, and draws the following conclusions:

(1) Based on the analysis of the output characteristics of the combined photovoltaic storage system and the analysis of the demand characteristics of commercial power loads in China, the conclusion is drawn that the coupling between photovoltaic power generation systems and commercial loads is the best, providing a research basis for future power consumers with the goal of 100% clean energy supply.

(2) Compared with Scheme 1 and Scheme 2, the energy storage capacity in Scheme 2 increased by 7%, the amount of wasted light and electricity decreased by 73%, and the deviation assessment cost decreased by 59%. The energy storage capacity allocation model proposed in this paper not only improves the economic benefits of the optical storage combined system, but also improves the fitting degree of the system output and load curve, and improves the utilization rate of green power.

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