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Day-ahead Optimized Allocation of Shared Energy Storage Considering Demand Response under Wind and Photovoltaic Economic Power Consumption

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In the context of the wide application of clean energy, the power grid is facing considerable volatility and uncertainty, and the construction of shared energy storage (SES) can effectively balance the renewable energy volatility and maintain the stable operation of the power grid. In this paper, we take the SES power station as the research subject, and from the problem of day-ahead optimized allocation, we propose an innovative method with the comprehensive consideration of the demand response (DR) and wind and photovoltaic generation system power economic consumption, in order to promote the economic and efficient application of SES and realize the mutual coordination of wind and photovoltaic storage and the win-win benefit of multiple main bodies. First, we introduce the concept of SES and its structure. Subsequently, we introduce the SES power station into the user alliance system. In this system, the energy-sensing device is responsible for collecting users' electricity consumption data, and then analyzing users' electricity demand information. From these data, combined with the DR mechanism, we can optimize the power storage and release strategy of the SES. Next, to rationally allocate the capacity of SES, we minimize the expenditure of the power plant–user alliance as an objective function. The results of a case comparison analysis show that after the SES plant is configured, the consumption rate of wind and photovoltaic energy is significantly increased to more than 94.56%, which effectively reduces the waste of energy. After considering the wind and photovoltaic power economic consumption and DR, the capacity of the energy storage configuration is reduced by 25.33%, and the reduction of the total expenditures of the system is up to 25.57%, and the above data verifies that the proposed methodology is effective.

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1. Introduction

Within the background of a dual-carbon goal, the structure of China's power grid has gradually transformed into one with a high proportion of renewable energy generation. The development and utilization of renewable energy are sustainable paths to reduce fossil fuel combustion and pollutant emissions and prevent the environment from being polluted.(1) However, one of the drawbacks of renewable energy, especially wind and photovoltaic energy, is its uncertainty, which exposes the grid to greater load uncertainty, making it difficult to fully consume these products, and the reliable functioning of the grid is facing serious challenges. To cope with these challenges, energy storage technologies have emerged.(2)

Stand-alone energy storage (SAES) is an energy storage system individually configured by a single user or entity, designed to store and release electricity when needed to balance the difference between supply and demand in the power system. However, SAES faces the following issues: (1) high construction expenditure and high burden on users,(3) which will reduce users' willingness to build energy storage plants and hinder the popularity and development of SAES, and (2) failure of the capacity of SAES to reach the upper and lower bounds of the power plant capacity curve, resulting in wasted power plant capacity and low energy utilization.(4)

Therefore, in order to remove the obstacles on the road of energy storage development, and combined with the current trend of "sharing economy", which is widely popular in various fields of society, an innovative solution has emerged: integrating the sharing concept into the operation of energy storage power stations(5) so as to build and develop the service provider of energy storage power stations centering on the shared energy storage (SES) with a power station operation model.

What is more advantageous than SAES is that SES puts more emphasis on resource sharing, and synergy SES is an electric energy interaction mode in which energy storage stations utilize a shared business model for profit, thereby maximizing the use of energy storage resources and avoiding inefficiencies in the use of energy storage equipment by individual users, which helps balance the energy supply and demand in different time periods and regions and more effectively realizes the synergistic operation balance of the power system.(6)

Currently, SES research is in its infancy. In terms of SES optimization configurations, Yang *et al.*(7) proposed a two-layer optimal allocation method for distributed SES oriented to source–network co-optimization, which ensures that the revenue of SES operation reaches the optimal level while taking into account the operating cost of new energy stations in distribution grids and realizes a balanced development of the economics of each subject. Han *et al.*(8) proposed a dynamic cooperative game optimization method for the coupling relationship between the capacity allocation and operation strategy of energy storage systems, which paved the way for the theoretical aspects of the extensive use of energy storage in a novel system.

Users' energy use behavior is also an important element that affects the trading outcome.(9) The demand response (DR) is a significant mechanism in the power industry and refers to the process of guiding electricity users in the electricity market through price signals or incentives to adjust their electricity usage patterns to reduce or increase load demand when electricity prices are high or the system is subject to instability.(10) The introduction of energy-sensing devices in this process can help monitor the user's energy consumption behavior, including changes in electricity consumption patterns and energy consumption, and provide data support for the implementation of DR.

Existing studies mainly focus on the study of the operation strategy, and there are only a few studies on the optimal configuration of SES. Tushar *et al.*(11) studied the problem of SES configuration but did not consider the DR strategy, whereas Ma *et al.*(12) considered the DR strategy. However, the study of new energy consumption is still based on complete consumption without considering the economics, and only a few current studies consider the economic consumption of new energy with reasonable power abandonment. Xie *et al.*(13) argued that choosing an appropriate, but not quite 100%, rate of dissipation can reduce energy waste and save costs.

On the basis of ensuring that the utilization rate of new energy is sufficiently high, we set a certain proportion of economically discarded power and allow new energy sources to carry out a certain degree of reasonable power abandonment. A definition of the economic consumption rate of wind and photovoltaic power is proposed. It refers to the most economical "utilization rate" during the user's use of wind and photovoltaic power. Considering the economic consumption rate of wind and photovoltaic power, the configuration expenditure of the SES power station will be further reduced, and the user's actual energy consumption behavior will also be changed, reducing the user's economic expenditures.

The contributions of this study are as follows.

(1) SES power plants are configured in user coalitions to effectively reduce energy waste.
(2) Considering wind and photovoltaic energy economic consumption, the impact of the wind and photovoltaic power consumption rate on the economic benefits of the system is analyzed, as well as the effect of allocation.
(3) Energy-sensing devices are used to monitor user electricity demand patterns, and DR measures are considered to analyze the impact of DR on the optimal allocation results.

The rest of the paper is organized as follows. In Sect. 2, we describe the wind-photovoltaic-SES system architecture and the mode of operation. In Sect. 3, we provide an objective function and constraints. In Sect. 4, four cases are analyzed and discussed. In Sect. 5, we summarize the entire text.

2. Framework of Wind-photovoltaic-SES System

As illustrated in Fig. 1, the whole system framework includes a multi-user coalition, SES, wind and photovoltaic power, and a large power grid.

The main task of a shared energy storage operator (SESO) is to manage charging and discharging demand for distributed new energy power stations and user consortia to optimize SES capacity allocation for cost efficiency.

The SESO centralizes and optimizes energy storage, ensuring that energy is stored and released as needed to meet the power system's requirements. By analyzing demand and market conditions, the SESO determines the optimal capacity configuration to minimize costs while meeting power system demands.

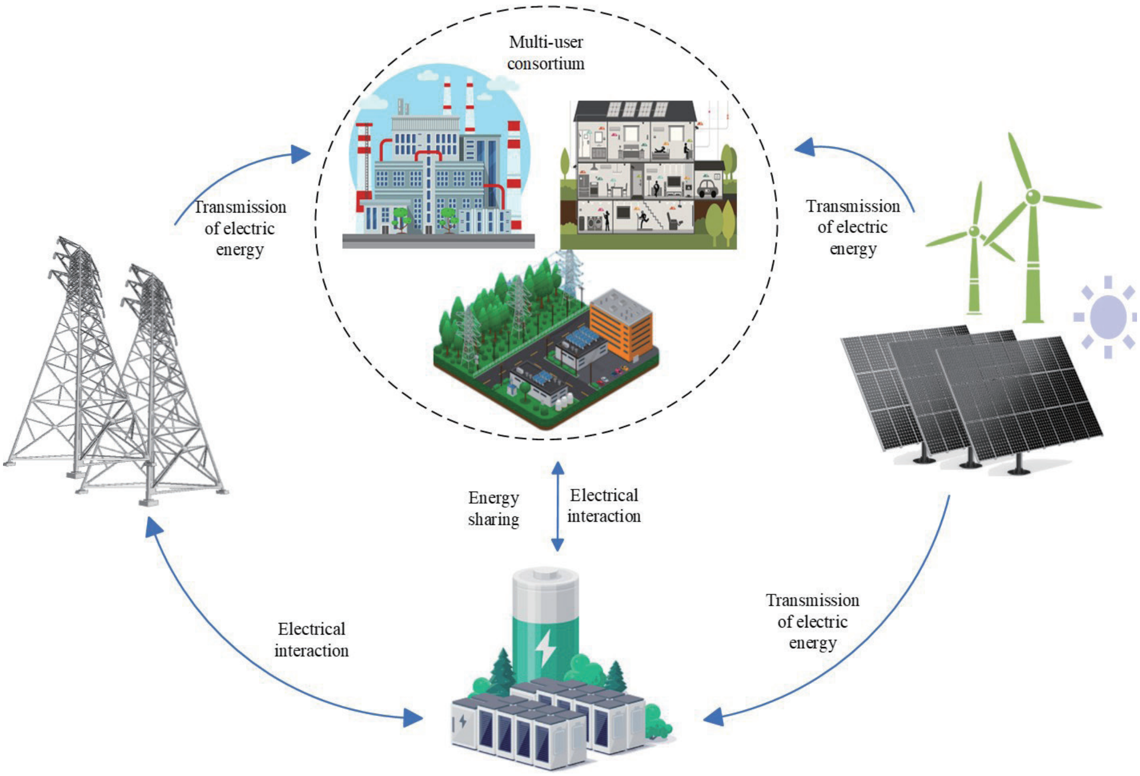


Fig. 1. (Color online) Framework of SES system.

The SESO adopts a "low-price storage, high-price discharge" strategy for power dispatch, storing energy when prices are low and releasing it when prices are high, thus maximizing economic efficiency. This model allows SESO to earn service charges while providing a stable supply of electricity to customers, further enhancing the system's economic viability.

3. Description of Optimal Scheduling Model for SES

The model described in this paper targets the user coalition of a typical industrial park under the application mode of SES. In this study, we aim to address the issue of the rational allocation of the capacity of SES, with the target being the lowest operational economic expenditure of the user coalition and the minimization of the expenditure of the SES.

3.1 Objective function

The comprehensive SES–user coalition objective function consists of two components: the economic expenditure of the SES and the user's typical daily operating expenditure.

3.1.1 Operating expenditures of user coalitions

The typical daily operating economic expenditure of the user coalition consists of four components. The objective function can be expressed as

$$\min F1 = C_{grid} + C_{ess,b} - C_{ess,s} + C_{serve} - C_{DR} \,, \tag{1}$$

where $F1$ is the typical daily operating economic expenditure of the user coalition, $C_{ess,b}$ is the fee paid to the SES when the user coalition purchases electricity, $C_{ess,s}$ is the revenue gained by the user coalition from the sale of excess electricity to the SES plant, C_{serve} is the service fee paid for the use of the energy interacted in the SES process, and C_{DR} is the expenditure of the DR penalty.

(1) Expenditures of power purchased from the grid by the users' coalition

$$\begin{cases} C_{grid}^{T,N} = \gamma(t) \cdot P_{grid,n}(t) \cdot \Delta t \\ C_{grid} = \sum_{n=1}^{N} \sum_{t=1}^{T} C_{grid}^{T,N} \end{cases} \tag{2}$$

Here, N denotes that there are N users, T is the number of times in the entire cycle, $\gamma(t)$ is the unit power tariff traded on the grid, $P_{grid,\,n}(t)$ is the power of the nth user interacting with the grid in time slot t, and Δt is the unit scheduling time slot duration.

(2) Expenditure of electricity purchased from SES by the user coalition

$$\begin{cases} C_{ess,b}^{T,N} = \gamma_b(t) \cdot P_{ess,b,n}(t) \cdot \Delta t \\ C_{ess,b} = \sum_{n=1}^{N} \sum_{t=1}^{T} C_{ess,b}^{T,N} \end{cases} , \tag{3}$$

where $\gamma_b(t)$ is the price of electricity per unit of electricity purchased by the user from the shared energy storage plant in time t, and $P_{ess,\,b,\,n}(t)$ is the power sold to the SES by the nth user in time t.

(3) Revenues from the sale of electricity to the SES plant by a coalition of users

$$\begin{cases} C_{ess,s}^{T,N} = \gamma_s(t) \cdot P_{ess,s,n}(t) \cdot \Delta t \\ C_{ess,s} = \sum_{n=1}^{N} \sum_{t=1}^{T} C_{ess,s}^{T,N} \end{cases} \tag{4}$$

Here, $\gamma_s(t)$ is the unit power tariff of electricity sold to the SES power station in each dispatching time, and $P_{ess,\,s,\,n}(t)$ is the amount of power purchased from the SES power station by the nth user in time t.

(4) SES service fees

$$\begin{cases} C_{serve}^{T,N} = \delta(t) \cdot \left[P_{ess,b,n}(t) + P_{ess,s,n}(t) \right] \cdot \Delta t \\ C_{serve} = \sum_{n=1}^{N} \sum_{t=1}^{T} C_{serve}^{T,N} \end{cases} \tag{5}$$

Here, δ(t) is the service fee per unit of power in $/(kWh) to be charged by the power plant when the user uses the power plant.

3.1.2 Expenditures for SES service providers

The economic expenditure of an SES consists of two parts: the construction and maintenance expenditure of the SES, and the power exchange service fee received by the SES.

$$minF2 = C_{inv} - C_{serve}, \tag{6}$$

where $F2$ is the operating economic expenditure of the SES plant and C_{inv} is the various expenditures required for the construction of energy storage facilities and maintenance expenditure of the SES.

Investment expenditure and operation and maintenance expenditure are

$$C_{inv}=\delta_M*P_{max}+\frac{\delta_E*E_{max}+\delta_P*P_{max}}{T_s}, \tag{7}$$

where $F2$ is the unit power maintenance expenditure of the SES power plant, δ_M is the unit power investment expenditure of the SES power plant, δ_p is the unit capacity investment expenditure of the SES power plant, P_{max} is the preconfigured rated storing and releasing power, E_{max} is the preconfigured rated capacity of the SES power plant, and T_s is the expected number of days of use. $\delta_M *P_{max}$ is the daily operation and maintenance expenditure.

3.1.3 Comprehensive objective function

The equation for the weighted synthesis of two objectives into one is given below. By adjusting the weights w, we can make trade-offs between different objectives to find a comprehensive optimal solution. This method can effectively deal with conflicts between objectives and makes decision-making more flexible.

$$minF = \omega * F1 + (1-\omega) * F2, \tag{8}$$

where F is the user coalition under the SES application and w is the weighting factor, $w \in (0.1)$.

3.2 Constraints

(1) Electrical power balance constraints

$$P_{PV,n}(t) + P_{WIND,n}(t) + P_{grid,n}(t) + P_{ess,b,n}(t) = P_{ess,s,n}(t) + P_{load,n}(t) \tag{9}$$

Here, $P_{pv,\,n}(t)$ is the power emitted by the photovoltaic for the nTH user in time t, $P_{wind,\,n}(t)$ is the actual power generated by the wind power for the nTH user in time t, and $P_{load,\,n}(t)$ is the load power required by the nTH user in time t.

(2) Power constraints on the purchase and sale of energy from SES by the users' coalition

$$\begin{cases} 0 \le P_{ess,b,n} \le P_{ess}^{max} U_{ess,b,n} \\ 0 \le P_{ess,s,n} \le P_{ess}^{max} U_{ess,s,n} \\ U_{ess,b,n} + U_{ess,s,n} \le 1 \\ U_{ess,s,n} \in \{0,1\}, U_{ess,b,n} \in \{0,1\} \end{cases}, \tag{10}$$

where P_{ess}^{max} is the maximum power that can be achieved by the user using the SES plant to sell and purchase power, and $U_{ess,\,b,\,n}$ and $U_{ess,\,s,\,n}$ are respectively the power purchase state bit and power sale state bit of the nth user using the SES plant in a 0–1 variable.

(3) Energy storage plant multiplier constraints

Mathematically, the capability of an energy storage plant to store energy is directly proportional to the rated power it provides as follows:

$$E_{max} = \varepsilon P_{max}, \tag{11}$$

where ε is the energy multiplier of the SES.

(4) Wind and photovoltaic economic consumption constraints[13]

$$\begin{cases} \sum_{i=1}^{N}\sum_{t=1}^{H}(P_{WIND,i}(t) + P_{PV,i}(t)) = \psi \sum_{i=1}^{N}\sum_{t=1}^{H}(P_{wind,i}(t) + P_{pv,i}(t)) \\ P_{WIND,i}(t) \le P_{wind,i}(t) \\ P_{PV,i}(t) \le P_{pv,i}(t) \end{cases} \tag{12}$$

Here, $P_{WIND,i}(t)$ is the actual output of wind power, $P_{PV,i}(t)$ is the actual output of photovoltaic, $P_{wind,i}(t)$ is the maximum output of wind power, $P_{pv,i}(t)$ is the maximum output of photovoltaic, Ψ is the coefficient of economic consumption of wind power, and t is the scheduling time.

(5) Storage/release power balance constraint of SES[13]

$$\sum_{i=1}^{N}\left[P_{ess,b,i}(t) - P_{ess,s,i}(t)\right] = P_{relea}(t) - P_{abs}(t) \tag{13}$$

(6) SES plant load state continuity constraints[14]

$$\begin{cases} SOC(t) = (1-u)SOC(t-1) + \left[\tau^{abs} P_{abs}(t) - \frac{P_{relea}(t)}{\tau^{relea}}\right]\Delta t \\ SOC_{min} \le SOC(t) \le SOC_{max} \end{cases} \tag{14}$$

Here, SOC_{max} and SOC_{min} are respectively the maximum and minimum values of the load state of the SES, $SOC(t)$ is the charging state of the energy storage plant in time t, u is the self-discharge rate of the SES plant, τ^{abs} and τ^{relea} are respectively the storing and releasing efficiencies of the SES plant, and $P_{abs}(t)$ and $P_{relea}(t)$ are respectively the storing and releasing powers of the SES plant.

(7) SES plant storing and releasing power constraints[15]

$$\begin{cases} 0 \le P_{abs} \le P_{max} U_{abs} \\ 0 \le P_{relea} \le P_{max} U_{relea} \\ U_{abs} + U_{relea} \le 1 \\ U_{abs} \in \{0,1\}, U_{relea} \in \{0,1\} \end{cases}, \tag{15}$$

where U_{abs} and U_{relea} are the storing and releasing state bits of SES, respectively.

3.3 Linearization

The constraints in the above model, Eq. (15), are nonlinear constraints that need linearization transformation, and the Big-M method[16] is often used to linearize the above constraints into Eq. (16), setting M to be a sufficiently large constant.

$$\begin{cases} 0 \le P_{abs} \le P_{max} \\ 0 \le P_{abs} \le U_{abs} \cdot M \\ 0 \le P_{relea} \le P_{max} \\ 0 \le P_{relea} \le U_{relea} \cdot M \\ U_{abs} + U_{relea} \le 1 \\ U_{abs} \in \{0,1\}, U_{relea} \in \{0,1\} \end{cases} \tag{16}$$

3.4 Integrated application of energy-sensing device monitoring and DR strategy

The energy storage and release strategies of the SES are dynamically adjusted on the basis of user load demand monitored by energy-sensing devices in real time. For users, its internal electrical load consists of unresponsive load, transferable load, and interruptible load,[17] as shown by

$$P_{Load}(t) = P_{Load,I}(t) + \sum_{m=1}^{n_m} L_{m,t}^{cut} + \sum_{t=1}^{T} L_t^{shift}, \tag{17}$$

where $P_{Load,I}(t)$, $\sum_{m=1}^{n_m} L_{m,t}^{cut}$, and $\sum_{t=1}^{T} L_t^{shift}$ are the demands of unresponsive load, interruptible load, and transferable load, respectively.

DR penalty expenditures are the interruptible and shifted load compensation expenditures paid by the grid to the customer.

$$C_t^{DR} = \sum_{m=1}^{n_m} (\lambda_m^{cut} L_{m,t}^{cut}) + \sum_{t=1}^{T} (\lambda_t^{shift} L_t^{shift}) \tag{18}$$

$$0 \le L_{m,t}^{cut} \le L_{m,t}^{cut,max} \tag{19}$$

$$L_{m,t}^{cut} = \sum_{m=1}^{n_m} L_{m,t}^{cut} \tag{20}$$

$$L_{m,t-1}^{cut} + L_{m,t}^{cut} \le L^{c,max} \tag{21}$$

$$\sum_{t=1}^{T} L_t^{shift} = \sum_{t=1}^{T} L_t^{s} \tag{22}$$

$$0 \le L_t^{shift} \le L_t^{shift,max}\,, \tag{23}$$

where n_m is the number of interrupt priority levels, λ_m^{cut} is the cost for making up for the interruptible load at the *m*th level, $L_{m,t}^{cut}$ is the level *m* interruptible load volume at *t*, $L_{m,t}^{cut,max}$ is the upper limit of the interruptible load at the *m*th level in *t*, $L^{c,max}$ is the maximum amount of interruptible load to be invoked in continuous time, L_t^{shift} is the transferable load after transferring in *t* and is the decision variable, L_t^{s} is the transferable load quantity in *t*, and $L_t^{shift,max}$ is the upper limit of transferable load in *t*.

4. Case Analysis

4.1 Case settings

An example is set up to analyze the SES, DR, and the wind and photovoltaic power economic consumption for three typical industrial users in a certain region, and the initial state of the SES plant is set to be 0.2. The capacity expenditure of the user load and renewable energy output curves are adopted from Li *et al.*[15] at the price of \$155/(kWh). The theoretical life cycle is set to 10 years. The grid electricity sales tariff reference[18] is a unit price of \$0.05/(kWh) for the service charge of the energy storage plant.

To analyze the interaction of SES capacity allocation with wind and photovoltaic power economic consumption and DR, the following four scenarios are set up for comparative analysis.

Scenario 1: No energy storage

Scenario 2: Configuring SES, considering economic consumption

Scenario 3: Configuring SES, without considering economic consumption

Scenario 4: Configuring SES, considering economic consumption, and integrating energy-sensing device monitoring and DR.

4.2 Analysis of results

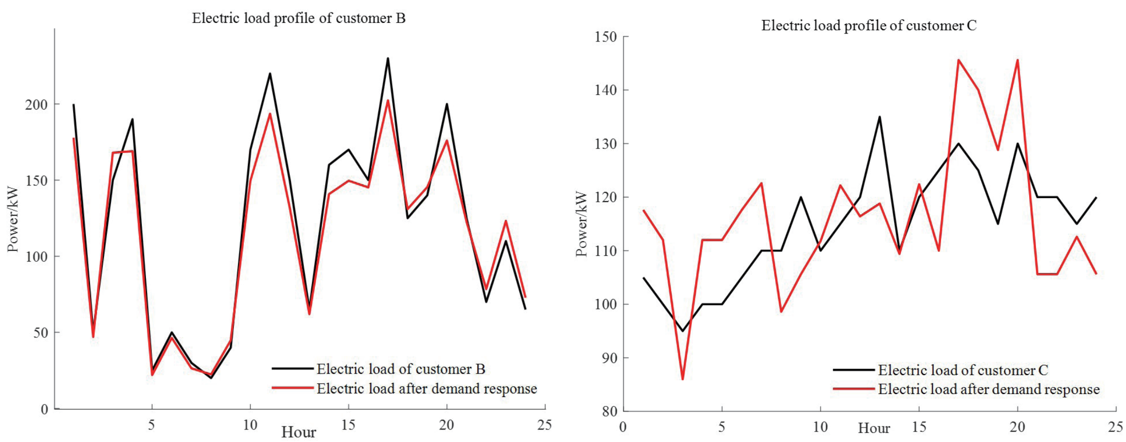
4.2.1 DR results analysis

Through the implementation of DR strategies, significant peak shaving and valley filling were observed, and good results were achieved. As illustrated in Fig. 2(a), User B's peak hour is during 10–12, and the customer is successfully guided to reduce the load demand by 64.8 kW, thus avoiding the risk of overloading of the power system. During the hours 22–24, the load before DR is 245 kW and the load after DR is 274.4 kW, which is an improvement of 29.4 kW; the user has been successfully guided to implement the DR strategy.

In Fig. 2(b), User C's peak hour is during 12 to 13, and the user was successfully guided to reduce the load demand by 19.8 kW and the the risk of overloading of the power system was avoided. In the valley time period of 0–7, the load is 715 kW before DR and 779.8 kW after DR, where the user response was to adjust the power usage by 64.8 kW, which filled the potential power waste of the system and realized the smooth adjustment of the load. The DR strategy plays a positive role in effectively reducing system stress and improving the stability of the system. It can be observed that the system shows higher flexibility during the execution of the DR strategy. Users can quickly adjust their energy consumption behavior to changes in system demand on the basis of incentive or price signals.

4.2.2 Analysis of results of optimized allocation of SES

The optimized scheduling results for typical industrial users after considering the SES configuration for DR and economic consumption of wind and photovoltaic energy are shown in Figs. 3 and 4. With 24 h as the scheduling duration and 1 h taken for power dispatch, the configuration of the SES results in a capacity of 1729.52 kWh and a maximum storing and releasing power of 631.21 kW.



(a) (b)

Fig. 2. (Color online) (a) User B and (b) User C's optimization results of electric load DR.

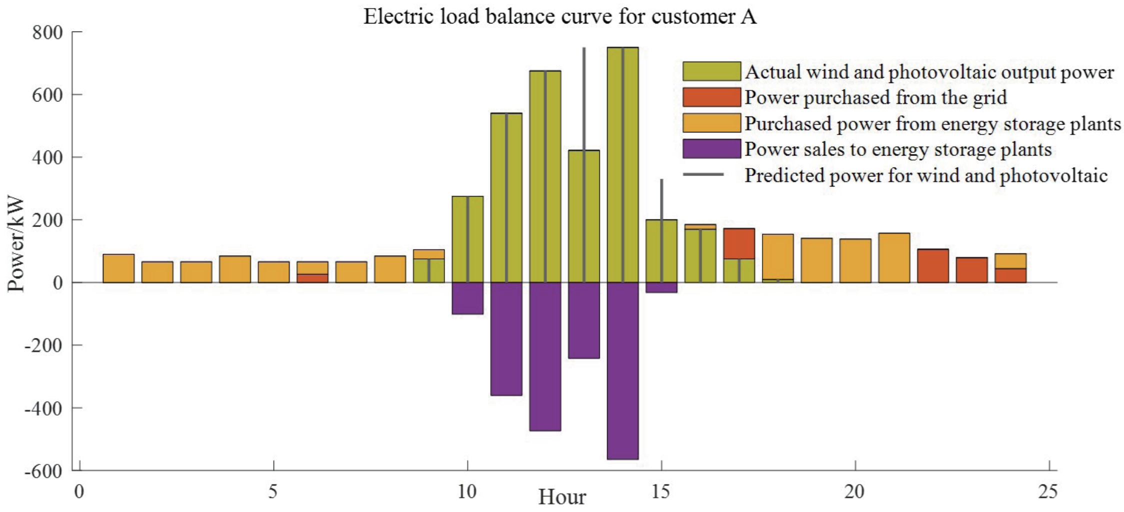


Fig. 3. (Color online) Electric load profile of User A.

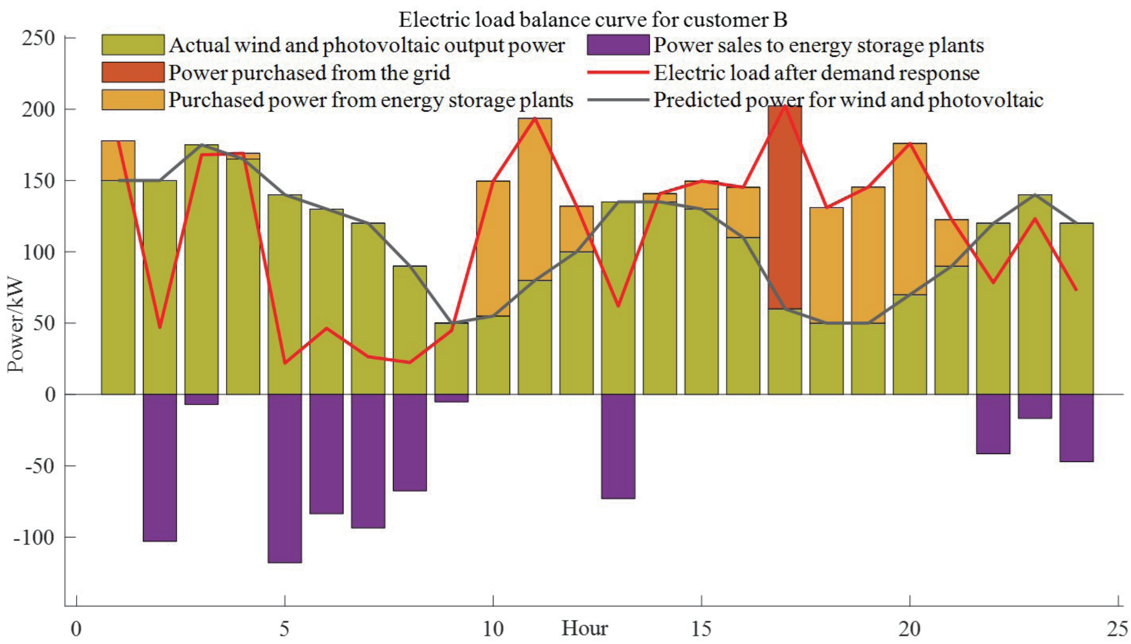


Fig. 4. (Color online) Electric load profile of User B.

As seen in Fig. 3, for User A in the time from 13:00 to 15:00, the actual exports of wind and photovoltaic power are 421.43 and 200 kW, whereas the forecast outputs are 750 and 330 kW, respectively. The actual exports of wind and photovoltaic power are less than the forecast output, which shows that wind and photovoltaic systems have made reasonable power abandonment. At this time, the outputs of wind and photovoltaic power are greater than the user's required load, and the user's demand is satisfied, and the remaining load is sold to the SES service provider for storage.

From Fig. 4, for User B at 02:00–03:00, 05:00–09:00, 13:00, and 22:00–24:00, the amount of wind and photovoltaic power generated is greater than the user's demand, which not only meets the user's demand for electricity, but also enables the surplus to be sold to the SES provider for storage. At 17:00, the amount of wind and photovoltaic power is insufficient to me*et all* the load requirements of the customer. At this time, the price of electricity is in the medium price range, so it is more cost-effective for users to buy electricity from the grid. At 10:00–12:00, 14:00–16:00, and 18:00–21:00, the actual amount of wind and photovoltaic power generated is less than the load required by users. At this time, wind and photovoltaic generation cannot meet the customer's electricity demand, so the customer needs to purchase electricity. However, since the price of electricity in the grid is high during this time period, in order to minimize expenses, the customer uses the SES service to purchase cheaper electricity.

In Table 1, wind and photovoltaic power economic consumption is considered in Scenario 2, but not in Scenario 3. The configured capacity of the power station considering wind and photovoltaic power economic consumption is reduced by 278.58 kWh, which is a decrease of 12.03%, and the configured power of the power station is reduced by 101.67 kW or 12.03%.

Scenario 2 is next compared and analyzed with respect to Scenario 4. After considering DR, the configured capacity of the SES is reduced by 308.07 kWh, which is a 15.12% reduction; the configured power of the power plant is reduced by 112.44 kW or 15.12%. The total expenditure of the system is reduced by $74.77, a reduction of 24.25%. These results indicate that the consideration of DR significantly reduces the construction scale of the SES, as well as the total expenditure of the SES and the user.

Scenario 1 in Table 2 is compared with Scenario 3. In contrast to the independently configured energy storage, the user expenditure after configuring SES is reduced by $172.07, a decrease of 45.46%, and the rate of elimination is increased by 61.27%. Therefore, the configuration of SES significantly reduces the user expenditure, improves the rate of elimination, and helps avoid waste.

Next, Scenario 4 is compared with Scenario 2. The user's operating expenditure is reduced by $62.79, which is a 28.59% decrease, and it can be seen that the implementation of the DR strategy realizes significant expenditure benefits. The overall expenditure of system operation is reduced by guiding users to increase energy consumption during low-electricity-price periods.

Table 1
Configuration results.

Scenario	Capacity Configuration (kWh)	SES Configuration Power (kW)	Daily operating expenditure of SES ($)
2	2037.59	743.65	88.69
3	2316.17	845.32	107.27
4	1729.52	631.21	76.71

Table 2
Expenditure and economic consumption rates.

Scenario	Running expenditures for users ($)	Total expenditure of the system ($)	Economic consumption rates of wind and photovoltaic (%)
1	378.53	–	38.73
2	219.58	308.27	95.72
3	206.46	313.73	–
4	156.80	233.50	94.56

This action not only reduces the economic burden on users, but also helps achieve a better economy of the power system.

4.2.3 Analysis of the impact of wind and photovoltaic energy economic consumption rate on energy storage allocation

To understand the effect of the wind and photovoltaic power consumption rate on the energy storage space allocation, Scenario 2 is computationally analyzed. Moreover, the consumption rate is used as a constraint to analyze the changes in the SES configuration and the system scheduling problem when the consumption rate is changed to determine the effect of the consumption rate on the optimal configuration.

Figure 5 shows the changes in the operating expenditures of the user coalition and SES with the wind and photovoltaic power economic consumption rate. From the curves, it can be judged that the customer expenditure shows a decreasing trend with increasing wind and photovoltaic power economic consumption rate. The expenditure of the SES shows an increasing trend with increasing wind and photovoltaic power economic consumption rate, and the total expenditure of the system shows a decreasing trend followed by an increasing trend with increasing wind and photovoltaic power economic consumption rate. The wind and photovoltaic power economic consumption rate of the overall system is 95.72%, and the total system expenditure is the lowest under the optimal wind and photovoltaic power economic consumption rate. When the wind and photovoltaic power economic consumption rate exceeds 95.72% and approaches 100%, the overall expenditure increases significantly.

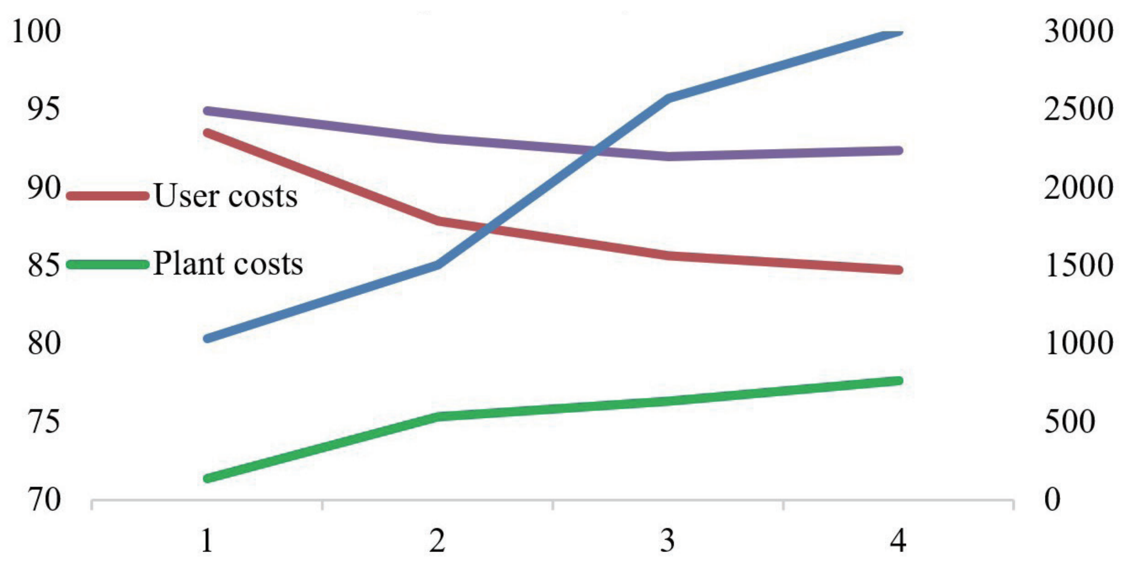


Fig. 5. (Color online) Effect of absorption rate on system economic benefit.

5. Conclusions

The method introduced in this study helps wind and photovoltaic power generation–SES–users realize a win-win-win situation.

(1) Compared with the user-independent configuration of energy storage scenarios, after the construction of SES, the reduction of the user expenditure reaches 45.46%, and the improvement in the consumption rate is increased by 61.27%.

(2) Compared with the wind and photovoltaic energy economic power abandonment considered in this paper and the SES without considering the wind and photovoltaic energy economic consumption scenario, the capacity of the user coalition configuring the SES power plant considering the wind and photovoltaic power economic consumption is reduced by 12.03% compared with the total configured capacity in Scenario 3, and the configured power of the storage power plant is reduced by 12.03% compared with the total configured power in Scenario 2.

(3) Compared with the SES without energy-sensing device monitoring or DR, the capacity of the user coalition configuring SES with energy-sensing device monitoring and DR is 15.12% lower than the total configured capacity in Scenario 2. The configured power of the SES is 15.12% lower than the total configured power in Scenario 2, and the total system expenditure is reduced by 24.25%.

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