Shared energy storage market operation mechanism to promote new energy consumption

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Abstract. The configuration of energy storage helps to promote renewable energy consumption, but the high cost of energy storage becomes a major factor limiting its development. Through shared energy storage, the utilization rate of energy storage can be improved and the recovery of energy storage investment costs can be accelerated. This paper first introduces the application scenarios of the proposed shared energy storage, then analyzes the characteristics of shared energy storage. Furthermore, the transaction process between new energy and shared energy storage is put forward, and the clearing model of shared energy storage market is established. To minimize the consumption cost of new energy generators by coordinating the sharing of idle energy storage capacity. Finally, the proposed method is verified through examples to analyze the benefits of shared energy storage for investors and new energy generators, as well as the changes in new energy consumption.

1. Introduction
With the continuous deterioration of the global environment, it has become the consensus of many countries to use non-fossil renewable energy to carry out energy transformation and deal with the global greenhouse effect. In recent years, the installed capacity of renewable energy in the world has been continuously increasing [1-2]. According to the National Energy Administration, by the end of August 2020, China's installed capacity of wind power and photovoltaic power had both reached 220 million kW. In order to achieve the goal of peaking carbon dioxide emissions by 2030, China's total installed capacity of wind power and photovoltaic power is expected to reach more than 1.2 billion kW. When new energy is connected to the power grid on a large scale, the volatility will have a significant impact on the power system. How to achieve a balance between supply and demand on the grid and ensure grid security will become a major challenge for the power system[3].

Energy storage can smooth out the volatility of new energy, storing electricity during times of abundant new energy generation resources and releasing it at low times, thus smoothing the output curve of new energy. At the same time, energy storage also plays an important role in power system peak and frequency regulation, providing reserve capacity, alleviating transmission congestion and so on. However, the current energy storage cost is still high, the scale of investment in energy storage is large, the investment return period is long, and the revenue model of energy storage is relatively single, all of which limit the development of energy storage [4]. Introducing the concept of sharing economy into energy storage can effectively solve the problem of cost and revenue model of energy storage. Different
types of users have different energy storage time and capacity. Users can get more benefits by sharing their own idle energy storage. At the same time, new energy can also save the investment of installing supporting energy storage.

Reference [5] proposed a new energy management method for residential communities consisting of distributed photovoltaic and energy storage, studied the uncertainty between solar power generation and power load, and minimized the cost of electricity for users through comprehensive utilization of userside energy storage. Reference [6] adopted model predictive control to optimize the scheduling of smart microgrid, mainly aiming at energy exchange between controllable load, energy storage, renewable energy and power grid. However, the market transaction process between energy storage and new energy has not been studied. At the current stage, the market mechanism that is conducive to the sharing of energy storage to give full play to its technical advantages has not been formed, and the multi-utilization value of energy storage has not been fully reflected. Therefore, this paper will study the trading mechanism of shared energy storage.

The main work of this paper is as follows: propose a shared energy storage operation scenario, and analyze the characteristics of each subject in the sharing. Then it proposes the transaction process between shared energy storage and new energy generators, and builds a market clearing model between the two entities, so that both parties can benefit from the transaction. The benefits of the proposed mechanism for new energy generators and energy storage users are analyzed through a case.

2. Overview of market mechanism

2.1. Shared energy storage concept

The main difference between shared energy storage and conventional energy storage is to encourage users to use idle energy storage to participate in power regulation. And the purpose of sharing is to separate the "ownership" and "use right" of energy storage. The generation side buys the energy storage "use right" to meet the needs of their own power regulation. At the same time, users can benefit from this part of idle energy storage and achieve the optimal allocation of existing resources.

2.2. Shared energy storage operation scenario analysis

The shared energy storage market consists of three players: new energy generators, user energy storage and shared-energy storage operators that organize transactions. Shared user energy storage comes from industrial users, commercial users, residential areas and electric vehicles equipped with energy storage. The main difference between shared energy storage and energy storage station lies in that it is invested by users. First of all, the energy storage needs of users should be met, and the energy storage during idle period of users should be shared with new energy to improve the utilization rate of energy storage.
As shown in figure 2, the sharing of energy storage mainly solves the intermittence of new energy generation and reduces the phenomenon of abandoning wind and light to promote the consumption of new energy. When new energy generation is at its peak, excess electricity needs to be sold to shared energy storage; when new energy generation is at its valley, it is necessary to buy electricity from energy storage to supplement the generation curve. In the shared market, considering the volatility of new energy, the characteristics of a large number of shared energy storage and random idle capacity, an effective market mechanism can guide the energy interaction between new energy and shared energy storage. At the same time, it can reduce the impact of the times and depth of energy storage charge and discharge on the life of energy storage. In this paper, the idle charge and discharge capacity and power of energy storage are reflected in the cost of energy storage.

2.3. Transaction mode

The shared energy storage transaction is mainly for the small and medium-sized new energy stations near the energy storage on the user side. Each new energy generator gives to the shared energy storage operator the amount of electricity that needs to be replenished or absorbed in each period of the next day, as well as the corresponding purchase and sale price. And the energy storage users reports to the operator the idle capacity of energy storage in each period of time, that is, the amount of electricity that can be absorbed or released. At the same time, energy storage users also need to declare the maximum and minimum state of charging (SOC), charge and discharge efficiency.

The shared energy storage spot market is cleared every 15 minutes, which means that 96 electricity prices for energy storage to supplement new energy output and 96 electricity prices for purchasing new energy surplus electricity are cleared every day. The two parties participating in the shared energy storage market settle accounts every hour, and the price takes the arithmetic average of four electricity prices within an hour. The shared energy storage operators publishes 24-hour settlement list of the shared energy storage market for new energy and energy storage users every day.

2.4. Transaction process

In the shared energy storage market proposed in this paper, both the new energy and the energy storage owner may be either party of the buyer or the seller. In the transaction, the buyer hopes to obtain the electric energy at a lower price, while the seller hopes that the electrical energy they own will generate greater value. The final transaction price should meet the incentive compatibility. The transaction process in this paper is show in figure 3.

![Figure 3. Transaction process.](image)

3. Shared energy storage clearing model

3.1. Objective function

In this paper, the lowest cost of new energy is taken as the objective function. Determine the electric energy of new energy purchased from or sold to the energy storage in each period. And analyze the transaction process between new energy and shared energy storage.

\[
F = \lambda_2 \sum_{i=1}^{T} \sum_{t=1}^{T_n} p_{i,t} - \lambda_1 \sum_{i=1}^{T} \sum_{t=1}^{T_n} p_{i,t} - \mu \sum_{i=1}^{T} \sum_{t=1}^{T_n} p_{i,t} \tag{1}
\]

\(F\) is the cost function of new energy in the shared energy storage market. \(p_{i,t}\) and \(\lambda_1\) are the excess electricity and electricity price sold to energy storage at the peak of new energy. \(p_{i,t}\) and \(\lambda_2\) are the electricity and electricity prices purchased from energy storage when there is a shortage of new energy.
3.2. Constraint condition

3.2.1. Electric power balance constraint. The purpose of building a shared energy storage market is to smooth the volatility of new energy sources. According to the energy output of new energy, the energy of stored charge and discharge is coordinated to make the combined power output be the curve required by dispatching.

\[
P_{\text{net}} = \sum_{i=1}^{n} P_{i,t} + \sum_{i=1}^{n} (P_{i,t} - P_{i,t})
\]

(2)

In the equation, \( P_{\text{net}} \) is the joint output after shared energy storage participates in new energy power generation in time period \( t \). \( P_{i,t} \) is the output of new energy power generation in the region in time period \( t \).

3.2.2. Energy storage operation constraints. The user's own useful energy demand will affect the maximum charge and discharge energy when the energy storage is shared. Assuming that the expected value of users at the end of \( t \) period is \( \text{SOC} \), and the initial value is \( \text{SOC}_0 \), the available capacity is:

\[
\text{ESS}(t) = (\text{SOC}_0 - \text{SOC}) E_{\text{ess}}
\]

(3)

In the transaction process of new energy and user energy storage, the limits of each energy storage capacity shall be met:

\[
\text{ESS}_{\text{min}} \leq \text{ESS}(t) \leq \text{ESS}_{\text{max}}
\]

(4)

\( \text{ESS}_{\text{min}} \) is the capacity of stored energy \( i \) in time period \( t \); \( \text{ESS}(t-1) \) is the capacity of the previous period; \( \eta_{\text{ch}} \) and \( \eta_{\text{dis}} \) are the charging and discharge efficiency of energy stored \( i \); \( \text{ESS}_{\text{ess}} \) and \( \text{ESS}_{\text{max}} \) are the minimum and maximum capacity of energy storage \( i \).

Power constraints of each stored energy charge and discharge:

\[
0 \leq P_{i,t} \leq P_{\text{max,}} U_{\text{ch}} \leq P_{\text{max,}} U_{\text{dis}} \leq 1
\]

(5)

In the equation, \( U_{\text{ch}} \) and \( U_{\text{dis}} \) are the charge and discharge states of energy storage \( i \); \( P_{\text{max,}} \) is the maximum charge and discharge power of energy storage \( i \). Energy storage is only one state of charge or discharge at the same time.

3.3. New energy consumption.

After comparing the power generation curve predicted by the new energy with the output curve issued by the dispatching department, the energy storage demand \( \Delta P_i \) can be reported to the shared energy storage operator.

\[
Q_{\text{net}} = \sum_{i} P_{\text{net}}
\]

(6)

\[
\Delta P_i = P_{\text{net,}} - P_{\text{net,}}
\]

(7)

\( Q_{\text{net}} \) is the daily total amount of new energy power generation, and the unit is \( k\text{Wh} \). \( P_{\text{net,}} \) is the generation of new energy, and the unit is \( k\text{Wh} \). \( \Delta P_i \) refers to the deviation between new energy and load demand. When it is positive, energy storage is needed to absorb excess electricity; when it is negative, energy storage is needed to supplement the generation curve.

3.4. Income of energy storage users.

The income of shared energy storage comes from the low-cost abandonment of wind and photovoltaic power purchased from new energy, and the amount of electricity sold to generators when new energy is
insufficient.

\[ M = \sum_{i=1}^{n} \sum_{t=1}^{T} (\mu_i - \lambda_i) P_{i,t} + \sum_{i=1}^{n} \sum_{t=1}^{T} \lambda_i P_{i,t} - \sum_{i=1}^{n} C_i \]  \hspace{1cm} (8)

\( M \) is the income of all shared energy storage, and \( C_i \) is the daily operating cost of energy storage. The energy storage cost is related to the installation capacity, charging and discharging depth and times of the energy storage system.

\[ C_i = \delta \sum_{i=1}^{n} E_{\text{max}}(i) + \delta \sum_{i=1}^{n} E_{\text{max}}(i) + \delta \sum_{i=1}^{n} E_{\text{max}}(i) \]  \hspace{1cm} (9)

\( E_{\text{max}}(i) \) is the charging and discharging depth of stored energy \( i \); \( E_{\text{max}}(i) \) is the over-charge and over-discharge capacity of energy storage \( i \); \( E_{\text{max}}(i) \) is the installation capacity of energy storage \( i \); \( \delta_i \) and \( \delta_n \) are the corresponding weight of energy storage cost respectively.

3.5. Determine the price of energy storage.

In order to reduce the times of charging and discharging of stored energy, when the charging and discharging energy of stored energy is closer to the usable capacity, the higher the charging price and the lower the discharging price is given.

\[
\begin{align*}
\lambda_1 &= \varepsilon_1 \frac{\Delta P_{\text{ESS}}}{\text{ESS}(t)} \lambda_1 &
\lambda_2 &= \varepsilon_2 \frac{\Delta P_{\text{ESS}}}{\text{ESS}(t)} \lambda_2
\end{align*}
\]  \hspace{1cm} (10)

\( \lambda_1 \) and \( \lambda_2 \) are the charge price and discharge price after accounting; \( \lambda_1 \) and \( \lambda_2 \) are the charge cost price and discharge cost price respectively; \( \varepsilon_1 \) and \( \varepsilon_2 \) are the coefficients.

4. Case study

In order to verify the effectiveness of the energy storage sharing scheme proposed in this paper in promoting new energy consumption, the 5MW distributed wind power consumption in a certain area is analyzed. Figure 3 shows the actual output and scheduling curve of the wind farm.
purchase electricity from new energy and sell electricity to new energy is high. When the energy storage SOC is high, there is more electric energy to sell, and the price of electricity purchased from new energy and sold to new energy is lower. The energy storage system cannot be in the state of charging and discharging at the same time, so it is considered that the user does not charge the energy when using the energy storage.

As shown in Figure 5, the simulation results of the example show that electric vehicles mainly participate in sharing from 23:00 to 3:00 in the evening. Residents mainly participate in energy storage sharing from 8:00-18:00. And industrial users mainly participate in sharing at night. In order to achieve the same absorbing capacity as shared energy storage, power generation companies need to configure 1.2MWh energy storage, which costs 1.2 million yuan at the unit price of 1 yuan /Wh of the energy storage system. The user-shared energy storage method can make the new energy gain new revenue by selling electricity when consuming the abandoned wind, and can reduce the penalty for prediction deviation. In the process of sharing energy storage, users can obtain new benefits by purchasing low-price electricity and buying low and selling high.

5. Conclusion
With the increasing proportion of new energy in the power supply, energy storage configuration is helpful to promote the consumption of new energy. This paper reduces the cost of energy storage configuration for new energy generation companies through the sharing of energy storage by users. The transaction flow between new energy and shared energy storage is proposed, and the market clearing model of shared energy storage is established. The results of the example show that the sharing of energy storage by users can also promote the consumption of new energy, save the high cost of independent configuration of energy storage. Shared energy storage improves the utilization rate of user energy storage and accelerates the payback period of energy storage investments.

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