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# Optimized Power and Capacity Configuration Strategy of a Grid-Side Energy Storage System for Peak Regulation

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**Abstract:** The optimal configuration of the rated capacity, rated power and daily output power is an important prerequisite for energy storage systems to participate in peak regulation on the grid side. Economic benefits are the main reason driving investment in energy storage systems. In this paper, the relationship between the economic indicators of an energy storage system and its configuration is first analyzed, and the optimization objective function is formulated. Then, according to the objective limitations of the energy storage system configuration and operation, the constraints are formulated. A set of typical parameters is selected, and the CPLEX (IBM ILOG CPLEX Optimization Studio) solver is used in MATLAB to solve the optimal configuration results. Several sets of optimization results are obtained by taking different subjective coefficient $\beta$ values, and the economic and social benefits of the optimization results are analyzed. When the economic benefits of the energy storage system are more important, the value of $\beta$ needs to be smaller, such as a value of 1000. Conversely, when the peak-regulation effect is more important, the value of $\beta$ should be larger. Finally, configuration results of the control groups are given, and the effect of optimizing the calculation for improving economic benefits is verified.

**Keywords:** energy storage; optimize configuration; peak regulation



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## 1. Introduction

Electricity is an indispensable part of modern life and production. The load connected to the power grid is also increasing and becoming more diversified with the development of society. The peak-to-valley difference of the load increases year by year, which increases the pressure on the capacity expansion of power transmission and distribution equipment, and it also reduces the equipment utilization rate. Battery energy storage [1–5] has the characteristics of fast response, convenient control, high energy utilization rate, and less environmental pollution, which make it applicable to energy services [6–8].

In recent years, many scholars have conducted research on grid-side energy storage systems. The authors of [9] provide a comprehensive review and outlook on the technologies and applications of grid-scale battery energy storage systems based on the current development status and engineering practices. In [10], based on the analysis of the operation mode of the Lang Li energy storage power station, the authors study the detection method of anti-island protection to help ensure the safe and reliable operation of grid-side energy storage power stations. Technical details, control strategies, testing methodology, and economic analysis of a real-world grid-connected battery energy storage system project are presented in [11], and the discussion aims to provide practical engineering experience and guidance for similar BESS projects. The authors of [12] provide a comprehensive review of energy management systems and optimization tools that are needed for the efficient operation of energy storage in the existing grid infrastructure and grids of the future, including energy storage models [13,14], optimization approaches [15,16], market applications [17,18], and so on.

The battery energy storage system is flexible to control and fast in response, and it can achieve good benefits after being put into the grid [19,20]. But, at the same time, its cost is relatively high [21]. Its configuration and operation control need to be optimized to obtain the best economic and social benefits, especially in large-capacity scenarios like the network side. In [22], the sizes of the battery energy storage systems required to support a grid-connected microgrid and a stand-alone microgrid for 12 months, considering hourly wind power potential, are investigated. The study considers three scenarios of operations and evaluates and analyzes the operational environmental effects and costs among these three scenarios. In [23], a capacity optimization configuration strategy for grid side-user side energy storage system is proposed based on the cooperative game method, considering the income of grid-side energy storage investors and user-side energy storage investors under the power supply income and whole-life-cycle cost. In [24], a multi-objective planning approach to the optimal site and size of the battery energy storage system for peak-load-demand support of radial distribution networks is presented. A set of trade-off solutions in view of the total investment and operational costs are given. The authors of [25] suggest a method to place and size the battery energy storage system optimally to minimize total system losses in a distribution system. The duck-curve phenomenon is taken into consideration, and it is optimized using a metaheuristic algorithm with high exploration and exploitation ability known as the Whale Optimization Algorithm (WOA) [26]. Meanwhile, the performance of the WOA was validated using other algorithms, i.e., Particle Swarm Optimization [27] and the Firefly algorithm [28]. In [29], a superior control strategy that uses distributed energy storage to reduce the peak-valley difference of the load curve is presented. Constraints such as energy storage capacity, power, and state of charge are considered. In [30], a capacity allocation method for an energy storage system under a peak-load regulation scenario is proposed. The optimization goal of the upper model is to maximize the net income of the energy storage life cycle, while the goal of the lower model is to minimize the net load of the system and the standard deviation of waste wind power. To sum up, there are currently many studies on the optimal configuration of battery energy storage systems and their participation in peak regulation. The configuration of energy storage devices in multiple scenarios, the detailed modeling of revenue models, and the improvement and optimization of optimization algorithms are all the focus of research. The configuration and operation mode of the energy storage system jointly determine its economic benefits and peak-regulation effects. Planning the output of the energy storage system while optimizing the configuration can further improve its comprehensive benefits, which is worth studying.

In the optimized power and capacity configuration strategy of a grid-side energy storage system for peak regulation, economic indicators and the peak-regulation effect are two key considerations. In this paper, the peaking effect is added to the economic indicators in the form of saving the cost of expansion. The economic indicators are supplemented by the load-smoothing effect on the load curve to obtain an optimized objective function. The relationship between the rated power, rated capacity, and daily operation mode of the energy storage system and the optimization objective function is studied in this paper. After the model is established, the energy storage system's rated power and capacity and the daily operation mode are optimized so that the energy storage system has good economic benefits while realizing the peak shaving function.

## 2. Mathematical Model for Optimization Calculation

### 2.1. Objective Function

The optimized configuration strategy proposed in this paper takes comprehensive economic indicators as the optimization objective function. The energy storage system mainly relies on arbitrage in time-of-use electricity prices to make profits, and the government usually provides certain subsidies as support. In terms of cost, a one-time investment cost is required, including the cost of energy storage batteries, power converters, and monitoring and protection facilities. In addition, daily operation and maintenance also consume money. Finally, after the grid-side energy storage system is put into use, it can flatten the load curve by shaving peaks and filling valleys, reducing the expansion pressure on the power grid. These are all potential benefits of the energy storage system.

Therefore, the optimization objective function of this paper combines the above factors and can be expressed as:

$$f = f_i + f_o - f_a - f_s - f_b \tag{1}$$

where $f$ is the objective function of the optimization model, $f_i$ is the investment cost of the energy storage system, $f_o$ is the operation and maintenance cost, $f_a$ is the arbitrage in time-of-use electricity prices, $f_s$ is the government subsidy, and $f_b$ is the potential benefit of the grid-side energy storage system investment.

The above values should be converted to daily values in order to optimize the daily operation mode of energy storage. The cost term in the objective function is positive, and the benefit term is negative. Therefore, the optimization calculation is to find the minimum value of the objective function so that the energy storage system can achieve good comprehensive economic benefits.

- Investment Cost

The energy storage system consists of energy storage batteries, power converters, and auxiliary equipment. Under the condition of consistent models, the investment cost of energy storage batteries is related to its quantity, that is, related to the capacity of the energy storage system. The power converter realizes the power control of the energy storage system, and its investment cost is roughly positively correlated with the rated power. The amount of auxiliary equipment is related to the scale of the energy storage system, so the investment cost of this part is approximately positively related to the rated capacity. The total investment cost of the energy storage system is given in Equation (2).

$$\begin{aligned} f_{ia} &= k_b C + k_c P + k_a C \\ &= k_{a,b} C + k_c P \end{aligned} \tag{2}$$

where $f_{ia}$ is the total investment cost; $C$ is the rated capacity of the energy storage system, MWh; $P$ is the rated power of the energy storage system, MW; $k_b$ is the investment cost of energy storage battery per unit capacity, USD/MWh; $k_c$ is the investment cost of the power converter per unit power, USD/MW; $k_a$ is the investment cost of auxiliary equipment per unit capacity, USD/MWh; and $k_{a,b} = k_a + k_b$.

To obtain an approximate daily investment cost, the total investment cost is converted to an equivalent annual value and divided by the number of days per year. The daily investment cost is given in Equation (3).

$$f_i = (k_{a,b} C + k_c P) \frac{r(1+r)^n}{365\left[(1+r)^n - 1\right]} \tag{3}$$

where $r$ is the annual interest rate, and $n$ is the service life of the energy storage system y.

- Operation and Maintenance Cost

The operating cost of the energy storage system is relatively fixed, and its labor and technical costs are related to the scale of energy storage. Therefore, it can be considered that the operating cost is approximately positively correlated with the rated power of energy storage. The maintenance needs of an energy storage system have a certain relationship with their usage. In this paper, it is considered that the maintenance cost is related to the amount of charge and discharge. These two constitute the operation and maintenance cost. The daily operation and maintenance cost of the energy storage system is given in Equation (4).

$$f_o = k_{lt}P + k_m\sum_{i=1}^{24}|P_i| \tag{4}$$

where $k_{lt}$ is the daily operation and maintenance cost per unit rated power, USD/MW; $k_m$ is the daily operation and maintenance cost per unit of charge and discharge, USD/MW; and $P_i$ is the output power of the energy storage system at time $i$, MW.

- Arbitrage in Time-of-Use Electricity Prices

The arbitrage in time-of-use electricity prices means that the energy storage system is charged from the grid during valley hours or at ordinary times, and it supplies power to the grid during peak hours so as to obtain the difference in price. The arbitrage in time-of-use electricity prices is given in Equation (5).

$$f_a = \sum_{i=1}^{24} e_iP_i \tag{5}$$

where $e_i$ is the electricity price at time $i$, USD/MWh.

When the energy storage system is discharged, the output power is positive, and when charging, the output power is negative.

- Government Subsidy

There are various forms of government subsidies. Energy storage systems can be subsidized only once according to the rated power or subsidized according to the amount of discharge. The government subsidy is given in Equation (6).

$$f_s = k_{sp}P\frac{r(1+r)^n}{365\left[(1+r)^n - 1\right]} + \frac{e_s}{2}\sum_{i=1}^{24}|P_i| \tag{6}$$

where $k_{sp}$ is the one-time subsidy for the unit-rated power, USD/MW, and $e_s$ is the subsidized price per unit of discharge, USD/MWh. Daily charge and discharge of the energy storage device should be conserved such that the discharge capacity is half of the absolute sum of the total charge and discharge capacity.

- Potential Benefits

The potential benefit of grid-side energy storage system investment is mainly reflected in the reduction effect on the peak value of the load curve, which directly reduces the expansion pressure on the distribution network. Potential investment in expansion equipment is saved. In addition, the energy storage system should help to smooth the load curve and improve the overall utilization of the transmission and distribution network. This benefit can be taken into consideration in the form of the load's standard deviation interpolation before and after the energy storage input. Potential benefit is given in Equation (7).

$$f_b = k_p(\max\{L_i\} - \max\{L_i - P_i\}) + \beta(\sigma_l - \sigma_{lb}) \tag{7}$$

where $k_p$ is the cost of expansion equipment per unit of power, USD/MW, which is converted to a daily value; $L_i$ is the load power at time $i$, MW; $\beta$ is the quantization coefficient of the smoothing effect of the energy storage system on the load curve, USD; $\sigma_l$ is the standard deviation of daily load power; and $\sigma_{lb}$ is the standard deviation of the daily load plus energy storage power.

Combining Equations (1) and (3)–(7), the objective function expression of the optimization model in this paper is obtained as follows.

$$f = \frac{k_{a,b}r(1+r)^n}{365\left[(1+r)^n-1\right]}C + \left\{\frac{(k_c-k_{sp})r(1+r)^n}{365\left[(1+r)^n-1\right]} + k_{lt}\right\}P + \left(k_m - \frac{e_s}{2}\right)\sum_{i=1}^{24}|P_i| - \sum_{i=1}^{24}e_iP_i - k_p(\max\{L_i\} - \max\{L_i - P_i\}) - \beta(\sigma_l - \sigma_{lb}) \tag{8}$$

In this objective function, $C$, $P$ and $\{P_i\}$ are decision variables. Their coefficients are objective values. Values of $C$ and $P$ correspond to the configuration of the rated power and capacity of the energy storage system. And the value of $\{P_i\}$ corresponds to the configuration of the output power of the energy storage system at different times of the day. The essence of the optimization calculation is to obtain the value of the decision variable when the objective function reaches the minimum value. The constant term in the objective function has no influence on the optimization calculation result and can be omitted, so the objective function can be simplified to:

$$f = K_{fc}C + K_{fp}P + K_{fpi}\sum_{i=1}^{24}|P_i| - \sum_{i=1}^{24} e_i P_i + k_p \max\{L_i - P_i\} + \beta\sigma_{lb} \tag{9}$$

where:

$$\begin{cases} K_{fc} = \frac{k_{a,b} r(1+r)^n}{365\left[(1+r)^n - 1\right]} \\ K_{fp} = \frac{\left(k_c - k_{sp}\right) r(1+r)^n}{365\left[(1+r)^n - 1\right]} + k_{lt} \\ K_{fpi} = k_m - \frac{e_s}{2} \end{cases} \tag{10}$$

*2.2. Restrictions*

The objective function of the optimization model proposed in this paper takes the rated power and capacity of the energy storage system and the output power of one day as the decision variables. The values of these decision variables are constrained by objective conditions and operation rules of the energy storage systems. The constraints considered in this paper are as follows:

- Constraints on Rated Power and Capacity

The configuration of the energy storage system needs to match the grid and load level of the access point, and it is limited by the site and investment scale, so there are corresponding upper and lower limits for its rated power and capacity. Constraints on the rated power and capacity can be expressed as:

$$\begin{cases} P_{\min} \le P \le P_{\max} \\ C_{\min} \le C \le C_{\max} \end{cases} \tag{11}$$

where $P_{\min}$ is the lower limit of the rated power, MW; $P_{\max}$ is the upper limit of the rated power, MW; $C_{\min}$ is the lower limit of the rated capacity, MWh; and $C_{\max}$ is the upper limit of the rated capacity, MWh.

- Output Power Limit for the Energy Storage System

The output power of the energy storage system should not exceed its rated power, so the output power limit for energy storage system is expressed as:

$$-P \le P_i \le P \tag{12}$$

- Conservation of Daily Charge and Discharge

This article optimizes the output power of an energy storage system over a day. In order to ensure the stability of operation, the daily charge and discharge power need to be balanced. Otherwise, the state of charge (SOC) of the energy storage battery will rise or fall day by day, reaching the charge or discharge limit. This is not conducive to the continuous operation of the energy storage system. This restriction can be expressed as:

$$\sum_{i=1}^{24} P_i = 0 \tag{13}$$

- SOC Limit for Energy Storage Batteries

In order to ensure the safe and stable operation of energy storage batteries, their SOC cannot exceed the set upper and lower limits. The SOC limit for energy storage batteries is expressed as:

$$Q_{\min} \leq Q_i \leq Q_{\max} \tag{14}$$

$$Q_i = Q_0 - \sum_{j=1}^{i} \frac{P_j}{C} \tag{15}$$

where $Q_0$ is the initial SOC of the energy storage batteries at the beginning of one day.

*2.3. Optimization Model*

As shown in Equation (9), the variables of the objective function proposed in this paper are $C$, $P$, and $\{P_i\}$. Therefore, the objective function can be expressed in a compact form as:

$$f = f(C, \boldsymbol{P}) \tag{16}$$

where $\boldsymbol{P} = (P, P_1, P_2, \ldots, P_{24})$.

Equation (13) constitutes the equation constraint of the optimization model and can be simplified as:

$$g(\boldsymbol{P}) = 0 \tag{17}$$

Equations (11), (12) and (14) constitute the inequality constraints of the optimization model and can be simplified as:

$$\boldsymbol{h}(C, \boldsymbol{P}) \leq 0 \tag{18}$$

In summary, the mathematical model for the optimized configuration strategy can be expressed as:

$$\left.\begin{array}{r} \min f(C, \boldsymbol{P}) \\ \text{s.t. } g(\boldsymbol{P}) = 0 \\ \boldsymbol{h}(C, \boldsymbol{P}) \leq 0 \end{array}\right\} \tag{19}$$

When the objective function of the optimization model is taken to the minimum value, the optimal state is reached. The corresponding decision variable value is the optimized power and capacity configuration of the energy storage system.

## 3. Case Study

In order to realize the power- and capacity-optimization configuration of a grid-side energy storage system for peak regulation, a mathematical model of the optimization calculation is proposed in the Section 2. The CPLEX (IBM ILOG CPLEX Optimization Studio V12.8.0) optimizer in MATLAB R2016b is used in this paper to solve the optimization model. It provides a flexible, high-performance mathematical programming solver for linear programming, mixed-integer programming, quadratic programming, and quadratic-constrained programming problems. CPLEX Optimizer's mathematical programming technology enables decision optimization to increase efficiency, reduce costs, and increase profitability.

As shown in (9), the variables in the objective function $f$ are $C$, $P$, and $\{P_i\}$. Values of the coefficients $K_{fc}$, $K_{fp}$, $K_{pi}$, $e_i$, and $k_p$ in the formula are determined by the actual value of the various energy storage system costs, electricity prices, subsidies, etc. These coefficients are relatively fixed for energy storage systems that are planned to be invested in the same region. The quantitative coefficient of the smoothing effect on the load curve is a subjective value, which indicates the importance of the smoothing effect in optimization problems. In this paper, a set of objective coefficients is selected to solve the model, the optimal configuration effect is verified, and the influence of subjective factors on the solution results is studied.

### 3.1. Model Data

The typical daily load curve and time-of-use electricity prices used in this paper are shown in Figure 1 below. The peak load is about 54 MW at 9:00 and the valley is 28 MW at 4:00. The peak-to-valley difference is nearly 26 MW.

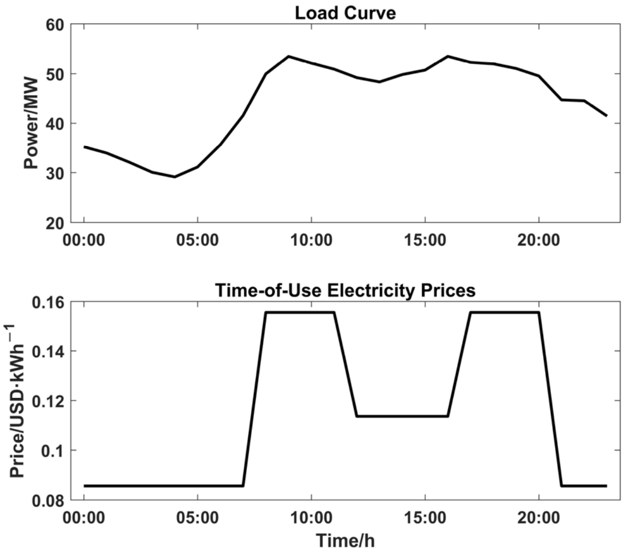


**Figure 1.** Typical daily load curve and time-of-use electricity prices.

This typical daily load is dominated by industrial and residential loads, with two peaks around 9:00 and 16:00. The two peak times coincide with peak times of the time-of-use electricity prices. Energy storage systems provide energy to the grid during peak load periods, relieving the load pressure while reaping the benefits of electricity sales.

The values of the objective parameters are shown in Table 1 below.

**Table 1.** Values of the objective parameters.

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $k_{a,b}$ (USD/MWh) | 315,000 | $k_c$ (USD/MW) | 67,900 |
| $r$ (%) | 4.2 | $n$ (year) | 10 |
| $k_{lt}$ (USD/MW) | 14 | $k_m$ (USD/MWh) | 12.04 |
| $k_{sp}$ (USD/MW) | 14,000 | $e_s$ (USD/MWh) | 21 |
| $k_p$ (USD/MW) | 167.16 | $P_{\min}$ (MW) | 1 |
| $P_{\max}$ (MW) | 10 | $C_{\min}$ (MWh) | 2 |
| $C_{\max}$ (MWh) | 50 | $Q_0$ (%) | 10 |
| $Q_{\min}$ (%) | 10 | $Q_{\max}$ (%) | 90 |

### 3.2. Calculation Results

Section 3.1 gives the set of objective parameter values selected in this paper. The quantitative coefficient $\beta$ of the smoothing effect on the load curve is a subjective value. A set of optimization results is obtained under different values of $\beta$, as shown in Figure 2.

The first chart of each panel shows the original load curve with a dashed line, and the comprehensive load curve after adding an energy storage system for peak regulation is shown with a solid line. The second chart shows the output power of the energy storage system for each hour of the day. When the energy storage system is discharged, the output power is positive, and when charging, the output power is negative.

The numerical results obtained from the four cases corresponding to Figure 2 are recorded in Table 2. In this paper, the daily income of the energy storage system and the smoothing effect are considered in order to compare the optimization schemes under different $\beta$ values. The daily income consists of members of Equation (1), while the smoothing effect index is characterized by the standard deviation of the comprehensive load curve after energy storage peaking:

$$\begin{cases} f_{di} = f_a + f_s - f_i - f_o \\ f_{se} = \sigma_{lb} \end{cases} \tag{20}$$

where $f_{di}$ is the daily income of the energy storage system, and $f_{se}$ is the smoothing effect of the energy storage system on the load curve.

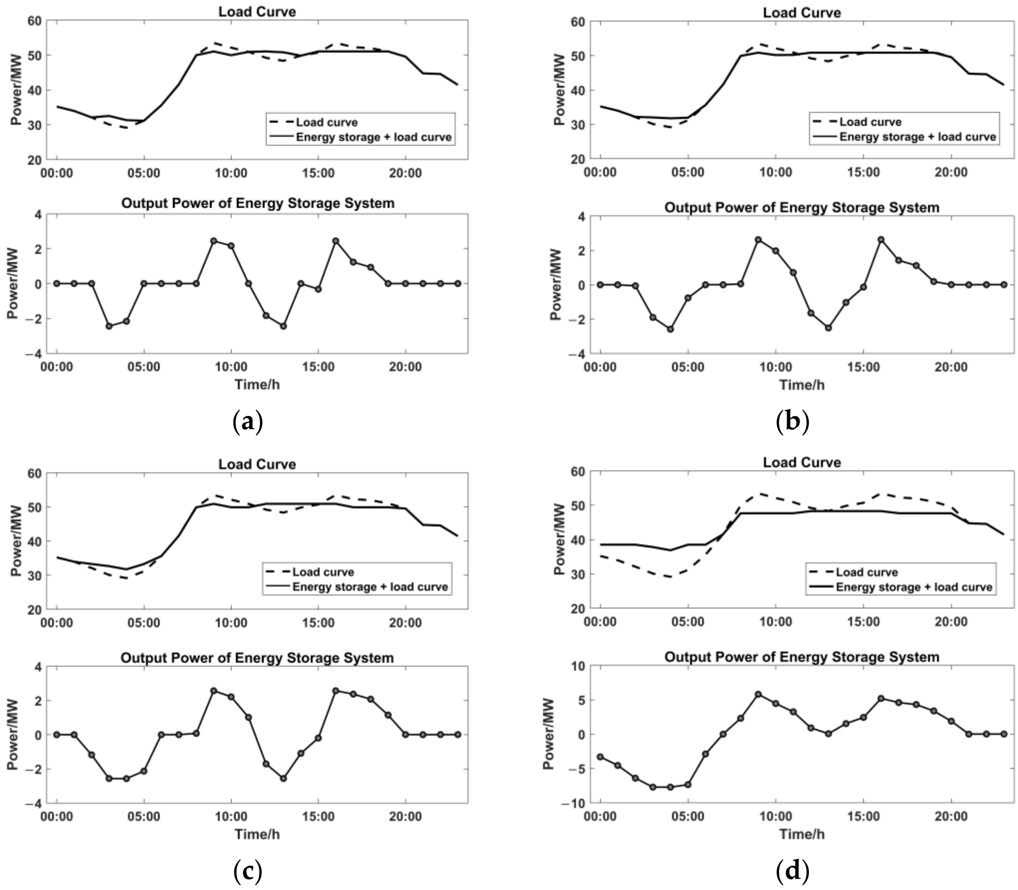


**Figure 2.** Optimization results under different values of $\beta$: (**a**) $\beta$ = 0; (**b**) $\beta$ = 1000; (**c**) $\beta$ = 5000; (**d**) $\beta$ = 10,000.

**Table 2.** Optimization results under different values of $\beta$.

| $\beta$ | $P$ (MW) | $C$ (MWh) | $f_{di}$ (USD) | $f_{se}$ (MW) |
|---|---|---|---|---|
| 0 | 2.4440 | 5.7627 | 95.4030 | 7.8988 |
| 1000 | 2.6275 | 6.6806 | 91.5096 | 7.8151 |
| 5000 | 2.5701 | 10.564 | −114.409 | 7.5038 |
| 10,000 | 7.7185 | 50.000 | −2502.78 | 4.4281 |

In order to verify the effect of the optimization method proposed in this paper, a conventional energy-storage device peak-regulation configuration is used as a comparison to compare the economical and smoothing effects of the energy storage system under the same peak-regulation effect. Figure 3 shows a schematic diagram of this peak-regulation configuration. The energy storage system discharges at the peak of the load and charges at the valley, which has the effect of peak shaving and valley filling. In order to make full use of the rated power of the energy storage system, the maximum power should be reached during discharge, which should not be exceeded at any time during discharge. In the case shown in Figure 3, the charging capacity of the energy storage in the early morning is not enough to balance the discharging capacity during the peak load. Therefore, the energy storage will also be charged during the local trough period at noon. In Figure 3, the amount of charge is represented by the blue area and the amount of discharge is represented by the red area. If this still fails to balance the charging and discharging capacity, the maximum power in the charging phase will exceed the maximum power in the discharging phase.

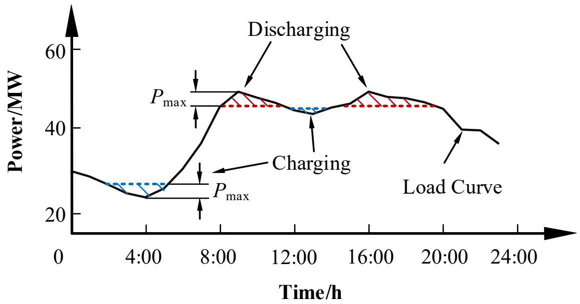


**Figure 3.** A conventional peak-regulation configuration for comparison.

In order to achieve a comparison effect, this paper performs this group of calculations under the same peak-regulation effect. The same peak-regulation effect means the same maximum output power of the energy storage system. The calculated results of this group of examples are shown in Table 3, and comparisons of the load curves after the participation of energy storage are shown in Figure 4. The parameters used are the same as before.

**Table 3.** Calculation results of the conventional configuration.

| Case | $P$ (MW) | $C$ (MWh) | $f_{di}$ (USD) | $f_{se}$ (MW) |
|---|---|---|---|---|
| a | 2.4440 | 5.5049 | −333.6144 | 7.9142 |
| b | 2.6275 | 6.1931 | −360.9550 | 7.8542 |
| c | 2.5701 | 5.9778 | −353.7505 | 7.8728 |
| d | 7.7185 | 38.543 | −2691.292 | 5.2925 |

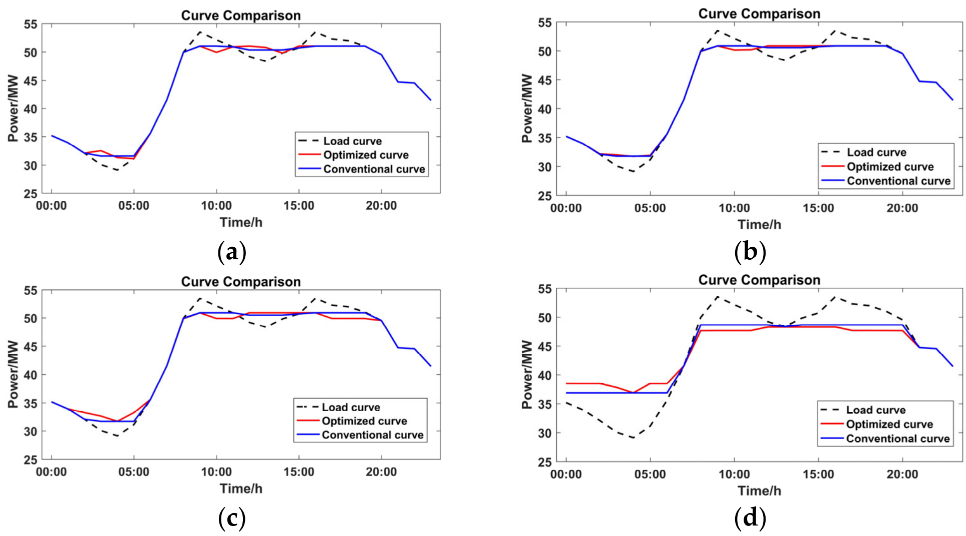


**Figure 4.** Comparison of load curves after the participation of energy storage: (**a**) $\beta$ = 0; (**b**) $\beta$ = 1000; (**c**) $\beta$ = 5000; (**d**) $\beta$ = 10,000.

## 4. Discussion

Figure 2 and Table 2 show the optimization results under four different $\beta$ values. In the Section 3, the $\beta$ value is gradually increased for the optimization calculation, and four groups of optimization results with different characteristics are selected. The $\beta$ value indicates the importance of the smoothing effect in optimization problems; the larger $\beta$

is, the smaller $f_{se}$ is, and the better the smoothing effect of the load curve obtained. In contrast, an energy storage system with greater power and capacity needs to be configured to achieve better smoothing results, which affects the economics. It is shown in Table 2 that daily income $f_{di}$ gradually decreases as $\beta$ increases. And when the $\beta$ value is large, the energy storage system is in a loss state.

When $\beta$ is 0, the optimization calculation process does not consider the smoothing effect of the energy storage system on the load curve. At this time, the daily revenue of the energy storage system is the highest, and the rated power and capacity are relatively small values. When $\beta$ is 1000, the energy storage and load curve shown in Figure 2b is smoother than that of Figure 2a. The rated power and capacity of the energy storage system increases slightly, and daily income declines. When $\beta$ is 5000, the rated capacity of the energy storage system is significantly increased, and an economic loss is incurred. However, there is no significant improvement in the smoothing effect. In the first three cases, the energy storage system operates in a similar mode, charging in the early morning and noon, and discharging during the morning and afternoon. Appropriately increasing $\beta$ can improve the comprehensive load curve, but it should not be too large. When $\beta$ is 10,000, a new energy storage system operating mode appears. The energy storage system is charged in the early hours of the morning and discharged in the morning and afternoon. The energy storage battery undergoes one charge and discharge cycle every day, so the capacity needs to be relatively large, reaching the upper limit of 50 MWh. In such an operating mode, the economic benefits of the energy storage system are very poor. The $\beta$ value should not be made larger than 10,000.

In summary, when the smoothing effect of the energy storage system on the load curve is not considered, the daily income of the optimized energy storage system configuration and operation scheme is the largest. After the smoothing effect is added to the objective function, the social benefit of the energy storage system can be improved at the expense of a little economic benefit, but the value of $\beta$ should not be too large.

The optimal configuration results of energy storage systems are affected by many factors. Cost factors, electricity prices, and subsidies are the most direct ones. From the values of the cases in this paper, it is not advisable to build a large-capacity energy storage system. When $\beta$ is 0 or 1000, the energy storage system can achieve profitability. At this time, the value of $\beta$ is small, and the smoothing effect of the load curve is not valued. When $\beta$ is 5000, the smoothing effect accounts for a larger proportion of the objective function. To enhance the smoothing effect, the energy storage system needs to charge more electricity in the early morning to smooth out the load spikes. This means that there needs to be a significant increase in rated capacity. The increased investment and operation and maintenance costs of energy storage system expansion cannot be compensated for by increased revenue, which ultimately leads to a deficit. The shape of the load curve directly determines the operating mode of the energy storage system, which also has an impact on the results of the optimal configuration. When $\beta$ is 10,000, the energy storage system presents another operating mode in order to further improve the peak shaving effect. The energy storage battery undergoes one charge and discharge cycle every day, so the capacity needs to be relatively large, reaching the upper limit of 50 MWh. The economic efficiency is even worse in this case.

Constrained by various costs, energy storage systems often need to choose between economic benefits and peak shaving effects when being constructed. When the power, capacity, or daily operation mode are inappropriate, the energy storage system is in a loss-making state, as shown for the cases in Figure 2c,d. Therefore, it is necessary to carry out optimization calculations in the configuration process and to select suitable calculation results. This helps to improve economic efficiency and prevent losses after the construction of the energy storage system.

In the control group, only the peak-regulation effect is consistent with the optimization calculation results, without considering the existence of arbitrage space caused by the tiered electricity price. A reasonable increase in the charging and discharging capacity of the energy storage device can improve the overall economic benefits. As shown in Table 3, except for the maximum power of energy storage being the same, the capacity scale, daily income, and smoothing effect are all lower than the corresponding optimized calculation results. The cases shown in Figure 2b,c are at a loss state, but despite this, the amount of the loss is still less than the result under the conventional configuration. The energy storage system is not recommended to work at a loss, but optimizing the calculation can improve its economy as much as possible. When the energy storage system has to lose money in order to better stabilize the load peak, it can also effectively reduce the loss.

## 5. Conclusions

Aimed at addressing the configuration and output optimization problems of an energy storage system subjected to peak regulation on the grid side, an optimization model considering the economy of energy storage and the effect of peak regulation is studied in this paper. The model is solved using the CPLEX optimizer in MATLAB under objective constraints. The main results can be summarized as follows:

1. The objective function of the optimization model includes elements such as the investment, operation and maintenance cost of the energy storage system, arbitrage in time-of-use electricity prices, government subsidy, and social benefits of grid-side energy storage system investment.
2. The profitability of the energy storage system under the data is verified through the solution of the cases, and the optimal rated power, capacity, and daily operation mode of the energy storage system under different subjective coefficients are given. The typical daily load curve used in this article has a peak in the morning and one in the afternoon, and the trough is in the early hours of the morning. Therefore, energy storage systems are usually charged at night and in the early hours of the morning, and they are discharged during the day to suppress load peaks.
3. The smoothing effect of the energy storage system becomes more important in the optimization calculation with the increase in $\beta$, which results in an increase in the power rating and capacity of the energy storage system, and the ability to suppress load peaks more effectively. At the same time, the investment and operation and maintenance costs of energy storage systems will have increased significantly. The increase in economic benefits cannot cover the increase in costs. When the value of B is 5000 or greater, the energy storage system is in a loss-making state. Therefore, in the optimization calculation process, there is a trade-off between economic efficiency and the peak-regulation effect.
4. In order to verify the optimization calculation effect, a control group is studied under the same peak-regulation effect. Under this peak-shaving configuration method, the charging and discharging capacity of the energy storage system is lower. There is an overall loss, and the economic benefits are not as good as the optimized calculation results. In Case a and Case b, the energy storage capacity is increased by about 5% in the optimized calculation results, and the daily income is increased by more than 400 USD. In Case c and Case d, the energy storage capacity is significantly increased in the optimization calculation results to enhance the smoothing effect, and at the same time, the daily loss is reduced by about 200 USD.

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