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ARTICLE

Typical Application Scenarios and Economic Benefit Evaluation Methods of Battery Energy Storage System

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ABSTRACT

Energy storage system is an important means to improve the flexibility and safety of traditional power system, but it has the problem of high cost and unclear value recovery path. In this paper, the typical application scenarios of energy storage system are summarized and analyzed from the perspectives of user side, power grid side and power generation side. Based on the typical application scenarios, the economic benefit assessment framework of energy storage system including value, time and efficiency indicators is proposed. Typical battery energy storage projects are selected for economic benefit calculation according to different scenarios, and key factors are selected for sensitivity analysis. Finally, the key factors affecting economic benefit of the energy storage system are analyzed.

KEYWORDS

Battery energy storage system; application scenarios; economic benefit evaluation; sensitivity analysis

1 Introduction

Since 2016, China has issued several policies related to energy storage, and energy storage has entered a new stage of rapid development. Based on the characteristics of energy storage system, energy storage has been widely connected in all links of power system generation, transmission and distribution, and has been typically applied [1–3]. In engineering application, the reasonable and effective evaluation of economic benefits of energy storage system is of great significance to improve engineering benefits and value [4,5].

Scholars at home and abroad have carried out various studies on the economic benefit evaluation of energy storage system. They have made in-depth studies on the application of energy storage technology in various links of power system generation, transmission, distribution and use [6–11], mainly focusing on energy market, renewable energy grid connection and other fields. Studies [12,13] established mixed integer nonlinear programming models for optimal operation and scheduling of vanadium battery and sodium-sulfur battery energy storage stations with 10 MW/70 MWh, respectively, taking into account peak-valley spread arbitrage, standby and frequency regulation income, and calculated the annual return rate according to the total cost of energy storage system. In the study [14], considering peak-valley spread arbitrage and frequency regulation income, the net income of 1 MW/10 MWh sodium-sulfur battery energy storage station and 1 MW/0.5 MWh flywheel energy storage station in New York under different operation schemes was calculated, and their economy was evaluated. Shen et al. [15] analyzed the potential economic benefits of distributed energy storage, gave an economic judgment method to judge the application of distributed electrochemical energy storage in peak-clipping and valley-filling, and compared the economy of lead-carbon batteries and lithium iron phosphate batteries in peak-clipping and valley-filling scenarios, and put forward relevant compensation suggestions.

However, the research on economic benefit evaluation of energy storage in power system generation-transmission-distribution-use lacks reasonable and complete economic benefit evaluation under different scenarios [16,17]. In order to fill the gap in this aspect of energy storage research, this paper first puts forward typical application scenarios from the application value of energy storage on the user side, power grid side and power generation side, then establishes the economic benefit evaluation model of energy storage based on the application scenario, and finally evaluates the economic benefit of the energy storage system under each scenario with actual cases. The current battery energy storage system is in a stage of development [18], on the user side and grid side, and the application of different scenarios such as power generation side benefit further research, this article will net present value, payback period, internal rate of return value index calculation method is applied to the user side and grid side, power generation side, and the economic benefit analysis of energy storage system. Through the economic benefit analysis, the benefit of energy storage system in each scenario is objectively analyzed, which provides reference for the investment of energy storage system in each scenario.

2 Typical Application Scenarios of Energy Storage System

The application of energy storage system in power generation side, power grid side and load side is of great value. On the one hand, the investment and construction of energy storage power station can bring direct economic benefits to all sides [19]. Such as the economic benefits generated by peak-valley arbitrage on the power generation side and the power grid side; Building energy storage system on the user side can promote the user side to participate in demand response. On the other hand, it can indirectly generate environmental benefits through its dual role of user and power source [20]. For example, the construction of energy storage system on the power generation side can promote the absorption and integration of wind power, photovoltaic and other new energy into the power grid; At the power grid side, its superior peak load balancing performance can relieve the peak load balancing pressure of regional power grid and reduce the environmental pollution caused by thermal power peak load balancing.

2.1 Typical Application Scenarios of User Side

Typical application scenarios of energy storage on the user side mainly include arbitrage of peak-valley price difference in power market, the formation of comprehensive energy system in the park, the guarantee of power quality of special users, participation in demand response and so on.

(1) Using Peak-Valley Spread Arbitrage

Configuring energy storage system on the user side can effectively alleviate the problem of peak-valley difference. At present, China mainly implements the time-of-use electricity price policy, and the user-side energy storage system can adopt the strategy of charge low and discharge high according to the time-of-use electricity price, charging at the low load and low electricity price period, discharging at the peak load and high electricity price period, and taking advantage of the difference between peak and valley price to obtain economic benefits.

(2) Building Park Integrated Energy Systems

The District Integrated Energy System is generally equipped with renewable energy generating sets with great fluctuation and randomness. Therefore, it is usually necessary to configure an energy storage system to adjust the balance between power generation and load, so as to maximize the use of renewable energy, reduce the operation time of diesel generators and improve the reliability of power supply.

(3) Guaranteeing the Power Quality of Special Users

As industries such as special user requirement for power quality increasing, the different power users can use energy storage devices to control power electronic devices, provide reactive power support, ensure system voltage stability, improve power quality of power grid, and alleviate power quality problems such as low power factor and unbalanced voltage in production process.

(4) Participating in Demand Response

When user-side energy storage participates in demand response, on the one hand, users' economic benefits can be improved and profits can be obtained through electricity price difference or policy subsidies; On the other hand, power grid companies and power sales companies participate in demand response through user-side energy storage to promote safe and reliable power supply and reduce redundant investment.

2.2 Typical Application Scenarios of Power Grid Side

Typical application scenarios of energy storage on the power grid side mainly include guarantee of power supply, peak regulation of power grid, delay the upgrading of power grid, and voltage support at the end of power grid.

(1) Guaranteeing of Power Supply

If the power generation equipment or power grid line temporary failure will bring huge losses to the society, so it is necessary to set up a certain number of emergency backup power sources to ensure the safety of power facilities and user equipment. With the adjustment flexibility of the energy storage system, it can be used as a backup power supply for quick start in emergency, and ensure the power supply of the regional power grid.

(2) Peaking Regulation of Power Grid

In recent years, many power grids have experienced varying degrees of power supply tension during the peak load period in summer, and the peak load regulation pressure of power grid is huge. Due to its quick response characteristics, large-scale battery energy storage system can adjust the charging and discharging power and state in real time and has excellent peak regulation performance. The energy storage system is built on the power grid side, which can provide efficient peak clipping and valley filling services, realize power generation and electrolysis coupling and load regulation, and effectively alleviate the peak clipping pressure of regional power grid.

(3) Delaying the Upgrading of Power Grid

The cost investment of traditional power grid planning or power grid upgrading and expansion is high. When the load growth will exceed the load capacity of distribution lines, if the power grid company chooses to configure energy storage devices with smaller capacity at overload nodes, it can reduce the large capital investment brought by transmission and distribution network upgrading [21]. Energy storage system can be used as a new means to enhance the transmission capacity of the power grid, improve energy efficiency and the overall asset utilization level of the power grid.

(4) Voltage Supporting at the End of Power Grid

In the power grid, transmission lines and transformers will generate reactive power loss, resulting in a low power factor of the system. Impulsive reactive load will also cause voltage fluctuation and flicker. Energy storage system can provide fast power buffer, absorb or supplement electric energy, provide active power support, and carry out active or reactive power compensation, so as to stabilize and smooth the fluctuation of grid voltage, reduce line loss and improve system power factor.

2.3 Typical Application Scenarios of Power Generation Side

Typical application scenarios of energy storage on the power grid side mainly include self-absorption of new energy, smoothing of new energy output, frequency modulation auxiliary services, and improving the regulation capacity of thermal power units.

(1) Consuming New Energy

The construction of energy storage system in new energy power station can store multiple renewable energy sources when the wind and solar resources are sufficient, and transport them out when the wind and solar resources are insufficient, so as to effectively alleviate the phenomenon of "curtailing wind and abandoning light and limiting power" in the new energy power station, improve the new energy consumption ability, and reduce the impact of power generation fluctuation on the power grid.

(2) Smoothing the Output of New Energy

Since the output of new energy power generation is greatly affected by weather and time factors, the output changes rapidly and fluctuates greatly. The construction of energy storage system in the new energy electric field is helpful to stabilize the fluctuation of renewable energy output, stabilize the output level, smooth the power generation output curve and meet the assessment requirements of the new energy output under the uncertainty of the external environment.

(3) Providing Frequency Regulation Auxiliary Service

Compared with traditional energy, energy storage has strong ability to track load change, fast response speed, accurate output control and bidirectional regulation ability in power system frequency regulation, which can realize the coincidence of frequency regulation tracking curve and command curve. The power generation side is equipped with energy storage system, which can independently or assist traditional thermal power units to provide frequency modulation auxiliary services, effectively enhance the frequency regulation capability of the power grid, and play a great role in improving the power supply quality and ensuring the safe and stable operation of the power grid.

(4) Improving the Regulation Capacity of Thermal Power Units

In order to efficiently absorb new energy, the deep peak regulation of thermal power units is proposed, and the peak regulation of thermal power units is rewarded and punished. However, the peak regulation ability is subject to the heating capacity and the operation mode of heating power. Clean heating can be realized by configuring energy storage, which can significantly improve the regulation capacity of cogeneration units, improve the flexibility of thermal power and promote clean energy heating.

3 Benefit Evaluation Model

Net present value, static payback period, dynamic payback period, internal rate of return and other evaluation indicators can be used to measure the economic benefits of a project [22]. Therefore, this paper uses these indicators to evaluate the economic benefits of energy storage system from the dimensions of value, time and efficiency.

(1) Value-Based Indicators-Net Present Value

Net present value (NPV) measures the annual cash flow during the life of a project. According to a certain discount rate, the net cash flow of the next year is discounted to the present value accumulated at the beginning of the period, which is the net present value. Net present value is the basic indicator to evaluate the feasibility of the project. If the net present value is greater than 0, the scheme is feasible, otherwise it is not feasible. The larger the net present value, the higher the income of the scheme [23].

$$NPV = \sum_{t=1}^{n} (CI - CO)_t (1 + i_0)^{-t} \tag{1}$$

where NPV represents the net present value; CI represents the cash inflow in year t; CO represents the cash outflow in year t; n represents the calculation period of the project; i_0 represents the base rate of return.

(2) Time-Based Indicator-Payback Period of Investment

The payback period of investment is the period required to recover all the investment with the net income of each year of the project from the date when the project is put into construction [24].

1) Static Investment Payback Period

Payback period without considering time value:

$$T_j = \frac{K_0}{A_t} \tag{2}$$

$$A_t = R_{al} - C_{fm} \tag{3}$$

where K_0 is the initial investment and A_t is the annual net income.

2) Dynamic Investment Payback Period

Investment payback period considering time value:

$$T_D = \frac{-\lg(1 - K_0 I_0 / A_t)}{\lg(1 + i_0)} \tag{4}$$

(3) Efficiency Indicators Internal Rate of Return

Internal rate of return (IRR) is the investment return rate of the investment project itself, which refers to the discount rate when the present value of the net cash flow of each year of the project is equal to zero in the whole calculation period [25]. The internal rate of return reflects the resilience of the project to the investment expenditure. The higher the value, the better the economy of the project. When the internal rate of return is greater than the benchmark rate of return, the project is acceptable.

$$\sum_{t=1}^{n} (CI - CO)_t (1 + IRR)^{-t} = 0 \tag{5}$$

(4) Cost and Structure Analysis of Energy Storage System under Typical Application Scenarios

Taking the user-side application scenario as an example, the cost-benefit composition of the energy storage system is shown in Fig. 1.

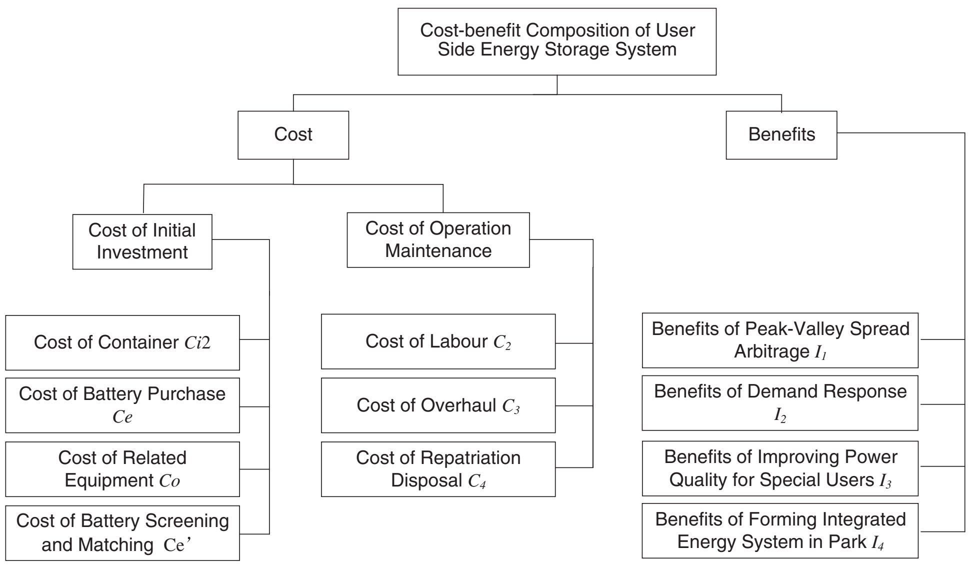

Figure 1: Cost-benefit composition of user-side energy storage system

Based on the above cost-benefit system, considering that the battery life configured by the energy storage power station is less than the operation period of the energy storage project, and there is battery replacement during the operation period, the economic benefit model of the energy storage system is constructed as shown in Eq. (6). Among them, since the user-side energy storage system is generally configured within the user park without additional land leasing costs, this part of the land construction only includes the container cost.

$$NPV = \sum_{t=1}^{x} \frac{I_1 + I_2 + I_3 + I_4 - C_2 - C_3 - C_4}{(1 + r)^t} - \left[\left(1 - \frac{\xi}{(1 + r)^{\Delta N}} \right) (C_e + C_o) + C_{i2} + C_e^{'} \right] \tag{6}$$

where x represents the operating life of the energy storage system, ΔN represents the service life of the energy storage battery, ξ represents the average residual value rate of fixed assets, r and C_{ex} are defined as the discount rate and other costs respectively. It mainly includes return and disposal costs, sales taxes and surcharges, income tax, etc. The remaining parameters are shown in Fig. 1.

The operational benefit evaluation model of energy storage system under the application scenarios of power grid side and power generation side is the same as that of user side, so it is only necessary to replace the income indicators under the corresponding scenarios, which will not be repeated here. Among them, because the power grid side energy storage needs to lease land especially due to site problems, it needs to increase the land lease cost compared with the user side energy storage. At present, there are also small-scale power grid side energy storage installed in abandoned substations, and there is no need for land lease cost at this time; Energy storage on the power generation side is generally installed inside the power plant, and the civil cost composition is the same as that on the user side, including only container cost and no land lease cost.

4 Case Study

Based on the method described above, this section selects actual battery storage power stations from the user side, power grid side and power generation side, respectively, and uses their data as the basic data for the case study.

4.1 Case I-User Side

Case I shows the economic benefit evaluation of the user side energy storage system. This section is based on a 300 kW/2000 kWh lead-acid energy storage power station on the user side to carry out a benefit analysis. The construction period of the energy storage system is about 6 months, and the designed operation period is 20 years. Lead-acid batteries are used for charging and discharging, with 4000 times of charging and discharging. It is designed to charge and discharge once a day, and the battery life is 5 years. The energy storage system detects the real-time load of the plant, controls the load demand under the premise of meeting the capacity limitation of the distribution transformer, and reduces the electricity demand through the peak clipping and valley filling operation strategy. At the same time, based on the local price difference, the charging and discharging control of the energy storage system is carried out during the peak-valley price period to reduce the electricity cost of the plant and obtain direct economic benefits.

(1) Basic Data

The parameters needed for benefit evaluation of energy storage power station include technical basic parameters, cost parameters and benefit parameters as shown in Tables 1 and 2.

Table 1: Technical basic parameters of user side energy storage system

Serial number	Name	Unit	Numerical value
1	Scale of installation capacity	kW	300
2	Rated capacity of energy storage Power station	kWh	2000
3	Construction period	month	6
4	Operation period	year	20
5	Depreciation life	year	20
6	Battery life	year	5
7	Charge and discharge times	time	4000
8	Discount rate	%	8

Table 2: User side energy storage system cost parameters

Serial number	Name	Unit	Numerical value	Remark
1	Capital ratio	%	100	
2	Land cost	million yuan	–	In-house installations without additional land costs.
3	Cost of container	million yuan	0.95	
4	Cost of battery purchase and related equipment	million yuan	165	Replacement of batteries every 5 years at 90% cost.
5	Cost of maintenance	%	0.8	Includes maintenance costs and breakdown costs, with a total investment base of 0.8% for the first five years and 0.5% for the next five years.
6	Cost of repatriation disposal	million	1	
7	Battery recovery residual rate	%	30	
8	Value-added tax	%	13	VAT implements a 50% immediate tax refund policy.
9	Urban maintenance and construction tax	%	5	
10	Extra charges of education funds	%	3	
11	Additional local education fee	%	2	
12	Income tax rate	%	25	The project enjoys three exemptions, three reductions and a half preferential policy. Operating income shall be exempted from income tax for 1–3 years from the tax year in which the first income tax is obtained, halved for 4–6 years, and then collected at 25%.

(2) Economic Benefit Evaluation

According to the benefit evaluation model, the cost and cash flow of the energy storage system are calculated, and the economic benefit evaluation results are shown in Table 3.

Table 3: Financial index of lead-acid battery energy storage system under user side application scenario

Serial number	Indicators	Computing result
1	Total battery investment/million yuan	475.48
2	Initial investment/million yuan	165.95
3	Operation maintenance cost/million yuan	70.30
4	Benefits of peak-valley spread arbitrage/million yuan	325.20
5	Benefits of integrated energy systems/million yuan	151.51
6	Benefits of power quality/million yuan	2.35
7	Recovery of residual value of fixed assets/million yuan	142.38
8	Net present value/million yuan	44.98
9	Payback period/year	16.69
10	Internal rate of return/%	11.85

It can be seen from the above table that under the user-side application scenario, the lead-acid battery energy storage power station has a total investment of 475.48 million yuan and an operation and maintenance cost of 70.30 million yuan during the 20-year operation period at a discount rate of 8%; The arbitrage income of peak-valley price difference totaled 325.20 million yuan, the comprehensive energy system income was 151.51 million yuan, the power quality income was 2.35 million yuan, and the residual value of fixed assets recovery was 142.38 million yuan. The dynamic payback period of the project is about 16.69 years, the financial net present value at the end of the project is 44.98 million yuan, and the internal benchmark rate of return is 11.85%. Among them, the data in the above table are the present value converted to Phase 0. The accumulated net cash flow is shown in Fig. 2.

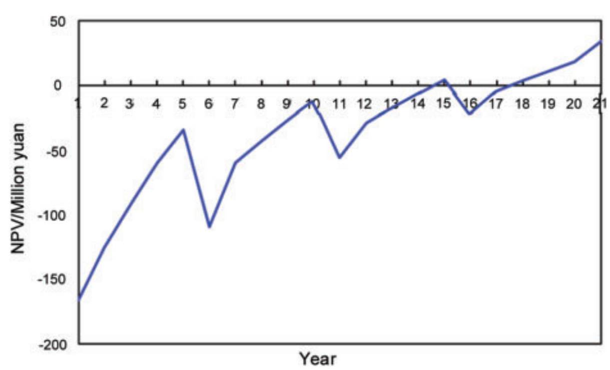

Figure 2: Cumulative net present value of lead-acid battery energy storage system under user side application scenario

It can be seen that under the current lead-acid battery cost and peak-valley electricity price level, the installation of lead-acid battery energy storage system on the user side can recover the cost within 20 years of the operation period, but it can only be recovered in the later life period, and the value recovery cycle is long, which is closely related to the high investment cost of energy storage at the present stage.

(3) Sensitivity Analysis

The sensitivity analysis of the influence of lead-acid battery purchase and related equipment cost, operation and maintenance cost and peak-valley electricity price difference on NPV is carried out, and the results are shown in Fig. 3.

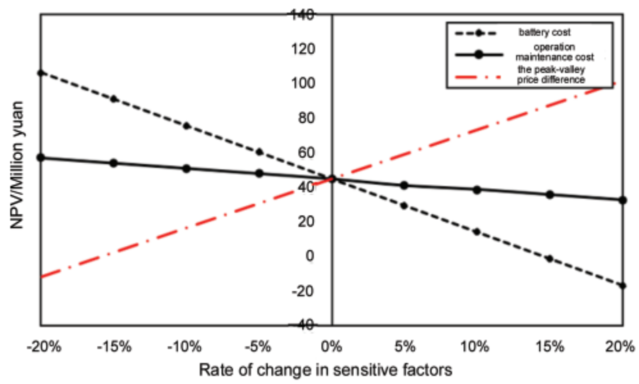

Figure 3: User side energy storage sensitivity analysis diagram

Fig. 3 shows that the profit and loss balance point of battery purchase and related equipment cost is 14.59%, that is, the cost of battery purchase and related equipment is 242.55 million yuan, that is, when the cost of battery purchase and related equipment is less than 242.55 million yuan, the lead-acid battery energy storage power station can recover the cost at the end of the 20-year life cycle.

The sensitivity break-even point of operation and maintenance cost is 72.62%, that is, the annual operation and maintenance cost is 12.36 million yuan, that is, when the operation and maintenance cost is less than 12.36 million yuan, the lead-acid battery energy storage power station can recover the cost at the end of the whole life cycle 20 years.

The break-even point of the peak-valley price difference factor is –15.87%, that is, the peak-valley price difference is 0.6915 yuan/kWh, and the peak-valley price difference is 0.4400 yuan/kWh. The lead-acid battery energy storage power station can recover the cost at the end of the whole life cycle 20 years.

According to the above analysis, it can be found that in the user-side application scenario, the peak-valley price difference is the most sensitive to the benefit of the energy storage system, followed by the battery purchase cost, while the user-side energy storage power station is less sensitive to the operating cost, that is, the peak-valley price difference and the battery purchase cost are the main factors affecting the economy of the user-side energy storage power station.

4.2 Case II-Power Grid Side

Case II shows the economic benefit evaluation of power grid side energy storage system. In this section, the economic benefit of a lithium-ion battery energy storage system with 5 MW/10 MWh installed capacity is evaluated. The construction period of the system is about 6 months and the design operation period is 20 years. The charging and discharging times of lithium-ion battery are 8000 times, and it is designed to charge and discharge twice a day, and the battery life is 10 years; Benefit evaluation is carried out under the discount rate of 8%, and comprehensive analysis of cost, cash flow, etc. Basic technical parameters and cost parameters of power grid side energy storage system are showed in Tables 4 and 5.

(1) Basic Data

Table 4: Basic technical parameters of power grid side energy storage system

Serial number	Name	Unit	Numerical value
1	Scale of installation capacity	kW	5
2	Rated capacity of energy storage power station	kWh	10
3	Construction period	month	6
4	Operation period	year	20
5	Depreciation life	year	20
6	Battery life	year	10
7	Charge and discharge times	time	8,000
8	Discount rate	%	8

Table 5: Energy storage system cost parameters on the grid side

Serial number	Name	Unit	Numerical value
1	Land lease area	acre	1.8
2	Land rental unit price	million yuan/acre	11
3	Cost of container	million yuan	6
4	Cost of battery purchase	million yuan	1,000
5	Cost of related equipment	million yuan	447
6	Personal expenses	million yuan/year	6
7	Personnel authorization	person	2
8	Cost of delivery disposal	million yuan	5

(2) Economic Benefit Evaluation

According to the benefit evaluation model, the cost and cash flow of the energy storage system are calculated, and the economic benefit evaluation results are shown in Table 6.

During the 20-year operation period of the energy storage power station, the peak clipping compensation income of the power station is 1,791.81 million yuan, the power supply guarantee income of the power grid is 203.84 million yuan, the investment income of the alternative power grid equipment is 569.91 million yuan, the terminal voltage support income of the power grid is 165.51 million yuan, and the battery recovery surplus-value is 178.24 million yuan. The initial investment of energy storage power station is 1,548.46 million yuan, and the operation and maintenance cost is 545.91 million yuan.

Table 6: Financial indexes of lithium-ion acid battery energy storage system under the application scenario on the side of power grid

Serial number	Indicators	Unit	Computing result
1	Benefits of Peak regulation compensation	million yuan	1,791.81
2	Benefits of power grid protection	million yuan	203.84
3	Benefits of investment in alternative grid equipment	million yuan	569.91
4	Benefits of end voltage support of power grid	million yuan	165.51
5	Battery recovery residual value	million yuan	178.24
6	Initial investment	million yuan	1,548.46
7	Operation maintenance cost	million yuan	545.91
8	Cumulative net present value	million yuan	104.06
9	Internal rate of return	%	10
10	Payback period	year	16.5

The profitability can be further analyzed through Fig. 4, and the cumulative net present value of the power station at the end of operation is 104.06 million yuan. The cost of energy storage project can be recovered within 20 years of operation period, and the dynamic payback period of investment is 16.5 years; The internal rate of return is 10%, and the benefit is good.

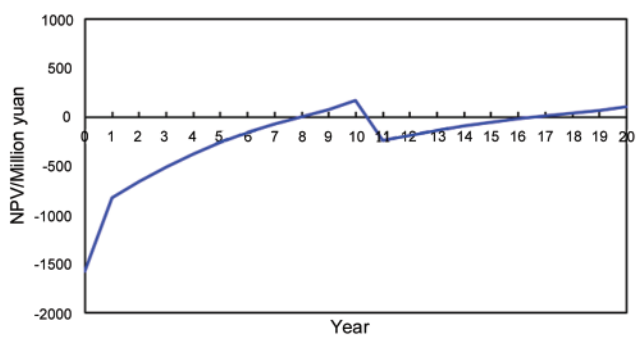

Figure 4: The accumulative net present value of lithium-ion battery energy storage system on the grid side

(3) Sensitivity Analysis

Fig. 5 shows that the profit and loss balance point of the battery purchase cost is 4.62%, and the purchase cost is 953.75 million yuan. That is, when the battery purchase cost is less than 953.75 million yuan, the lithium-ion battery energy storage system in the grid side application scenario can recover the cost at the end of the whole life cycle 20 years.

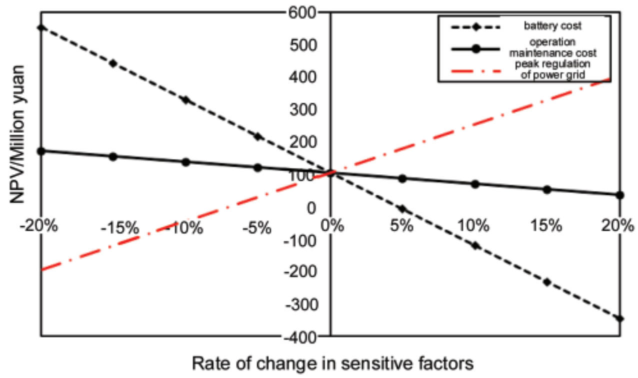

Figure 5: Grid side energy storage sensitivity analysis diagram

The break-even point of operation and maintenance cost is 30.90%, that is, when the operating cost is less than 287.73 million yuan, the lithium-ion battery energy storage plant can recover the cost at the end of 20 years of the life cycle.

The break-even point of the power grid peaking compensation income is –6.95%, that is, when the unit peaking compensation is higher than CNY 465.25 /kWh, the lithium-ion battery energy storage power station can recover the cost at the end of the 20-year life cycle.

Based on the above analysis, it can be seen that in the grid-side application scenario, the battery cost is the most sensitive to the benefit of energy storage system, followed by the peak shaving compensation of power grid, and the operation and maintenance cost with the worst sensitivity, which indicates that the battery cost of energy storage is the most important factor affecting the economy of user-side energy storage power station in the grid-side application scenario.

4.3 Case III-Power Generation Side

Case III shows the economic benefit evaluation of power generation side energy storage system. The lithium-ion battery has the strongest applicability in the power generation side scenario. In this paper, a lithium-ion battery energy storage system with an installed capacity of 50 MW/100 MWh is used to evaluate the benefits of the energy storage system in the power generation side application scenario. The construction period of the system is about 12 months and the design operation period is 20 years. The charging and discharging times of lithium-ion batteries are 8,000–10,000 times, and the life span is 10 years; The initial investment of the project is 20% of its funds and 80% of its capital. Assuming that the long-term loan interest rate is 4.90%, it will be repaid in equal amount and paid off in 16 years. The basic technical parameters are shown in Table 7, and the cost parameters are shown in Table 8. The values of personnel costs, maintenance costs, other costs, depreciation years and tax rates are the same as those in other scenarios, which are no longer listed here.

(1) Basic Data

Table 7: Basic technical parameters of power generation side energy storage system

Serial number	Name	Unit	Numerical value
1	Scale of installation capacity	MW	9
2	Rated capacity of energy storage Power station	MWh	4.5
3	Construction period	month	12
4	Battery life	year	10
5	Charge and discharge times	time	8,000–10,000
6	Benchmark return ratio	%	8

Table 8: Cost parameter of energy storage system on generation side

Serial number	Name	Unit	Numerical value	Remark
1	Proportion of own funds	%	20	
2	capital ratio	%	80	
3	Land cost	million yuan	–	Power plant installation, no additional land costs.
4	Cost of container	million yuan	60	
5	Cost of battery purchase and related equipment	million yuan	1,035	
6	Personnel authorization	person	7	
7	Cost of delivery disposal	million yuan	10	

(2) Economic Benefit Evaluation

The benefit evaluation results of 50 MW/100 MWh lithium-ion energy storage system configured under the application scenario of power generation side are shown in Table 9.

Table 9: Financial index of lithium-ion battery energy storage system in the power generation side application scene

Serial number	Indicators	Unit	Computing result
1	Gross investment	million yuan	21,964
2	Operation maintenance cost	million yuan	1,919.04

(Continued)

Table 9 (continued)

Serial number	Indicators	Unit	Computing result
3	Financial cost	million yuan	2,718.61
4	Benefits of new energy self-consumption	million yuan	11,348.11
5	Benefits of FM ancillary services	million yuan	1,021.09
6	Benefits of smooth output of renewable energy	million yuan	2,945.44
7	Benefits of clean heating	million yuan	553.15
8	Recovery of residual value of fixed assets	million yuan	951.43
9	Internal rate of return	%	11
10	Net present value	million yuan	472.25
11	Payback period	year	18.9

The results of the above table analysis show that under the scenario of power generation side application, the total investment of 50 MW/100 MWh lithium-ion energy storage power station is 21,964 million yuan, and the operation and maintenance cost is 1,919.04 million yuan. In addition, 80% of the fund of the power station is from long-term borrowing, so the interest cost is 2,718.61 million yuan. The income from self-consumption of new energy is 11,348.11 million yuan, the income from frequency regulation auxiliary services is 1,021.09 million yuan, the income from smooth output of renewable energy is 2,945.44 million yuan, the income from clean heating is 5,531.5 million yuan, and the residual value of recovered fixed assets is 951.43 million yuan; The internal rate of return of the project is 11%, the net present value of the financial accumulated at the end of the operation period is 472.25 million yuan, and the dynamic investment recovery period is about 18.9 years. Fig. 6 shows the accumulated net cash flow of lithium battery energy storage during the operation period under the power generation side scenario.

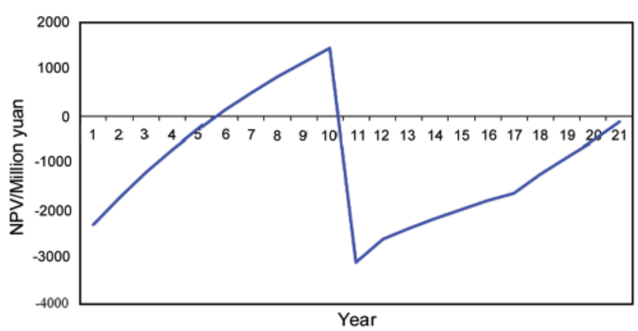

Figure 6: Lithium-ion battery energy storage system in the power generation side application scene

(3) Sensitivity Analysis

Summarize the changes of NPV in main sensitive factors such as battery purchase cost, new energy self-consumption income, frequency regulation auxiliary service income, renewable energy smooth output income and clean heating income, as shown in Fig. 7.

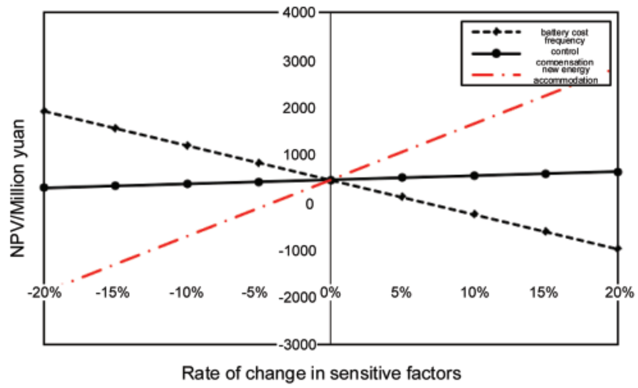

Figure 7: Sensitivity analysis diagram of power generation side

Fig. 7 shows that the break-even point of battery purchase cost is 6.50%, that is, when the battery purchase cost is 12,247.5 million yuan, the lithium-ion battery energy storage power station can just recover the cost at the end of the whole life cycle of 20 years.

The sensitive break-even point of reducing new energy consumption is –3.99%, that is, when the monthly assessment fine is less than 24.5 million yuan/month, the lithium-ion battery energy storage power station can recover its cost at the end of 20 years in the whole life cycle.

The break-even point of FM compensation is –55.30%, that is, when the FM capacity compensation is 5.364 yuan/MW and the electric quantity compensation is 35.76 yuan/MWh, the cost of lithium-ion battery energy storage power station will be recovered at the end of 20 years in the whole life cycle.

It can be seen that the battery purchase cost is the most sensitive to the benefits of energy storage system in the application scenario of power generation side, followed by the assessment penalty of renewable energy, while the energy storage power station is less sensitive to the operating cost.

5 Conclusions

Based on the classification of different application scenarios of energy storage system, this paper evaluates and analyzes the economic benefits of energy storage system based on the research results of scenario classification and cost-benefit quantification, and draws the following conclusions: Under the scenarios of user side, power grid side and power generation side, the energy storage system can recover the cost within 20 years. On the user side application scenario, the energy storage system is the most sensitive to the peak-valley price difference, while in the power grid side and power generation side application scenarios, the battery purchase cost is the most sensitive. Therefore, when installing an energy storage system on the user side, we should pay attention to the local peak-valley price difference. The higher the peak-valley price difference is, the more benefit the user-side energy storage system will get. When installing the energy storage system on the power grid side and the power generation side, we should pay attention to the battery cost, and compare the cost of each type of battery before the construction of the battery energy storage system, and use cheaper batteries on the premise of ensuring the battery performance, so as to ensure the stability of the energy storage system benefit.

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