Economic Evaluation and Investment Decision-Making of Energy Storage System Under the Perspective of Uncertain Market Returns

Ying Meng [1] and Yuming Huang[2, *]

[1]Sinopec Lubricant Company, Beijing, 100085, China
[2]North China Electric Power University, Beijing, 100096, China
huangyuming2023@163.com

Abstract. Under the dual-carbon background, China is vigorously developing a new type of power system mainly based on renewable energy power generation, and energy storage technology, as a key support for energy transition and large-scale application of renewable energy, is facing challenges in investment economics, technology and policy environment, despite its huge potential. Among them, investment economics is the most pressing, with uncertainties such as return on investment cycles and market fluctuations seriously affecting investors' motivation to invest, which is not conducive to attracting investment in energy storage projects. In view of the exorbitant risk of energy storage investment. This paper uses a techno-economic assessment to evaluate energy storage's financial viability, focusing on a typical electrochemical storage plant in Shandong. It conducts a sensitivity analysis to understand key factors influencing the economics of such projects, aiming to inform market participants' decisions.

Keywords: Energy storage plant, Economics, NPV, IRR, Sensitivity analysis

1 INTRODUCTION

The power industry, a major carbon emitter, should build a new energy-driven power system, promote renewable sources like wind & solar, and accelerate decarbonization[1]. Energy storage is a crucial solution to renewable energy challenges, enhancing energy regulation, efficiency, and security. It supports new energy systems and is vital for carbon neutrality[2].

Energy storage in power systems offers benefits but faces uncertainty in returns. Unlike traditional power equipment, storage costs vary based on charging prices, battery degradation, and maintenance. This uncertainty complicates investment decisions for market players, requiring accurate predictions of future electricity prices, demand, and storage cost-effectiveness. However, predicting storage costs is difficult due to complex, variable factors, leading to higher investment risks. Assessing the economics of energy storage investments is needed to guide market players.

The primary methods for evaluating energy storage project economics are NPV, IRR, and levelised quasi-energy storage cost. For NPV, projects with a positive value

V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_64

are investable. An energy storage plant's IRR must exceed 8% to 9% to meet investor thresholds. The project is economically viable only if its levelised cost is below peak-valley tariffs[3].

Based on the above, this paper firstly analyses the status quo of energy storage development at home and abroad; secondly, takes a typical electrochemical energy storage power station in Shandong as an example, constructs a model for measuring the economics of energy storage investment, and explores the impact of the main influencing factors on the economics of the energy storage power station through sensitivity analysis; and finally, puts forward the policy opinions, which are aimed at providing decision-making references for the market members.

2 CURRENT STATUS OF DOMESTIC AND FOREIGN ENERGY STORAGE RESEARCH AND DEVELOPMENT

China, Europe, and the U.S. dominate the global energy storage market with 86% share. The U.S. remains a key market despite slower growth. Independent and new distributed energy storage account for over 90% of installed capacity[4]. China reached 13.1GW/27.1GWh cumulative capacity, with 128% and 141% growth rates. In 2023's first half, 159 projects, mainly new energy storage, with 7.05GW/14.66GWh capacity, were operational in China.

Existing studies have mainly evaluated the economics of energy storage from the perspectives of social benefits, FM costs, and real-time power benefits of energy storage plants. Literature[4] suggested a mechanism to recover energy storage value across competitive, regulated, and hybrid business models, factoring in storage value characteristics and business scenarios. Literature[5] Proposes a cost-effective battery lifecycle optimization algorithm for various power storage systems, analyzes storage capacity allocation in active markets, and calculates daily price arbitrage. Few studies evaluate energy storage economics from an investment perspective. Therefore, this paper focuses on assessing the investment economics of energy storage and analysing the extent of the impact of factors that influence the investment economics of energy storage.

3 CONSTRUCTION OF AN ECONOMIC MEASUREMENT MODEL FOR ENERGY STORAGE INVESTMENT

NPV, IRR, and levelised energy storage cost are key indicators for energy storage investment decisions. NPV shows if the ROI exceeds the cost of capital[6]. IRR helps assess project profitability and rank multiple projects. Levelised energy storage cost provides a comparison index for assessing the economics of different storage technologies. This paper uses these indicators to analyse energy storage investment economics.

3.1 NPV Calculation Model

Use NPV to assess project benefits in cash, comparing NPV to 0: NPV>0 means the project is beneficial and viable; NPV<0 means it's not, resulting in loss, making it infeasible. The calculation method is as follows:

$$NPV = \sum_{y=1}^{Y} \frac{CI_y - CO_y}{(1+BY)^y} \tag{1}$$

CI_y is the annual return on the system[7]; CO_y is the total life-cycle cost, which covers all the expenditures required in all aspects of the system, such as design and development, fabrication and assembly, operation and management, up to the final end-of-life disposal, and adds up to the overall price of the product; Y is the life span; BY is the baseline rate of return for system projects.

Grid-side energy storage[8] system annual earnings and system revenues:

$$CI_y = E_1 + E_2 + E_3 \tag{2}$$

E_1 is spot market revenue; E_2 is capacity compensation revenue; $E_3$is capacity lease revenue, all in millions of yuan.

Grid-side energy storage system annual revenues and full system life cycle costs:

$$CO_y = C_y + C_s + C_t + C_g + C_b + C_n + C_m \tag{3}$$

C_y is O&M cost; C_s is the cost of equipment; C_t is the cost of land; C_g is construction costs; C_b is the cost of charging; C_n is finance cost; C_m is the cost of the battery, all in millions of yuan.

Capacity Compensation Revenue:

$$E_1 = P \bullet C_C \tag{4}$$

P is the available power in kW; C_C is the unit price of capacity compensation, in yuan/kWh.

Spot market revenue:

$$E_2 = C_d \bullet C_{discharge} \tag{5}$$

C_d is the annual discharge power in kWh; $C_{discharge}$ is the discharge tariff in Yuan/kWh.

Capacity Rental Revenue:

$$E_3 = C_{rent} \bullet C_R \tag{6}$$

C_{rent} is the capacity lease price; C_R is the size of the capacity lease.

Charging Costs:

$$C_b = C_{charge} \bullet C_a \tag{7}$$

C_{charge} is the charging tariff in Yuan/kWh; C_a is the annual charging power in kWh.

Finance costs:

$$C_n = C_{invest} \bullet \alpha \bullet (t_n - t_0) \bullet i \tag{8}$$

C_{invest} is the total investment estimate in yuan; α is the cost factor; tn is the current year; t_0 is the initial year; i is the annual interest rate.

Battery Costs:

$$C_m = \begin{Bmatrix} 0, C \neq 200 \\ C_{battery} \bullet \beta, C = 200 \end{Bmatrix} \quad (9)$$

C is the available battery capacity; $C_{battery}$ is the cost of the battery; β is the battery cost change factor.

3.2 Internal Rate of Return Calculation Model

The internal rate of return[9] is calculated excluding external factors such as risk-free interest rate, inflation rate, various financial risks, etc. The calculation is done as follows:

$$\sum_{y=0}^{Y} \frac{CI_y - CO_y}{(1+IRR)^y} = 0 \quad (10)$$

IRR is the internal rate of return.

3.3 Levelised Cost Model

Levelised Cost of Energy Storage (LCOS) allows for a more intuitive comparison of the differences in the whole life cycle costs of various energy storage technologies[10]. The calculation method is as follows:

$$LCOS_{s,i} = \frac{C_y + C_s + C_t + C_g + C_b + C_n + C_m}{E_f} \quad (11)$$

E_f is the total discharge during the investment period in kW.

3.4 Uncertainty About the Benefits of Energy Storage Systems

The current energy storage revenue mainly comes from spot market revenue mainly comes from spot market revenue, capacity compensation revenue, capacity leasing revenue, and the cost mainly comes from investment cost and operation and maintenance cost. Meanwhile, among the above economic evaluation indicators, internal rate of return (IRR) is the core indicator. In summary, the internal rate of return is chosen to characterise the impact of the main influencing factors on the economics of energy storage power plants.

Spot market revenues hinge on charge/discharge spreads, while capacity compensation depends on annual cycle counts; investment costs are tied to battery costs. These factors are volatile: market dynamics and policies can sway charge/discharge spreads, impacting plant revenues and economy. Cycle counts vary with usage depth, temperature, and charging rates, affecting battery life and plant economics. Battery costs fluctuate with raw material prices and tech advances, adding to investment cost uncertainty

4 CALCULATIONS

4.1 Basic Data

This chapter exemplifies a Shandong 100MW/200MWh lithium iron phosphate energy storage station. The leasing price ranges from RMB 260-330/kW-year, with compensation twice the monthly independent storage standard at RMB 30/kW-year. Factoring in 80% conversion efficiency, 6% discount rate, 15-year lifespan, charging tariff of RMB 0.202/kWh, and discharging tariff of RMB 0.772/kWh, the leasing price is set at RMB 300/kW, compensation rate at RMB 60/kW-year, with a discounted duration of 20 years.

4.2 Cost And Revenue Share Analysis

Table 1. Costs and revenues of energy storage plants.

Notation	Name	Results
E1	Spot market revenue	26056.00
E2	Capacity Compensation Revenue	6881.95
E3	Capacity rental income	34409.76
Py	O&M costs	9175.94
Pb	Charging Costs	8522.20
Pn	Financial cost	5258.28
Pm	Battery Costs	17243.61

By checking the annual report of Shandong Power Grid Company, you can get the data of other equipment costs, land costs, construction costs, etc.(see Table 1), and the costs and revenues account for the following(see Fig. 1):

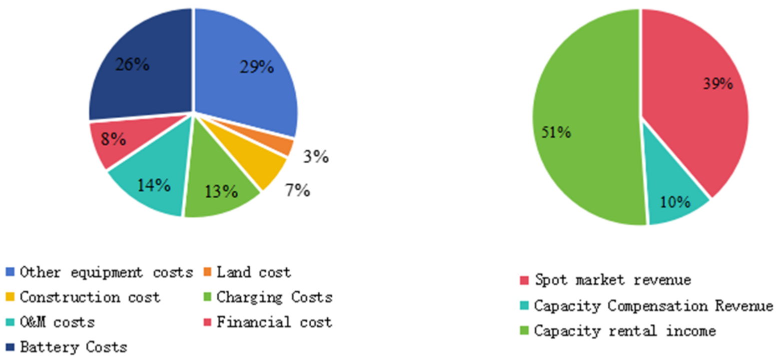

Fig. 1. Cost and Revenue Share.

It is calculated that, Battery costs account for 33% of total costs, followed by equipment costs at 26%. Revenue from capacity leasing is highest at 57.6%, with spot market and capacity compensation accounting for 30.9% and 11.5% respectively. The energy storage plant's net present value is -148.99 million yuan, and the IRR is 1.5257%. The energy storage plant's NPV is negative, and its IRR is below the benchmark, indicating weak investment economics and difficulty in cost recovery via the electricity spot market, given the small peak-valley price gap. The plant's levelized cost of electricity is high (RMB 1.66/kWh), making cost recovery through the electricity market alone unfeasible. Capacity leasing and compensation are vital income sources for the plant in the current low-difference electricity market environment.

4.3 Sensitivity Analysis

Analyse the impact of charge/discharge spreads, battery costs and the annual number of charge/discharge cycles on energy storage plants. Combine the main influencing factors to analyse the impact on the economics of the energy storage plant.

Charge/discharge spread sensitivity analysis. Only the discharge tariff is changed, and other parameters remain unchanged. In this study, five charging and discharging spreads are set as 0.3, 0.5, 0.7, 0.9 and 1.1, respectively, to calculate the IRR under different charging and discharging spreads. The calculation results are as follows(see Fig. 2):

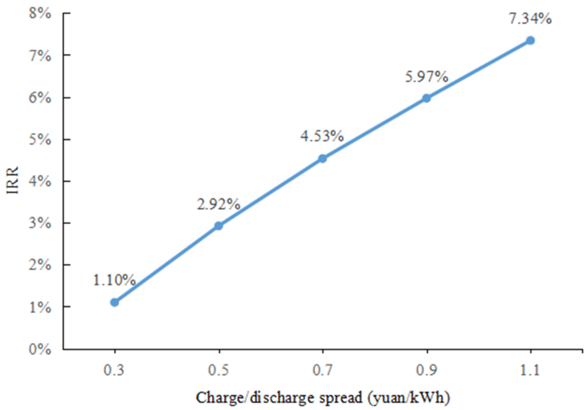

Fig. 2. Internal rate of return for different charge/discharge spreads.

Calculation results show that as the charging/discharging spread grows from 0.3 yuan/kWh to 1.1 yuan/kWh, the internal rate of return grows from 1.10 per cent to 7.34 per cent, and the charging/discharging spread is at 0.905 yuan/kWh, IRR reaches 6 per cent, which is basically able to recover the investment cost, and when the charging/discharging spread is at 1.199 yuan/kWh, the internal rate of return is at 8 per cent, which has a certain investment economics When the charging/discharging spread is 1.199 yuan/kW, the internal rate of return is 8%, which has certain investment economics.

Battery investment cost sensitivity analysis. Battery investment cost accounts for the largest proportion in the cost composition of the energy storage power station, with the development of energy storage technology in the future, the cost of energy storage battery has a large space for decline, this part of the study on the impact of the changes in the battery investment cost on the economy of the energy storage power station, calculating the changes in the internal rate of return of the battery investment cost in the reduction of 10 per cent, 20 per cent, 30 per cent and 40 per cent of the case, and the results of the calculations are as follows(see Fig. 3):

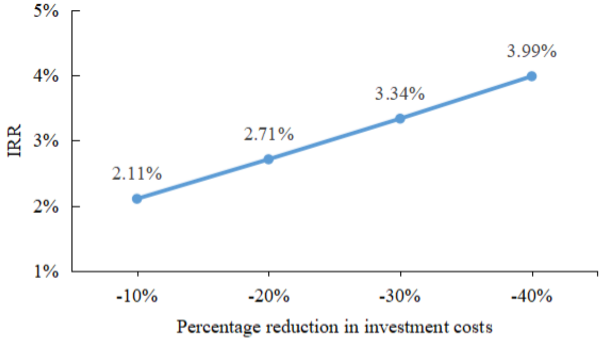

Fig. 3. Change in internal rate of return with reduced equipment costs.

Calculation results show that IRR is 2.11%, 2.71%, 3.34% and 3.99% for battery investment cost reduction of 10%, 20%, 30% and 40%, respectively. The reduction of battery investment cost can improve the economy of energy storage power station, only when the battery investment cost decreased by 69% can basically recover the investment, although the cost of energy storage battery will decrease in the future, but the space of its decline is limited, relying solely on the cost of energy storage batteries to drive the economic development of energy storage power station is limited.

Sensitivity analysis of the number of annual cycles.

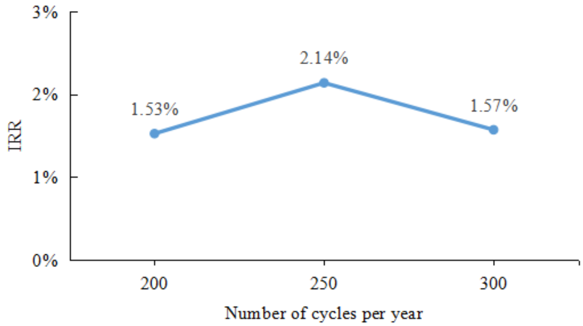

Fig. 4. Changes in internal rate of return for different number of annual cycles.

Under the condition of 2000 times of service life, the internal rate of return (IRR) is calculated to be 1.53%, 2.14% and 1.57% when the annual cycle times are 200, 250 and 300 times, respectively, and the IRRs are all at a low level(see Fig. 4).

Charge/discharge spreads and battery costs impact energy storage plant economics. The impact on the internal rate of return (IRR) of the energy storage plant is analysed by combining the charging and discharging spreads of 0.344, 0.5, 0.7, 0.9 and 1.1yuan/kWh with the proportionate reduction of the battery investment cost(see Table 2).

Table 2. Impact of charge/discharge spread and battery cost on energy storage IRR.

Spread (yuan/kWh) / Battery Cost Changes	0.344	0.5	0.7	0.9	1.1
0%	1.53%	2.92%	4.53%	5.97%	7.34%
-10%	2.11%	3.50%	5.09%	6.56%	7.97%
-20%	2.71%	4.10%	5.69%	7.20%	8.64%
-30%	3.34%	4.71%	6.33%	7.87%	9.35%
-40%	3.99%	5.36%	7.02%	8.60%	10.13%

Out of 25 scenarios, 4 yield an 8%+ IRR, indicating good investment returns for energy storage plants. 7 show a 6-8% IRR, allowing for cost recovery with some profit. 14 have an IRR below 6%, resulting in poorer economic performance and cost non-recovery.

5 SUMMARY AND POLICY RECOMMENDATIONS

Future energy storage battery costs will fall, but with limited scope. Relying on battery cost alone to spur energy storage plant economic growth is insufficient. Increasing annual charging/discharging cycles for greater power market revenue may not boost the plant's IRR. It's also crucial to consider the impact of more cycles on battery lifespan. The storage plant's economics will increasingly depend on the combined effects of multiple factors, not just one, leading to better financial outcomes. Policy recommendations based on these findings will follow in this chapter.

Reduce costs. The government should back R&D in energy storage tech and drive down battery costs. Also, energy storage makers should enhance efficiency, streamline supply chains, and cut production costs.

Optimising market mechanisms. The electricity market should implement a fairer peak-valley pricing mechanism to showcase the value of energy storage to the grid. Additionally, further power market reforms should be advanced to offer more revenue streams for energy storage plants, including the capacity and ancillary services markets.

Encouraging diversified sources of income. The government can offer policy support like capacity leasing and compensation to supplement energy storage plant revenues. Also, these plants should be encouraged to join grid scheduling and offer services like emergency backup to diversify their income.

Formulation of sound policies. The government should formulate a clear policy on the development of energy storage power stations, specifying development objectives, policy measures and regulatory requirements. At the same time, it should strengthen policy implementation and supervision to ensure the effective implementation of the policy.

REFERENCES

1. Chen Q et al.: Participation of energy storage in electricity market mechanism: current status and outlook. Power System Automation, 45(16): 14-28 (2021) .
2. Guan Q et al.: Analysis of economic and operational benefits of battery energy storage power plant on grid side. Southern Energy Construction, 9(4): 103-107 (2022) .
3. Cao Z et al.: Economc analysis of peak shifting of energy storage plant under independent or shared leasing mode.J. Solar Energy,7(351): 40-53 (2023) .
4. Liao J et al.: Energy Storage System Value Analysis and Value Recovery Mechanism Research. In: 2021 IEEE 5th Conference on Energy Internet and Energy System Integration (EI2). 3471–3476. IEEE, Taiyuan, China (2021) .
5. B. Zakeri, S.: Syri, Economy of electricity storage in the Nordic electricity market: The case for Finland. In: 11th International Conference on the European Energy Market (EEM14). 1–6. IEEE, Krakow, Poland (2014).
6. LI Jianlin, TIAN Liting, LAI Xiaokang. Outlook of power storage technology in the context of energy internet. Power System Automation, 39(23): 15-25(2025).
7. X. Yin, X. Yang, G. Fu, S. Zang.: Economic and Technical Optimization Configuration Methods for Energy Storage on the New Energy Side. In: 2023 5th International Conference on Power and Energy Technology (ICPET). 1699–1705. IEEE, Tianjin, China (2023).
8. D. Wang et al.: Factorial Analysis for Evaluating the Effect of Energy Storage on Renewable Energy Accommodation. In: 2021 IEEE 4th International Conference on Renewable Energy and Power Engineering (REPE). 260–264. IEEE, Beijing, China (2021).
9. Sun Wei-Qing et al.: System value assessment method for energy storage in power systems. Power System Automation, 43(8): 47-55(2019).
10. K. Loudiyi, A. Berrada.: Operation optimization and economic assessment of energy storage. In: 2014 International Renewable and Sustainable Energy Conference (IRSEC). 901–906. IEEE, Ouarzazate, Morocco (2014).