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Research on Technical and Economic Feasibility Evaluation Model of Energy Storage Power Station

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Abstract. With the advancement of smart grids, energy storage power stations play more and more significant role in the power system, especially in the utilization of users. Environmental issues and energy crisis have also promoted the development and application of energy storage power stations. In this paper, a research is performed on the technical and economic characteristics of energy storage power stations. A feasibility evaluation method for lithium battery energy storage power stations is proposed. Considering the time dimension, this method proposed a total value evaluation model which is based on the cost-benefit structure. And then, an actual lithium battery energy storage power station is selected as a case to verify the model. Finally, through the sensitivity analysis of the investment and operation of the energy storage power station, the conclusions are as follows: the most sensitive is the benefits of peak and valley electricity price difference.

1. Introduction

As the key technology of distributed renewable energy and smart microgrid [1,2], energy storage can improve its system stability and power supply reliability, cut peaks and fill valleys, and participate in demand response [3,4]. When building energy storage power stations on user side, the enthusiasm of large power users to build energy storage power stations will increase significantly. Users can invest in energy storage power stations to obtain direct benefits such as benefits of peak-valley electricity price difference, and also obtain indirect benefits, including benefits of reducing the capacity of distribution station, the power outage losses, and the distribution loss[5].This paper will consider power users to invest in energy storage power stations, in order to analyze the demands and trends of future power users to invest in energy storage.

This paper analyzes the economics of installing lithium-ion battery energy storage system in an enterprise with high requirements on power supply reliability. The enterprise has an independent distribution line with an access voltage level of 35kV. It is assumed that the enterprise invests in the construction of a 1.5MW·3h lithium-ion battery energy storage system, and the cost and benefit parameters of energy storage for the enterprise are shown in Table 1 and Table 2.

Table 1. Parameters of cost model on user side

First grade indexes	Second grade indexes	Parameters			
		Lithium-ion battery		Lead carbon battery	
		Short-term	Long-term	Short-term	Long-term
Initial investment cost	Civil engineering cost/¥10000	19.71	19.71	147.85	147.85
	Container cost/¥10000	24	24	45	45
	Batteries and related equipment cost/¥10000	259.7	187.6	259.7	187.6
Operation and maintenance cost	Labor cost/¥10000 annually	9(Increasing at a rate of 7.5% per year)			
Repairing cost	Equipment repairing cost /¥10000 annually	5.4	5.4	5.4	5.4
Failure cost	/	2.25	2.25	2.25	2.25

Table 2. Parameter value of the user-side revenue model

First grade indexes	Second grade indexes	Parameters	
		Lithium-ion battery	Lead carbon battery
Benefits of reducing capacity of user distributing substation	Battery charging and discharging efficiency, %	95	95
	Unit cost of consumer distribution system, ¥10000/MW	100	100
	Rated power of energy storage station, MW	1.5	1.5
	Depreciation rate of fixed assets of distribution equipment, %	8	8
	Difference between peak load and mean load, MW	1.3	1.3
Benefits of peak-valley electricity price difference	Battery charging and discharging efficiency, %	70	90
	Battery charge and discharge times, times/day	2	2
	Rated capacity of energy storage power station, MWh	2	2
	Critical Peak Pricing, yuan/kWh	1.0444	1.0444
	Peak load price, yuan/kWh	0.8654	0.8654
	Off peak load price, yuan/kWh	0.3924	0.3924
Benefits of reducing transformer loss	Average load power, MW	10	10
	Short circuit loss	7%	7%
	Distribution transformer capacity, MV·A	20	20
	Load power factor, cosθ	0.95	0.95
Benefits of reducing power outage losses	User's annual production time, h	8000	8000
	Interrupted energy assessment rate, ¥10000/MWh	8.15	8.15
	Minimum power required for normal production of users, MW	9	9
	Outage rate of user bus side power supply without input energy storage device, times/day	0.34	0.34
	Outage rate of user bus side power supply with input energy storage device, times/day	0.15	0.15
	Expected value of economic loss caused by power interruption to the user, ¥10000	1	1
	Power supply reliability of the distribution network	99.9764%	99.9764%
net present value	Total charge and discharge times of a single batch of batteries	8000	4000
	a single batch of batteries, %	5	40
	Discount rate, %	8	8
	Fixed asset residual rate, %	5	5

2. Technical and economic feasibility evaluation model

The life cycle cost of the energy storage power station includes initial investment cost, operation and maintenance cost, repairing cost, and failure cost.

$$C_1 = C_j + C_e + C_e^{'} + C_o \tag{1}$$

$$C_2 = Q_m \times r \times W_a \tag{2}$$

$$C_3 = Q_m \times p_m \tag{3}$$

$$C_4 = P_{gz} \times p_{gz} \tag{4}$$

Where C_j is the civil construction cost, C_e is the battery cost, C'_e is the battery test and screening composition cost, C_o is the related equipment cost, Q_m is the rated capacity of the battery energy storage system, r is the number of operation and maintenance personnel of the unit power storage system, p_m is the annual equipment maintenance cost per unit capacity, P_{gz} is the annual average failure rate, and p_{gz} is the average repair cost of the failure.

The benefits of the energy storage power station are as follows:

$$I_1 = 365P_m\left(k(e_P h_1 + e_H h_2) - e_L h_3 / k\right) \tag{5}$$

$$I_2 = \begin{cases} \gamma_d C_d \eta P_{\max} & P_{\max} \le P_c \\ \gamma_d C_d \eta\left(2P_c - P_{\max}\right) & P_{\max} > P_c \end{cases} \tag{6}$$

$$I_3 = n\sum_{i=1}^{24} \frac{\left[P_i^2 - \left(P_i - P_i^+ + P_i^-\right)^2\right] P_k e_i}{\left(S_N \cos\phi\right)^2} \tag{7}$$

$$I_4 = \lambda_s R_{IEA} E_{ENS}\left[1 - p\{W_i < E_{ENS}\}\right] + \left(\lambda_s - \lambda'_s\right) E_\lambda \tag{8}$$

Where P_m is the rated power of the battery energy storage system, k is the charging and discharging efficiency, $P_{\max}$ is the rated power of the lithium-ion battery, C_d is the unit cost of the power distribution system, γ_d is the fixed asset depreciation rate of the power distribution equipment, P_c is the difference between the peak load and the mean load, P_i is the load power of the ith hour, P_k is the short-circuit loss of the distribution, e_i is the electricity price of the ith hour, S_N is the capacity of the distribution, W_i is the remaining power in the i th hour, λ_s and λ'_s is the power failure rate of the bus side power supply without the energy storage device and with the energy storage device respectively, E_λ is the expected value of economic loss to the user when the power supply is interrupted.

Based on the above cost and benefit items, this paper proposes a total value evaluation model for energy storage power stations:

$$NPV = \sum_{t=1}^{x} \frac{AI_x - C_2}{\left(1+r\right)^t} - \left[\left(1-\xi\right)\left(C_j + C_o\right) + C_e + C_e^{'}\right], \quad x < \Delta N \tag{9}$$

$$NPV = \sum_{t=1}^{x} \frac{AI_x - C_2}{\left(1+r\right)^t} - \frac{\left(C_{e1} - R_{re} \cdot G_{re}\right)}{\left(1+r\right)^{\Delta N_1}} - \left[\left(1-\xi\right)\left(C_j + C_o\right) + C_e + C_e^{'}\right], \quad x \ge \Delta N \tag{10}$$

Where ΔN is the life of the battery energy storage system, AI_x is the annual income, R_{re} is the income of recycling used batteries, ξ is the average residual value of fixed assets, and r is the discount rate.

3. Economic Analysis of Lithium Battery Energy Storage Power Station

Bringing the indicator data into the total value evaluation model of the energy storage power station, the net present value (NPV) and dynamic payback period of the energy storage system can be obtained in different scenarios, as shown in Figure 1.

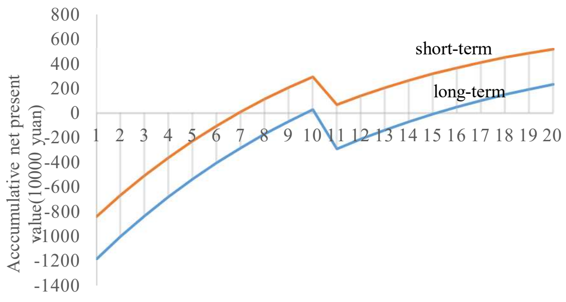

Figure 1. Accumulative discounted value and dynamic payback curve under different scenarios

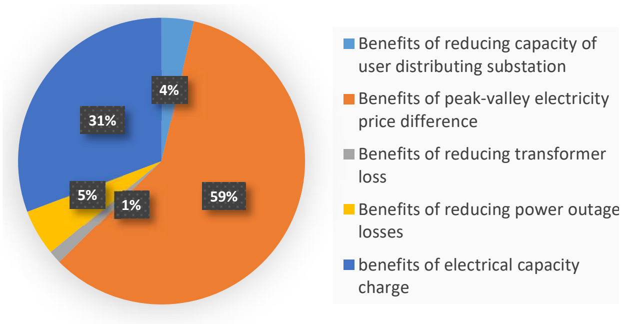

Figure 2. The proportion of all kinds of benefits

As can be seen from Figure 1, in the short-term scenario, using lithium-ion battery energy storage can recover costs in the 10th year. Since the battery needs to be replaced at the end of the 10th year, the user must fully recover the cost and achieve profitability in the 15th year. In the long-term scenario, the dynamic investment payback period of lithium-ion batteries is about 7 years.

The proportion of the income of each part of the user side is shown in Figure 2. It can be seen from Figure 2 that the largest benefits of the lithium-ion battery energy storage station installed on the user side is the peak-to-valley spread income, accounting for 59% of the total benefits; the second is the benefits of capacity electricity fee, accounting for 31% of the total benefits; benefits of reducing power outage losses, reducing capacity of user substation construction and reducing transformer loss, respectively, accounted for 5%, 4% and 1% of total benefits. This shows that the most important source of benefits for power users is the benefits of peak-valley spread.

4. Sensitivity analysis of lithium battery energy storage power station

4.1. Cost item sensitivity analysis

There are many influencing factors on the cost of energy storage power station invested by users. Among the cost factors, the battery cost which accounts for a large proportion of the total investment cost, is selected to analyze its impact on the payback period of investment.

With the progress of technology, market is expected to lower battery cost [6-7]. So, this paper analyze the sensitivity of battery cost. When the battery cost is reduced proportionately, we get the curve for cumulative discounted value and dynamic payback period of investment, which is shown in Figure 3.

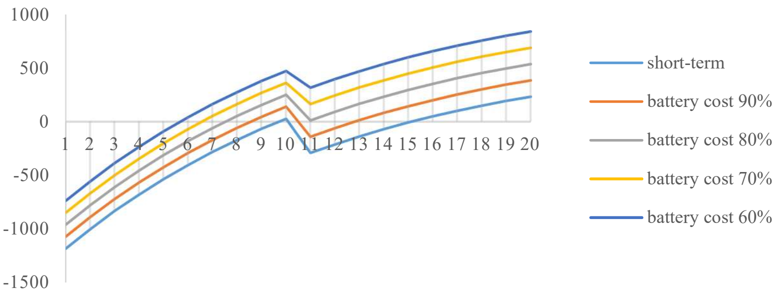

Figure 3. The curve for cumulative discounted value and dynamic payback period when reducing battery cost

As shown in Figure 3, as the battery cost decreases in proportion, the profitability of lithium-ion battery energy storage increases constantly. When the battery cost drops to 90%, the payback period becomes 8.6 years. If the battery cost continues to decrease to 70%, it will be profitable for the energy storage power station until the 6th operation year. When the purchase cost of the battery is reduced to 60%, the payback period of the energy storage power station is reduced to 5.7 years. It can be seen that the user-side energy storage power station is highly sensitive for the battery acquisition cost.

4.2. Sensitivity analysis of earnings

It can be clearly seen from the benefits ratio of the lithium-ion battery energy storage power station on user side that its benefits mainly come from the reduction of the electricity charge and the capacity charge. While the electricity charge is derived from the difference in peak and valley prices. Therefore, This section analyzes the sensitivity of capacity charge and peak-valley electricity price difference.

When the peak and valley electricity price difference increase in proportion, the accumulative discounted value and the dynamic payback period curve are obtained, as shown in Figure 4.

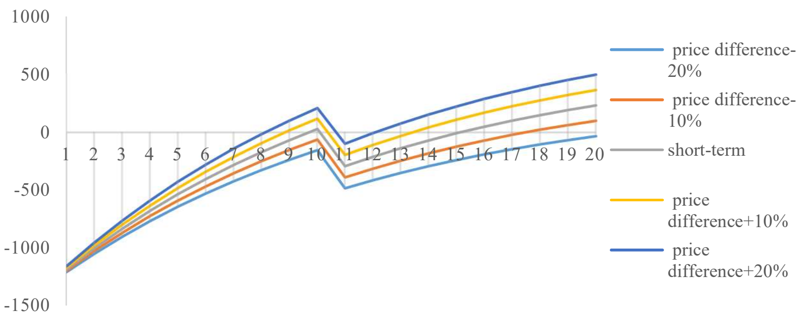

Figure 4. The curve for cumulative discounted value and dynamic payback period when increasing the difference in peak and valley electricity prices

As shown in Figure 4, with the increase of benefits of the peak and valley electricity price difference, the economic benefits of lithium-ion battery energy storage keep increasing. When the price difference is increased by 10%, the profit can be realized in 8.9 years. With the price difference continues to increase, the profit can be realized in about 8.2 years when the price is increased by 20%. When the price difference is reduced by 10%, the energy storage power station realizes profit delayed to the 17.5th year due to the replacement cost of battery in the decade. As the price difference continues to decrease, the lithium-ion energy storage plant is impossible to realize profit over the 20-year operating period when the price is reduced by 20%.

4.3. *Sensitivity analysis diagram*

The change of NPV about three major sensitivity factors including the cost of battery acquisition, annual cost and the peak and valley electricity price difference is summarized in Figure 5.

As shown in Figure 5, the break-even point of the profits of peak and valley price difference is -17.53%, that is, the peak and valley price difference is 0.4841 yuan/KW • h. When the peak and valley price difference is higher than 0.4841 yuan/KW • h, the power station of lithium-ion battery can recover the cost at the end of the 20 years' lifecycle. The break-even point of battery acquisition cost is 15.33%, that is, the cost of battery cost is ¥12,836,300. When the cost of battery acquisition is lower than ¥12,836,300, the lithium-ion battery energy storage power station can recover the cost at the end of the 20 years' life cycle. The sensitive break-even point of annual expenditure cost is 98.53%, that is, the initial annual cost is ¥330600. When the total cost is lower than ¥330600, the lithium-ion battery energy storage power station can recover the cost at the end of the 20 years' life cycle.

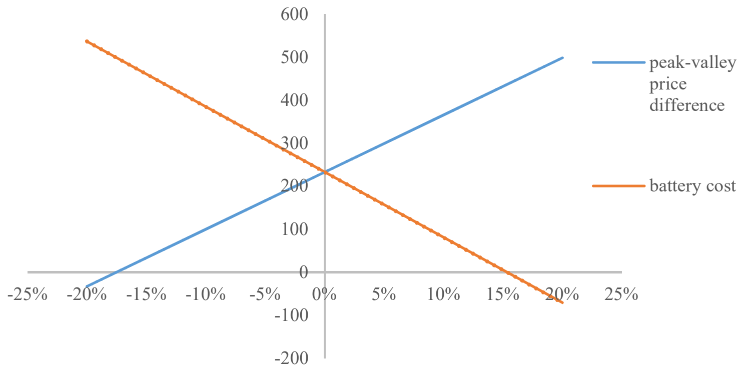

Figure 5. Sensitivity analysis results of each uncertainty factor

5. Conclusion

The most sensitive one is benefits of the peak and valley electricity price difference, which means that it is the most important factor affecting the economics of the user-side energy storage power station, followed by the battery acquisition cost, and the energy storage station on user side is less sensitive to annual cost.

Acknowledgments

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