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Abstract. With the advancement of smart grids, energy storage power stations in power systems is becoming more and more important, especially in the development and utilization on generation side. Environmental issues and energy rises have driven the development of distributed energy, and have also promoted the development and application of energy storage power stations. This paper analyses the indicators of lithium battery energy storage power stations on generation side. Based on the whole life cycle theory, this paper establishes corresponding evaluation models for key links such as energy storage power station construction and operation, and evaluates the reasonable benefits of lithium battery energy storage power stations on generation side. Compared with the existing evaluation methods at home and abroad, the model in this paper is more in line with the construction progress of China's energy storage power station, and has great significance for the commercial application evaluation of China's lithium battery energy storage power stations on generation side.

Key words. energy storage station; generation side; evaluation model.

1. Introduction

With the promotion of China's low-carbon green energy strategy and the implementation of supporting policies of new round of electricity reform, the application value of energy storage technology has been recognized by the market, and energy storage technology has become a highlight to promote China's energy transformation and energy structure adjustment [1]. At present, with the continuous improvement of energy storage technology and the announcement of related support policies, the energy storage station is gradually developing from the stage of research and demonstration to the early stage of commercialization [2].

Firstly, this paper analyzes the typical application scenarios of energy storage stations on generation side. Based on this, the economic benefit calculation model of energy storage stations on generation side is constructed, and the typical case is selected for analysis. Finally, in the perspective of the grid company, the business model of energy storage stations on generation side is studied.

2. Typical application scenarios on generation side

The main application scenarios of energy storage stations on generation side include energy output smoothing of renewable energy, thermoelectric decoupling, self-consumption of new energy, and frequency regulation auxiliary service.

1) Energy output smoothing of renewable energy

Building energy storage stations in the renewable energy electric fields can help to fully realize the value of renewable energy power generation. In the case of changes in the external environment, the energy storage station can stabilize the output level of renewable energy power generation, smooth the power generation output curve, and then satisfy the new energy output power assessment [3].

2) Thermoelectric decoupling

The configuration of energy storage can achieve thermoelectric decoupling, significantly improve the adjustment capacity of combined heat and power units, improve thermal power flexibility, and promote clean energy heating. At the same time, the output of the combined heat and power units can also better match the wind power output with the configuration of energy storage, and the ability of the grid to absorb wind power can be improved.

3) Self-consumption of new energy

Due to distance, technology and institutional obstacles, the new energy consumption is still a problem that plagues the development of the industry, although new energy sources such as wind power and photovoltaics are developing rapidly. The construction of energy storage stations in large-scale ground power stations can save more electricity from renewable energy when resources are sufficient, and transport them out when resources are insufficient. Therefore, the phenomenon of abandoning electricity in new energy power station can be effectively alleviated, and the self-dissipation ability of new energy power station can be improved [4].

4) Frequency regulation

Traditional energy sources, especially thermal power, have hysteresis in response to signals, so it is difficult to meet the added needs of frequency regulation. Energy storage stations on generation side can assist the traditional thermal power units and provide frequency regulation auxiliary service relying on large-scale new energy units [5].

5) Accident backup

Since the power generation equipment may have temporary or even permanent failures that affect the power supply, the system must set a certain number of accident backup power sources. The adjustment flexibility of the energy storage station makes it a backup power source that can be quickly started in an emergency.

The construction of energy storage stations on generation side can help improve the quality of grid-connected power, help promote the consumption of renewable energy, reduce waste of resources, ensure the reliability of power supply, and maintain the safe operation of power systems.

3. Economic Benefit Calculation Model and Case Analysis

In recent years, the electrochemical energy storage station has developed rapidly. The lithium-ion battery energy storage station has irreplaceable advantages in many applications due to its high energy density and high rate of charging and discharging [6]. To this end, this section analyzes the economics of lithium-ion battery energy storage stations.

3.1. Cost Analysis

The full life cycle cost of building a storage energy station includes five items: initial investment cost, operation and maintenance cost, overhaul cost, failure cost and return disposal cost [7].

(1) Initial investment cost

The initial investment cost refers to the one-time investment required in the previous period during the development process. The total initial investment cost can be expressed as:

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

Among them, C_j is the cost of civil engineering. C_e is the cost of battery purchase. C_e' is the cost of testing and matching for battery. C_o is the cost of purchasing the associated equipment.

1) The cost of civil engineering

At present, the container is a simple and low-cost construction method for the energy storage station. The cost of civil engineering in this paper mainly refers to land lease cost and container cost.

$$C_i = S \cdot P_1 + P_2 \cdot n \tag{2}$$

Among them, S is the lease area of the energy storage system, and P_1 is the lease price of the local land. P_2 is the unit price of the container. n is the number of containers

2) The cost of purchasing the associated equipment

The relevant equipment of the energy storage station is composed of power distribution equipment, battery box, battery cabinet and monitoring system. Therefore, the related equipment costs can be expressed as follows:

$$C_o = C_{eq} + C_{b1} + C_{b2} + C_{mo} \tag{3}$$

Among them, the C_{eq} is the cost of the power distribution equipment, and the power distribution equipment includes the isolating transformers (IT), the power conversion system (PCS), and the battery management system (BMS). C_{b1} refers to the cost of the battery box. C_{b2} refers to the cost of the battery cabinet. C_{mo} is the cost of monitoring the system.

3) The cost of battery purchase

The battery purchase price can be expressed as:

$$C_e = p_e \times P_{pz} \tag{4}$$

Among them, p_e is the price of unit capacity lithium-ion battery. P_m is the initial configuration capacity of the energy storage power station.

According to research and analysis, the life of lithium-ion battery is about 10 years, and the battery system needs to be replaced in the 11th year.

4) The cost of testing and matching for battery

The cost of testing and matching for battery consists of four aspects: equipment investment C_{eq}, labor costs C_{la}, storage costs C_{st}, and parts replacement costs C_{pa}. It can be expressed as:

$$Ce' = C_{eq} + C_{la} + C_{st} + C_{pa} \tag{5}$$

(2) Operation and maintenance cost

Operation and maintenance costs mainly include labor costs during daily use. Among them, the labor cost is the wages, benefits and corresponding subsidies of the maintenance workers of the energy storage power station. It can be expressed as:

$$C_2 = Q_m \times r \times W_a \tag{6}$$

Among them, Q_m is the rated capacity of the energy storage system. r is the number of personnel working for operation and maintenance of the unit power storage system.

(3) Overhaul cost

Equipment overhaul costs can be expressed as:

$$C_3 = Q_m \times p_m \tag{7}$$

Among them, p_m is the annual maintenance cost per unit capacity.

(4) Failure cost

The failure cost mainly includes the repair cost of the energy storage station. It can be expressed as:

$$C_4 = P_{gz} \times p_{gz} \tag{8}$$

Among them, p_{gz} is the annual average failure probability, and P_{gz} is the average repair cost of failure.

(5) Return disposal cost

It mainly includes the decommissioning treatment cost of the energy storage facility, the residual value of the equipment decommissioning or the remaining use value of the equipment.

3.2. Income Analysis

The revenue of the energy storage station on generation side mainly comes from three aspects: promoting new energy consumption, reducing the conventional spare capacity required for new energy power generation, and reducing carbon emission. Under the condition that the electricity spot transaction is mature in the future, investing in energy storage stations can obtain additional peak-to-valley electricity price gains in the long run.

(1) Income from promoting new energy consumption

Energy storage stations can help promote new energy consumption. This paper focuses on the income of energy storage stations to reduce wind abandonment.

By configuring a certain proportion of energy storage systems, when the wind power output is low, the stored energy that cannot be transported out during peak hours of wind power output can be released. This can alleviate the wind abandonment problem of wind power plant. The reduced revenue generated by the abandoned wind power is the benefit of the energy storage system in the wind farm. The income I_1 generated by energy storage to promote new energy consumption can be expressed as:

$$I_1 = Q_1 e_1 + Q_2 e_2 \tag{9}$$

Among them, e_1 is the on-grid price of wind power, which is approved as the benchmark price of 0.57 yuan/kWh. e_2 is the spot market price. Q_1 is the on-grid abandoned wind power. Q_2 is the abandoned wind power involved in spot market transactions.

(2) The income from reducing the regular spare capacity required for new energy generation.

The randomicity and intermittence of new energy power generation have an impact on the grid. The battery energy storage device can quickly adjust the power that new energy power generation consumes/emits, which makes it replace the conventional power as a spare capacity for new energy generation. The income I_2 obtained in this way can be expressed as:

$$I_2 = 0.5 P_{\max} T e_s \tag{10}$$

Among them, e_s is the spare capacity price. P_{max} is the maximum long-term charge and discharge power of a lithium-ion battery. T is the duration of the low load.

(3) The income of C emission reduction

The income of C emission reduction is measured by reducing carbon dioxide emissions. The specific mathematical model is as follows:

$$I_3 = 365 \cdot tCO_2 \cdot P_c \tag{11}$$

$$tCO_2 = \beta \cdot Q_c \tag{12}$$

Among them, tCO_2 is carbon dioxide equivalent, β is power emission factor, P_c is carbon trading price, and Q_c is electricity consumption.

(4) The income from the peak-to-valley electricity price

The income from the peak-to-valley electricity price refers to the income generated by the energy storage device using the peak-to-valley electricity price. In this situation, the energy loss of the energy storage system should be considered. At present, the unidirectional conversion efficiency k of the domestic mainstream converter is about 95%. Therefore, the annual income from the peak-to-valley electricity price can be expressed as:

$$I_4 = 365P_m \left(k(e_P h_1 + e_H h_2) - \frac{e_L h_3}{k} \right) \tag{13}$$

Among them, P_m is the rated power of the battery energy storage system. e_P, e_H, and e_L are the prices of the peak load period, the high load period, and the low load period, respectively. h_1, h_2 and h_3 are the daily charge and discharge time of the peak load period, the high load period, and the low load period, respectively.

3.3. The total value evaluation model

The net present value of the battery energy storage stations operating for x years is:

$$NPV = \sum_{t=1}^{x} \frac{AI_x - C_2}{(1+r)^t} \tag{14}$$

3.4. Case Analysis

In order to comprehensively analyze the economic benefits of energy storage stations, this section assumes a scene that a power generator in Zhejiang Province independently invests in the construction of energy storage power stations. Assumed that the grid-connected capacity of a wind farm is 50MW, and a 15MW*3h lithium-ion battery energy storage power station is invested in constructing. The cost and benefit model parameters are shown in Table 1 and 2.
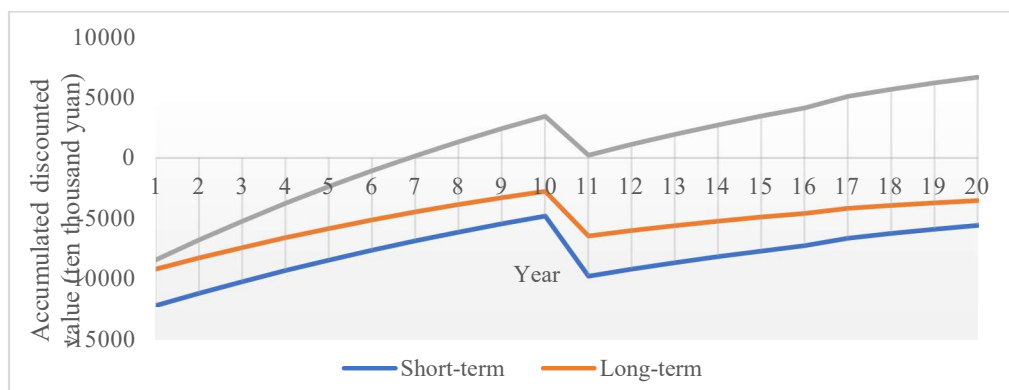
Table 1. Parameters of the cost model on generation side

Primary indicator	Secondary indicators	Parameter	
		Short-term	Long-term
initial investment cost	the cost of civil engineering/ten thousand yuan	19.71	19.71
	container cost/ten thousand yuan	24	24
	the cost of the battery purchase and other associated equipment acquisition/ten thousand yuan	11130	9938
operation and maintenance cos	labor cost / ten thousand yuan per year	90(in increments of 7.5% per year)	
overhaul cost	equipment maintenance cost / ten thousand yuan per year	54	54
failure cost	/	22.5	22.5
return disposal cost	/	5	5

Table 2. The parameters of the income model on generation side

Primary indicator	Secondary indicators	Parameter
income from reducing new energy consumption	wind power on-grid price, yuan/ kWh	0.57
income from reducing the regular spare capacity required for new energy generation	the spare capacity price, ten thousand yuan per MW· per year	40
	the duration of the low load, h/day	8
the income of C emission reduction	power emission factor, ton/MWh	0.7598
	carbon trading price, yuan/ton	60
net present value	total number of charge and discharge cycles per batch, times	8000
	battery recovery residual rate, %	5
	discount rate, %	8
	fixed asset residual rate, %	5

The net present value and dynamic payback period of the energy storage system in different scenarios can be obtained by bringing the indicator data into the total value evaluation model of the energy storage power station, which is as shown in Figure 1.

Figure 1. Accumulated discounted value and dynamic payback period in different scenarios

It can be seen from the figure that in the short-term and long-term scenarios, the lithium-ion battery energy storage power station cannot recover the cost within 20 years. At present, Zhejiang Province is actively building a power spot market. Referring to the real-time transaction data of a typical week in the PJM market of USA, and combining the US and Zhejiang wind power price, the income from the peak-to-valley electricity price under the spot market can be roughly calculated. As can be seen from the above figure, the power producer can recover the cost in the seventh year or so. Therefore, the development of the spot market can greatly increase the profitability of energy storage power stations and provide reasonable economic incentives for energy storage.

4. Business model of energy storage stations on generation side

In the current policy scenario, in the short-term situation, grid companies can participate in energy storage investments in joint venture mode, lease mode, and PPP mode and so on. With the establishment of the spot market and the auxiliary service market in the long-term situation, the economy of energy storage stations increases, for which the grid company can operate independently.

In the joint venture mode, the grid company invests and establishes a new joint venture with the fund. The grid company is responsible for the design, construction and maintenance of the energy storage

system and the joint venture acquires the energy storage system. The energy storage system is leased to energy owners such as power generation companies. These companies pay the lease fee to the joint venture company. The pattern is characterized by the fact that the fund controls the ownership of the asset before the cost is recovered. At the same time, through the accelerated depreciation and tax recovery of the investment during the borrowing period, the fund can obtain a cash return rate. The grid company gets most of the rent.

In the leasing mode, the grid company can sign long-term contracts with energy service providers such as the distribution and retail companies, and provide energy storage or "energy & energy storage" system leasing services. Energy-saving services and contract energy management are included. The lease object is the energy service subject such as power generation companies. The main source of income is rental income. In this mode, the energy storage station has less revenue.

In the PPP mode, the grid company undertakes most of the work of designing, constructing, operating, and maintaining the infrastructure of the energy storage station. And the grid company obtains a reasonable return on investment through "user pays" and necessary "government payment". The government department is responsible for the price and quality supervision of energy storage facilities and public services. The advantage of this mode is that the government can share the investment risk and reduce the difficulty of financing. The cooperation between the two parties can also coordinate the different goals of different stakeholders and maximize the social benefits.

The establishment and improvement of the spot market is the fundamental guarantee for energy storage technology to truly realize large-scale application, reflect value and achieve profitability. Therefore, after the establishment of the spot market in the future, no special policy and subsidy support is needed, and the energy storage system can achieve profitability. The economics of energy storage stations can be greatly improved, and further grid companies can operate energy storage power stations independently.

5. Conclusion

In this paper, the economic benefit calculation model of energy storage stations on generation side is constructed, and a typical case is selected for analysis. The calculations show that in the short-term and long-term scenarios, the cost cannot be recovered within 20 years. After the spot market is established, the power producer can recover the cost in about the seventh year, and the grid company can independently invest in the energy storage station.

Acknowledgments

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