Construction of a new levelled cost model for energy storage based on LCOE and learning curve

Zhe Chai [1], Xing Chen [1], Shuo Yin [1], Man Jin [1], Xin Wang [2], Xingwu Guo [1], Yao Lu [1]

[1] State Grid Henan Electric Power Company Economic and Technical Research Institute Zhengzhou, China
[2] Henan University of Economics and Law Zhengzhou, China

Abstract. New energy storage is essential to the realization of the "dual carbon" goal and the new power system with new energy as the main body, but its cost is relatively high and the economy is poor at present. This paper studies the levelized cost of new energy storage based on the whole life cycle perspective. Based on LCOE and learning curve methods, a new levelled cost estimation model and prediction model for energy storage are constructed. Based on the latest development status of electrochemical new energy storage, the levelized cost of energy of lithium-ion batteries, flow-aluminum batteries, and flow-zinc batteries were measured, the cost composition and proportion of various types of energy storage are analyzed, and on this basis, the levelized cost of lithium-ion batteries was predicted. Comparative analysis shows that the levelized cost per kilowatt-hour of lithium-ion batteries is the lowest. This article provides a certain reference for the construction and layout of energy storage on three sides of the source network and load.

Keywords: New energy storage; levelized cost model; cost forecast model; LCOE; learning curve.

1. Introduction

In recent years, energy shortages and pollution problems have become increasingly obvious. The development and utilization of new energy sources such as wind and light, improvement of energy structure and reduction of pollutant emissions have become urgent problems to be solved by countries all over the world [1]. New energy power generation such as wind power and photovoltaic power generation has strong randomness and volatility. After large-scale access to the grid, it will lead to a large demand for system regulation resources, and the large-scale and long-period power balance of the system will be significantly more difficult, posing a serious threat to grid security[2]. Energy storage plays a key role in promoting the implementation of China's "emission peak and carbon neutrality" goals and ensuring the smooth construction of new power systems with new energy as the main body. It is an important support for ensuring the large-scale development of new energy and China's energy security[3] . New types of energy storage, such as electrochemistry, have the advantages of fast response speed, short construction period, and small development scale due to resource constraints. They will play an important role in the construction of new power systems. However, its current cost is relatively high, it cannot make up for investment and operating costs, its self-financing capability is poor, and its business model is unclear, which has a certain negative impact on the application and development of new types of energy storage such as electrochemistry[4-6]. Therefore, it is necessary to analyze and predict the technical and economic costs of new types of energy storage such as electrochemistry, so as to study and judge the future cost changes and provide decision-making references for relevant stakeholders of the power system.

2. Analysis of the cost composition of new energy storage

The cost of new energy storage mainly includes investment and construction costs, operation and maintenance costs, financial costs, residual value, etc. The specific connotations and characteristics are as follows.

2.1 Investment and construction costs of new energy storage

The system construction cost of a new energy storage power station, also known as construction cost, refers to the cost of an energy storage system per unit capacity. The cost of energy storage projects varies greatly, mainly due to the power-to-energy ratio, project scale, project complexity, configuration redundancy, and local regulations. The construction cost of the energy storage system accounts for about 83% of the total cost[7-9].

The construction cost of an energy storage power station, also known as the system cost, refers to the cost of the energy storage system per unit capacity. It is mainly composed of equipment installation cost (including battery cost) and construction cost (not counted and land cost). Energy storage equipment includes energy storage batteries, battery management systems, energy storage inverters and power distribution systems, etc. The purchase cost of these equipment constitutes the equipment installation cost[10]. Construction costs mainly include construction engineering fees, installation engineering fees, and equipment and facility design and commissioning expenses.

2.2 Operation and maintenance costs of new energy storage

Operation and maintenance costs refer to the funds that are dynamically invested to ensure the normal operation of the energy storage system during the life cycle[11]. The operation and maintenance costs of energy storage power stations mainly include the labor costs, maintenance costs and the replacement cost of some energy storage devices. Operation and maintenance costs account for about 5% of the total cost. The survey shows that the ratio of operation and maintenance costs to the cost of the energy storage system is 5.5%[12]. After conversion, it accounts for about 5% of the total cost.

The operation and maintenance cost of the energy storage power station is the cost required to maintain the energy storage power station in a good standby state. Operation and maintenance costs include photovoltaic panel cleaning costs, power station management, and maintenance costs[13]. No matter how much storage is used, the fixed maintenance costs are the same. Variable maintenance costs are directly proportional to the frequency and duration of storage usage. The operation and maintenance cost is generally obtained by multiplying the initial investment by the transportation inspection rate[14]. Considering that the energy storage system (ESS) has a limited service life, certain losses will occur during the operation of the system, resulting in system life loss costs. Therefore, when calculating the operation and maintenance costs of energy storage power stations, it is necessary to comprehensively consider parameters such as the total construction cost reduction ratio, operation and maintenance rate, unit energy construction cost, and energy storage capacity[15].

2.3 Financial costs of new energy storage

Financial cost refers to the financing expenses incurred by an enterprise to raise funds in the process of production and operation. Financial costs generally include interest generated by bank loans, bond issuance and other financing measures. The financial cost of this study mainly considers the interest generated by long-term bank loans. The ratio of the financial cost of the energy storage system to the cost of the energy storage system reaches 15%. After conversion, it accounts for about 12% of the total cost [16].

2.4 Residual value of energy storage

When the life of each part of the energy storage system is exhausted, it needs to be treated in a harmless manner, and the capital invested is the disposal cost. The cost is mainly divided into two aspects: recovery expenditure and equipment residual value[17]. The residual value of energy storage power station is between 3% and 40%, and the specific value is related to the type of technology.

Ideally, the disassembled battery and its chemical substances can be recycled, which can offset the loss caused by partial disassembly and disposal of hazardous materials, but the final disposal-related costs should be included in the total cost of the energy storage power station among. In the foreseeable future, the impact of recycling value on the economics of battery energy storage will become greater and greater due to the establishment and improvement of energy storage battery recycling mechanisms[18]. However, this mechanism has not yet been fully established, and the recycling of waste lithium batteries is facing many problems because of its complex recycling technology. The residual value of the power station is the residual value after the end of service of the energy storage power station, excluding the disposal cost. The metal materials and some devices in the energy storage power station have the value of recycling and reuse. At present, the recycling value of lead-acid batteries and all vanadium flow battery is relatively high, about 20% to 40%[19]. Because the electrode material contains noble metal elements such as cobalt and nickel, the recycling value of ternary lithium batteries is about 10% to 18%, while the recycling value of lithium iron phosphate batteries is low. In addition, the power conversion components of the electrochemical energy storage power station at the end of its life are still of use value. Therefore, the residual value of energy storage power station is between 3% and 40%, and the specific value is related to the type of technology.

The cost composition ratio of each part of the new energy storage is shown in Figure 2-1.

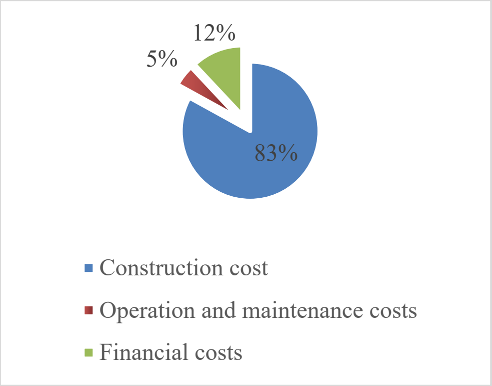

Figure 1. The cost proportion of each part of the energy storage system(data sources: Bloomberg NEF)

3. New-type energy storage levelling cost estimation and forecasting model construction

3.1 New type of energy storage levelling cost estimation model

The levelization of the cost of new energy storage, that is, the levelization of costs, requires consideration of the life cycle costs of the new energy storage, including investment costs, operating costs and maintenance costs, and sometimes the effect of project residual value needs to be considered. Considering the life cycle refers to considering the time value of energy storage in different periods. This evaluation method relatively effectively avoids the problem of NPV and other methods that are difficult to compare between different technologies, and achieves comparability among various energy storage technologies and even power generation technologies. Energy storage projects need to consider the level of total power consumption from the perspective of life cycle costs. The National Renewable Energy Laboratory originally issued the LCOE formula, as shown in equation (1), by calculating project operations Life cycle cost and power generation during operation cycle, and discount the cost and power generation of the whole operation cycle according to a fixed discount rate to obtain the calculation formula of the levelized electricity cost.

$$\mathrm{LCOE}=\frac{\left[\mathrm{I}_0+\sum_{n=1}^{N}\mathrm{O}\&\mathrm{M}_n\right]}{\sum_{n=1}^{N}\mathrm{G}_n} \qquad (1)$$

In the formula: I0 represents the initial investment of the energy storage project, including construction costs and equipment-related purchase costs. O&Mn represents the operation and maintenance costs of the nth year, this value includes common personnel costs, insurance costs, etc. during the project period. Gn is the amount of energy storage and discharge in the nth year. N is the service life of energy storage.

The above-mentioned LCOE calculation model has not yet considered the time value of money. In response to this problem, this article comprehensively considers its technical characteristics and service life from the perspective of the full life cycle of energy storage projects, and introduces the discount rate of funds to consider the time value of money, as shown in formula (2) .

$$\mathrm{LCOE}=\frac{\left[\mathrm{I}_0+\sum_{n=1}^{N}\frac{\mathrm{O}\&\mathrm{M}_n}{(1+i)^n}\right]}{\sum_{n=1}^{N}\frac{\mathrm{G}_n}{(1+i)^n}} \qquad (2)$$

In the formula: V represents the residual value of the project, and i represents the discount rate of funds.

In formula (2), the electricity generation needs to be discounted is actually not a discount to the electricity generation itself but a discount to a conceptual electricity revenue. Specifically, the discounted value of electricity in the denominator can be moved to the left end of the equation and multiplied, which shows the essence of the levelized cost, that is, the discounted electricity revenue measured by the levelized cost needs to be equal to the discount of each year's expenditure. Therefore, the discount rate of the denominator is necessary.

3.2 New energy storage levelling cost prediction model

The learning curve theory used to measure the progress of energy technology is currently a widely used method in the world. The learning curve is a graphical representation of the learning rate of a certain activity or tool, also known as the proficiency curve, which is a dynamic production function. The learning curve theory originated from the study of aircraft manufacturing in the 1930s, and was developed and applied to other fields in the following decades. Since the 1990s, due to the need for energy technology policy analysis, the learning curve theory has been widely used to estimate changes in the cost of energy technology [20].

The basic logic of the learning curve is: the current unit output cost of new energy technology is higher than that of conventional energy technology; however, with the development of new energy technology and the accumulation of production experience, its unit cost is showing a gradual decline.

The original model of the learning curve can be expressed by the following formula:

$$Y = aX^b \qquad （3）$$

In the formula: Y is the unit cost of the product; a is the unit cost of the first product; X is the cumulative output of the product; b is the learning rate index, $0 \le b \le 1$.

Taking the logarithm of both sides of the learning curve equation can be converted into a straight line form. Therefore, it is usually necessary to linearly fit the logarithmic form of the learning curve during calculation. Specific steps are as follows:

(1) Data collection. Collect the output and cost of each time period according to a specific time period (using output as the standard).

(2) Data processing. Calculate the unit cost under different cumulative production levels and take the logarithm.

(3) Regression analysis. Perform regression analysis on the dependent variable and independent variable to get the regression equation.

(4) Goodness of fit test. Use the learning curve equation for cost forecasting, compare it with the actual situation, and make necessary corrections to the original equation.

At present, there are three forms of energy technology learning curve: single factor learning curve model, which describes the unit cost of an energy technology as a function of its cumulative total output. With the deepening of energy technology research, some scholars believe that the single-factor learning curve has certain limitations on the description of the development of energy technology, and then developed a two-factor learning curve model, by integrating R&D's promotion of energy technology progress separating and considering the growth of output independently is, to a certain extent, a refinement and beneficial exploration of the learning curve theory. On the basis of the two-factor learning curve model, some scholars have further considered the energy technology learning curve model from the perspective of the Cobb-Douglas-like production function, and obtained a number of factors including cumulative output, cumulative knowledge, scale effect, and input factor price factors. Factor energy technology learning curve model.

Considering the availability of data, this project constructs a two-factor learning curve model for energy storage cost. The cost learning curve of energy storage mainly considers the development scale of energy storage and the impact of R&D investment on the initial investment cost of energy storage. In view of the availability of data, this project selects the sum of the R&D investment of several typical listed companies in the energy storage industry as a substitute variable for the overall R&D investment. This project builds a cost learning curve for energy storage and predicts the future trend of energy storage cost changes. The cost learning curve can be expressed as the following form:

$$C(x_t,y_t)=C(x_0,y_0)\left(\frac{x_t}{x_0}\right)^{-\alpha}\left(\frac{y_t}{y_0}\right)^{-\beta} \qquad (4)$$

In the formula: C(xt,yt) is the unit cost of energy storage technology in year t; C(x0,y0) is the initial unit cost of the technology in the base year; xt is the cumulative development scale of energy storage technology in year t; x0 is the cumulative development scale of the technology in the base year; α is the cumulative output elasticity coefficient; yt is the cumulative R&D investment of energy storage technology in year t; y0 is the cumulative R&D investment of the technology in the base year; β is the cumulative R&D investment elasticity.

4. Conclusion

The proposal of the "Double carbon" goal and the construction of a new power system with new energy as the main body will play a rapid role in promoting the development of China's wind, solar and other renewable energy. As a flexible energy storage method, new energy storage plays a key role in solving the impact of large-scale grid connection of renewable energy on the safety and stability of the power system, but the cost is still high, which has an adverse impact on its promotion and application. From the perspective of the entire life cycle, this paper uses LCOE and learning curve methods to construct a levelized cost calculation and prediction model for new energy storage. Based on the latest development status of new energy storage, the levelized cost per kilowatt-hour of the three new electrochemical energy storage batteries of the flow-zinc battery has been calculated, and the results show that the levelized cost per kilowatt-hour of lithium-ion batteries is the lowest. At the same time, this article uses lithium-ion storage as an example to predict its cost. The results show that the levelized cost of lithium-ion electrochemical storage will drop to 0.55 yuan/Wh and 0.32 yuan/Wh by 2025 and 2030, its application in the new power system will have a certain economic efficiency.

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