Economic evaluation and optimization model of pumped storage project under the background of new power system construction

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Abstract. Pumped storage is the main regulating power supply of power system. It is more urgent to build a new power system with new energy as the main body. In order to accelerate the development of pumped storage projects, it is urgent to improve the economic evaluation method of pumped storage projects under the background of new power system construction. Firstly, the value of pumped storage in ensuring the safety and reliability of the new power system, improving the utilization level of renewable energy, and improving the performance of power generation, distribution and consumption of the new power system is analyzed. Then, the economic evaluation model of pumped storage project is optimized, and an index system covering value contribution to the new power system, financial profitability and anti risk ability is constructed. Finally, through the comparative analysis of pumped storage and coal-fired power generation projects, the scientificity and rationality of the model are verified.

1. Introduction
In the past, pumped storage power stations played an active role in ensuring the safe and stable operation of the power system and orderly power supply. Restricted by the reality of low coal power cost, loose power supply and demand, and limited grid connected consumption scale of renewable energy, the comparative advantages of pumped storage power stations have not been significant [1,2]. With the accelerated construction of new power system and the great leap forward development of renewable energy, pumped storage power station, as the most mature and economical regulating power supply, ushers in a major development opportunity.

For a long time, the price mechanism of pumped storage has been not scientific and reasonable, resulting in poor investment income. To meet the needs of new power system construction, the national development and Reform Commission issued a sound policy document in May 2021, which clearly takes the two-part electricity price policy as the main body, further improves the pumped storage price formation mechanism, forms the electricity price in a competitive way, and brings the capacity price into the recovery of transmission and distribution electricity price, which is beneficial to promoting the healthy development of pumped storage power stations and improving the comprehensive benefits of power stations, Will play an important role in promoting. Accordingly, it is necessary to optimize the economic evaluation method of pumped storage projects under the background of new power system construction, so as to accelerate the development of pumped storage projects.

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Firstly, the value of pumped storage in the construction of new power system is analyzed, then the economic evaluation optimization model of pumped storage project is constructed, and an example is carried out to verify the scientificity and rationality of the model.

2. Value analysis of pumped storage in the construction of new power system

The most important feature of the new power system is that it takes new energy as the main body, especially the intermittent and volatile renewable energy such as wind power and photovoltaic. The value contribution of pumped storage to the new power system is mainly concentrated in the following aspects [3]:

2.1. Ensure the safety and reliability of the new power system

Act as emergency power supply for accidents, ensure frequency stability and control power flow within the operation limit after high power loss of the system. Compared with coal power and gas power, the pumped storage unit has short start-up time and fast regulation rate, and can start from shutdown to full power in about one minute; Compared with conventional hydropower, the pumped storage power station is closer to the load center, the substantial additional power generation does not affect the system stability, and the role of supporting the system voltage is stronger.

In addition, it can also be used as a black start power supply to restore power supply in time after a blackout. Bear the peak load of the system, ensure the orderly supply of power, and the capacity benefit is obvious.

2.2. Improve the utilization level of renewable energy

Pumped storage plays an obvious role in peak shaving and valley filling, which can reduce the startup mode of conventional units, reduce the minimum technical output of conventional units in the system, and make room for the consumption of clean energy. During the period of wind and light abandonment, pumped energy storage can be used to store the abandoned power, so as to improve the utilization level of clean energy.

In addition, pumped storage regulation has the characteristics of rapid start and stop and flexible regulation. It is an effective means to deal with the increase of active power fluctuation of high proportion of renewable energy, and effectively deal with the regulation pressure brought to the system by the sharp increase of the installed proportion of renewable energy.

2.3. Improve the performance of power generation, distribution and consumption of the new power system

With the widening of load peak valley difference and large-scale access of new energy, the demand for system peak shaving is gradually expanding. If thermal power and nuclear power undertake the peak shaving task, it will increase the potential safety hazards of the system and reduce the operation efficiency of power generation equipment. The peak shaving of pumped storage power station can reduce the peak shaving pressure of thermal power, nuclear power, hydropower and other power sources, improve the system efficiency and reduce the system energy consumption.

When a large number of distributed generators are connected to the power system, the local voltage of distribution network will rise and the power transmission capacity to the main network will be limited. The combined operation of pumped storage with distributed generation, using the voltage regulation and electric energy storage capacity of pumped storage power station, can solve the high-voltage problem caused by the access of distributed generation, alleviate the transmission capacity constraints of distribution network, and effectively improve the system's ability to accept distributed generation.

The pumped storage unit starts and stops quickly, operates flexibly and reliably, and can adjust the output in a wide range. It can well adapt to the rapid change trend of system load, improve the frequency qualification rate of power grid, reduce the frequency deviation, and improve the power quality at the user side.
3. Optimization model for economic evaluation of pumped storage project

The traditional economic evaluation of pumped storage projects focuses on calculating the financial benefits and expenses directly incurred by the project, preparing financial statements, calculating evaluation indicators, and investigating the profitability, solvency and other financial conditions of the project according to the cost management system of traditional hydropower projects and the current national fiscal and taxation system, price system, construction and operation management mechanism, To judge the financial feasibility of the project. The supporting role and sharing of promoting the construction of new power system can not be reflected, so the evaluation system needs to be optimized.

Considering the value of pumped storage power station to the new power system and the income uncertainty in the operation process, the traditional economic evaluation index system of pumped storage project is optimized [4], and the economic evaluation index system of pumped storage project under the background of new power system construction is constructed, as shown in Table 1:

Table 1 Economic evaluation index system of pumped storage project under the background of new power system construction

| Primary index                                                                 | Secondary index                                      | Tertiary indicators                                                                 |
|------------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------------------------------------|
| Value contribution to new power system                                       | Safety and reliability contribution                  | Power support                                                                        |
|                                                                                  |                                                      | Capacity support                                                                    |
|                                                                                  | Promoting the contribution of renewable energy utilization | Peak power generation replaces renewable energy power generation space               |
|                                                                                  |                                                      | Waste wind and photovoltaic power generation                                        |
|                                                                                  |                                                      | Eliminate the impact of renewable energy fluctuation on power system                |
|                                                                                  | Improve system performance contribution              | Improve the utilization efficiency of existing power supply of the system            |
|                                                                                  |                                                      | Ease the transmission capacity constraints of distribution network                 |
|                                                                                  |                                                      | Improve the qualified rate of power grid frequency                                  |
| Financial profitability                                                        | Cost and tax                                         | Total cost                                                                          |
|                                                                                  |                                                      | Taxes                                                                               |
|                                                                                  | Annual power generation income                       | Capacity sales revenue                                                             |
|                                                                                  |                                                      | Electricity sales revenue                                                          |
| Anti risk ability                                                              | Coping with policy uncertainty                       | Changes in capacity price and electricity price                                     |
|                                                                                  | Dealing with uncertainty in construction             | Changes in alternative investment, construction period, etc                         |
|                                                                                  | Dealing with operational uncertainty                 | Changes in annual power generation, pumping electricity price, etc                  |

3.1. Value contribution to new power system
(1) Safety and reliability contribution

Power support index is the output prediction of pumped storage to ensure frequency stability and control power flow within the operation limit for the loss of high power in the power system.

The capacity support index is that pumped storage can bear the peak load of the system, ensure the orderly supply of power and predict the capacity benefit.

(2) Promoting the contribution of renewable energy utilization

The space index of peak power generation replacing renewable energy power generation is the prediction of pumped storage peak shaving and valley filling, reducing the start-up of conventional units and increasing the power generation of renewable energy.

The power generation index of pumped storage is the prediction of the amount of electricity consumed during the operation of pumped storage during the period of wind and light abandonment.

Eliminating the impact of renewable energy fluctuation on power system is the prediction of pumped storage short cycle and high-frequency operation.
(3) Improve system performance contribution

Improving the utilization efficiency index of the existing power supply of the system is the prediction of the increase in the utilization hours of stock units.

The index of alleviating the transmission capacity constraint of distribution network is the prediction of the delayed or avoided investment scale of transmission and distribution network after the construction of pumped storage power station.

Improving the qualified rate of power grid frequency is a prediction of the improvement of power quality on the user side.

3.2. Financial profitability

The analysis of financial profitability of pumped storage project mainly focuses on the profitability of investment, mainly on the internal rate of return. Internal rate of return is the main evaluation index to measure whether the project is financially feasible. It is the discount rate when the cumulative net present value of each year is equal to zero during the calculation period of the project. The financial internal rate of return of all investment and capital shall be calculated respectively. When the financial internal rate of return of all investment and capital is greater than or equal to the financial benchmark rate of return of power industry and the financial benchmark rate of return of capital, the project is financially feasible [5,6].

(1) Cost and tax
   a) Total cost
      The total cost of power generation includes operating cost of power generation, depreciation expense, amortization expense of intangible assets and deferred assets and interest expense. Among them, the operating costs include material costs, total wages and welfare expenses of employees, repair expenses, pumping expenses, insurance premiums, reservoir fund water resources expenses and other expenses.
   b) Taxes
      Project taxes include value-added tax, surtax and income tax.

(2) Annual power generation income
   The annual power generation sales revenue of pumped storage power station includes capacity sales revenue and electricity sales revenue.

   \[ \text{Capacity sales revenue} = \text{capacity price} \times \text{On grid capacity} \] (calculated according to the annual average operating capacity during the initial operation period)

   \[ \text{Electricity sales revenue} = \text{electricity price} \times \text{On grid power} \] (annual power generation deducting auxiliary power consumption)

   According to the Interim Provisions on economic evaluation of pumped storage power stations and its implementation rules, the on grid electricity price can be calculated according to the marginal cost theory, that is, the capacity price and electricity price of the project can be calculated by using the avoidable capacity cost and electricity cost of the power system.

   a) Capacity price calculation
      Due to the purchase of the designed power station on grid capacity, Thus, it can avoid the necessary cost (avoidable capacity cost) for obtaining the unit capacity of peak load, which can be used as the basis for determining the capacity price. The alternative power supply scheme is determined according to the optimization calculation results of power grid power expansion (power supply scheme can be avoided). Taking the fixed cost, fixed tax and investment profit of the alternative scheme as the calculation basis of the capacity value of the power station, the capacity price is calculated as follows:

      \[ \text{Avoidable capacity cost} = \text{avoidable power scheme capacity cost} + \text{system fuel cost difference} = \text{avoidable power generation cost} + \text{VAT and surcharges} + \text{investment profit} + \text{avoidable fuel cost} \]

      \[ \text{ Avoidable capacity price} = \frac{\text{Avoidable capacity cost}}{\text{design power station on grid capacity}} \]

   b) Electricity price calculation
      Because the power grid purchases the on grid power of the designed power station, it can avoid the necessary expenses (avoidable power cost) for obtaining the unit power of peak load, which can be used as the basis for determining the on grid power price. The variable operating cost of the alternative
scheme (avoidable power scheme), fuel cost related to power generation and variable tax are used as the power value of pumped storage power station. The ratio of electricity value to annual on grid electricity of pumped storage power station is its electricity price.

3.3. Risk resistance
In order to analyze the impact of uncertain factors on the economic evaluation indexes of pumped storage power station, it is necessary to conduct uncertainty analysis to predict the possible risks of the project and determine the economic reliability of the project. This paper mainly analyzes and predicts the impact on economic evaluation indexes when the main factors of pumped storage power station change.

(1) Coping with policy uncertainty: the ability to cope with changes in capacity price and electricity price, fixed asset investment, construction period, borrowing conditions, capital ratio and profit margin.

(2) Response to construction uncertainty: the ability to respond to changes in design scheme and alternative scheme investment, construction period, fuel price and load characteristics.

(3) Coping with operational uncertainty: the ability to cope with changes in annual power generation, pumping electricity price, etc.

Analyze the impact on internal rate of return when the above factors change alone or multiple factors change at the same time.

4. Example analysis
Comparing pumped storage projects and coal-fired thermal power generation projects with the same regulation effect, assuming that the full score of single index is 3, the economic evaluation results of the two types of projects are shown in Figure 1:

On the whole, promoting the construction of new power system, reducing coal-fired power supply, reducing coal output and maintaining a high price in the future have a great impact on the economy of coal-fired thermal power generation. On the contrary, the price policy of national policy supporting the sustainable development of pumped storage is stable and the economy is good as a whole. Specifically:

(1) Value contribution to new power system
In terms of contribution to safety and reliability and improvement of system performance, pumped storage is significantly better than coal-fired power generation projects, which is related to the technical characteristics of short start-up time and fast regulation rate of pumped storage.

In terms of contribution to promoting renewable energy utilization, pumped storage and coal-fired thermal power generation are close in terms of replacing renewable energy power generation space by peak power generation, but pumped storage has more advantages than coal-fired thermal power.
generation in absorbing wind and light power generation and eliminating the impact of renewable energy fluctuation on power system.

(2) Financial profitability

The cost and tax of coal-fired thermal power generation are better than pumped storage projects. Pumped storage projects have large scale, high investment cost and long construction cycle.

In terms of annual power generation income, affected by the rising coal price, the future of annual power generation income from coal power is not optimistic, and the profit of pumped storage is stable.

(3) Anti risk ability

In terms of dealing with policy uncertainty, the policies encouraged by the state for pumped storage projects are clearer and the expectation is clearer. Restricting the development of coal-fired power and stopping the approval of new coal-fired thermal power generation projects have a high negative impact on coal-fired power generation.

Coal fired thermal power generation is superior to pumped storage in dealing with the uncertainty of construction links, mainly because the large-scale development of pumped storage is still in the initial stage, and the policy system and rules and regulations of project management are still in the stage of continuous improvement. In addition, the complexity of pumped storage project construction is significantly higher than that of thermal power generation, so the anti risk ability is naturally weaker than that of thermal power generation.

5. Conclusion

In this paper, an optimized project economic evaluation index system is adopted to study pumped storage projects. The main conclusions include: (1) under the background of new power system construction, the value of pumped storage in ensuring the safety and reliability of new power system, improving the utilization level of renewable energy and improving the performance of all links of new power system needs to be included in economic evaluation. (2) After considering the value contribution to the new power system, the competitiveness of pumped storage projects is improved compared with coal-fired thermal power. (3) The large-scale development of pumped storage has just started, with the characteristics of long construction cycle and complex construction, and the anti risk ability needs to be further improved. In terms of the future work, In the future, innovating the design scheme, construction technology and project management mode of pumped storage power station should be carried out to improve the quality and efficiency of pumped storage project construction.

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