Analysis on the uncertainty factors of pumped storage power station construction investment under the Chinese characteristic power market environment

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Abstract. Pumped storage power stations provide security and support for the new power system with new energy as the main body. Pumped storage power stations are encouraged to participate in the spot electricity market and form electricity price in a competitive way. Based on the identification of the uncertain factors and the calculation of price fluctuation of the pumped storage power station participating in the electric power spot market with Chinese characteristics in the electric power market environment, this paper adopts the sensitivity analysis method to analyze the impact of the change rate of the price spread on the internal rate of return on capital of the pumped storage power station in the trading day, and draws the following conclusions according to the calculation examples: When the sensitivity coefficient is positive, the extraction spread is greater than the benchmark extraction spread by 25%, and with the increase of the extraction spread, the internal rate of return is greater.

1. Introduction
The clean and low-carbon transformation of energy and electricity has become a common consensus in today's human society. China is accelerating the construction of a new type of power system based on new energy, contributing to the goal of "carbon peak" and "carbon neutral". The power generation output of new energy is characterized by intermittence, fluctuation and seasonality, which is difficult to predict, which brings greater challenges to the complete and stable operation of the power system [1]. Therefore, the power system needs more and more standby power supply and balanced power supply capacity to ensure the safety of operation. Pumped storage units have the characteristics of fast and flexible start-stop, absorb the abundant electric energy of the system at the low point of load, and send power to the system at the peak of load, which has the unique function of peak clipping and valley filling [2]. The extensive construction of pumped storage power station provides a guarantee for the construction of new power system [3]. Combined with the actual situation of China's energy development and power system reform, pumped storage power station is gradually promoted to enter the power market. This paper first identifies the uncertain factors of the pumped storage power station participating in the spot market of electric power, then establishes an analysis model of the uncertain factors, and finally verifies the model through an example.
2. Uncertainty analysis and identification of uncertain factors

2.1. Uncertainty analysis and risk analysis
Uncertainty is a concept opposite to certainty. It refers to not knowing all possible consequences beforehand, or knowing the consequences but unable to determine the probability of their occurrence [4].

Uncertainty and risk are closely related, and the main difference between them is reflected in probability and influence. ① the availability of probability: the probability of the occurrence of risk is known or can be known through efforts, or can be measured, generally can be described by probability distribution; The probability of the occurrence of uncertainty is unknown, so it is difficult to measure. ② Influence size after occurrence. Uncertainty represents an unknowable event that is likely to have a larger impact, and the impact of the same event can be prevented and effectively reduced if the risk can be quantified [5].

2.2. Identification of the main uncertain factors for pumped storage power stations to participate in the spot market of electricity
The two-part electricity price for pumped storage power stations shall be checked and ratified in accordance with the principle of reasonable cost plus permissible income. Among them, the cost includes construction cost and operation cost [6]; The yield is allowed to be assessed at the risk-free rate (the interest rate of long-term Treasury bonds) plus the risk rate of 1%~3% [7]. Two system electricity price, namely electricity price and capacity electricity price. Electricity price reflects the value of peak-regulating service provided by pumped storage power stations [8]. Pumped storage power stations recover the operating costs of pumping and power generation through electricity price. Capacity electricity price reflects the value of auxiliary services provided by pumped storage power stations, such as frequency modulation, voltage regulation, system standby and black start. Pumped storage power stations recover other costs besides pumping operation costs and obtain reasonable benefits through capacity electricity price. The relationship is shown in Figure 1.

Fig. 1 Relationship diagram of electricity price verification for pumped storage power station

In May 2021, the latest pumped storage price policy document issued by the National Development and Reform Commission pointed out: "Give play to the role of spot market in the formation of electricity price. In places where the spot market of electricity is operated, the price of pumped storage power station and the price of on-grid electricity shall be settled according to the price of spot market and rules. Pumped storage power stations do not pay the electricity transmission and distribution price, and do not bear government-managed funds or additional charges [9]."

The participation of pumped storage power stations in the electric spot market mainly influences the electricity price, which influences the pumping operation cost, the permitting cost and finally the electricity price verification. Before participating in the spot market, the unit efficiency of general pumped storage power stations is 75%, that is, the price of pumping water is 75% of the price of electricity generation, and the peak service cost is covered by the pumping price difference. After participating in the spot market of electricity, the price of pumping electricity and the price of feed-in
electricity are settled according to the spot market price, and the difference between the price of pumping electricity and the price of feed-in electricity fluctuates with the market price. The fluctuation of the extract spread conforms to the characteristics of uncertainty. First, the fluctuation of the extract spread does not have probability availability, that is, the probability of the occurrence of the extract spread is unknown and difficult to measure. Second, the fluctuation of pumping price difference is unknown, and the profit and loss brought to the operation cost of peak-shaving service for pumped storage power stations is unknown. Therefore, the main uncertainty factor for pumped storage power stations to participate in the spot electricity market is the pumping price difference. The commonly used uncertainty analysis methods include sensitivity analysis and break-even analysis. This paper uses sensitivity analysis to find out the impact of price difference fluctuations on construction and operation costs.

3. Sensitivity analysis method

3.1. Selection of analysis indicators

There is a whole set of index system in project economic evaluation, usually the necessary index in sensitivity analysis is the internal rate of return of project investment. Internal rate of return (IRR) is selected as the analysis index, and IRR can be expressed as:

\[
(CI_t - CO_t) (1 + i)^{-t} + (CI_t - CO_t) (1 + i)^{-t+1} + \cdots + (CI_n - CO_n) (1 + i)^{-n} = 0
\]  

(1)

\(CI_t\) represents the capital input in the t year, \(CO_t\) represents the capital outflow in the t year, and \(n\) represents the working years of the project.

For general power generation construction, if the annual fuel cost, generating capacity and electricity price are set to remain unchanged within a certain period, then the internal rate of return balance equation of power generation investment decision can be expressed as:

\[
-TCR + (-CF + Cθπ) [\sum_{n=1}^{m} (1 + i)^{-n}] = 0
\]  

(2)

\(TCR\) represents the present value of the construction cost, \(n\) is the life of the project, \(CF(n)\) is the fuel cost, \(C\) is the generating equipment capacity, \(θ(n)\) is the annual average equipment utilization rate, and \(π(n)\) is the predicted market price.

3.2. Select the uncertain factors and the degree of change of the uncertain factors

In sensitivity analysis, uncertainty factors should be selected and the degree of their deviation from the basic situation should be determined. The pumping price difference of pumped storage power station participating in the spot market should be selected as the uncertainty factor, and the pumping price difference of 25% when pumped storage power station does not participate in the spot market should be selected as the basic situation. Sensitivity analysis is usually conducted for adverse and favorable changes of uncertainty factors in order to observe the effects of various changes on the analysis indicators.

3.3. Calculate sensitivity analysis indexes

The sensitivity coefficient is the ratio of the percentage change of the item analysis index to the percentage change of the uncertainty factor. A high sensitivity coefficient indicates that the project analysis index is highly sensitive to the uncertainty, so attention should be paid to the influence of the uncertainty on the project analysis index. The calculation formula of sensitivity coefficient is as follows:

\[
E = (ΔA/A)/(ΔF/F)
\]  

(3)

\(E\) is the sensitivity coefficient of analysis index A to uncertainty factor F; \(ΔA/A\) is the corresponding change rate (%) of the analysis index A when the uncertainty factor F changes; \(ΔF/F\) is the rate of change of uncertainty factor F (%).
4. Analysis on the change rate of uncertain factors in the electricity market with Chinese characteristics

4.1. Analysis of price fluctuation range in spot market
In August 2017, the state selected 8 regions including South China (starting from Guangdong) as the first batch of pilot construction of power spot market. The upper and lower lines of the first spot pilot prices are shown in Table 1.

Table 1 China's first batch of spot pilot prices up and down

| provinces | Declared price upper and lower line (yuan/kWh) | Clearance price upper and lower line (yuan/kWh) |
|-----------|-----------------------------------------------|-----------------------------------------------|
| Guangdong | 0–1                                           | 0.07–1.5                                      |
| Shandong  | -0.08–1.3                                     | -0.1–1.5                                      |
| Zhejiang  | 0–0.8                                         | 0–1.2                                         |
| Gansu     | 0.005–0.36                                    | 0–1                                           |
| Sichuan   | 0–0.4413                                      | /                                             |
| Mengxi    | 0–0.8                                         | /                                             |
| Shanxi    | 0–1.5                                         | /                                             |

By table 1 shows that China's current electricity spot market price fluctuations interval between $[-0.1, 1.5]$ yuan/kWh, due to the provisions of the generating set prices up and down the line, to declare the smoke hair spreads in the fluctuate within a certain range, and smoke spread to the influence of electricity price shall be also controlled in a certain range, the influence of the pumped storage on will control within a certain range.

4.2. Calculation method of variation degree of extraction spread and internal rate of return
When the pumped storage power station does not participate in the electric power spot market, the rate of change of pumping price difference 25%, the analysis index IRR 6.5% and the pumped storage power station project service life of 40 years are selected as the reference values to calculate the change degree of the pumped storage power station's participation in the electric power spot market. The IRR of the pumped storage power station can be expressed as:

$$\frac{1-(1+IRR)^{-40}}{IRR} = \frac{TCP}{CP} - CF$$  \hspace{1cm} (4)

$TCR$ represents the present value of construction cost, $CF$ is the average annual pumping and electricity purchase cost in the operating period, $C$ is the capacity of power generation equipment, and $P_i$ is the pumping clearance price in the spot market.

5. Calculation examples and analysis
Taking a pumped storage power station in a province as an example, the sensitivity analysis is carried out. The total investment cost is about 4 billion yuan. The operating period is approved on the basis of 40 years. During the operating period, the average annual cost of water pumping and electricity purchasing is about 1.5 billion yuan. The basic internal rate of return is calculated at 6.5%. The feed-in price shall be considered according to the benchmark feed-in price of coal-fired units in 2021 of this province of 0.4 yuan/kWh. The average price of pumping water during the trading day is 0.3376 yuan/kWh. According to the sensitivity coefficient of the internal rate of return (IRR) of the above analysis index to the extracted price difference, the calculation result is shown in Figure 2.
Fig. 2 Analysis diagram of sensitivity factors of pumping and power generation spread
When the sensitivity coefficient is positive, it means that the extraction spread is greater than the benchmark extraction spread by 25%. Within the price fluctuation range, the internal rate of return will increase with the increase of the extraction spread. For the same change rate of uncertainty, the absolute value of the sensitivity coefficient decreases after the analysis index is lowered, indicating that the greater the absolute value of the sensitivity coefficient is, the higher the sensitivity of the uncertainty to the analysis index is.

6. Conclusion
In this paper, the sensitivity analysis method is used to analyze the risk of the pumped storage power station's participation in the spot electricity market, which brings to the construction and operation cost. The established model provides a reference for the pumped storage power station to participate in the power spot market to recover the construction and operation costs, further perfect the formation of the pumped storage electricity price in a competitive way, give full play to the function of the electricity price signal, and create a more favorable theoretical basis for the pumped storage power station to accelerate the development and give full play to the comprehensive benefits.

Acknowledgments
This paper was supported by the Science and Technology Project of State Grid Corporation Headquarters "Research on the Functions of Pumped Storage and the Scientific and Orderly Development"

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