Investment economy of pumped storage power plant in East China

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Abstract. The economic development of East China is in a leading position in China, the demand for electricity is growing rapidly, and the load peak-to-valley ratio continues to increase. During the 14th five-year Plan period, as the amount of new energy access continues to increase, the pressure on peak shaving in the region will continue to rise. Based on peak-regulating demand, this paper calculates the investment economic level of pumped storage power stations in east China under different utilization hours and different capacity electricity prices, so as to provide reference for investment and cost control of pumped storage power stations at various stages, and puts forward suggestions on the coordinated development of pumped storage power stations and new energy installations.

1. Introduction

With the development of the market economy and the continuous improvement of people's living standards, the reliability of power supply and the guarantee of power quality are increasingly concerned by the society. East China is one of the regions with rapid economic development, especially in the Yangtze River Delta, and its economic development rate has been higher than the national average in recent years. Power grid of East China, located in the southeast coast of China, is the largest regional power grid. It supplies power to Shanghai, Jiangsu, Zhejiang, Anhui and Fujian, covering the economic engine of the Yangtze River Delta city cluster. It plays a pivotal strategic supporting role in China's modernization and economic and social development.

At present, the overall control of energy conservation and emission reduction has become stricter, and the requirements for improving the ecological environment have become more stringent. The growth rate of coal power projects with more emphasis on peak capacity has slowed down. On the other hand, in order to promote the transformation and upgrading of domestic energy consumption structure and ensure the implementation of the air pollution prevention and control plan, the state actively promotes the construction and development of new energy projects such as wind power, hydropower, and photovoltaics on the power supply side.

The value of pumped-storage power plants is firstly reflected in the advantages of peak shaving. When the system load is in peak hours, it can be used as a hydropower station to generate electricity. When the system load is in the low period, it can be used as a load to pump and store energy by using...
the surplus power in the low period, so as to adjust the peak valley difference of the power system artificially, improve the daily load characteristics of the power system, and the economy of the whole power system. Second, it is the advantage of frequency modulation. Due to the flexible operation of pumped storage units, strong climbing ability, fast speed of output rise and fall, it can quickly track the load change of power grid, so it is an excellent frequency modulation power supply. Thirdly, it is the advantage of phase modulation. Pumped storage units can absorb or emit some reactive power while generating or pumping water, and assist other phase modulation equipment to jointly maintain the reactive power balance of the grid. Finally, it can also be used as a backup system. When an emergency occurs in the power system, the pumped-storage power station can be put into operation quickly and flexibly and is the best emergency backup power source.

Although there is a certain loss in the two energy conversions of converting electrical energy into potential energy and converting potential energy into electrical energy, the project cost is relatively high. From the perspective of the operation of the entire power system, it is currently a relatively economic adjustment mode. Therefore, studying the economics of pumped-storage power stations and analyzing the cost control levels of pumped-storage power stations under different boundary conditions provide an important reference for power supply companies to build pumped-storage power stations and provide an important basis for business decision-making. In view of this, on the basis of previous studies, this article analyzes the cost level of pumped storage power plants under boundary conditions.

2. Summary of research status
From the academic point of view, most of the foreign studies are based on the price fluctuation of the electricity market, and the feasibility of obtaining reasonable income from the market bidding of pumped storage power station is analyzed; the economic analysis of pumped storage power station in China mostly starts from the specific power station, and analyzes the actual operation effect of the power station. Research related to the economics of pumped storage mainly focuses on independent operation, joint operation, and economic analysis from the perspective of power grid systems.

In terms of economic research on independent operation, Chin-Chu Tsai et al. (2009) showed that the benefits of pumped-storage power plants are dominated by the benefits of participating in the auxiliary service market [1]. Some scholars believe that if the settlement price adopts the results of the quotation in the electricity market before the day, the pumped-storage power station will have better returns. If the settlement price adopts the real-time market price after the pumped-storage power station is put into operation, the operation of the pumped-storage power station will offset the spread which will lead to a decline in power plant revenue or even negative [2]. F. Cristina Figueiredo et al. (2013) analyzed that there are large differences in the trend of electricity price changes in various power markets, and the economics of power stations are also significantly different [3]. Xiaorong Jiang and Jun Liu (2001) based on the actual situation of the Beijing-Tianjin-Tangshan power grid, studied the impact of the Shisanling Pumped-storage Power Station under different operation modes on the system operating cost and the start-stop and output of other units [4]. Zhaoqi Zeng (2001) introduced the operation of Tianhuangping Pumped-storage Power Station under different operation modes and put forward relevant suggestions for the next operation and management of the power station [5]. Wenzhu Guo (2000) studied the suitable operation mode and operation mode of Xianghongdian Pumped Storage Power Station [6].

In terms of economic research of joint operating entities, pumped storage is usually used in conjunction with wind power, nuclear power and other base-load power sources to reduce the peak load of the power grid. GARCIA-GONZELEZ J et al. (2008) established a two-stage stochastic optimization model from the perspective of maximizing the benefits of the joint operation of wind farms and pumped storage power stations to study the operation and economy of the joint [7]. CASTRONUOVO ED et al. (2004) analyzed its operation mode and economic benefits based on the Portuguese electricity market [8]. The biggest difference with GARCIA-GONZELEZ J et al. is that the paper further studied the suitable energy storage capacity of pumped storage power stations.
Deyou Liu et al. (2006) aimed at maximizing the utilization rate of wind power and analyzed the operation and economic benefits of the system [9]. In the research of nuclear storage joint operation system, Jianhua Bai et al. (2007) proposed incomplete tracking mode, three-stage tracking mode and complete tracking mode, which verified that the proposed scheme is reasonable and effective [10] [11]. This conclusion is also supported by similar studies by Jie Zhao et al. (2011) [12].

In terms of system economic analysis, Chunmei Fu (2011) analyzed the operation mode and economic benefits of the water-fire system, and compared the economic benefits of the water-fire system under a single objective [13]. Jie Yu and others (2009) also based on the perspective of multiple optimization of hydro-thermal power system, the construction of the minimum cost of electricity purchase, the smallest emissions of polluting gases from thermal power units and the largest amount of hydropower generation optimization model, with the system power balance, thermal power unit force and climbing rate limit, hydropower unit force and flow limit, water balance as the constraints [14]. Like Zheng et al. (2007) established a joint optimization model of hydro-thermal power system based on the refinement of power-flow constraints and water flow lag constraints of cascade hydropower units with the goal of minimizing system operating costs. The article focuses on the solution method improvement, rather than an analysis of economic benefits [15].

3. Economic calculation of pumped storage investment

This paper takes the construction of a 1200MW (4×300MW) pumped storage power station in East China as an example to analyze the investment level of pumped storage power stations under the conditions of different capacity electricity prices and utilization time.

3.1. Boundary conditions

There are seven boundary conditions are presented below.

(1) A pumped storage power station is constructed in East China with capacity of 1200MW (4×300MW).

(2) Calculated according to the two-part electricity price system, including electricity price and capacity price. Pumped storage power generation electricity price is temporarily based on the coal-fired benchmark electricity price of 0.41 yuan / kWꞏh, pumped electricity price in accordance with the relevant provisions is the use of coal-fired benchmark electricity price of 75%.

(3) The interest of the loan is calculated on an annual basis, the bank short-term loan interest rate is 4.35%, and the long-term loan interest rate is 4.9%.

(4) The construction period of the project is 8 years, and the operation period is 30 years.

(5) The source of project construction funds is considered based on domestic funds, and the capital ratio is 20% of the total project investment. The remaining construction funds are financing or loans.

(6) The financial benchmark rate of return on capital after tax is 8%.

(7) Other parameters refer to the requirements of the current specification.

3.2. Methodology

The unit cost of pumped-storage power station takes the pumped-storage power price (capacity price and electricity price) as a known input condition, and calculates with reference to the relevant financial indicators of the construction and operation of pumped storage power stations in the past. There are 20 parameters of specific financial indicators in total, including total value added tax and additional tax, total income tax, net interest rate of project capital and internal rate of return.

According to the above financial indicators, the unit cost of pumped storage power station is calculated. Investment economic analysis sets investment scenarios from the two dimensions of capacity electricity price and power generation utilization hours, and calculates the unit kilowatt cost of pumped storage power plants in different scenarios. Among them, the pumping capacity electricity price, according to the 1200MW historical project capacity electricity price level, is divided into four situations: 650 yuan/kW, 700 yuan/kW, 750 yuan/kW, and 800 yuan/kW for calculation. And the annual utilization hours of power generation are divided into four situations: 700h, 1000h, 1300h and
1600h. The above four gears are used for the calculation of the annual utilization hours because the common utilization hours of the current pumped storage power station are 1000h. According to the simulation results of power system optimization and daily adjustment of pumped storage, the actual operation of the energy plant has increased the utilization hours of the above-mentioned gears.

According to the boundary conditions set above, the capacity electricity price and power generation utilization hours are used as independent variables, and the engineering unit investment is used as the dependent variable for calculation. There are 16 calculation scenarios in total.

3.3. Analysis of the results
When the annual continuous full-generation hours of the installed power generation capacity are 700h and the capacity electricity price is 650 yuan/kW, the unit cost level of the pumped storage power station is controlled below 4926 yuan/kW, which can be considered as the project's economic efficiency and high-risk resistance ability. When the annual continuous full-generation hours of the installed power generation capacity are 1000h and the capacity electricity price is 700 yuan/kW, the unit cost level of the pumped storage power station is controlled below 5106 yuan/kW, which can be considered as the project’s economic efficiency and high-risk resistance ability. When the annual continuous full-generation hours of the installed power generation capacity are 1300h and the capacity electricity price is 750 yuan/kW, the unit cost level of the pumped storage power station is controlled below 5298 yuan/kW, which can be considered as the project’s economic efficiency and high-risk resistance ability. When the annual continuous full-generation hours of the installed power generation capacity are 1600h and the capacity electricity price is 800 yuan/kW, the unit cost level of the pumped storage power station is controlled below 5451 yuan/kW, which can be considered as the project’s economic efficiency and high-risk resistance ability. The detailed calculation results are shown in Table 1 below.

| Annual continuous full-generation hours (h) | Capacity price (yuan/kW) |
|---------------------------------------------|--------------------------|
| 650                                        | 700                      |
| 4926                                       | 5129                     |
| 700                                        | 750                      |
| 5321                                       | 5298                     |
| 1000                                       | 800                      |
| 4903                                       | 5087                     |
| 5291                                       | 5260                     |
| 1300                                       | 5451                     |
| 4882                                       |                          |
| 5066                                       |                          |
| 1600                                       |                          |
| 4863                                       |                          |

It is worth noting that the estimated cost is using static investment. Also, in the actual construction and operation process of pumped storage power station, continuous full-time hours are also affected by installed capacity and storage capacity, that is, the cost level of pumped storage power station is not only related to continuous full-time hours and installed capacity, but also related to other factors such as storage energy. In order to simplify the calculation, this paper only takes continuous full-generation hours and installed capacity as the main factors affecting the cost of pumped-storage power stations, and weakens the impact of other factors such as storage energy. Therefore, under the premise of the same capacity electricity price in Table 1 above, the negative correlation between the number of continuous full-generation hours and the unit cost may change when other factors are considered.

3.4. Function construction of the results
According to the results above, the relationship between two independent variables (annual continuous full-generation hours and capacity price) and dependent variable (unit cost of pumped storage power station) are explored. The final equation is a polynomial equation and the codes using Matlab to draw the graph are shown below.

Linear model Poly11:
\[ F(x,y) = p00 + p10*x + p01*y \]
Coefficients (with 95% confidence bounds):
p00 = 2477 (2401, 2492)
p10=−0.0662 (−0.07625, −0.054)
p01=3.889 (3.829, 3.949)

The surface of the equation is exhibited in the following figure.

![Fig.1 Surface of the equation](image-url)

4. Conclusion and recommendation

According to the typical 16 schemes selected by the conventional capacity electricity price, the annual utilization hours of conventional power generation installation and set measurement conditions, the cost control of pumped units is within the scope of the measurement results, which can indicate that the project is basically feasible economically. But in order to ensure the economy of the power station as far as possible, it is suggested that the project investment should be reasonably controlled at all stages of the project construction.

The pumped storage power station can undertake the tasks of peak load regulation, frequency modulation, phase modulation and emergency standby of the power system in which it is located. It will play a greater role in improving the quality of power supply, coping with system emergencies, and ensuring the safe operation of the system. In order to improve the efficiency of new energy access to the grid and reduce the pressure on peak regulation of the grid, it is recommended to make overall planning for the construction of hydropower, wind power, solar power and pumped storage power stations, so that the pumped storage power stations as supporting peaking power sources can give full play to their regulation capabilities and maximize overall benefits.

Given that the benefits of pumped storage power plants are aimed at the entire power grid and the whole society, they cannot be directly quantified, and it is even more difficult to reflect in a single project of pumped storage power plants. With the continuous development of pumped storage power station, it is suggested to improve the pricing mechanism of peak load regulation and auxiliary services, and give policy support and encouragement to the construction of pumped storage power station.
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