Development and Construction Management System of Pumped-Storage Power Plants in China

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Abstract. Pumped-storage power plant (PSPP) is a special form of power supply. It is expected that the installed capacity of PSPP in China will reach 90GW by 2025. This paper summarizes the development of PSPP in China, and analysis the influencing factors of the configuration of PSPP, introduces the typical operation mode of PSPP and the existing problems in its development, and puts forward relevant policy suggestions for the development of PSPP.

1. Introduction
As a special form of power supply, pumped storage power plant (PSPP) can not only realize peak-valley load regulation, optimize the working position of all kinds of power sources in the system, but also undertake dynamic functions such as frequency control, phase shifting, emergency reserve and black start-up, so as to improve the quality of power supply, ensure the safety of power supply, reduce power outage time and reduce environmental pollution[1]. The construction of reasonable scale PSPP is an important means to solve the problem of peak-valley load regulation, ensure the safety of power grid operation, and promote the economic operation of all kinds of power sources.

2. Development Situation of PSPP in China
Since 1968, the first PSPP in China, which called Gangan pumped storage power plant was built in Hebei Province, the construction and operation of PSPP in China lasted more than 50 years. By the end of 2017, the operating scale of PSPP in China has reached 29645MW, the capacity of PSPP under construction has reached 38710MW, and the installed capacity under construction and in operation ranks first in the world. The State Grid Xinyuan Company LTD. operates 25 PSPP with a total installed capacity of 20610MW, accounting for 66% of the national PSPP capacity. The operating power stations are distributed in 16 provinces (cities) in China. Five PSPP with a total installed capacity of 7800 MW are operated by China Southern Power Grid[2-3]. Statistics of installed capacity of PSPP are shown in figure 1.
Since the 13th Five-Year plan, China’s economy has entered a new normal, from high-speed development to medium and low-speed development, economic growth has changed from External Oriented Development to Connotative Development, and the domestic economy’s demand for electricity has slowed down. A number of PSPP have been in a state of loss after completion, which has aroused the vigilance of operating companies. The construction of PSPP has entered the stage of prudent development.

In addition, according to the relevant report of the State Energy Administration on Pumped Storage in 2018, the annual utilization hours of PSPP in service are generally far lower than the design hours. From 2008 to 2012, the average utilization hours of PSPP decreased from 2649 hours to 1419 hours. Due to the requirements of new energy development, the average utilization hours of PSPP of the State Grid Xinyuan Company LTD. restored to 2659 h in 2018. The existing ability of PSPP is far from being utilized.

### 3. Development Demand of PSPP in China

(1) The steady and swift development of economy and society demands higher quality of electricity power guarantee. Therefore, it is necessary to increase the process of building pondage power plant moderately. Till the end of 2011, the capacity of machines in China’s pondage power plant that put into operation has reached to 18695MW, which occupies 1.8 % of the total capacity of machines in China. At the beginning of 2020, the installed capacity of PSPP in China has exceeded 30GW, accounting for 1.5% of the total installed capacity in China. In North China, East China and Guangdong power grids, the installed capacity of PSPP accounts for 2.4%, 2.3% and 4.1% of the total installed capacity respectively. The level of PSPP development in different countries differentiates with each other due to the features of energy and resources, structures of power source, features of electricity demand and level of PSPP.
of economic development and other factors. Nowadays, the installed capacity of PSPP in many
developed countries has occupied a certain proportion (France 13 %, Germany 11.2 % and Japan
10.99 %)[4]. The development scale of China’s PSPP is still at a lower level when compared with some
developed countries.

(2) Constructing Certain Scale of PSPP Helps China Realize the Goal of Saving Energy and Reducing
Emission. China has made a clear commitment to the world that the use of non-fossil fuels will increase
to 15 % of total use of energy in 2020, and the emission of carbon dioxide per GDP will decrease 40 %
to 50 % when compared with the data of 2005. To guarantee the supply of energy, reduction of emission
and realizing the sustainable development of power industry, China has to actively develop nuclear
power, wind energy and solar energy and other renewable energy. To realize the goal of saving energy
and reducing emission, the scale of nuclear power in China is expected to reach to 600 to 800 GW and
the scale of wind energy is expected to reach to 1500 to 2000 GW in 2020. However, the renewable
power, like energy power and solar energy, is nonadjustable, so it is difficult to adjust the safety of power
grid, which increases the uncertainty of power system. Because the nuclear fuel needs to be changed
periodically, so the nuclear power crew needs to generate the electricity as much as possible and use up
the fuel as soon as possible during the period of consuming nuclear power, to economical and safe. It
demands the adjustment of power grid can guarantee the steady operation of nuclear power crew rather
than drastically variable load. To guarantee the steady and safe operation of power grid, promote the
development of renewable energy, like wind energy and other renewable energy, and realize the optimal
allocation of energy and resources and the optimization of power source structure, it is of need to
construct PSPP in certain scale.

(3) Along with the acceleration of the process of transferring the electricity power from western
China to eastern China and constructing national grid, PSPP plays a more and more important role in
operating the national power grid[5]. After the separation of factory and grid, the number of power plant
that can be directly regulated by the power grid is decreasing. Due to the lack of regulation means and
high cost make more and more difficult to maintain the safe and stable operation of power grid. Building
PSPP at receiving side can not only provide emergency power supply for receiving power grid, but also
makes up for the defects of long-distance DC can’t output reactive power at high peak value and absorb
reactive power at low power consumption, which can play an important role in ensuring the safe and
stable operation of power grid. In addition, PSPP can significantly increase the ability of long-distance
power transmission of the power grid, improve the transmission efficiency of the line and improve the
operation of the line. Therefore, the service of PSPP is no longer for the local power grid, but forming a
number of PSPP to play a complementary role in the regional power grid and inter regional
interconnected power grid.

4. Construction and Management of PSPP in China

4.1. The Situation of the Construction of PSPP
Based on the actual situation of the built power station in China, there are three kinds of construction
systems. The first kind is the power grid holding the stock and the local investment companies hold the
shareholding, the second kind is wholly owned by power grid and the last kind is the non-grid companies
investing. The first kind of system is most common to see in China.

4.2. The Operation and Management Mode of the PSPP
There are three kinds of operation and management modes of China’s PSPP. The first kind is unified operation
and management, the second kind is independent operation and management and the last kind is lease
operation management.

4.2.1. The Unified Operation Management Mode of the Power Grid. In this mode, PSPP is solely funded
to construct by the power grid and functions as a branch company or an independent workshop of the
power grid, which ownership and management of assets belong to the power gird. In this management
mode, the PSPP is not an independent legal person, does not possess separated property, does not endowed with rights and does not undertake responsibilities solely. Its income belongs to the power grid company. What’s more, it should operate totally according to the adjustment of the power grid company and its finance should be controlled and inspected by the power grid company. However, the risk of operation and responsibilities should be taken up by the company.

The PSPP that adopt this management mode is invested and operated by the power grid company and the costs of operation and paying the principal and interests should be burdened by the power grid company. The power grid company assesses and manages the power station mainly based on its rate of successful initiation, EAF and voltage stabilization. The main task of PSPP is to meet the operation requirements of power grid, such as peak-valley load regulation, frequency control, phase shifting, emergency reserve and black start-up. For the power station, its main tasks are to guarantee the operation, overhaul and maintenance. The power grid will assess the power station according to the regulation.

4.2.2. Independent Operation and Management. According to the requirements of the “company law” of the state, an independent limited liability company for PSPP is established. The board of directors is composed of all financing parties, and the financing parties share the rights and obligations according to the proportion of the investment amount. As the legal person of the project, the PSPP company is responsible for the management, operation and loan repayment of the power station after construction and completion. The financial income of the power station is calculated according to the annual capacity and electricity quantity provided for the power grid and the approved grid price.

4.2.3. Lease Management Mode. In this mode, PSPP company is the legal person of the project, and be responsible for the operation management and repayment after construction. When the power station is leased to the power grid company after completion, and the grid company pays the rental fee to the PSPP. And the rental fee includes the total cost of the power station (excluding electricity used for pumping), taxes, profits, investor returns, repayment of loan principals, etc. The ownership of the power station and the right to process the operation and dispatch are separated, and the PSPP is uniformly dispatched by the power grid. The cost of the lease fee adding to the grid company is borne by the grid company, but the operation and management of the power station is still the responsibility of the power station builder. The relationship between PSPP and power grid company is lease contract.

5. Current Problems of the Development of PSPP in China

In the process of the construction and development of PSPP in China, the economic issues about its “consuming 4 degrees to produce 3 degrees” have been controversial. Over the years, with the increase of the speed and scale of China’s economic development, the role of PSPP in the power system is becoming more and more important, and all parties have gradually reached a consensus on this. However, under the current power system and market structure in China, the source of compensation for PSPP has not been reasonably solved. In addition, the planned depth of PSPP in China is insufficient and the interference factors are increasing. On the one hand, the overall progress of the construction of PSPP is slow, which is difficult to meet the demands of China’s economic, social and power development. On the other hand, it shows certain randomness in the project construction arrangement, which affects the healthy and orderly development of PSPP. The specific manifestation is as follows:

5.1. Poor Planning of PSPP

The planning of PSPP needs to be further improved, and the authority and seriousness of planning need to be strengthened. Unlike conventional power sources, PSPP are one of the tools for regulating the power grid operation. Whether a district needs to build a PSPP, in addition to the site itself, it needs to be analyzed and demonstrated from the requirements of power market, power development planning, power optimization, etc. Optimize the layout of PSPP in the region or larger scope, and determine the construction sequence reasonably. In recent years, China has carried out the site selection and planning work of it in different degrees in areas with demand for PSPP. However, some local governments, from the perspective of promoting projects and stimulating local economy, have carried out site selection and preliminary work of PSPP in local
areas, which interferes with the overall planning of PSPP, resulting in great negative impact.

5.2. Unreasonable Electricity Price Planning
At present, the pricing models such as approved electricity tariffs or lease fees do not reasonably solve the problem of the source of compensation fees for PSPP. They do not reflect the principle "He who is benefited should share the responsibilities" of market economy and cannot fundamentally suppress the unreasonable rise in sales price. At present, the PSPP in operation in China adopt the two-part electricity price, single electricity price, rental fee and the cost statistics and accounting of power transmission and distribution, etc. At present, the PSPP in operation in China adopt the two-part tariff, single electricity price, rental fee and unified accounting for the distribution cost of the power grid, etc. No matter which mode is adopted, it has to be accounted with the power grid company. Under the existing electricity tariff mechanism, because it is difficult for the power generation side to compensation for the PSPP, so the construction cost of the PSPP can only enter the transmission and distribution cost, and dredge it through the adjustment of the sale electricity tariff, which promote unreasonable increase of sales electricity price. The unreasonable phenomenon of "finding the wrong object and buying the wrong order" makes the system economy of the PSPP unable to reflect and thus is questioned. The state has also imposed strict control over this irrational phenomenon. In the case of poor cooperation of all parties, it is inevitable that the operation of the storage PSPP is difficult.

5.3. Auxiliary services Cannot Achieve Reasonable Returns
An important feature of electricity is that production, transmission and use are completed at the same time. This feature requires the supply and demand of the power be instantaneous in the power system. The imbalances between power supply and demand can cause power system frequency and voltage fluctuations. This kind of fluctuation will worsen the quality of power, even endanger the safety of the power grid and cause power grid accidents, resulting in large-scale power outages. Therefore, there must be sufficient backup power and auxiliary service adjustment equipment in the power system to provide frequency and voltage adjustment services for the grid at any time. In the event of a grid accident, the grid can be quickly supported to prevent accidents from expanding and ensure safe and stable operation of the grid.

The PSPP can provide auxiliary services such as peak shaving, valley filling, frequency modulation, phase modulation, accident backup and black start for the safety and stability of the power grid. However, the auxiliary service market in China is still in the exploration stage, so the mechanism of power coverage, related auxiliary services and the payment so on are still not perfect. The auxiliary services provided by the PSPP (dynamic benefits) cannot achieve a reasonable return. According to the principle of the market economy “He who is benefited shares”, the main beneficiaries of static benefits of PSPP are power generation side and power grid, which should be compensated by power generation side and power grid. By adjusting the interests of stakeholders to achieve balance, reasonable peak valley price can be implemented in the generation side according to the market supply-demand relationship, and part of the incremental benefit of the generation side is compensated to the power grid. The final beneficiary of dynamic benefit is the user, so the it should be compensated by the user. Since the cost of the auxiliary service is not directly related to the sales volume of the power grid, it should be studied to implement the two-part electricity tariff for the sales tariff and compensate the auxiliary service through the capacity income portion of the sales income. At the same time, when the PSPP provides auxiliary services, it can’t give full play to its static function. Therefore, PSPP should make a choice between the two markets, and one is electricity market, the other is auxiliary service market, to realize their investment income.

6. Suggestions on the Development of PSPP in China
(1) Reasonable Planning and Construction of PSPP. Under the current power system and market structure, the source of compensation fees for PSPP has not been properly resolved. In addition, the planning depth of PSPP in China is not enough, and the interference factors are increasing. On the one hand, the overall construction progress of PSPP is slow, which is difficult to meet the needs of China's
economic, social and power development. On the other hand, the project construction arrangement shows certain randomness. These factors affect the healthy and orderly development of PSPP.

(2) Deepen the Reform of Electricity Price Mechanism. The research results show that in the mature foreign power market, PSPP have strong market competitiveness, but it’s difficult to operate in China. The deep reason is that the power market is not mature enough, and government pricing cannot accurately reflect the relationship between the supply and demand of the market, of which the positioning of PSPP is vague. Only in accordance with the requirements of rules of market economy, deepening the reform of the price mechanism and establishing a more realistic price system, can we thoroughly solve the problems faced by the development of PSPP.

(3) Restrain the Unreasonable Increase of Selling Electricity Price. Compensating for PSPP through the nuclear power and coal-fired power on the generation side is the only way to avoid unreasonable rise in sales price.

(4) Improve the Auxiliary Service Market. In foreign mature power market, there are more perfect auxiliary service market, and the revenue from the provision of auxiliary services by some PSPP accounts for about 50% of the total revenue of the PSPP. China’s ancillary service market is still at the stage of exploration, and the coverage of power supply and the payment mechanism of related ancillary services are still not perfect. Under the current single electricity pricing system, the auxiliary services provided by the pumped storage power station (dynamic benefits) cannot achieve a reasonable return. In the process of deepening the reform of China's power market in the next stage, we should vigorously promote the construction of auxiliary service market as the next important content.

7. Conclusion
The development of PSPP has a history of 130 years. International operation experience shows that PSPP has good static and dynamic benefit, and it’s the effective and indispensable regulation tool of modern electric system. At present, China is moving to the rapid development of PSPP and should consider the influence factors of scale of PSPP configuration, learning from other countries’ operation experience, defining the function orientation of PSPP during different periods and arranging construction scale and time series reasonably. In terms of policy, it is suggested that the relevant departments should further sort out the price policy of pumped storage energy, so as to ensure that the independent power generation companies have basic income. In terms of investment and management system, we can consider liberalizing social capital and no longer emphasize the investment and construction of power grid enterprises in principle. In terms of management system, we can consider increasing the operation mode of pumped storage and new energy integration, like "Integrate Nuclear Power Plant and PSPP" and "Integrate New Energy and PSPP", to promote the development of pumped storage industry in a more open and innovative environment.

References
[1] Gong Wei. (2012) The important role of pumped storage power stations in accelerating the development of new energy. Energy Conserv.,9:48-9.
[2] Guozhong, Liu, F., L., Zheng, & Y., et al. (2019) Analysis on operation situation and main functions of pumped-storage power plants in china southern power grid. The Journal of Engineering.
[3] Kong, Y., Kong, Z., Liu, Z., Wei, C., Zhang, J., & An, G. (2017) Pumped storage power stations in china: the past, the present, and the future. Renewable & Sustainable Energy Reviews., 71: 720-731.
[4] Punys, P., Baublys, R., Kasiulis, E., Vaisvila, A., Pelikan, B., & Steller, J. (2013) Assessment of renewable electricity generation by pumped storage power plants in eu member states. Renewable and Sustainable Energy Reviews, 26, 190-200.
[5] Bao-Rong, Z., Zhi-Gang, C., Jian-Fu, C., Jin-Qiang, S., & Yong-Hua, C. (2007) Research on application of dynamic reactive power compensators in west-east electricity transmission systems of china southern power grid. Southern Power System Technology.