The characteristics and main building layout of pumped storage power stations in China in recent years

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Abstract. The installed capacity of pumped storage power stations in China is in the world's leading position. Due to the special geographical and geological conditions and specific use scenarios, the building characteristics of pumped storage power stations in China can bring some references to the world. Based on the common power station types, main characteristics and main building forms, the composition of the main buildings of the pumped storage power station is expounded.

Keywords: pumped storage power station, layout, buildings, characteristics

1 Introduction

In 1882, the world's first pumped storage power station was built in Switzerland[1]. However, the more large-scale development began in the 1950s, mainly in Europe, the United States and Japan and other economically developed countries[1]. Since the 1990s, the focus of pumped storage power station construction has shifted to Asia, especially China. After nearly 60 years of development in the construction of pumped storage power stations, China has made rich achievements and outstanding achievements through a large number of construction engineering practices and technical research and exploration[2]. In 2018, China's installed capacity of pumped storage power stations has ranked first in the world[3]. In China, with the release of a series of policies, it has laid a solid foundation for the rapid and sound development of pumped storage energy[4]. Pumped storage power station has been defined as a very important supporting link in the development of new energy[5]. At present, it has become a global consensus to vigorously develop renewable energy, and pumped storage projects play a prominent role in ensuring energy security and promoting energy transformation[6]. Therefore, the characteristics of the construction of pumped storage power stations in China are summarized[7], Can provide some reference for the development of the world energy system and new energy sources.

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2 Type of pumped storage power station

The principle of pumped storage power station is to use the electric energy during the trough of power load, pump water from the lower reservoir to the upper reservoir, and then release water from the upper reservoir to the upper reservoir to the lower reservoir during the peak of power load.

Usually, pumped storage power stations are divided into two types according to the development mode, one is pure pumped storage power station, and the other is mixed pumped storage power station. Among the pumped storage power stations built in China, most of them are pure pumped storage power stations.

2.1 Pure pumped storage power station

When the upper reservoir has no natural runoff or the natural runoff is small, and the water required for the operation of the pumped storage power station comes from the upper and lower reservoirs, the power station is a pure pumped storage power station.

The pure pumped storage power station mainly uses the natural height difference between the upper and lower reservoirs, and sets the water transmission system to obtain the water head. The water head is mostly between 200m and 800m. Because its storage capacity can meet the minimum installed capacity demand, the storage capacity is usually small, so the site selection constraint of the power station is small. The upper / lower reservoirs of pure pumped storage power stations are of various types, which can be used in mountainous areas, rivers, lakes or already built reservoirs, and the factories are mostly in the form of underground workshops, such as Guangzhou, Ming Tombs[8]· Tianhuangping, Tai'an, Xilong Pond, Zhanghewan, Hohhot and other pumped storage power stations.

See the schematic diagram of pure pumped storage power station.As shown in Figure 1.

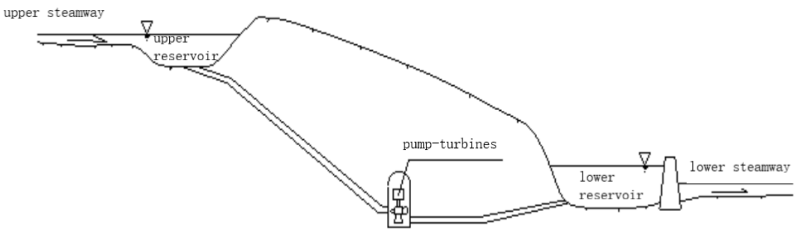

Fig. 1. Schematic diagram of the pure pumped storage power station

It is worth noting that, because the pure pumped storage power station has great freedom in the site selection, such power stations often choose to build near the power point or load center to reduce the related power loss during the sending and receiving power.

2.2 Hybrid pumped storage power station

When the natural runoff of the upper reservoir is large, in order to make use of this part of the natural runoff, both pumped storage units and some conventional hydropower units are installed, so this power station is a mixed pumped storage power station.

Hybrid pumped storage power stations generally have a large natural storage runoff in the upper reservoir, which is usually formed by combining the construction, reconstruction or expansion of conventional hydropower stations. The water head of this kind of power station is generally not high, mostly between tens of meters to more than 100 meters. The water diversion and power generation system can be arranged together with or separately from the conventional power station plant.

See the following diagram of the hybrid pumped storage power station.As shown in Figure 2.

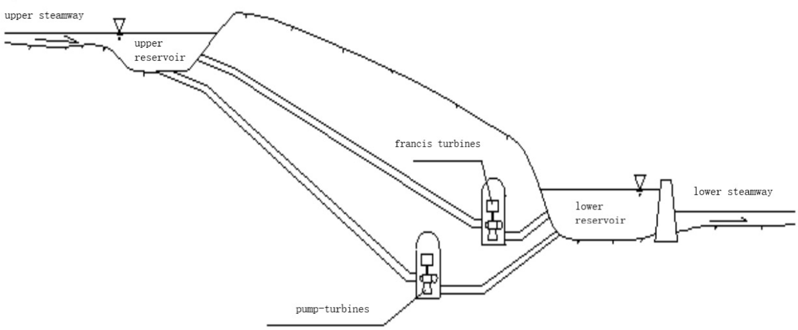

Fig. 2. Schematic diagram of the hybrid pumped storage power station

Examples of hybrid pumped storage power stations include Gangnan, Panjiakou, Xianghongdian, Baishan and other hydropower stations[9]. Throughout the common points of these power stations, we can find that the upper reservoirs of such power stations are large and medium-sized comprehensive utilization reservoirs, and their storage power stations are often combined by the construction, reconstruction, expansion and installation of conventional hydropower stations[10].

It is generally believed that the new, rebuilt or expanded conventional hydropower station has the following advantages:

1) Through the storage and storage effect of the upper / lower reservoir, the power generation peak regulating capacity of the conventional unit is increased;

2) The joint operation of the energy storage unit and the conventional unit improves the discharge capacity of the reservoir and is conducive to the flood control operation of the reservoir. However, it should be noted that the superposition of the natural flood and the power generation flow should not be greater than the natural flood flow, so as to avoid the downstream man-made flood.

3) The joint operation of energy storage units and conventional units can generate electricity from the comprehensive utilization tasks of abandoned water and irrigation in flood season, and improve the hydropower utilization rate of the power station.

3 Main characteristics of pumped storage power station

As the "stabilizer", "regulator" and "balancer" in the safe operation of the power grid, the pumped storage power station is to undertake the tasks of peak modulation, frequency modulation and accident reserve of the power system. Compared with conventional hydropower stations, there are many different characteristics.

3.1 With two upper and lower reservoirs

Because of its specific pumping ~ power generation working mode, the pumped storage power station uses the electric energy from the low power load and pumps the water from the lower reservoir to the upper reservoir to store the energy. During the peak power load, it releases the water through the upper reservoir to the lower reservoir to obtain the electric energy, so it must have the upper and lower reservoirs.

3.2 The water level of the reservoir varies greatly and rises and falls frequently

Compared with conventional hydropower stations with the same installed capacity scale, the reservoir capacity of pumped storage power stations is usually smaller. In these power stations, in order to undertake the task of peak regulation and valley filling in the power grid, the flow of power generation or pumping is very large. The daily variation of reservoir water level of 10m~20m is common, and the daily variation of more than 30m or even 40m also exists. The water level of the reservoir is fast, and some power stations can reach 5m / h 8m / h.~ Such a large water level variation and water level rate will not occur in conventional hydropower stations.

3.3 Reservoir seepage prevention requirements are high

Pumped storage power station storage capacity is generally not big, through the natural runoff, rainfall supply water is limited, mainly using the power load trough from the reservoir pumping reservoir, filling water, such as reservoir leakage, evaporation of water caused by a lot of loss, will undoubtedly reduce the power generation, at the same time increase the cost of filling water and water, reduce the comprehensive efficiency of the power station, so the reservoir seepage control requirement is very high. Due to the high head of the pumped storage power station, the large variation of the reservoir water level and the frequent rise and fall, in order to prevent seepage from deteriorating the hydrogeological conditions of the engineering area, higher seepage prevention requirements are put forward for the pumped storage reservoir. For example, the Ming Tombs pumped storage power station, which is responsible for the peak regulation and emergency backup power supply in Beijing, is the first power station in China with reinforced concrete in the upper reservoir.As shown in Figure 3.

Fig. 3. Upper reservoir of a pumped storage power station
(This image comes from the Internet)

3.4 High water head

The head of pumped storage power stations is generally high, mostly between 200m and 800m. With the increasing research and development technology of pumped storage power station units, the number of high head and large capacity power stations in China is increasing. The 1700 MW Zhejiang Tiantai pumped storage power station under construction has become the highest pumped storage power station in the world with a rated head of 724 meters[11].

3.5 Unit installation elevation is low

Pumped storage power station installation of reversible hydrogenerator set, the pump erosion coefficient is much larger than the turbine condition, the pump condition requires suction high often between-20~ 80m, the ground plant, in order to overcome the buoyancy and seepage on the plant, and make full use of the surrounding rock characteristics, the construction of large pumped storage power station in recent years most underground workshop.As shown in Figure 4.

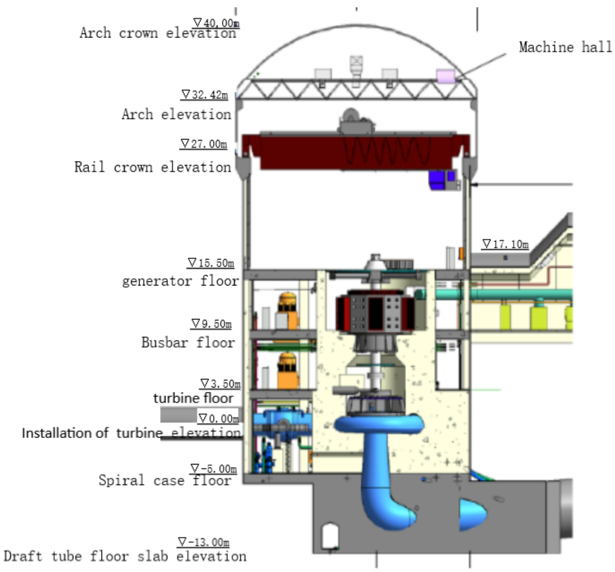

Fig. 4. Profile diagram of a pumped storage power plant
(This image comes from the Internet)

4 Composition of the main station buildings of pumped storage power

The main buildings of pumped storage power station generally include: upper / lower reservoir, water transmission system, plant system, other special buildings, etc[12].

4.1 Upper / lower reservoir

The layout of the upper / lower reservoir should be according to local conditions, according to the project area hydrometeorology, terrain, geological conditions, construction conditions, environmental impact and operation requirements, integrated the functional requirements and natural conditions of the building, clear the layout of the buildings and related relationship, in the system research and technical and economic comprehensive comparison.

On / under the reservoir site selection, pay attention to the reservoir seepage control condition is better, can form the natural height difference between two reservoirs, have certain natural capacity and reasonable water level amplitude, attaches great importance to the influence of the stability of the leakage slope, pay attention to the layout of the building necessity, pay attention to the influence of the downstream channel, attaches great importance to the harmony of engineering and the environment.

As for the combination selection of upper / lower reservoirs, there are generally the following ways: or using the existing reservoir or natural lake, or pass dam to form a reservoir, or platform ring dam and reservoir basin excavation to form a reservoir, or using one dam or more dam to close the peak depression or pass to form a reservoir. The final selection of each dam should be determined after technical and economic selection. If the natural storage capacity cannot meet the demand of regulating storage capacity, the storage basin should be expanded and dug.As shown in Figure 5.

Fig. 5. Upper reservoir of a pumped storage power station
(This image comes from the Internet)

4.2 Water transmission system

The water transmission system is generally composed of inlet / outlet of the upper reservoir, diversion tunnel, diversion pressure regulating chamber, high pressure pipeline, tailwater regulating chamber, tailwater tunnel, and inlet / outlet of the lower reservoir, etc.

The inlet / outlet type of the upper / lower reservoir mostly adopts side inlet, and some pumped storage power stations adopt shaft inlet due to the limitation of terrain and geological conditions, such as the inlet / outlet of the upper reservoir of Xilongchi. Diversion tunnel and tailwater tunnel are pressure tunnel, according to the geological conditions, permeability pressure and other concrete lining. High pressure pipeline in the elevation layout, there are shaft, shaft, shaft and shaft combination of other types, in the layout can be divided into single pipe single machine, one pipe and two machine and one pipe and multiple machine and other types. The high pressure pipe and fork pipe are mostly lined with steel plate, depending on the height of the water head, the depth of burial and the conditions of the surrounding rock. The pressure regulating chamber can be located in the upstream or downstream of the plant, or may be located in both the upstream and downstream, depending on the length of the upstream and downstream water transmission system and the calculation results of the regulation and protection.As shown in Figure 6.

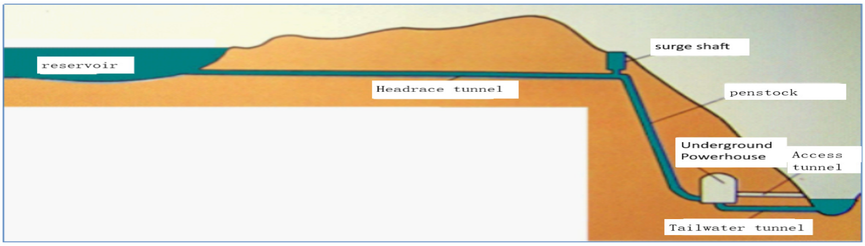

Fig. 6. Schematic diagram of the water transmission system of a pumped storage power station **(This image comes from the Internet)**

4.3 Plant system

The plant system of pumped storage power station mostly adopts underground workshop, and the development mode is divided into first, middle, tail and other ways. The general composition includes the main workshop, auxiliary workshop, main transformer room, switch station and outlet field, as well as bus hole, outlet hole, factory traffic hole, ventilation hole, drainage corridor and other auxiliary caves. The main and auxiliary workshop, the main transformer room are often placed underground, and the switch station and outlet field are arranged in the ground or underground hole room.As shown in Figure 7.

Fig. 7. The underground workshop of a pumped storage power station **(This image comes from the Internet)**

4.4 Special buildings

4.4.1.Block and discharging sand buildings.

In the pumped storage power station built in the sediment river, high attention must be paid to the sediment problem. Generally, the problem of sediment storage can be solved by the sand drainage project (such as flood discharge and sand drainage tunnel), and also by the problem through the shutdown in the main flood season[13].As shown in Figure 8.

Fig. 8. Exit of the sand tunnel in the lower reservoir of a pumped storage power station **(This image comes from the Internet)**

As an important sand retaining measure, sand retaining dam is widely used in pumped storage power stations, such as Zhanghewan, Hohhot, Fengning and other pumped storage power stations. The lower reservoir of Hebei Fengning Pumped storage power station uses the lower reservoir, and the barrage and sand dam divide the lower reservoir into the lower reservoir and the energy storage power station. The sand reservoir and the flood discharge tunnel are responsible for flood control and sand discharge, and the lower reservoir of the energy storage power station can completely solve the sediment problem. Flood discharge sand hole will be the water along the river "bend straight" discharge, flood discharge sand hole is straight and short, easy to discharge sand and discharge, and save investment[14].As shown in Figure 9.

Fig. 9. Overlooking the sand barrage effect of a pumped storage power station **(This image comes from the Internet)**

4.4.2.Refill the building.

The storage capacity of pumped storage power stations is mostly small, and the leakage and evaporation of reservoirs and waterways cause the water loss that needs to be replenished through water replenishment works[15]. For example, the upper / lower reservoirs of Xilongchi Pumped storage power station are made of artificial excavation and filling, without natural runoff supply, and the lower reservoir is equipped with special pumping station facilities for water replenishment. Another example is that Hohhot Pumped storage power station is located in the arid area, and the upper reservoir is completely formed by artificial excavation and filling, and the water replenishment facilities are also set up. The water replenishment is fed by the buried pipe in the sand dam and the water stored in the lower reservoir in the current way.

4.4.3.Taking (inlet) water building.

Taking (inlet) water building refers to the first building of the water transmission building, such as the inlet section of the diversion tunnel, irrigation head, water supply sluice for water, water pumping station, etc. In the pumped storage power station, due to the specific pumping ~ power generation working mode, the taking (inlet) water building mainly refers to the near / outlet section connected to the upper and lower reservoirs.As shown in Figure 10.

Fig. 10. Construction of the upper water inlet / outlet outlet of a pumped storage power station **(This image comes from the Internet)**

4.4.4.Traffic engineering.

Pumped storage power stations often include two reservoirs with large distance and height difference between the upper and lower, as well as a complex group of underground caves. Therefore, the traffic between the upper and lower reservoirs and the caves of the power station is also an indispensable part of the hub layout. Traffic engineering should be combined with the local transportation development planning, the transportation capacity should meet the needs of materials, materials and equipment during the construction period, and the transportation indicators should be economical and reasonable and safe and reliable operation[16].As shown in Figure 11.

Fig. 11. Road connecting the upper and lower reservoirs of a pumped storage power station **(This image comes from the Internet)**

4.4.5.Other special buildings.

Special buildings built to meet the specific functions or functions such as irrigation and dam crossing are often encountered in the construction of pumped storage power stations, such as irrigation channels, ship lift, fish channel, etc., without making too much description.

5 Conclusion

After more than 60 years of development, China has a leading position in the construction of pumped storage power stations, and these power stations have certain reference significance for the world. Common types of pumped storage power plants include hybrid and pure pumped storage power plants, which are characterized by large energy storage capacity, fast response speed, and environmental friendliness. The main building forms include upper reservoir, lower reservoir, water delivery system and plant system. The main building components of the pumped storage power station include workshops, switching stations, office buildings, warehouses and storage yards, and various auxiliary facilities. With the continuous progress of technology and the continuous expansion of application scenarios, the development prospects of pumped storage power stations will also be broader.

Furthermore, it is worth noting that:

5.1. According to the characteristics of different regions, design and build pumped storage power stations according to local conditions. For example, in arid areas, how to use the limited rainwater resources to build pumped storage power stations should be studied.

5.2. Strengthen the application of intelligent and automated technology to improve the operation efficiency and safety of pumped storage power stations. For example, the use of technologies such as the Internet of Things, big data and artificial intelligence to achieve intelligent monitoring and management of power stations.

References

1. LUO S S,LIU Y ,LIU G Z,et al. (2013)Pumped storage power sta- tion development in foreign countries and inspiration for China [J]. SINO-Global Energy,18(11) : 26-29.(in Chinese)
2. ZHOU Xuanyang.(2023)Discussion on Typical Technical Innovation in the Construction of Pumped Storage Power Stations in China[J].lectric Power Survey & Design,(S2):217-222.(in Chinese)
3. YU Xianhua.(2017)China's installed capacity of pumped storage power stations has jumped to the world's first place,[N]. STATE GRID NEWS,2017-06-07(01).(in Chinese)
4. HAN Dong,ZHAO Zenghai,YAN Bingzhong,CUI Zhenghui,REN Yan.(2022)Status and Prospect of China's Pumped Storage Development in 2021,[J].Water Power,48(05):1-4+104.(in Chinese)
5. A. K. Srivastava and R. K. Srivastava, "Optimal operation of pumped-storage hydropower plants with uncertain inflow and demand using fuzzy programming,"Renewable Energy, vol. 176, pp. 1242-1254, 2022.
6. J. P. S. Catalano, A. C. Pereira, and M. A. S. Martins, "Pumped-storage hydroelectricity: A review of its technology, environmental impacts, and economic valuation,"Renewable and Sustainable Energy Reviews, vol. 141, pp. 110251, 2022.
7. G. P. H. Godwin, M. Azapagic, and M. Zhou, "Life cycle assessment of pumped hydro storage systems: A review,"Renewable and Sustainable Energy Reviews, vol. 149, pp. 111221, 2022.
8. Zhang Zong liang,Liu Biao,Wang Fu qiang,etal.(2023)Innovation and development of conventional hydropower and pumped storage technology in China [J].Water Power,2023,49(11):1-6+114.(in Chinese)
9. Li Guangcheng, Wang Sijing,(1999)LOCATING UNDERGROND POWER-HOUSE FOR MING TOMBS PUMPING STORAGE STATION.[J]Journal of Engineering Geology,1999(2).(in Chinese)
10. LIU Xiu-mei, JIANG Hong-jun, GAO Zhao-kun,(2009)Design of water conveyance system for Baishan pumped storage power station.[J]Water Resources & Hydropower of Northeast,2009(6).(in Chinese)
11. Li Wenwu,Xiong Xiaocui,Wu Xixi,(2014)Long-term Stochastic Optimization Research of Cascaded Reservoirs Operation with Hybrid Pumped storage Power Station.[J]Water Resources and Power,2014(9).(in Chinese)
12. ZHANG Chunsheng ,WANG Xiaojun ,JIANG Zhongjian,(2018)Critical Technology of Tianhuangping Pumped Storage Power Station.[J]Hydropower and Pumped Storage,2018(5).
13. ZHOU Xuanyang,(2023)Discussion on Typical Technical Innovation in the Construction of Pumped Storage Power Stations in China.[J]Electric Power Survey & Design,S2.(in Chinese)
14. LIU Na,WU Jin hui,DU Zhi shui,(2015)Study on Sedimentation Accumulation and Prevention Measures for Zhen′an Pumped Storage Power Plant.[J]Northwest Hydropower,2015(6).(in Chinese)

15. LIU Shubao,(2010)Study on sediment deposition and sand prevention measure for Fengning pumped storage power station.[J]Water Resources & Hydropower of Northeast,2010(12).(in Chinese)
16. Ding Xueqi,(2007)On layout of pumped storage station.[J]Northwest Hydropower,2007(3).(in Chinese)