Development and Prospect of the Pumped Hydro Energy Stations in China

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Abstract. Pumped hydro energy storage (PHES) has been recognized as the only widely adopted utility-scale electricity storage technology in the world. It is able to play an important role in load regulation, frequency and phase modulation and black starts in power systems. Due to its outstanding functions, this technology has been widely used worldwide.

This paper introduces PHES including its functions and the technologies briefly to supply a comprehensive cognition of this technology. The key technologies of PHES, such as design and manufacture of reversible pump-turbine runners, design of heavy-duty thrust bearings and shaft sealings, startup of unit etc., are important for the PHES. In addition, more and more new technologies, such as operation with seawater, underground lower reservoirs, adjustable speed units etc., were put forward and used in PHES to make it perform better.

This paper focuses on the development of PHES in China. Thanks to a rapid development of China's economy in the recent years, PHES has gained a fast development. At present, China has owned the biggest installed capacity (29.9 GW by the end of 2018) of PHES the world. PHES has been an indispensable part of the power grid to increase the stability of the grid and improve the penetration of sustainable energy such as wind power, solar energy etc. With the employment of new technologies. China’s new PHES stations, such as Guangzhou, Tianhuangping, Xilongchi PEHS etc., have become the representatives of the world’s most advanced level. Based on the requirement of the current power grid for PHES, some new PHES have been under construction and more PHES are in the planning and design stage.

Keywords: Pumped hydro energy station (PHES), function, China, development

1. Introduction
Pumped hydro energy stations (PHES) is the only proven large-scale (>100 MW) energy storage technology [1]. Apart from the energy storage, it can also help in the load regulation, promoting grid-connected clean energy and maintaining the security and stability of the electric power system. The benefits of PHES on electricity system operations are well documented in textbook and journals [2]. PHES has been widely used worldwide, especially in the developed countries and regions [3]. Until 2018, pumped storage hydropower has remained the dominant source of large-scale energy storage, accounting for an estimated 96% of global energy storage capacity [4]. Global pumped storage capacity rose by more than 7 GW in 2018, for an estimated year-end total of 160 GW [5].
As the world’s second economy, China has a huge generation of electricity. However, the coal-based power grid is difficult in peak shaving and village filling, fast startup and accommodating the renewable energy. To guarantee the stable operation and to improve the renewable energy, an effective power storage technology is urgently needed in China. Due to its satisfactory performances, PHES is expected to be China’s primary peaking power source in the future [6].

In the present paper, a brief introduction of PHES are presented firstly. Some of the key technologies of PHES are classified and discussed. The development of Chinese PHES are introduced with showing the distribution of the PHES and the updating of the technology in detail. Meanwhile, the prospect of PHES in China is also depicted based on the policy.

2. Description of PHES
The main motivation of PHES is to compensate the random nature of consumption of thermal power. It is implemented by storing energy in excess by pumping water to a higher reservoir or delivering energy in consumption peak by releasing water to push the hydraulic turbine. In Figure 1, a sketch of a PHES are depicted showing the flow direction of the water in different modes.

![Figure 1. Sketch of the pumped hydro energy station as well as the pump mode and turbine mode.](image)

Koutnik et al. [7] claimed that PHES play an important role in improving the development of the renewable energy, such as wind power, solar power etc. PHES can help to reduce the impact of renewable energy on the power system by smoothing their generation and suppressing their variability [7]. Although, large scale energy storage systems such as underground compressed air energy, battery storage and large flywheels can also store the renewable energy, the energy storage in elevated water remains the most economical method of load leveling for the power stations [8]. PHES also have some other advantages including flexible start/stop and fast response; tracking load changes and drastic load changes adaption; frequency modulation as well as maintenance of the voltage stability [2].

3. Technology of PHES

3.1. Key technology of PHES
The unit in PHES plays the most important role as energy storage/generation. The whole unit can be divided into four parts including flow passage, bidirectional shaft, generator, and the relevant systems. A summary of the key technologies is displayed as the following shows:

a. The technology of pump-turbine runners:

1) Hydraulic design and optimization of pump-turbine runners; 2) Manufacture of the runners.
b. The technology of bidirectional thrust bearing and shaft:
   1) Design calculation and experiment technology of large scale bidirectional and heavy-duty thrust bearing for the generator; 2) Analysis technology of shaft stability, stiffness and dynamic characteristics for large generators; 3) Technology of shaft seal.

   c. The technology of startup.
   d. The technology of the relevant system:

   3.2. Potential technologies of PHES

Some potential technologies are summarized according to the new trend.

   1) Seawater PHES: PHES can operate with seawater. Seawater PHES is a solution of coastal energy storage, especially in an insular system. The quantity of water required for the operation of a PHES is often not available in insular systems due to the low annual rainfalls [9]. Therefore, in such a lacking fresh water region, seawater PHES shows its advantage.

   2) Adjustable speed unit: The inherent limitations which may reduce PHES ability to contribute to the balancing of the rapidly varying output of new renewable energy and ancillary services provision [10]. Compared with the fixed-speed unit, adjustable speed unit offers several advantages for both pump and generation modes such as (1) the possibility of an almost instantaneous active power control, (2) reactive power control and (3) higher efficiency and a wider range of operation [11].

   3) Underground reservoirs: Some sites are not suitable to build PHES only due to the flat topography. However, underground PHES could be one alternative [12]. Underground PHES also has two reservoirs, but the lower one is underground while the upper one is located at the surface or at shallower depth [13]. That makes these PHES possibly be built in the flat region [14].

4. Development of PHES in China

4.1. Power system structure

Coal-based stations developed quickly and have become the main way to generate electricity in China. However, this electricity grid lacks an economic means of providing peaking power. To solve this problem, pumped hydro energy stations were paid more attention. From the late 1960s, many PHES were built in China and China has owned the greatest installed capacity of PHES at present.

![Figure 2. Chinese power system structure in 2017.](image)

In China's power system, thermal energy is no doubt the dominant occupying about 62% of capacity at end of 2017. Hydropower including pumped storage, nuclear energy, wind energy and solar energy take the second to fifth place as Figure 2 shows [15]. With the rapid increase of power
system, the stability and environment friendliness were paid more attention. Reduction of the CO2 emission, peak shaving and valley filling have been paid more and more attention.

At present, China is zealously popularizing renewable energies. Development of renewable power can provide obvious environmental benefits, but renewable power may reduce the power system’s security and stability. Therefore, an effective and economic energy storage method is needed in China.

4.2. Significance of PHES in China

The functions of PHES are summarized as:

1) PHES’s peak shaving and valley filling help the coal-based station to save fuel, to avoid restarting, to smooth the output and to improve the load efficiency [16].
2) PHES can adapt quickly load changes and modulate the frequency as well as maintain the voltage [17]. PHES can just be used as an emergency backup to prevent system collapses.
3) PHES is a complement with balancing the disequilibrium of renewable power generation and regulating the frequency of grid.

4.3. Development of PHES in China

Gangnan station is the beginning of the development of PHES in China in 1968 with 11 MW capacity. The second PHES is Miyun station with installed capacity of 22 MW. After these two PHES, the development remained dormant until 1990s. The end ten years of the last century is a period of

Figure 3. Locations of PHES in operation and under-construction by the end of 2018.
rapid progression for PHES station. Coming to the 21st century, the second climax of PHES construction appeared. Several large-scale PHES stations were built, such as Taishan, Langyashan, Yixing, Zhanghewan, Xilongchi, Baoquan, Bailanhe, Heimifeng, Pushihe, Xiangshuijian. Figure 3 show the operating and under construction PHES at the end of 2018 [18, 19].

The development of PHES equipment in China can be divided into three stages. At the beginning, only small and middle size units can be manufactured in China and the stations were designed by foreign companies; Secondly, new technologies were absorbed from the foreign companies; Finally, the capability of design, manufacture and site installation for large scale PHES units were grasped.

China's stations built in recent years have already employed the forefront technologies. Guangzhou and Huizhou stations were the second PHES in terms of installed capacity only less than the bath country pumped storage station in USA (maximum capacity is 3030 MW) [20]. Fengning PHES in Hebei province will rank the first place with a total installed capacity of 3600 MW [21] and it will be the first adjustable speed unit in China [22]. The maximum head of the single stage reversible pump-turbine in Changlongshan PHES is 710 m [23], which ranks only second to Kazunogawa PHES in Japan (714 m) [24]. As to civil engineering, the Shisanling PHES station utilized the reinforced concrete in the whole reservoir to reduce the permeability, which is also the leading level in the world. The technology of asphalt concrete face slab used in whole reservoir bottom against penetration for the Tianhuangpin, Zhanghewan and Xilongchi PHES stations is on the world advanced level.

4.4. Prospect of PHES in China

China has planned to build more PHES in the future. Total installed capacity of pumped storage is set to reach at least 40 GW by 2020 from its current 28.49 GW, and with 60 GW either under construction or in the planning stages according to Chinese “13th Five Year Plan” [25]. Some new technologies will be employed. A nationwide general investigation of seawater PHES has been finished which shows an installed capacity of 42083 MW. China also has begun to employ adjustable speed units in the world’s largest PHES in Hebei province [22].

5. Conclusions

PHES plays an important role in the power grid. PHES is made of many complex subsystems. Each of them consists of some key technologies and some potential technologies.

The development and the prospect of China’s PHES are introduced in the present paper. Some conclusions can be drawn as follow: 1) PHES is important in China’s power grid in improving the stability and promoting the development of the renewable energies such as wind power and solar energy; 2) The installed capacity and generation of PHES increased rapidly, in the same time, China's PHES had been in the world advanced level and the relevant design and manufacture technologies are improved rapidly; 3) PHES in China has a promising future with building more stations and employing advanced technologies.

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