Renewable and Sustainable Energy Reviews (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Pumped storage power stations in China: The past, the present, and the future

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ARTICLE INFO

Keywords:
Pumped storage power station
China
Power grid
Load regulation
Electricity price
Planning

ABSTRACT

The pumped storage power station (PSPS) is a special power source that has flexible operation modes and multiple functions. With the rapid economic development in China, the energy demand and the peak-valley load difference of the power grid are continuing to increase. Moreover, wind power, nuclear power, and other new energy sources also develop very fast. Developing the PSPS is of great importance to the power source structure adjustment, and the secure and stable operation of the power grids in China in the 21st century. This paper provides a survey of the PSPS development in China. Over the last two decades, China's PSPS has developed quickly. The PSPS installed capacity had reached 21.83 gigawatts (GW) by the end of 2014, ranking among the top in the world. 27 PSPSs have been completed and put into production, and many with the installed capacity of more than 1200 megawatts (MW) are still under construction, including Fengning PSPS. In addition, a lot of sites suitable for the PSPS construction have been planned. With regard to the challenges existing in the exploitation course, some suggestions are proposed. There is a bright future for the PSPS development in China.

1. Introduction

The PSPS is a special hydropower station, which can use the electricity to pump water up to the upper reservoir when the energy demand is low, and release the water back down to the lower reservoir to generate electricity when the energy demand is high. As an adjustable power source that can operate flexibly, the PSPS has become an important measure to ensure the secure and stable operation of the power grid in China [1].

1.1. Naissance of the PSPS in China

On May 14, 1968, the first PSPS in China was put into operation in Gangnan, Pingshan County, Hebei Province. It is a mixed PSPS. There is a pumped storage unit with the installed capacity of 11 MW. This PSPS uses Gangnan reservoir as the upper reservoir with the total storage capacity of 1.571×10^9 m^3, and uses the daily regulation pond in eastern Gangnan as the lower reservoir with the total storage capacity of 3.5×10^6 m^3. For the application of the pumped storage unit, Gangnan hydropower station owns the ability of load regulation. Erenow, it can only generate seasonal power [2].

Although the scale of this PSPS is small, it is designed reasonably and utilized appropriately. Its construction initiates the history of the PSPS development in China.

1.2. Present power source structure of China

The PSPS construction in the world has more than 130 years of history. Its installed capacity in the United States, Japan and Germany had accounted for 2.2%, 11.13%, and 4.65% of the national total, respectively. Among them, the ratio of Japan was the largest [3–5].

In China, power sources include thermal power, the conventional hydropower, the pumped storage, wind power, nuclear power, and other power sources (e.g. solar power, tidal power and geothermal power). Their compositions in the installed capacity and energy generation of power source are shown in Table 1 (China mainland only) [6].

Obviously, as to the installed capacity, thermal power accounts for the largest with the share surpassing 65%, the conventional hydropower ranks the second, and the pumped storage only occupies 1.60%, whose share is rather low. As a result, the structure is not reasonable enough, and it remains to be adjusted [6].

1.3. Rapid development of the new energy sources in China

Wind power is a clean and renewable energy source, and nuclear

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http://dx.doi.org/10.1016/j.rser.2016.12.100
Received 6 July 2015; Received in revised form 13 December 2016; Accepted 23 December 2016

Table 1
Power source structure of China in 2014 [6].

	Total	Pumped storage	Conventional hydropower	Thermal power	Nuclear power	Wind power	Others	Unit
Installed capacity	1360.19	21.83	280	915.69	19.88	95.81	26.98	GW
Share	100%	1.60%	20.59%	67.32%	1.46%	7.04%	1.98%	
Energy generation	5545.9	12.8	1053.3	4173.1	126.2	156.3	24.2	TWh
Share	100%	0.23%	18.99%	75.25%	2.28%	2.82%	0.44%	

(TWh means TeraWatt Hours).

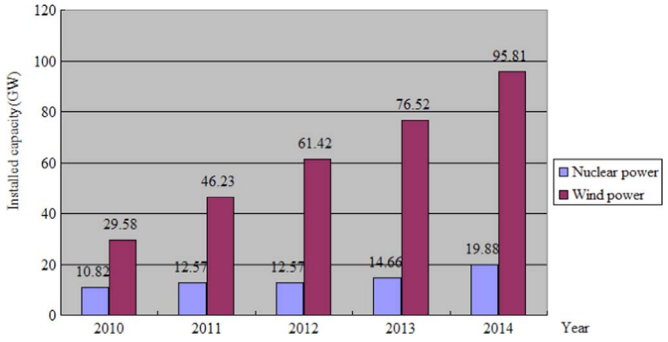

Fig. 1. The installed capacity of wind power and nuclear power in China during 2010–2014 [3,7–11].

power is a new energy source to China. Both powers are encouraged to be exploited by Chinese government, and they have developed very fast in the past five years (Fig. 1) [3,7–11].

Supporting the PSPS construction can not only lower the maintenance cost of nuclear power unit and prolong the life span, but also effectively reduce the impact of the parallel operation of wind farms on the power grid, and improve the safety and stability of power grid operation.

1.4. Literature review on the PSPS

The pumped storage is the only proven large scale (> 100 MW) energy storage scheme for the power system operation [12]. For the past few years, the increasing trend of installations and commercial operation of the PSPS has been observed [13]. There are more than 300 PSPSs on our planet, with a total capacity of 127 GW [14].

In the United State, there are 40 PSPSs with a total capacity of about 20 GW [15]. In addition, 32 proposed PSPS projects that will be built have the capacity of 28.6 GW in total, more than the existing PSPS capacity in this country. The PSPSs operating all over the European Union (EU) were studied based on key statistical indicators found in the European Hydropower database (HYDI) [16]. In 2010, the EU had approximately 140 operational PSPSs with an installed capacity of more than 19.5 GW, and 84 of them were of mixed-type. The largest number of PSPSs was found in Germany (31) and Italy (21). In Japan, there is currently approximate 25.4 GW installed capacity accounting for 11.13% of its domestic total capacity [3]. Within India there are 11 PSPSs operational with an installed capacity of 4.804 GW and another 1 GW capacity plant is under construction [12]. Moreover, 56 potential sites were identified suitable for developing the PSPSs, with a probable installed capacity of 94 GW [17]. In Turkey, the PSPS has become a very important measure to meet the fast growing wind power generation [18]. As to the PSPS prospect of German, in spite of the challenge in profitability, the government aimed to enhance the available capacity by up to 60% [19].

The PSPS brings a lot of benefits to the power system. They are well documented in literatures [13,20–24], which are summed up as follows.

1. The flexible generation of PSPSs can provide both up and down regulation in the power system. This can stabilize the intermittent output of renewable energy sources.
2. The PSPS can start quickly, which makes it suitable for black starts and provision of spinning and standing reserve.
3. It can provide power during times of high demand and allow base-load power stations (such as coal station and nuclear station) to run at high efficiencies in times of low demand.
4. It can act as the fast response peaking plant to make up high inertia nuclear power in the power network.
5. It can play the role as an integrator for variable power (such as wind power and solar power) in the power network.

This paper provides a survey of the PSPS development in China. On the basis of summarizing the development status of the PSPS in China, the characteristics and the development policies have been analyzed, and then the problems existing in the exploitation course are identified. The countermeasures are finally put forwards for its future development.

2. Major characteristics of the PSPS

2.1. Technical characteristics

To sum up the technical characteristics, the PSPS is not a power supply point, but a running tool of the power grid [1,25,26].

(1) The PSPS is both the load and power source.
The reversible pumped storage unit is used as a pump to consume the temporarily surplus power when the energy demand is low. On the contrary, the unit can run as a generator when the energy demand is high. This is not possessed by any other type of power plants.
(2) The PSPS consumes some electricity in running, instead of adding new energy to the power network.
It is a tool for power conversion and reserve. At present, the comprehensive efficiency of the PSPS is about 75% (the ratio of power generated to power consumed) in China, which is also called "using 4 degrees to produce 3 degrees".
(3) The PSPS is the best tool for energy storage.
The pumped storage has the function of energy reserve, and it solves the problem of electricity production and consumption at the same time, and not easy to store. Thus, it can effectively regulate the dynamic balance of the power systems in electricity generation and utilization.
Except the PSPS, the energy storage devices that can be applied in large scale currently include the compressed-air energy storage ones, and part of the chemical batteries. Compared with them, the PSPS investment is lower, the service life is longer, and the efficiency of energy conversion is more stable. As a result, the PSPS is currently the most mature and practical way for large-scale energy storage in the power system.
(4) The PSPS is the optimal tool for load regulation.

There are five kinds of generating units that can regulate the load of power networks. Their regulation characters are shown in Table 2.