The Present Situation Analysis and Future Prospect of Pumped Storage Technology

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Abstract. Pumped storage technology is well-developed, cost-effective, and offers promising future growth. It is crucial to the development of energy storage technology. The work discussed in this paper is concentrated on advancements in pumped hydro storage. The development of pumped storage is demonstrated in three ways in this essay including development history, current situation and future prospects. The use of pumped hydro storage dates back more than a century. Over the past 100 years, it has been split into four distinct periods of development. To get pumped hydro storage to its maximum, several optimization approaches have been made made at each stage. Regarding the state of development, the size of the world's pumped storage has continued to increase. In order to create a new sort of system, pumped storage technology can be combined with other technologies. That is, form a new type of power system, so there is a lot of room for development. Generally speaking, the future development of pumped storage, has great development and good prospects.

Keywords: Pump-Storage Hydroelectricity, Technology, Industry.

1. Introduction

Energy is one of the most crucial components for the people all around the world because it is the energy that makes everything work. For example, it provides the electricity to light and warm up the buildings, offers the power of transportation and produces all the products that human needs, to list just a few. In order to store the electricity like chemical energy and to solve the consumption contradiction, people have been developing energy storage technology in hundreds of years, which is a key part of energy application since it provides a certain space for people to use energy. Among the various forms of the existing electric energy storage technologies, pumped storage is currently most widely applied energy storage technology and of the largest scale. Pump-storage electricity is a special type of hydro power plant. It mainly consists of upper and lower reservoirs, tunnel, plant and switch station. catchment, surge chamber, pressure pipeline, water tail channel and surge chamber can be built selectively. The system composition of pumped storage power station varies greatly due to different geographical conditions. For example, if the pressures channel draws water directly from the upper reservoir, the diversion tunnel and surge chamber can be eliminated; if the plant is located underground and the water tail channel is long, the tail water pressure regulation is essential. Pumped storage power stations use pumped storage units that can operate in both pump and turbine modes. At night, without large scale of electricity consumption, the pump-storage plant can use the energy produced by other electricity plant like hydro, thermal and nuclear power plants to pump the water in the lower elevation up to the higher reservoir. During peak hours in the daytime, the pump-storage plant can release the upper water, driving the hydro-generator set to generate electricity for the consumers. In terms of basic principle, the pump stored hydroelectricity stations operate on the principle of electric energy conversion, which is between the hydroelectricity and electricity. With the ability to converse and store the energy, the pump-storage hydroelectricity plant is able to achieve the goal of operating the power system safely and economically, making it be indispensable to the modern power system. It still brings a lot of benefits for the human beings, although it is inevitable to have an energy loss during the process of conversion. In the following content of this article, the authors briefly introduce the development history of pumped storage and explain in detail the development status of pumped storage from two aspects of technology and industry and the development prospect of this technology.

2. Development history

More than a century has passed since the invention of pumped hydro storage. To put it another way, this technology is more developed when compared to other technologies, and it is also more cost-effective [1]. The first pumped storage power station was constructed in Zurich, Switzerland, in 1882, and it has a long history. Then, pumped storage power systems around the world quickly advanced after the 1960s. Pumped storage power plants have mostly gone through four stages of development worldwide.

Eighty years later, in the first half of the 20th century, pumped storage power stations gradually began to develop, and the first stage of pumped storage officially began. At this stage, the development of pumped storage technology was still relatively slow, mainly based on water storage. However, in the 1950s, the average annual installed capacity increased by 200MW, and by 1960 the world's installed capacity was 3420MW. After the end of the Second World War, the economic recovery period ended, and with the advent of the industrialization era, the power load required by developed countries such as the United States, Japan and Europe also increased rapidly. As a result, pumped storage power stations with good performance in peak load regulation and valley filling can also develop rapidly. This is enough to show that Western European countries are leading the world towards the peak of pumped storage construction [2].

In the 1960s to 1980s, the second stage of the development of pumped storage began. In the late 1960s, the installed capacity of pumped storage in the United States ranked first in the world. However, many developed countries led by the United States and many regions have successively built a large number of nuclear power plants. In order to cooperate with the operation of nuclear power plants, these countries built more pumped storage hydropower plants during this period. Therefore, this period can also be called the "golden development" period of pumped storage. During this stage, the average annual growth rates reached 11.26% and 6.45%, respectively [3].

From the 1990s to the early 21st century, this belongs to the third stage. In the second stage, the economic development of the developed countries was too fast, but at this stage, the economic growth rate of the developed countries slowed down. The average annual growth rate of pumped storage power station construction dropped from 6.45% in the 1980s to 2.75%. By 2000, the installed capacity of pumped storage power stations worldwide had reached 114,000MW. This is undoubtedly a huge change. However, in the 1990s, Japan surpassed the United States to become the country with the largest installed capacity of pumped storage power stations [3].

The 21st century to the present is the fourth stage. The economies of developed countries in the West are slowing down again, but the economies of Asian countries are growing rapidly, and the demand for pumped storage hydropower stations has suddenly increased, especially in China, South Korea and other Asian countries. In 2010, the installed capacity of pumped storage power stations worldwide reached 135,000MW, with an average annual growth rate of 1.71%. However, it already reached a new height of 159,490MW in 2020, with an average annual growth rate of 1.68%. At the same time, in 2017, China surpassed Japan to reach 28,490MW, becoming the country with the largest pumped storage power station in the world, and it still is so far [3].

3. Current situation

3.1. Current development of the technology

3.1.1 Classification of pump-storage technology

The pump-storage hydroelectricity can be classified in several different ways including structure, function, and geographical location. According to the different exploiting methods, it can be classified into pure pumped storage power stations and hybrid pumped storage power stations [4]. With various regulating periods, they can be classified into daily, monthly and yearly regulated pump-storage hydroelectricity plants. There are mainly three kinds of pump-storage hydroelectricity technologies.

(1) Technique of construction

This technique, generally speaking, includes information management technology, which is used to follow and oversee the all operation process, mechanical tunneling technology which is used to excavate the underpasses and tunnels, flexible support technology to maintain the economic benefits as well as the surrounding slope steady and anti-leakage techniques for asphalt and reinforced concrete panels.

(2) Electromechanical manufacturing technology

Long and short blade runners, high head and large capacity pump turbines, and variable speed turbines are widely used electromechanical manufacturing technologies. To be more specific, these technologies are used to improve the efficiency of the pump turbine, integrate economic profits and realize the requirement of variable speed operation of an energy storage unit.

(3) Variable speed pumped storage technology.

The transmission modes of variable speed units in the pumped storage power station are split speed including variable pole speed and double rotor double stator speed, and continuous speed which is widely used and rapidly developed, which contains doubly-fed frequency control and full power frequency control. In detail, the reason for the need for the controllability of adjustable speed is the optimal generation efficiency caused by the change of water level of upper and lower reservoirs and the change of water head in a pumped storage power station corresponds to different rotational speeds [5].

In certain places with distinct topography and extreme climates, special pump-storage technologies are needed to be used, such as ocean water and severe cold district operation technologies: first, seawater pump-storage technology can help to keep the balance between active and reactive power in the power system, relieve the energy shortage brought by the dwindling of freshwater, and build a safe, stable, economic and clean coastal energy supply system; for the pump-storage hydroelectricity located in a high and cold area, the establishment of the pumped storage power station is very crucial for the local high demand on the peak regulating the capacity of power grid brought by strong wind and strong light, thus prompting the consumption of the wind power.

3.1.2 Installed capacity scale

The global energy storage scale reaches 180.9GW. Among them, as shown in Figure 1, the proportion of pump-storage hydroelectricity is the biggest, reaching 94% [6].

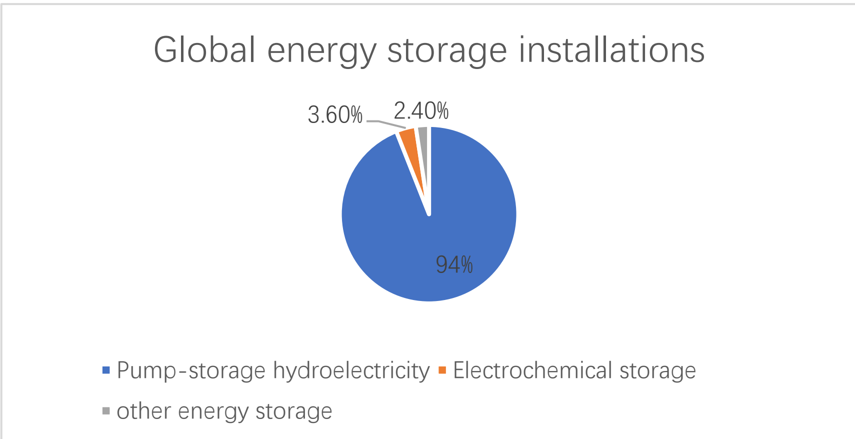

Figure 1. Global energy storage installations [6]

In terms of the added hydropower capacity of different countries, as depicted in Figure 2, China reached 390 GW capacity scale, remaining the position of the world leader in installing capacity. Brazil, the United States and Canada followed by, with data of 109 GW, 102 GW and 82 GW. Other countries have various increases, including India, Russia and Japan in 2021.

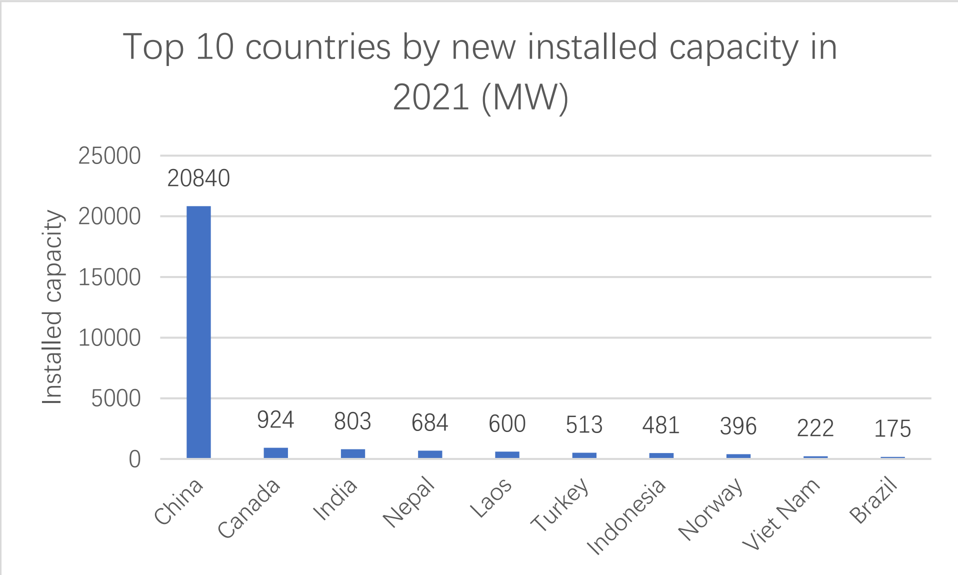

Figure 2. Top 10 countries by new installed capacity in 2021(MW) [7]

For pump-storage hydroelectricity national capacity, in 2021, as illustrated in Figure 3, China claimed that the national capacity will reach 62 GW in 2025 and will be doubled to 120GW by 2030. India proposed that the potential pump-storage hydroelectricity of it is enabled to reach 96.5 GW, but until now, India only realized 4.78 GW of its announcement. For the United States, approximately 70 MW has been added in 2021 and the country is keeping opening some new platforms and projects to more users to explore the potential of pump-storage hydroelectricity.

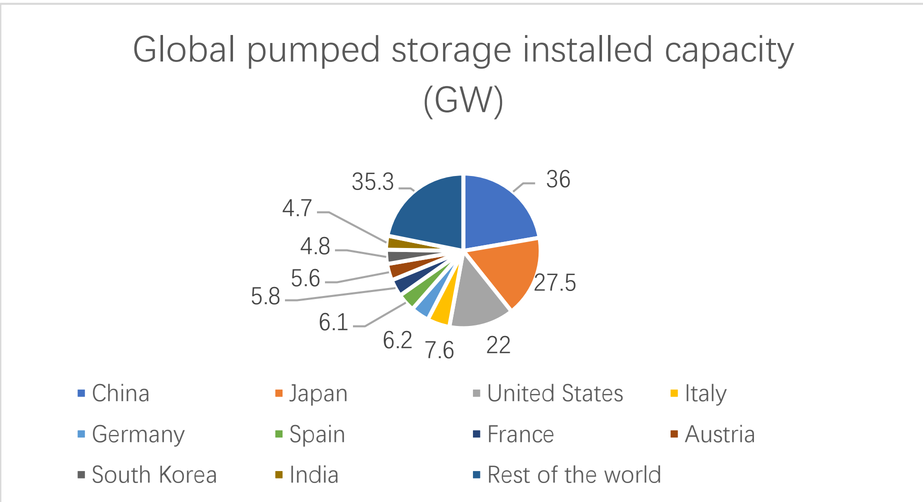

Figure 3. Global pumped storage installed capacity (GW) [7]

3.1.3 The speed of development and the reasons for its limitation

As shown in Figure 4, to respond to the greater need for system flexibility in the countries like China and area like Asia-Pacific countries, Europe, and the MENA region to integrate variable renewable, the pump-storage hydroelectricity capacity is predicted to increase by roughly 26 GW in the next five years. The largest growth which is 18 GW, happens in China. The growing need for system flexibility, especially to reduce wind electricity curtailment, and optimize coal as well as nuclear plant operations is the main driver for the development of this technology in China [8]. For Europe, the capacity of pumped storage hydroelectricity is expected to increase by 2.8 GW by 2023 from additions in 5 countries in Europe (Switzerland, Portugal, Austria, the United Kingdom, and Germany). The main drivers for growth in Europe are the mass of suitable topography and the requirement for system flexibility which can balance increasing wind and photovoltaic (PV) generation.

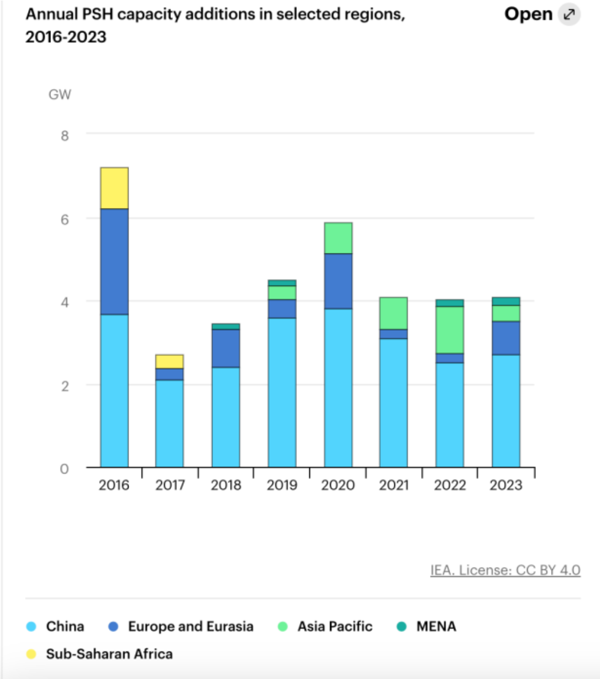

Figure 4. Annual PSH capacity in selected regions, 2016-2023 [9]

3.2. Current status of the industry

Besides the content of the current status from the perspective of technologies, the analysis of the industry is vital to the development of pump-storage hydropower. This is mainly because the activities of the governments and consumers can directly affect the policy establishment and market fluctuations, which are explained deeply in the followed by parts [10].

3.2.1 Policy

The participation of governments is necessary for long-term investment in sustainable energy to establish the policy and oversee the implementation of the rules. The IFPSH Policy and Markets Working group asserts several recommendations for the global governments from seven major points of view: assessment of energy storage needs, comparison methods, licensing management, guarantee compensation, risk sharing, terrain assessment, and green development [11]. Here are some worldwide classical policy measures. First, Europe revises its market order electric to cope with the change in the Europe market, allowing the storage technology to enter the market and abolishing the market barrier. In addition, allowing storage to take part in various markets, such as wholesale electricity market, generation market, and ancillary services market, to list just a few, Federal Energy Regulatory Commission Directive 841 requires independent system operators and territorial transmission organizations by modifying existing market rules. Furthermore, the regulator can improve the market development and the application of the energy system. Proper overseeing is essential to improve the flexibility of the electric system [10].

3.2.2 Market

To analyze from the side of consumers, the specific price of the on-grid quotation and charging electricity price of the grid-side independent energy storage power station needs to be decided, because the decision of price directly determines the sustainable development ability of the project. Besides, investment in the power grid enterprises and social capital is crucial to the innovative development of business patterns. In this situation, the lack of cost channeling mechanism of energy storage facilities that are invested by power grid enterprises results in a reduction in the expected profitability of projects in which social capital is invested [12].

3.3. Potential issue

Pump-storage hydroelectricity is the main method to store energy today. However, it still has several issues. First, the building of the pump-storage hydroelectricity plant and the application of facilities depend on the specific situation of topography. It needs enough high elevation difference as well as two bodies of water in the upper and lower reservoirs respectively. Second, pump-storage plant construction is expensive and has a long construction time. There are multiple expenses. To explain deeply, during the construction process, building a dam is requisite to block the water from the water body. The building of large-scale pumped-storage facilities can cost between $1.3 billion and $3.3 billion [13]. The costs for installation, operation, and maintenance are also expensive.

4. Trends and prospects

The development trend of pumped storage in the future has actually been on the rise. Although many new energy storage technologies will develop well in the future, the development of pumped storage will still dominate the energy storage market. Because the power system around the world needs to be guaranteed, but pumped storage is an important way to ensure its safe operation.

First of all, pumped storage can be combined with other technologies to build a new power system. The advantages of pumped storage and combined technologies first need to be summarized, and then their disadvantages need to be gradually improved. It seems that the development space of the integrated system is huge and can bring more benefits.

Second, wind energy is also a renewable energy source that can also be used for the step of pumping water. Therefore, the development trend of wind energy and pumped storage grid-connected power generation in the new power system is also continuously rising [14]. Moreover, the combination of them can be used to achieve a wide range of applications such as "filling the valley". The pumped storage power station is the best way to solve the problem of peak-shaving and valley-filling of the power grid. For power grids with rich wind power resources, a certain scale of pumped storage power stations should be built to realize the joint development of wind and storage. Combining the two together, the various functions and flexibility of pumped storage power stations can be used to make up for the uncontrollability of wind energy. Therefore, it is also a good development trend for pumped storage and wind energy to generate electricity together.

5. Conclusion

The whole article discusses the development of pumped storage. On this basis, it is concluded that the development of pumped storage has a large space and good prospects, and the global development of pumped storage keeps increasing. Although pumped storage has many advantages, it is not perfect, and there are still some shortcomings. For example, resource reserves do not match development needs. This type of resource reserve is rare. This creates a mismatch between demand and the status quo. In addition, the degree of marketization is not high. Due to the lack of resources obtained through marketization, non-grid enterprises and social capital are not very enthusiastic about developing pumped storage power stations, so the relevant supporting implementation details and rules for pumped storage power stations need to be further improved. These two problems are only part of the problems. By improving these problems, the development of pumped storage energy can be more promising and further developed better.

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