Development and application of pumped storage power generation system

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Abstract. As one of the most crucial energy storage facilities in modern times, pumped storage technology utilizes the principle of gravitational potential energy and mechanical energy conversion of water to pump energy facility when the eelectric load is low, and release water to generate power when it is high. The technology mainly includes pumping pump, turbine and generator and other equipment, through the two stages of pumping and power generation cycle, to realize the storage and release of electric energy. Pumped storage power generation technology has the advantages of large scale, high efficiency, clean and environmental protection, and is widely used in power systems with stability and reliability, but it is still limited by geographical factors. With the use of clean energy and the growth of electricity demand on the electricity side, pumped storage power generation technology will continue to innovate and develop, and become an important part of energy facility in the future electricity system.

1 Introduction

The earliest development and use of pumped storage technology is used for large-scale power supply to meet the electricity needs of residential and industrial production. In the 20th century, people gradually have an advanced comprehension of environmental protection, and tend to gradually replace fossil fuels with renewable and clean energy sources,which reduced the impact on climate change to a certain extent. Because renewable energy sources often exhibit variability in their energy supply, the future of energy storage technology has become particularly important. Among these technologies, pumped storage power generation has attracted much attention because of its use of water as a power generation medium and its high efficiency in power production.

The basic working rule of pumped storage technology is composed of several different modules, including the turbine, upper reservoir, lower reservoir, pump, generator, and grid [1]. The whole system of this power generation is mainly composed of two reservoirs of different heights connected to each other. When the power demand on the power side is low, the surplus power generated by pumped storage power generation will be used for water pumping between reservoirs; When the demand for electricity on the power side is high, the water is released due to the difference and through the power of turbine returnedthe reservoir [2].

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This technology first appeared in the 1890s, with the earliest invention using an individual pump impeller and group turbine generators in the Swiss, Austrian and Italian Alps. Then in the early 20th century, large hydropower stations began to appear, and during the construction process the single reversible pump turbine had become the main trend. By the middle of the 20th century, many large hydropower stations had been built, and the power sources used in the pumping process began to trend toward clean energy, such as wind, solar or a mix of energy sources. Today, pumped storage technology has been very mature, in the power supply system has played an irreplaceable role [3,4].

This paper aims to introduce the development of pumped storage technology at the present stage, give specific cases and data analysis, and make future development prediction by analyzing the advantages and disadvantages of this technology. Through such analysis, this technology can be better applied to the future large-scale power supply applications.

2 Technical principle and performance parameters

2.1 Workflow

The working process of pumped storage power generation mainly includes two stages as pumped energy storage and released water power generation.

During periods of low power demand, the entire system will be pumped for storage. This process usually uses the natural water source near the hydropower station as the raw water supply. In the pumping procedure, the pumping apparatus is actuated. With the motor serving as the power origin, water is pumped from the lower reservoir to the upper reservoir (high - level reservoir) by consuming electrical energy. In this process, electrical energy is converted into water and stored as potential energy. After pumping is completed, the water is stored for use during the power generation phase [3].

During the peak time of electricity demand or when the supply of the grid is deficient, water release power generation process starts. The stored water is released by opening the sluice gate or related control equipment at the bottom of the upper reservoir. When water flows through a turbine or turbine generator set, the kinetic energy of the water flow is converted into mechanical energy and transmitted to the generator set. At this juncture, the generator set transmutes mechanical energy into electrical energy by dint of the principle of electromagnetic induction and exports it to the grid so as to satiate the power demand [4,5].

2.2 Performance Parameters

The energy conversion efficiency is in the range of 66% to 82% [6]. Compared with other energy storage power generation methods, this power generation efficiency is already at a high level. Despite the various factors that can potentially impact the efficiency of power generation, the primary contributors to this inefficiency are likely to be energy dissipation within the unit and transformer operations, evaporation and seepage losses within the reservoir, electrical resistance encountered during the operation of the associated equipment, and fluctuations in the demand for grid power supply. These factors collectively contribute to the overall reduction in power generation efficiency.

In terms of power generation, one kilogram of water generates about 0.001 to 0.002 kWh of electricity [7]. And the gravitational potential energy generated by this water can not be all converted into electricity, there is energy loss in the process, so we multiply this data by the power generation efficiency, then 1 kg of water can be converted into electricity can be calculated. This number is so small that it's almost negligible. This is mainly because we assume a very idealized scenario in the calculation process, and the power generation

efficiency is also relatively high. In reality, due to various factors, 1 kg of water can be converted into electricity will be much lower than this value.

In addition to the above data, there are also important factors such as service life, generation response time, risk response time, etc. These factors depend on the size of the hydropower station and its construction conditions [8].

3 Practical Application

Firstly, it can be used for power storage. The power of the grid in the trough is used for pumped storage, and the stored power is released in the peak time, so as to ensure the stable operation of the grid. Pumped storage technology is used to store backup power to ensure that the grid can provide stable power during peak hours or emergencies. Furthermore, it has a short - lived start - up time and a fast - paced adjustment rate. It can be utilized as an exigency power supply to promptly increase the power generation yield after the high - power loss within the system, thus guaranteeing the safe and stable functioning of the system [9].

This technology plays a significant role in regulating and optimizing power systems. Through the function of peaking and valley filling in pumped storage power station, the load fluctuation of power grid can be balanced and the energy utilization efficiency and power supply quality of power grid can be improved. In addition, the pumped storage power station can also be used as a start power supply to restore power supply in time after the occurrence of a major power outage to ensure the rapid and orderly recovery of the power system. It also play an important role in coping with the adjustment pressure brought by the continuous increase in the proportion of new energy installed capacity. Such as the Grand Guli hydropower Station in the United States, China's Fengman Hydropower Station has such a function.

The application of pumped storage power generation technology has also brought remarkable economic and social benefits. The construction and operation of pumped storage power stations will also help be conducive to local economic development, provide more jobs, protect and improve the local ecological environment. In recent years, the number of jobs that can be provided in the energy storage industry has exceeded 100,000 [3], and because of the important position of pumped storage power generation the proportion of jobs related to power stations is very large.

4 Technical Advantages and Limitations

Pumped power storage technology has been fully utilized after nearly a hundred years of development, some of its advantages are other energy storage technology can not be replaced, but there are still some shortcomings.

4.1 Technical Advantages

First, the principle of pumped storage power generation is well known. The technology has high maturity and reliability and stability, and can operate even under complex environmental conditions. Secondly, the pumped storage power station can adjust the power generation in a short time according to the demand of the grid, and has a strong adaptability. This also makes pumped storage power stations become one of the key means to solve the peak regulation of the power grid. The response speed is very fast, and the operation of regulating the power can be completed in a few seconds. Compared with other power generation methods, it has significant advantages when power grid emergencies and emergency accidents occur.

More importantly, pumped storage power generation technology has high power generation efficiency, which can save energy and improve energy utilization to a certain extent. This also means that this technology has the advantages of environmental protection and energy saving, pumped storage power stations do not produce additional carbon dioxide emissions, there is no pollution to the environment, compared to traditional thermal power stations, it is a very environmentally friendly and energy-saving way to generate electricity.

Finally, its comprehensive cost is low. Although the investment of pumped storage power stations is higher when they are initially built, the maintenance costs during operation are lower. Considering its long-term operation benefits, the comprehensive cost is low, and the investment payback period is short. And the electricity bill generated by pumped storage power generation is also less for ordinary residents [3].

4.2 Technical Limitations

These stations have high requirements for the geographical conditions of site construction, because of the particularity of its need for water generation, pumped storage power stations need suitable geographical conditions to build reservoirs and dams, which limits its wide application in some areas, and the construction period is long, which may affect the speed of its timely use. The power generation energy density of this technology is low, and its power generation is large and stable, but under the unit density or the same energy storage capacity, pumped storage power stations need to occupy more land and resources. Although the response of pumped storage power stations has developed rapidly, it is still difficult to fully keep up with the rapidly changing output of renewable energy sources such as wind power. This has limited its application in the field of renewable energy generation to a certain extent.

5 Future Outlook

As a mature and widely used energy storage technology, it will continue to maintain rapid growth in the future. Technological innovation will play a key role in the construction and operation of pumped storage power stations. With the application of digital and intelligent technology, the dispatching operation of pumped storage power stations will be more flexible and efficient, and the engineering construction technology and equipment manufacturing technology will also achieve innovation and improvement. A more complete industrial system and specialized development mode will enhance the competitiveness and sustainable development ability of the entire industry. In terms of policy, the government will continue to introduce relevant policies to support the development of pumped storage industry, improve the market mechanism, reduce electricity prices, and promote the cost reduction and high-quality development of the whole industry.

At the same time, some parts of the world are also facing challenges, some areas of pumped storage development there is not deep work, unclear demand and other problems, and some pumped storage unit production capacity is not yet able to meet the peak demand. Therefore, it is necessary to scientifically and reasonably plan the unit manufacturing and capacity transformation to avoid the problem of insufficient or excess capacity.

6 Conclusion

Pumped storage power generation is already a well-mastered energy storage technology. When the demand for electricity on the power side is low, the pumped storage power generation facility uses the extra electricity generated to draw water from the reservoir to store energy. When the demand for electricity on the power side is high, the stored water in

the upper reservoir will be released for electricity generation, using the gravitational potential energy generated by the falling height of the water flow to convert into electricity release. The main advantages of pumped storage power generation are high efficiency, large energy storage scale, environmental protection, etc., but it is also limited by geographical factors and environmental impacts, and has high construction costs. Pumped storage power generation has been widely used in the world, and is an environmentally friendly, low-carbon, convenient and clean energy storage facilityy for power systems. In the future, with the rapid development of renewable energy, pumped storage will become an important means of energy storage, and government support and technological innovation will further promote the application of it. In summary, pumped storage power generation, as an efficient, reliable and economical way of energy storage, plays an important role in the power system. Although there are certain disadvantages and challenges, with the development of technology and policy support, its application prospects are still broad.

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