

# Feasibility Analysis of Converting Hydropower Stations into Power Regulation Centers-Taking the Three Gorges Project for Example

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**Abstract:** In order to effectively respond to the global climate change and energy crisis, the structural transformation of energy has become an irreversible trend in the future development of China's energy system. As a new kind of clean and renewable energy source, wind power technology has made great progress in recent years and has become relatively mature. The penetration rate of wind power in China's power system increases continuously, playing an important role in promoting energy saving and emission reduction. However, because of their instability in time and space, wind power and solar power may pose great challenges to the safety of the power grid. To ensure power supply, thermal power generating units, combined with pumped-storage power stations, are still mainly used for peak load regulation nowadays, which is inconsistent with the long-term goal of carbon neutrality. This essay mainly studies the feasibility of turning hydropower stations into power regulation centers, taking the Three Gorges Project as the analysis object.

**Keywords:** Hydropower station; Power regulation center; Three Gorges Project

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**Publication date:** October 2021; **Online publication:** October 26, 2021

## 1. Introduction

It is estimated that, in the world's energy systems, over 85 percent of electricity consumption depends on fossil fuels, which is the main cause of global climate change<sup>[1]</sup>. Under significant pressure, including global climate change, environmental protection problems, resource depletion and so on, it is necessary to research clean and renewable alternative energy during the development of our energy system. Methods of optimizing the energy industry structure have also become the consensus of the world, in which context, improving the supply and comprehensive utilization rate of clean and renewable energy gradually becomes a fundamental energy policy of many countries. As a result, the supply of clean energy is growing rapidly. Correspondingly, due to the instability of renewable energy supply in time and space, the demand for peak load regulation in the power system with large-scale grid-connected new energy rises sharply.

Hydropower plants are an important part of China's modern power system. The hydropower generating units therein, because of their specific advantages such as strong automatic grade ability, quick starting and stopping speed, and good flexibility, can undertake various tasks of the power system simultaneously, including the peak load regulation, frequency modulation and load preparation<sup>[2]</sup>. Therefore, this study will mainly analyze the feasibility of converting existing hydropower stations into power regulation centers with the dramatic increase of wind and photovoltaic power generation.

## **2. The current situation of wind and solar power in China**

### **2.1. The current situation of wind and solar power in China**

#### **2.1.1. The current situation of wind power in China**

China's research on wind power technology began in the late 1950s, which was relatively late. In the beginning, the research was limited to some low-power, small-scale wind power equipment, which could only operate alone. For a long time afterward, the development of wind power technology in China stagnated. Then, until the late 1970s, when many countries attached great importance to wind power generation, China began to pay more attention to it and conducted researches more extensively [3].

Since the late 1970s and 1980s, China has gradually started to invest in wind farms in Shandong and Hainan. One year after the official investment of the Hainan Integrated Wind Farm, the Shandong Integrated Wind Farm was successfully constructed, which was the first grid-connected wind farm put into operation [4]. Many large wind farms were built in South, Northwest, and East China in the following years.

At present, the cost of wind power generation in China is relatively high, and the distribution of wind energy is unbalanced among different regions. It is hard to effectively manage and improve the quality of wind energy, which hinders the healthy development of wind power projects in contemporary China. To solve these problems, the government introduces preferential policies of wind power towards enterprises. Large-scale grid-connected wind turbines are deeply involved in the wind power market, and the development of the wind power tech industry receives policy assistance.

On January 19, 2021, the National Energy Administration announced last year's new energy installed capacity data. In 2020, the wind and solar power installed capacity increased 71.67 million kilowatts and 48.2 million kilowatts separately. The sum of newly increased wind power and solar power installed capacity was approximately 120 million kilowatts. By the end of 2020, the cumulative installed capacity of wind power nationwide was 281 million kilowatts, and that of solar power was 253 million kilowatts.

#### **2.1.2. The current situation of solar power in China**

In recent years, China's solar power generation has grown rapidly. During the past three years, the annual new installed capacity exceeded half of the world's total new capacity. By the end of 2020, the total photovoltaic installed capacity reached 253 million kilowatts.

## **2.2. Disadvantages of wind power and solar power**

The large-scale grid-connected power generation of new energy is significant to the energy saving and emission reduction of the energy system. However, restricted by many factors such as overload capability and grid structure, the power system is weak in absorbing the fluctuating and intermittent new energy generation. The too-high proportion of new energy power stations connected to the grid makes it difficult for the power system to absorb all new energy generation, resulting in "wind curtailment" or "photovoltaic curtailment." Taking the situation in 2016 as an example, the installed capacity of wind power and photovoltaic waste in China went as high as 46.5 billion kWh. Curtailment has gradually become a key factor restricting the development of China's renewable energy industry.

There are various reasons for the curtailment of new energy. In essence, fossil energy is responsible for the electricity supply and the peak load regulation of the power system. To realize the structural transformation of the power system through clean energy, it is necessary to ensure that the power system is still equipped with enough flexibility after the use of clean energy. However, due to the high volatility, intermittence and randomness, the output process of the existing wind power and photovoltaic-based new energy power generation technologies cannot be controlled. It is often significantly different from the load demand of the system, showing strong anti-regulation characteristics. The power generation process of the new energy alone cannot meet the real-time balance of the system's load demand. Thus, other flexible

power sources are needed to balance the system. There is a contradiction between the increasing demand for flexibility in the power system caused by the grid-connected new energy and the squeezed generation capacity due to the large-scale replacement of fossil energy, which is the fundamental reason for the curtailment of new energy [5].

To avoid this situation and ensure power supply, thermal power generating units and pumped-storage power stations are still mainly used for peak load regulation, which is inconsistent with the long-term goal of carbon neutrality. Therefore, it is quite necessary to establish power regulation centers.

### 3. Overview of hydropower

#### 3.1. Overview of the existing hydropower

With advantages like environmental protection and sustainable use, hydropower has a crucial position in energy allocation across the country. Hydropower is a kind of clean, renewable energy without environmental pollution and has low operating costs [6]. It is convenient for peak load regulation and is beneficial to improving resource utilization rate. Confronted with the increasingly serious situation of traditional energy globally, many countries prioritize hydropower and strive to make full use of natural hydropower and other new resources. China ranks first in the world regarding existing or undetected natural hydropower reserves or all the natural hydropower resources that may be researched and developed in the next few years. As a clean and renewable energy source, hydropower technology occupies an extremely important position in the development of China's clean energy utilization and greatly supports the healthy and sustainable development of the economic society. In 2019, China's hydropower generation amounted to 1301.9 billion kWh, increasing 69.8 billion kWh compared with 2018, and the year-on-year growth was 5.67 percent. In 2020, China's hydropower generation reached 1.3378 billion kWh and would continue to grow in the future.

**Table 1.** Statistics of hydropower generation from 2014 to 2020 (Unit: ten thousand kilowatts)

	2014	2015	2016	2017	2018	2019	2020
Generation (Ten thousand kW)	10601	11127	11748	11931	12321	13019	13378

Hydropower is clean and pollution-free. It meets China's strategic goals and requirements for sustainable development and has significant edges compared with other power generation technologies. In recent years, China's hydropower installed capacity has continued to grow. In 2019, it reached 356.4 million kilowatts, increasing by 3.81 million kilowatts compared with 2018, and the year-on-year growth was 1.08 percent. In 2020, China's hydropower installed capacity completed 362.38 million kilowatts.

**Table 2.** Statistics of hydropower installed capacity from 2014 to 2020 (Unit: ten thousand kilowatts)

	2014	2015	2016	2017	2018	2019	2020
Capacity (Ten thousand kW)	30468	31954	33207	34359	35259	35640	36238

Since 2018, China's hydropower's new equipment and power generation capacity have begun to decline significantly. In 2019, the new equipment and power generation capacity reached 4.17 million kilowatts, decreasing 4.42 million kilowatts compared with 2018. However, there was a sharp rise in 2020 compared with 2019, when the new equipment and power generation capacity reached 10.79 million kilowatts in 2020, exceeding the whole of 2018.

**Table 3.** Statistics of new hydropower installed capacity from 2014 to 2020 (Unit: ten thousand kilowatts)

	2014	2015	2016	2017	2018	2019	2020
Capacity (Ten thousand kW)	2180	1375	1179	1287	859	417	1079

### 3.2. Overview of existing pumped-storage power stations

By the end of 2019, there were 17 pumped-storage power stations in China, with a total installed capacity of 39.23 million kW. The sum of electric energy storage was 550 million kWh, which is equivalent to 1.98E15 joules.

## 4. Feasibility analysis of converting the Three Gorges Project into a power regulation center

### 4.1. Introduction to the basic situation of the Three Gorges Project

The Three Gorges Project is the largest hydropower station globally and the largest construction project ever built in China. However, the relocation, environmental problems, and many other issues caused by it have made it controversial from the moment it was built. The Three Gorges Hydropower Station has more than ten functions, including shipping, power generation, planting, etc. The construction of the Three Gorges Hydropower Station was approved in 1992 and officially started in 1994. The water storage and power generation began on June 1, 2003, and the construction was completed in 2009.

The Three Gorges Hydropower Station dam has an elevation of 185 meters, a storage elevation of 175 meters, a total storage capacity of 39.3 billion m<sup>3</sup>, and a regulating storage volume of 22 billion m<sup>3</sup>. With 32 sets of 700,000 kW and two sets of 50,000 kW hydroelectric generator sets, it has a total installed capacity of 22.5 million kW, being the world's largest hydroelectric power station and clean energy production base.

### 4.2. Feasibility of converting the Three Gorges Project into a power regulation center

#### 4.2.1. Theoretical feasibility

The large-scale reservoirs in the Three Gorges Basin need to undertake the comprehensive utilization tasks of multiple departments, such as the hydroelectricity system. The operation mode will change with the improvement of relevant understanding and changes in comprehensive utilization. After the large-scale grid connection of new energy, the power system's adjustment requirements for hydropower operation have changed. Hydropower also needs to balance the fluctuation of new energy output and support the grid-connected operation of new energy. The traditional operation mode can hardly meet the new demands of the power system, which pursues maximum power generation in the long run while ensuring a certain output level. Therefore, the operation method of the hydropower station group should be adjusted according to the demand of the peak regulation tasks<sup>[7]</sup>. During the medium and long-term reservoir operation, it is necessary to regulate the temporal and spatial distribution of natural runoff to maximize the comprehensive utilization benefits of the reservoir while guaranteeing the basic needs of various departments. The critical periods of the reservoirs' various departments are often different. Thus, in different periods, the priority of the comprehensive utilization of reservoirs is dynamically changing<sup>[8]</sup>.

The reservoirs in the mainstream of the Yangtze River Basin pay more attention to flood control in the flood season, during which period the river basin's safety must be ensured. Furthermore, it is necessary to provide guarantees for agricultural water use in the irrigation period as well as the domestic, industrial, and ecological water use throughout the year. On this basis, the demand for power generation should also be taken into consideration. In response to the peak regulation requirements, the new energy generators and large-scale grid-connected high-pressure hydraulic systems, we need to not only meet the tasks of long-term water supply, flood control, and flood prevention, but also optimize the distribution of water volume

in different periods, so that hydropower stations can maintain a certain peak regulation capacity in different periods and then formulate reservoir operation plans that are conducive to the long-term operation of the power system. In the short term, we should combine the resource status in the power system and the comprehensive utilization requirements of the water conservancy system within the time; In the medium and long term, based on the available water volume within a certain period, the peak regulation capacity of the hydropower station group can be fully utilized through refined scheduling, to reduce the power generation demand and peak shaving demand of the thermal power units and enlarge the new energy absorption space in the system, which is beneficial to the development demand of energy saving and emission reduction.

#### 4.2.2. Actual feasibility

(1) Calculate the estimation of the maximum storage capacity of the Three Gorges Reservoir.

$W_s = mgh = 220 \times 10^9 \times 9.8 \times 108 = 2.37 \times 10^{16}$  Joules.  $W_s$  is the static storage energy of the reservoir.  $m$  is the regulating storage volume of 22 billion  $m^3$ .  $g$  is 9.8m per square second.  $h$  is the water head of 108m.  $W_d = m_dgh = (7.2 \times 10^6 \times 86400) \times 9.8 \times 108 = 6.58 \times 10^{14}$  Joules.  $W_d$  is the minimum daily new storage capacity of the reservoir.  $m_d$  is the average flow during the dry season, which is 7200  $m^3$  per second.  $g$  is 9.8m per square second.  $h$  is the water head of 108m. The  $W_s$ , total static energy storage, of the Three Gorges Reservoir is  $2.37 \times 10^{16}$  Joules, which is about 12 times the total energy storage of all 17 pumped-storage power stations in China ( $1.98 \times 10^{15}$ ). Even if the daily minimum new storage capacity is calculated according to the inflow during the dry season, the  $W_s$  is equivalent to 27 percent of the total water storage capacity of the 17 power stations.

(2) Calculate the possible maximum output power during the Three Gorges Reservoir's operation, supposing it converted into a regulation center.

Based on the minimum flood-carrying capacity of the Jingjiang River downstream of the Three Gorges Project, which is 60,000  $m^3/s$ , with the 108m water head, it can be calculated that the maximum possible output power of the Three Gorges Project is 63.5GW, which is 1.62 times the total installed capacity of the pumped-storage power stations that have been built. The calculations show that whether in terms of the water-energy storage amount or the provision of regulation power, the Three Gorges Project's regulation capacity is much greater than the sum of the existing pumped-storage power stations in the country. Noticeably, its water energy storage capacity is 12 times better. Moreover, the center completely avoids the defect that the pumped-storage power station can only be used as a daily adjustment reservoir. The adjustment depth can be monthly or even quarterly. Even in large-scale rainy or windless weather across the country, it can also provide enough power. It needs to be pointed out that the scale of the Three Gorges Project only accounts for 5.7 percent of the current installed capacity of all hydropower in China, so the existing hydropower stations have great potential in terms of regulation capacity. There is the possibility of in-depth exploration.

#### 4.3. Advantages of turning the existing hydropower stations into regulation centers.

- (1) Compared to constructing pumped-storage power stations with the same power, this method will be much more economical for there is no need to build upper and lower reservoirs. The output power can be increased simply by adding more peak-regulating generator sets based on the existing power station, and the cost will be only 30 percent of building a new power station. The hydropower station, which serves as the regulation center, generates as much electricity as before, while the increased regulation capacity only costs 30 percent of building a new pumped-storage power station.
- (2) The regulation center built based on the existing reservoir can store more energy under the same

regulation power. Taking the Three Gorges Project as an example, it can store up to 12 times as much water energy. This is because the existing reservoir sites are mainly well-selected natural topography, providing a large storage capacity. It is much better than the artificially modified topography selected by pumped-storage power stations. In addition, there will be no need to worry about the coordination between the upper and lower reservoirs. Therefore, the gap in energy storage can be counted with orders of magnitude, while the increase in energy storage will provide a strong guarantee for power safety.

- (3) Power station turbines will only be used in power generation, which provides quicker starting and stopping speed and more timely peak regulation and frequency modulation. There will not be energy loss in pumping conditions, so the water turbines can be much more efficient.

## 5. Conclusion

In summary, because of the instability in time and space, it is difficult for wind power and solar power to meet the electricity demand in China at present. Therefore, regulation centers based on the existing hydropower stations should be constructed. The electricity from the wind and solar power stations in West China will be transmitted to these regulation centers, which will become stable and controllable after unified adjustment and then be sent to load centers in East China through UHV transmission lines.

## Disclosure statement

The author declares no conflict of interest.

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