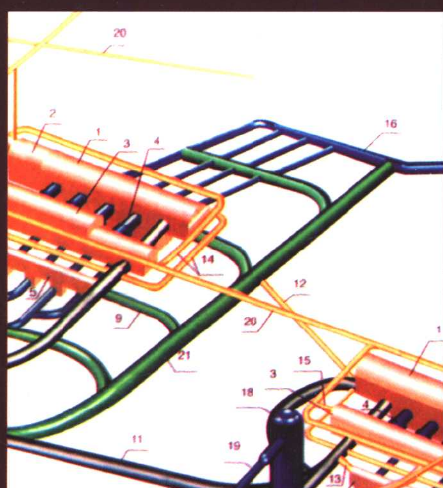
Chinese Society of Hydroelectric Engineering
Guangdong Pumped Storage Power Station JVC
Chief Editors: Pan Jiazheng He Jing

THE CONSTRUCTION OF PUMPED-STORAGE POWER STATION IN CHINA



中国电力出版社
www.cepp.com.cn
China Electric Power Press

The Construction of Pumped-Storage Power Station in China

Chinese Society of Hydroelectric Engineering
Guangdong Pumped Storage Power Station JVC
Chief Editors:Pan Jiazheng He Jing

中国电力出版社
www.cepp.com.cn
China Electric Power Press

图书在版编目(CIP)数据

中国抽水蓄能电站建设 = The Construction of Pumped-Storage Power Station in China:英文/中国水力发电工程学会,广东抽水蓄能电站联营公司编.—北京:中国电力出版社,2000.8

ISBN 7-5083-0319-9

Ⅰ.中… Ⅱ.①中…②广… Ⅲ.抽水蓄能水电站-水利建设-概况-中国 Ⅳ.TV743

中国版本图书馆 CIP 数据核字(2000)第 66160 号

ISBN 7-5083-0319-9

The Construction of Pumped-Storage Power Station in China

Published and Distributed by China Electric Power Press
6 Sanlihe Road, Beijing, China, 100044
Printed in the People's Republic of China

中国电力出版社出版、发行
(北京三里河路 6 号 100044 http://www.cepp.com.cn)
水电印刷厂印刷
*
2000 年 9 月第一版 2000 年 9 月北京第一次印刷
787 毫米×1092 毫米 16 开本 6.25 印张 216 千字 24 插页
印数 0001—1200 册

Editorial Committee

Foreword

China is rich in energy resources. The proved exploitable reserves of hydraulic energy, coal, oil and gas account for about 11% of the world's total, in which hydraulic energy accounts for about 17% of the world's total, occupying first place in the world, the proved amount of coal makes up about 11% of the world's total, ranking third in the world, and the predicted reserve of coal is 44 times greater than the proved amount. Due to restrictions on the structure and total amount of resources, in China, coal-fired power will take first place for a long period of time. Now, the installed capacity of hydropower accounts for only some 23% of the nation's total, and it is possible that it will be raised to about 30% after 2010 through adjustment of power source structure and by making greater effort to develop hydropower. The distributions of China's coal and hydraulic energy resources are very uneven. The majority of existing coal reserves concentrates in North China and Northwest China, including Shanxi province, Inner Mongolia and Ningxia regions, Shaanxi province, among which, only Shanxi province accounts for 1/3 of the nation's proved amount. About 77% of hydraulic energy resources is distributed in the west of China, developed coastal regions in the east of China possess only 7% of the nation's hydraulic energy resources. It can be seen that almost half of the country is short of energy resources. Power consumption in the east and central parts of China is dependent on transmitting power generated by hydropower stations in the western regions, or transporting coal-fired power (coal) from the north, and the transmission distances is 1,000 - 2,000 km. In order to bring power grids to operate stably and economically, therefor, through comparative studies of technical and economic alternatives based on load characteristics and power source mix, building pumped storage power stations is a first choice in the load centers for serving as the functions of peaking, utilizing power at base load, frequency regulation, reactive power modulating and emergency reserve. Studies at home and abroad have shown that an appropriate proportion of pumped storage capacity in the total capacity of power grid is about 10%. By estimate with the proportion, a necessary installed capacity of pumped storage units will be 30,000MW in 2010 for 16 provincial and municipal power grids in the east and center parts of China. Up to now, the capacity of pumped storage units completed and under construction is nearly 6,000MW. Thus it can be seen that pumped storage power in China will be certainly developed more speedily and more extensively in the 21 century.

In China, making a beginning of construction of pumped storage power station was relatively late, only several pumped storage power stations were built in 1970s. Since 1980s, load demand has been increasing day by day due to raised proportion of tertiary industry along with quickly developed economy and improved living standards. While power consumption has been increasing, load structure changed greatly, and it is especially clear that increase of maximum load was always faster than that of energy output, so as to result in an urgent need of peak-lopping. For this reason, some large-sized pumped storage power stations have been completed as required, such as Panjiakou (270MW), Shisanling (800MW), Tianhuangping (1,800MW), Guangzhou (2,400MW). In China, development of pumped storage power stations has taken a sound step.

For development of pumped storage power, it is quite important to summarize experience obtained formerly and open up the way to better growth in future. The editors of this book have gone to the trouble of organizing and collecting papers on topics which sum up the construction of pumped storage station, and introduce the achievements and prospect of pumped storage station development in China in the past twenty years. This book also presents the general situations, effects and technical achievements of over ten typical pumped storage power stations separately. They include the following examples:

Gangnan — construction of China's first pumped storage station.

Panjiakou — economic benefit of combined operation with reversible and conventional units.

Guangzhou — important role in guaranteeing safe and economic operation of the Guangdong and Hong Kong power grids, and design and construction experience in high pressure bifurcated pipes and slide form of large diameter inclined shaft.

Shisanling — important role in Beijing as capital city and its environs, monitoring of surrounding rocks, and concrete lining and winter operation measures for the upper reservoir.

Tianhuangping — asphalt concrete lining and slope failure treatment for the upper reservoir.

For three medium-sized pumped storage stations, Xikou, Yanghu and Xianghongdian, this book introduces their respective necessity, economy, construction features in high elevation region and manufacturing technology of home-made reversible units. Besides, the book also describes characteristics and achievements of the Minghu and Mingtan pumped storage stations, taking famous Sun Moon Lake as water sources, in Taiwan. These stations represent the development level of China's pumped storage power at present.

The book, excellent in both picture and essay, has a greater reference value for personnel engaged in planning, design, research, construction and operation of hydropower and for teachers and students in hydropower discipline. Moreover, it helps relevant leaders at various levels and management staff to know important role of a pumped storage station in safe, economic and premium-grade operation of power grid, thus promotes development of pumped storage power in China. Moreover, this book, published at the time of that the 20th International Congress on Large Dams will soon be opened in 2000 in Beijing, helps foreign friends to understand the present situation and future development of hydropower in China and promote international exchange and cooperation.

On the basis of absorbing experience from home and abroad, I believe that the development of pumped storage power in China will establish mechanisms for economic benefit assessment and management which are accord with the state's conditions, occupy an indispensable place in the power industry and obtain more and greater progress in pace with the arrival of a new century.

He Jing

March, 1999

Contents

COMPREHENSIVE REPORTS

I

Pumped Storage in China

Luo Shaoji

(Guangdong Pumped Storage Power Station JVC)

1. Present Status

1968 saw the emergence of Gangnan pumped storage project near Shijiazhuang, the capital city of Hebei province. Small as it was, it was the first ever of its kind in China, built downstream of Gangnan reservoir and equipped only with one 11MW unit introduced from Japan. Then came in 1972 the Miyun pumped storage scheme in the outskirts of Beijing, with two 12MW home-made units fed by Miyun reservoir. These two completed pumped hydro projects, however, had hardly any big role to play and seldom caught much attention because of their small low-head machines, sometimes tricky, powered by irrigation-intended reservoirs.

1978 ushered in the economic reform and open-up program in China and its economic development came onto a fast track. The power sector was gearing up to meet the increasing demand of the general public, since household appliances of various kind topped the consumption list of more and more Chinese families, load difference between on-peak and off-peak hours became bigger and bigger. With the presence of more and more large coal-fired plants, most power systems had to face up to an increasing generating capacity shortfall rather than the previous energy crunch. Such systems had to run at higher frequencies during off-peak hours because of minimal demand, but at lower frequencies during on-peak hours, or simply resorted to brownout and blackout sometimes to annoy customers. With the advent of nuclear power plants in late 80's the pumped storage began to turn over a new leaf. Panjiakou, a mixed-type pumped hydro in Hebei province, was quick to start by adding three 90MW reversible variable-speed units to the existing 150MW conventional hydro. The reversible machines were manufactured in Italy and Switzerland, commissioned respectively in June 1991, August and September of 1992 to serve the North-China power system.

The South-China Guangdong power system was particularly hard pressed by the peaking capacity shortage. With the launch of the 1,800MW Daya Bay nuclear power project in 1987, Guangzhou pumped storage I (Guangzhou I), equipped with four 300MW reversible units operating at a 535m head, got off the ground in 1988 and completed in 1994 to serve both Guangdong and Kowloon systems. Its operation experiences show Guangzhou I helps Daya Bay realize stable operation. That is to say, the nuclear is able to be block-loaded and its generation between 1994 and 1997 totals 44,000GWh, or 22.2% above the designed 36,000GWh. Besides, the pumped storage has helped ensure the supply quality and thus won praise from home and abroad. At present the 2×1000MW Ling'ao nuclear power scheme, the second of its kind in Guangdong is under construction and the 4×300MW Guangzhou II was kicked off in 1994, its commissioning is set for 1998 and its overall completion by the year 2000 when it will be the biggest pumped storage (8×300MW) in our current world.

North-China power system is badly in need of peaking capacity because its hydro makes only an insignificant 5% of its energy mix coupled stringent rules over the quality and reliability for Beijing service area. To cater for the demand, Shisanling pumped storage project, 40km from Beijing, was launched in 1989. The project with four 200MW machines working at 430m head was commissioned at the end of 1995 and its full commercial service was realized in June 1997. The existing Shisanling reservoir serves as the lower pond and the upper pond was cut and covered with a reinforced concrete membrance. Ever since its commissioning the project has played a remarkable role in, say, peaking and emergency reserve, frequency regulation, and synchronous condenser operation, all for the sole benefit of the power system. The World Bank financed Tianhuangping pumped storage project in Anji, about 80km northwest of Hangzhou, was commenced in 1994. The project comprises an upper pond cut and faced with imperious bitumen concrete slabs, a lower pond with abundant natural inflow and a 1,428m waterway in between resulting in $L/H=2.5$. Its six 300MW units are incorporated to back up Qinshan nuclear power plant (2 × 300MW), and to serve the shareholders, i.e. Shanghai, Jiangsu, Zhejiang and Anhui, all under the interconnected East-China grid.

Yanghu is a natural plateau lake elevated at 4,440.5m. It is situated 85 km southwest of Lhasa, Tibet, with a long-term storage capacity of 15 Gm^3. Yanghu pumped storage uses this plateau lake as the upper reservoir and Yalung Zangbo river as the lower one with an elevation difference of 840m. As a backbone power project in Tibet, the 4×22.5MW scheme got start in 1991 and went into service in 1996. Xikou pumped storage with an installed capacity of 2 × 40MW in Zhejiang came into operation in 1997. The 2×20MW Xianghongdian pumped hydro in Anhui is actually an extension to the existing conventional hydro. Small as they are, the machines are flexible in operation and can generate rich profit for the local communities.

By the year 2000 the installed capacity of pumped hydros of all sizes across mainland China will have reached 5,570MW, 5% of the world's 110GW total of the same sort, or 1.9% of the national aggregate generating capacity of all kinds. Investigations indicate China is pretty rich in pumped hydro potentials, and the power systems predominated by thermals either in coastal areas or hinteland provinces would need to develop pumped hydro business where actual conditions so warrant to optimize their own energy mix.

As far as Taiwan is concerned, Minghu is its first pumped storage equipped with four 250MW units. The upper pond is the natural Riyuetan Lake, one of the scenic attractions in Taiwan, and the lower pond was formed of a dam on Shuilixi brook with an elevation difference of 321m. The project got off the ground in 1979 and completed in 1985. By using the same lake and brook as its upper and lower ponds, Mingtan pumped storage with six 275MW units installed, started in 1987 and completed in 1995. Up till 1997, the generating capacity in Taiwan totaled 25,740MW, of the which 5,140MW was nuclear while the pumped storage contribution is 2,600MW, 10.1% of the total, or 50.9% of the nuclear capacity, for the sake of safe and economic operation of the whole system.

2. Construction Experiences

Although modern pumped hydro is a new comer to the Chinese power sector, China has had decades of experiences with building large-size conventional hydro projects. Our reform and open-up policy coupled with foreign technical know-how and management expertise have brought a new upsurge to pumped storage developments with modern features. True, there are currently only a few pumped hydros in China and their total installed capacity represents an insignificant proportion on the whole. The physical size of some of the projects, however, is remarkable. Take Guangzhou II pumped storage project for example. When its phase II is rounded off, it will become the biggest of the sort in our current world. The actual progress from power cavern topheading to initial commissioning normally ranges between 49 and 54 months, as is the case with Guangzhou I and II, Shisanling and Tianhuangping. Such an actual progress is certainly not pale before most similar foreign projects in the developed countries. The cost level per kW installed for Tianhuangping and Shisanling hovers around RMB 4,000 to 5,000 yuan, or US 500 to 600 dollars equivalent, but only RMB 2,500 yuan or US 300 dollars equivalent for Guangzhou I and II, all apparently lower than that of their foreign counterparts. It is also noticed that the per kW cost level for Guangzhou I and II is not as much as what it should be for a coal-fired development with peaking duties. The construction experiences typical of fast progress and lower cost provide a helpful guidance for the system planners, also a catalyst to further pumped storage development.

With the execution of Chinese pumped hydros over the last decade, the following proven techniques have been gained.

2.1 Project management

The project management for Guangzhou, Tianhuangping and Shisanling pumped storages represents a new Chinese practice centering around the employer's responsibility, quality supervision and contract award on a competitive bidding basis. In the light of the new practice the employer is held responsible for the project financing, implementation, business operation and loan repayment, and is thus entitled to the related power of decision-making or autonomy. In search for the overall project benefit, the employer is ready to mobilize all necessary social resources, introduce new techniques, and build up his contract administration. All this effort results in fast progress, good quality, cost savings and a balanced environment, as evidenced by Guangzhou pumped storage project.

2.2 Leakage of upper pond

Yanghu pumped storage in Tibet uses a plateau lake as its upper pond with no leakage headache. The upper storage facility for Guangzhou pumped hydro is constructed of a natural basin and a concrete-faced rockfill dam with no more than 1.0 L/s leakage, due to its favorable topography, geology and sound construction techniques. These two engineering precedents show the sitting of the upper pond has to be adequatedly addressed in feasibility studies.

The upper pond for Shisanling or Tianhuangping is simply a cut basin encircled with a ring dam. The impervious blanket for Tianhuangping is of bitumen concrete with minimal leakage, similar to its foreign precedents. Shisanling uses reinforced-concrete facing with cracks developed during construction but healed before its operation. The leakage now is minimal in summer, but about 10 L/s in winter. These two engineering examples indicate Chine has gained experiences with leakage treatment of the cut reservoir basin.

2.3 Support of power cavern

The power cavern for Guangzhou pumped storage is 21m span and is supported with rock bolting and shotcreting – 3.7 to 5.0m dowels for the roof and 4.3 to 7.0m for the side wall finished with a wiremesh and 15 cm shotcrete, which represents the world's modern support techniques. Tianhuangping follows this example but pre-stressed bolts were added where geological structures outcropped. The successful cavern support practice has fully endorsed the support designs and skills.

2.4 Rock-anchored crane beam

The powerhouse crane, 400t load capacity for Guangzhou and 500t for Tianhuangping, is running on concrete beams doweled onto the side wall, instead of the time-honored pillar-supported type. The new technique results from a reasonable design philosophy and construction skills, and results in cost savings because a smaller span and a shorter scheduling are all achievable in the circumstances.

2.5 Headrace tunnel and concrete manifold

By making the best use of the elastic resistance of the surrounding rock, the headrace tunnel and manifold for Guangzhou and Tianhuangping are all lined with a 40 – 60cm reinforced shell concrete with a single-layer rebar included. The Guangzhou I manifold, the first largest of its kind in China, subject to a high pressure, was co-designed by the Chinese and American engineers and constructed by a local contractor. The high pressure manifold for Tianhuangping and Guangzhou were designed and constructed all by ourselves. The Guangzhou I manifold has been in good service for 5 years and few cracks developed thereupon as varified by emptying inspections for three times. The total leakage collected all around the Guangzhou I powerhouse measures less than 1.0L/s, an eloquent indicator of the skillful power tunnel design and construction.

2.6 Slipforming of inclined penstock

Either vertical or inclined penstock is possible for a pumped storage. The inclined design is favored by Chinese engineers because of a shorter waterway, a better hydraulic transient, a lower cost and a higher efficiency than otherwise. After careful comparison the inclined option survived in Guangzhou, Tianhuangping and Shisanling, and relative methods have been developed for penstock piloting and concrete-line slipforming, both in a safe and quick way. The penstock excavation was initiated by a raise climber for Guangzhou and Tianhuangping, but by a raise drill in the case of Shisanling. The inclined penstock for Guangzhou I and Ⅱ was lined by a slipforming equipment with foreign assistance. The shutters were moved on, and guided by, a central mast, and the average daily climb rate reached a better-than-expected 4m for Guangzhou I and even better, 6m for Guangzhou Ⅱ. The non-stop slipform for Tianhuangping moved along the rails on the penstock invert and performed satisfactorily.

2.7 Plant operation management

Guangzhou I is equipped with the France-made machines funded with a French government loan. Along with the plant imports, the operation management expertise of Electricite de France was also introduced and practiced on the basis of the national and occupational requirements of our own. Thus an operation management regime has been established typical of unmanned plant operation with minimal attendance. The 1,200MW Guangzhou I is staffed with 88 employees, or 0.73 person per 10MW installed. When Guangzhou with another 1,200MW is completed, the staffing level will further drop to 0.66 person. This established regime need to be continuously optimized and refined. Its safety rules, for example, have been tuned to the international accepted 5-star qualifications. In order to spread the plant operation experiences across China, training courses have been prepared for operators from other hydro projects, say, Tianhuangping (6×300MW), Xikou (2×40MW), Songjianghe (510MW) and Ertan (3,300MW).

Minghu and Mingtan in Taiwan use the common upper reservoir but have two separate lower reservoir under two separate management, staffed at about 1 person per 10MW. It is said that Taiwan power grid is going to group-control and streamline these two pumped storages, and that Minghu is going to have its machines overhauled ten years after their initial service.

Though modern pumped hydro has just made its debut in China and only a few are currently in service, the completed ones are always busy in their respective systems. Take Guangzhou I and Shisanling the number of their machine starts per annum ranges between 1,000 and 500 and the annual running hours in various modes of operation reach 2,500. Their machines are regularly serviced or maintained, and the availability and starting reliability are relatively high, though the operation crew seems quite slim. Minghu and Mingtan have about the same situation, while the annual running hours are more than their mainland examples.

3. Economic Evaluation

It is easy to understand the technical advantage of a pumped storage, but is remains a difficult task to fully quantify its economic benefits to ensure a reasonable return to the developers.

Based upon the experiences at home and abroad, China has just begun drafting rules on the