AN OVERVIEW AND OUTLOOK OF HYDROPOWER BASES DEVELOPMENT IN CHINA

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1. INTRODUCTION

China is rich in hydropower resources by thetechnically feasible potential of660GWand annual production of 3000TWh. Hydropower resources are mainly concentrated in the 13 hydropower bases of Changjiang river, Jinsha river, Yalong river, Dadu river, Wujiang river, Yellow river, Lancang river, Nujiang river, Hongshui river, Yarlungzangbo river, Three-northeast-provinces, Fujian-Zhejiang-Jiangxi Provinces and west of Hunan province. Technically feasible hydropower potential of these 13 hydropower bases is 460GW which is around two third of technically feasible hydropower potential in China.

The rapid hydropower development for the past 70 years since establishment of P.R. China in 1949, especially after the opening-up policy in 1978 is mainly triggered by fast growth of energy demand during the economic growth,power system reform and market-oriented operation of energy system. The total installed capacity of hydroweris only 3.63GW and 17.28GW at the end of 1949 and 1978 respectively, while the figure is rapidly refreshed and the record of 100GW, 200GW and 300GW are quicklybeaked in 2004, 2010 and 2015 respectively. by the end of 2019, it reached 321GW (excluding pump storage station). Refer to Figure 1 for China hydropower development in the past.

The total installed capacity of 13 hydropower bases increased 17 times from 13GW in 1978 to 225GW at the end of 2019. China is leading the global hydropower development and become a major force for promoting global hydropower technology development with continuesprogresses in the field of river basin plan, project design & construction , scientific research, operation &maintenance, and information technology application. Meanwhile, China hydropower and hydropower bases development are still facing various challenges in the general background of global energy transition trend which is characterized by low carbon, renewable, electrification and intellectualization. During the steadilyHydropower base development, more attention should be paid on studying and applying a comprehensive cascade operation model in order to develop and utilize the water resources in a reasonable and sustainable way.

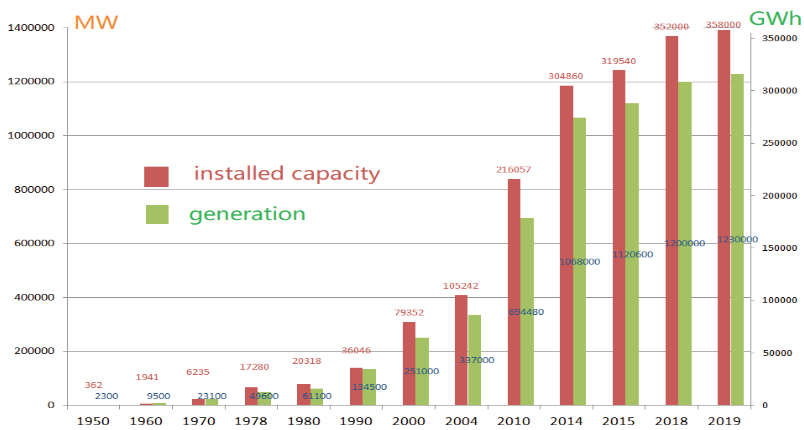

Figure 1： China Hydropower development in the Past(including pump storage station)

2. OVERVIEW OF HYDROPOWER BASES DEVELOPMENT IN CHINA

2.1 River planning of all 13 bases have been fully accomplished

River planning is vital for hydropower cascade development and integrated river basin management. The all proposed projects ofthree hydropower bases (three-northeast-provinces, Fujian-Zhejiang-Jiangxi Provinces and west of Hunan province) are being accomplished during the end of 1950s to the beginning of 1990s according to the river planning. River planning for other major large rivers are started at 1980s, such as "Comprehensive Utilization Planning for Honghe River" in 1980, "Planning for Dukou-Yibin stretch of Jinsha River" in 1981, "Cascade Planning for Long-Qing stretch of upstream of Yellow River" in 1983, "Planning for main stream of Dadu River" in 1984, "Planning for middle to downstream stretch of Lancang River" in 1986, "Planning for main stream of Wujiang River" in 1987, "Planning for main stream of Yalong River(Kala-Jiangkou)" in 1987, etc. River planning works have made historical progress in the 21centurary in terms of not only numbers of rivers and cascades but also scale of the projects, height of dams and volumes of reservoirs. A series of mega hydropowerprojects studies and river planning of Jinsha River, DaduRiver, Yalong River, Yellower River and Lancang River are completed during this period.Till now, all river basin cascade development plan have been accomplished which laid a sound foundationfor hydropower bases development in China.

2.2 Eleven hydropower bases have been basicallydeveloped

There are only 5 of 13 hydropower bases are partially developed before the year of 1978, such as few small to medium scalehydropower stations being built in three-northeast-provinces, Fujian-Zhejiang-Jiangxi Provinces and west-of-Hunan-province, few large hydropower projectsbeing built in large rivers such as Yellower River and Dadu River. Main stream of the large rivers of other 8 hydropower bases are basically left untouched except Gezhouba hydropower station on Changjiang River just start construction. With the fast growth of hydropower after 1980' till 2018, except main stream of Nujiang river and Yarlungzangbo river still not being developed yet, other 11 hydropower bases have been basically developed. Refer to Table 1 for hydropower development status of 13 hydropower bases in China.

Table 1 : Hydropower development status of 13 hydropower bases in China (unit: MW)

No.	Name of Hydropower Base	Total installed capacity		Under construction till end of 2018	Development ratio
		Till end of 1978	Till end of 2018		
1	Jinsha River	0	34,020	30,950	78.1%
2	Nujiang River	0	0	0	0.0%
3	Lancang River	0	15,700	7,030	71.4%
4	Upstream of Yangzi River	0	25,215	0	80.6%
5	Yalong River	0	14,700	4,500	66.6%
6	Yellow River*	2,157	17,398	2,200	58.7%
7	Dadu River	708	17,022	3,464	82.1%
8	Hongshui river	0	12,079	1,600	90.7%
9	Wujiang River	0	11,100	0	95.4%
10	Yarlungzangbo River	0	510	1,020	1.8%
11	The three-northeast-provinces	3,597.3	6,280	0	41.7%
12	Fujian-Zhejiang-Jiangxi	3,810.1	23,840	0	~100%
13	Hunan Province**	2,666.5	14,500	0	~100%
In total		12,938.9	194,032	50,764	~56.0%

Remarks: * include upstream and north main stream of Yellow River; ** include hydropower base of west-of-Hunan-province.

2.3 Hydropower engineering technology reached the advanced level

The number and scale of hydropower stations built on the 13 major hydropower bases are highest concentratedin the world. The high dams and large-scale reservoirs constantly created new world records.

In terms of dam engineering technology, a large number of the extra high damhave been built on the 13 major hydropower bases, such as concrete dams inThe Three Gorges, Longtan, Guangzhao, Jinping-I, Xiluodu, Xiaowan, Huangdeng Hydropower Stations, andembankment dams inShuibuya, Xiaolangdi, Pubugou, Nuozhadu Hydropower Stations. The highest concrete faced rock-fill damin the world at the time of ShuibuyaHydropower Station, the world's highest RCC dam of Longtan Hydropower Station, the world's highest archdam of Jinping-1 Hydropower Station, the first in Asia the world's third high earth-core rockfill dam of Nuozhadu Hydropower Station, have all been put into operation. And the world's highest earth corerock fill dam (312m) of ShuangjiangkouHydropower Station is under construction.

The key technical problems of flood discharge and energy dissipation in the condition of "high water head, large discharge and narrow valley", key technical problems of stability and anti-seepage of dam foundation with deep overburden under complicated geological conditions, and key technical problems of stability of high and steep slope have all been overcome.

In terms of underground engineering, the span of the underground powerhouse constructed in China has exceeded 33m, the height has reached 80m and the length has reached 300 m.The maximum length of a singleheadrace tunnel has reached 17km even under the karst geology conditionwith large overburden, high geo-stress and sophisticated underground water.

In terms of construction technology, theconcrete placement rate, construction depth of cutoff wall and construction difficulty of underground engineering have reached the top of the world. The research and development and application of construction simulation system and construction management in canyon area are world's leading.

In particular, the theory and practice of seismic design for dams has reached the frontier of scientific development.The theory and method of seismic design has been independently innovated, forming a relatively complete set of working methods and evaluation standard system.China is at the international advanced level inseismic study of hydraulic structures, treatment of complex dam foundations, and treatment of high cut slopes.

2.4 Hydropower equipment technology achievedout standing development

The construction of large-scale and extralarge-scale hydropower stations in China's hydropower bases has promoted the development of hydropower equipment technology.Through the three stages of "technology introduction, digestion and absorption, and independent innovation" of Francis turbines, large-scale axial-flow hydropower units have achieved a great leap forward in large-scale hydropower equipment manufacturing industry through independent design and manufacturing.The design and manufacturing capacity of conventional hydropower units remains the world's leading level.

The 170MW turbine generator unit in Gezhouba Hydropower Station, designed and manufactured in China, is still the world's largest Kaplan turbine unit.Francis turbine unit with the single-unit capacity of 700MW has been a maturetechnology for manufacturing. The Francis turbine unit with the single-unit capacity of 800MW has been put into operation at Xiangjiaba Hydropower Station, and the single-unit capacity of the Francis turbine under construction at Baihetan Hydropower Station has reached 1GW.Regarding to the supporting equipment closely related to hydropower generating unit includes inlet valve, governor,SCADA, excitation, SFC starter, generator outlet switchgear, large-capacity main transformer, high-voltage cable, GIS HV switchgear, etc., domestic supporting equipment has been widely used. The equipment and technology of hydraulic steel structure has reached the international leading level bylarge gate size, high water head, large capacity and high lift of hoist equipment. The maximum design head of bottom outlet gate of XiaowanHydropowerStation is 160m, and the operating head is 105m.

2.5 Large-scale long-distance transmission of hydroelectricity has been realized

The long-distance transmission of hydroelectricity has been started since the Gezhouba Hydropower Station was put into operation in the early 1980s.The first unit of Three Gorges Hydropower Station starts generating in 2003, which increases the capacity of "west-to-east transmission" of hydroelectricity.Regarding to hydropower base development, especially the completion of western hydropower base has resulted in a large number of "west-to-east transmission" hydropower projects, such as Hongjiaduand Yinzidu Hydropower Station, on Wujiang River, the extension project of Wujiangdu Hydropower Station, the Three Gorges Hydropower Station on Yangtze River, SuofengyingHydropower Station on Wujiang river, Xiaowan Hydropower Station on Lancang River, Nuozhadu Hydropower Station, XiluoduHydropower Station on Jinshajiang River, Xiangjiaba Hydropower Station, Longtan Hydropower Station on Hongshui River, Jinping I, Jinping II, and Ertan Hydropower Station on Yalong River, Laxiwa Hydropower Station on the Yellow River, etc.. Total capacity is close to 100 GW.

Due to the "west-to-east transmission" of hydropower, China's transmission technology has also developed rapidly, promoting the rapid development of large power grids and high voltage technology. For example, China's first ultra-high voltage DC power transmission project -- Gezhouba - Shanghai ±500kV DC power transmission project.The 1000kV AC and ±800kV DC power transmission technologies independently developed, designed and built by China have been put into operation, and the UHV power transmission technology remains a world leader.

2.6 A strict policy of ecological environment protection has been applied

Environmental Protection Law of People's Republic of China was promulgated in 1979 establishing the concept of "three simultaneous" environment protection regulation for construction projects. In 1988, Specification of Environmental Impact Assessment for Water Conservancy and Hydropower Projects was enacted. Law of People's Republic of China on Environmental Protection Assessment issued in 2003 has been promoting the EIA works on hydropower projects while prompting the EIA of river basin development or hydropower cascade development of Lancang River, Jinsha River, Dadu River, etc. In the meantime, several technical codes of EIA were formulated such as

Specification of Environmental Impact Assessment of Hydropower Planning and Specification of Post-environmental Impact Assessment of Hydropower Projects.

During the hydropower development over the 40 years, our practitioners kept conducting scientific researches on key technologies and technological innovations in terms of ecological flow, low temperature water mitigation, fish protection, etc. as well as the planning, design and construction of ecological and environmental protection facilities. Landmark environmental protection projects have been built successively such as the layered water intake facilities for Guangzhao hydropower station, the fish breeding and releasing stations of Xiangjiaoba and Xiluodu hydropower stations, and the fish channel of Changzhou hydropower station. The ecological environmental protection measures has been promoted comprehensively and implemented efficiently in the design and construction.

3. STATUS AND CHALLENGES OF HYDROPOWER DEVELOPMENT IN CHINA

3.1 The energy restructuring is an inevitable requirement for energy development in China

At present,the production and consumption of energy in Chinaare dominated by fossil fuels still. Coal accounts for 60% of energy consumptions; coal power is the mainlyelectric power. Energy and electric power are deeply dependent on fossil fuels, especially coal, and the energy consumption on foreign countries is increasing year by year. The problems of energy security and ecological environment areserious.

Therefore, to build a stable, economic, clean and safe energy supply system is a long-term and important task during the China's modernization period. We should promote the structural reform of the energy supply firmly, promote the clean development of fossil fuels and scale development of the non fossil fuelsenergetically, and focus on improving the capacity for sustainable development of renewable energy.

We also should adhere to the concept of resource development and utilization which is economical intensiveand recyclable, strive to improve the comprehensive benefit of energy resources. We should keep promoting the revolution in energy technology, optimizing the mode of energy production and management, and improving the efficiency of energy conversion. Reduce the proportion of coal in the energy structure and increase the proportion of new energy and renewable energy, can make clean energy basically meet the new energy demand in the future.

3.2 Under the new situation, the development of hydropower needs to undertake new tasks.

Hydropower projects have the traditional comprehensive utilization functions and benefits, such as power generation, flood control, shipping, water supply, irrigation, water resource distribution, etc.

Under the new situation, the development of hydropower also needs to undertake the lots of tasks, such as the protection of ecological environment, the prosperity of immigrants, the development of local economy, and the development and utilization of wind power and solar power.

Considering the developmentlevel of water resources around the world, the developed countries give priority to the development of water resources and have basically completed. Developing countries are actively developing hydropower right now. At present, the development level of hydropower in China has exceeded 50%, but there are nearly 200GW hydropower capacities undeveloped in the thirteen hydropower bases, which is need to be promoted continuously, especially the Nujiang River and the YarlungZangbo River.

At the same time, renewable energy will be the global trend of energy transition. In recent years, Wind power and solar power in China are developing rapidly. Renewable energy is changing from alternative energy to dominant energy. Hydropower is still the best power for grid to balance the energy production and consumption, because it can promote the optimal operation of power system in a flexible and efficient way with fast response speed. In the diversified development pattern of energy, hydropower needs to play an irreplaceable role in promoting the evacuation of new energy.

3.3 Issues related to sustainable development of hydropower bases need to be solved

In the future, the development of hydropower in China will be mainly concentrated in the southwest, which is in the upstream of the river, high altitude,and gorge region. Restricted by natural conditions, construction conditions, economic and social conditions, the cost of hydropower bases development will be increased in the future. The long-distance power transmission, ecological protection, and the resettlement works will be more difficult.

Hydropower construction needs to undertake more tasks about local economic and social issues. Consider all factors, the difficulty and cost of hydropower development have increased, which is need to be solved through the innovation of management and engineering technology.

The impact of the dam on the environment is objective, and there are both advantages and disadvantages.During the process of hydropower development, we need to deal with the relationship between resource development and ecological protection, to understand and evaluate the impact of hydropower projects on the environment correctly, to reduce the adverse effects and establish a reasonable environmental impact assessment standard through take appropriate engineering measures or ecological restoration technology.

In addition, it is necessary to carry out the optimal jointoperation of cascade reservoirs in the river basintotake full advantageof its comprehensive utilization benefits and .

4. OUTLOOK OF HYDROPOWER BASES DEVELOPMENT IN CHINA

4.1 Hydropower bases will be further developed

The approval of river planning in hydropower bases issupposed to accelerate so as to intensify the preliminary works for a series of key projects. The construction of hydropower bases that are still in progress will be keep pushing forward, such as Wudongde, Baihetan, Suwalong and Yebatan hydropower plants on Jingsha River, Lianghekou and Yangfanggou hydropower plants on Yapan River and Shuangjiangkou on Dadu River. Lawa, Xulong, Benzilan and Longpan hydropower plants on Jinsha River, Kala and Mengdigou hydropower plants on Yalong River and Yangqu and Ningmute hydropower plants on Yellow River were now actively strived for starting. The hydropower station on south-western trans-boundary rivers are also required to develop and start the preliminary works as soon as possible which is showed in the Table 2. At present, the hydropower projects with the installed capacity of 48GW are under construction.

The plan over the period 2021 to 2025 is to develop 50GW of conventional hydropower capacity, Correspondingly an annual hydropower generation to 1550 TWh in 2025 could be expected. 51.7% of the technically feasible potential are exploited by 2025.

During the construction of hydropower bases, it is required to implement proper measures of ecological environmental protection and resettlement works and also assume the responsibility for the local economic and social advancement. The electric energy generated by the hydropower bases in the southwest China should be well evacuated by improving the coordination mechanism on the basis of optimal consolidated configuration of the whole country and the connection between power grid and hydropower station.

Table 2 : Projects under constructing and upcoming next in China

No	River	**Projects under construction**	**Upcoming projects**	**Total capacity MW**
1	Jinsha	Wudongde, Baihetan, Yebatan, Lawa, Batang, Jinsha	Changbo, Boluo, Gangtuo, Xulong, Benzilan, Longpan, Yinjiang	56000
2	Lancang	Tuoba、Ganlangba	Yumei、Cege、Quzika, Gushui, Guxue	11800
3	Yalong	Lianghekou、Yangfangguo, Yagen-1, Mendigou、Kala	Yagen-2, Lengu	7000
4	Dadu	Shuangjiangkou, Jinchun, Badi, Yinyanbao, Zhengdouba-2, Shaping-1	Anning, Danba	5200
5	Yellow	Maerdang、Yangqu	Cihaxia, Ningmute, Hongshanxia, Xiaoguanyin, Daliushu	2000
6	Nujiang	Liuku	Saige, Maji, Yabiluo	4000
7	Yarlungzangbo	Lenda	Bayu, Zhongda, Jiexu	1500
8	others	Lingzhi、Baima	Aqing, Zhongyu, Kanggong, Zhala	2000
Total				89500

4.2 Operation mode of cascades of hydropower bases will befurther optimized

Cascade reservoirs in large and medium-sized rivers has been built which has motivated the operation mode of hydropower stations from independent mode to joint mode, therefore researches about the optimal joint operation of cascade hydropower bases seem to be imperative to carry out.

The river basins of Lancang, Wujiang, Dadu, Yalong, Jinsha and Yellow Rivers will be monitored in terms of hydrology, sediment, ecological environment, seismic activity, project safety, and resettlement.

As information tools, comprehensive monitoring platforms are being establishing to achieve the objectives of real-time monitoring, field inspection, information sharing, optimal operation and supervision.

Reformation of joint optimal operation system for flood control, power generation and other comprehensive utilization is conducted to achieve standardization, institutionalization, scientization and benefit maximization by mobilizing the initiative of all parties. Exploring the joint operation and unifying the price-bidding model and mechanism is an effective way to improve the optimal joint operation system, power evacuation and economic benefit of cascade hydropower stations.

4.3 Technical Innovation will be further enhanced

The topographical, geological, hydrogeological andother related boundary conditions is progressivelytrend to complicated in future hydropower development, meanwhile, morestrict requirements on engineering safety, ecological protection and resettlement work are requested, therefore, technical innovation becomes vital important to ensure the technical feasibility and economic rationality by optimize the design scheme and decrease the investment, it is also an important wayto guarantee the sustainability during operation.

During the cascade development of rivers and construction of huge reservoirs and high dams, the effects of global climate change and extreme climate should be studied;some other issues such as river sediment, reservoir sedimentation, river basin flood controlandseismic safety of high dams must be taken into account at the same time. Engineering design methodology and project management system must be improved in the perspectiveof basin-scale and life-time with strictly consideration of systemic risks.

It isnecessary to promote the comprehensive application of modern information technology in the design, construction and operation management during river basin cascade development, to advocate the improvement of the digitalization, networking and intelligent on the design, construction and management of hydropower projects.In addition, it is also very important to research and establish digital-river-basin and digital-hydropower system to enhance the friendly interactions between intelligent hydropower stations, intelligent power grids and intelligent energy.

4.4 Multi-energy / hybrid systems will be further improved

Hydropower is characterized by its flexibility of operation and capacity of regulation, these characters could be further utilized with the multi-energy/hybrid systems to achieve a more reasonable energy structure and better utilization of regulation capacity of hydropower bases. It is increasingly important in the future for hydropower to play an important role inpower system with the increased capacity of other renewable energyintegrated to the grid.

With the consideration of the needs of hydropower-hybrid system development and the specified site conditions of each hydropower project, additionalstudies should be done to evaluate the rationality of the capacity of the projects under planning and the possibility of capacity improvement of existing or under construction hydropower projects.

In order to promote the development of multi-energy integrated systems for overall energy-bases in China, the following works are suggested: first to optimize the cascade development planon typical rivers, such as Yellow river and Yalong River, and then to establish reasonable capacity for developing, so, knowledge learned during the development process could be shared with other river basins. Integratedoperating system need to be established for the cascade hydropower stations, wind power and solar power based on an overall consideration of the all resourcesavailable in the basin.

5. CONCLUSION

Hydropower development in China play an important role in energy safety, ecological environment protection and water resources integrated utilization. To combat climate change and promote economic growth, China will also develop hydropower in the future. The new hydropower development will mainly located on the upstream of rivers in south-west of China where is the bases of Hydro-energy.

Solutions to continue hydropower development adapted to the sustainable development areto discover the value of the hydro projects and attract more investment, and to optimize technical scheme to reduce construction costs of the project andto maximize the benefits By optimizing cascade reservoirs joint operation design.

Cascade reservoirs operation are realized in main river basins with the continuous development of hydropower bases, which in turn to promote the transition from construction mode to construction & operation mode, from isolated flood controlcombined with energy generation operation mode to cascade integrated water resources utilization operation mode.

In the future, hydropower will still be treated as an important measure for energy mix adjustment, energy security and sustainable development. For the purposes of realization of ecological river basin management and promotion ofmultipurpose hydropower bases development, more attentions should be paid on innovations and the renewable, more measures should be put on the integrated management of dam safety and cascade reservoirs in the river basin, in addition, more state-of-art technologies such as multi-energy complementary system and AI technologyshould be applied to increase the rationality and sustainability.

REFERENCES

China society for hydropower engineering, Hydropower technology development report, Beijing, China Electric Power Press, 2013.

Zhou Jianping, Qian Gangliang, Development Status and Planning of 13 hydropower bases, China hydropower 1910-2010[M], Beijing, China Electric Power Press, 2010.

Zhou Jianp. Role of dams and hydro as renewable energy in China [J]. Journal of Hydroelectric Engineering，2014. Vol.33 No.1.p1-5.

Peng Cheng, China hydropower Projects in 21 century, Beijing, China Water&Power Press, 2006.

Liu Ning, Dong Zheren, etc., Strategy Study on water technology development[M], Beijing, China Water&Power Press, 2006.

Zhu Tiezheng, Hydropower planning of River in China, Beijing, China Electric Power Press, 2002.