Early demonstration and research on the key technical issues of large-basin hydropower development under the concept of harmony

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Abstract

As a typical representative of hydropower development in China, the Dadu River is characterized by abundant water resources, poor geological conditions, many resettlements and limited environmental capacity. Therefore, the technical problems faced by Dadu River hydropower development are numerous and complex. We analysed these technical problems, such as the hydropower-development mode, normal water level, dam-site selection, damming technology, migration resettlement and environmental protection. The concept and characteristics of harmonious hydropower development are identified. The harmonious hydropower-development concept has been applied to all aspects of the Dadu River hydropower-development feasibility study to solve the key technical problems of hydropower development on the Dadu River and to promote the development of China’s hydropower.

Keywords: concept of harmony; Dadu River; key technology; early stage; trial

Introduction

China is the richest country in the world in hydropower resources, with a theoretical storage capacity of 694 GW [1]. China produces 25% of the world’s electricity and is the world’s largest producer of hydropower. As the largest clean and renewable energy source in China, hydropower plays an irreplaceable role in safeguarding national energy security and realizing green and low-carbon development. However, only 39% of China’s hydropower has been developed—far lower than that of the USA (67%), Japan (73%), France (88%) and Switzerland (92%) [2].

Since the 1990s, China has increasingly become the centre of world hydropower development. In south-west China, where hydropower is particularly abundant, a number of world-class hydropower projects are under construction or are about to be built [3]. However, the construction of hydropower projects in this area faces technical problems, such as complicated topographic and geological conditions, huge project scale, difficulty in dam construction, difficulty in resettlement and high environmental-protection requirements. These technical problems directly challenge China’s existing hydropower construction, and the successful solution of these problems will play an important role in ensuring the safety of the projects and enhancing the capability for hydropower construction. Therefore, it is essential to study hydropower projects in the early stages. Since the preliminary trial and research of hydropower projects cover a wide range of issues and involve a lot of work, we...
1 Overview of hydropower development in the Dadu River

The Dadu River is one of the important tributaries in the upper reaches of the Yangtze River, with a total length of about 1062 km, a natural drop of 4175 m and annual run-off of 47 billion m$^3$. Its permanent and ephemeral water resources accounted for 23.6% of the total hydropower resources in Sichuan province, ranking fifth among the 12 major hydropower bases in China. According to the latest planning and design results for the cascade hydropower stations on the Dadu River, there will be 28 cascade power stations with a total installed capacity of 27 GW.

Because of the complex topographic and geological conditions of the Dadu River, a number of geological problems will affect hydropower development, such as deep-bed overburden, high seismic intensity and many geological disasters. As a result, the construction of cascade hydropower stations on the Dadu River faces several technical challenges, such as the construction of the 312-m Shuangjiangkou hydropower station, which is the highest dam in the world already under construction. The Dagangshan arch dam, which is 210 m high and 0.557 g in earthquake acceleration, is the highest seismic intensity arch dam in the world. The Pubugou dam, built in 2010, was the highest rock-fill dam built on a thick overburden layer in China at that time. The Houziyan project, completed in 2016, is the second highest face rock-fill dam in a narrow river valley and high-intensity seismic area. The Danba hydropower station, which is working in the early stages, is the highest gate dam in the country, with a >100-m-thick overburden layer. Further construction faces a rare geological cavitation problem of 17 km of soft rock. Jinchuan hydropower station is the first panel rock-fill dam that is built on the foundation of a sand lens more than 50 m thick. Therefore, it is necessary to solve many difficult engineering problems in the early stages of development.

In addition, as the Dadu River is located in the hinterland of Sichuan province, it is known as the ‘first ring road’ of Sichuan hydropower. The reservoir inundation will be relatively large and the land-reserve resources in the Dadu River basin are limited. Traditional agricultural resettlement schemes are difficult to implement, especially in many hydropower stations located in Tibetan areas, and the social and natural environments are very special. Recognizing China’s desire to pay more attention to the ecological environment, the development of Dadu River hydropower needs to establish practical and scientific resettlement and environmental-protection schemes and measures in the preliminary trial and research phases.

2 The harmonious hydropower-development concept

This paper analyses the early trials and research ideas into the technical problems in Dadu River hydropower development. According to the definition of a social-harmony hydropower project [4], the following characteristics should be contained in the concept of harmonious hydropower development. First is the scientific and rational use of water resources; second, is harmony with the ecological environment; and third is harmonious development with the local economy and society. Therefore, harmonious hydropower development balances the scientific and rational use of hydropower resources with maintaining the local ecological environment and local economic and social development. As will be explained, preliminary trials and research use the concept of harmonious hydropower development to successfully solve the key technical problems of Dadu River hydropower development.

2.1 Relationship between scientific and rational use of hydropower development and resources

In the preliminary trials and research into the key technical problems in the development of Dadu River hydropower, the current demand for hydropower resources was considered along with the difficulties faced by local social and economic development. Research also considered the carrying capacity of the environment and the long-term impact of hydropower development on the natural and social environment of the basin. It is important to consider the impact on important market towns, cultural relics, enterprises and other sensitive objects, rather than simply the pursuit of economic efficiency, and to assess how hydropower development could try to reduce the number of resettlements. It is also important to try to avoid or reduce the adverse impact on the environment, and the disturbance to the natural and social environment, by shifting the focus of the Dadu River hydropower development from the original ‘full development and utilization of hydropower resources’ into ‘the scientific and rational use of water resources’.

2.2 Relationship between hydropower development and ecologically friendly development

In the preliminary trials and research of the key technical problems in the development of the Dadu River hydropower development, the Dadu River Hydropower...
Development Organization insisted on the concept of harmonious hydropower development. For example, in the early trials and research of hydropower, special schemes and measures were designed to protect the ecological environment in the Dadu River. Although the cost in the project has increased, it is beneficial for the survival of fish. The Zhentouba-1 and the Shaping-2 hydropower stations increased investment by about 200 million Yuan in order to construct a fishway. In addition, research into key technology for the Jinchuan concrete-face rock-fill dam not only solved the construction and design problems, but the establishment of the concrete-face rock-fill dam also saved scarce Tibetan arable-land resources. These examples demonstrate the importance of harmonious hydropower development in the Dadu River for environmental protection, and also indicate that hydropower development can be carried out more effectively with regard to environmental protection. The two must be mutually complementary.

2.3 Relationship between hydropower development and local economic and social development

First, the hydropower project was temporarily unable to start because of technical bottlenecks, and the clean and high-quality water resources are not available to serve social purposes at present. The breakthroughs on key technologies, such as the Shuangjiangkou core-wall rock-fill dam, the Dagangshan anti-seismic project, the Jinchuan concrete-face rock-fill dam and the Danba high gate-dam and soft-rock formations, will enable the power stations to be built at an early date, which will provide clean and renewable energy for local economic and social development. Second, hydropower development must fully consider the influence of migration, environmental protection, land and other factors. We need to make sure that the relocation and resettlements and the protection of the ecological environment are balanced, and actively assume social responsibilities. This can achieve win–win results for all parties and achieve harmonious development. This approach has been fully reflected in the research on the Pubugou resettlement of inhabitants and Dadu River hydropower development. Third, the direct investment in hydropower-project construction can significantly increase the investment in fixed assets in the project location. The required materials and labour force are relatively large. The construction of a hydropower project can drive the GDP growth of the project location through investment and consumption. In addition, during the construction and operation of hydropower stations, hydropower enterprises will contribute local taxes and fees. Therefore, the construction of hydropower projects can improve local public infrastructure, promote local people’s employment and improve the level of urbanization.

3 The early trials and research of typical technical problems

3.1 Hydropower-development mode

In 2003, the Report on the Adjustment of the Hydropower Planning in Sichuan Dadu River pointed out that there are still problems in some of the cascade development plans, which need to be studied in the next stage. The first is that the Danba cascade hydropower station is only in the upper reaches of Danba county, and there is a landslide on the bank of the dam, so the engineering geological conditions are poor. The second is that the construction of Laoyingyan cascade hydropower station, in addition to the poor geological conditions, will flood the Red Army Anshun ferry, memorial and other protected cultural relics. The third is that, for the Zhentouba cascade, in addition to the Dadu River canyon national geological park, the water-inlet project of the Yongle power station has been built in the reservoir area. In the future, the relationship between environmental protection, landscape and established power stations needs to be coordinated.

Fourth, the development value and the development mode of the submerged Chengkun railway (11 km) will need to be further studied [5]. To accelerate the hydropower development, the following elements are needed: rational use of water resources, reasonable arrangements of the hydropower cascade, adequate handling of the hydropower development and submerged reservoir, protection of the ecological environment and local economic development, immigrant relocation, and minimizing and avoiding impacts on the Chengkun railway, important cultural relics, towns and nature reserves. It is necessary to study the hydropower-development mode of the local river section of the Dadu River.

In this regard, the comprehensive comparison of water-energy use and power-generation benefits, engineering geology, land acquisition and resettlement, environmental impact, hub layout and building, project construction, economic benefit and so on was considered in the development plan covering from Jinchuan to Danba (Anning cascade, dam development of Badi cascade, hybrid development of the Danba cascade). The development of Laoyingyan first grade and Laoyingyan second grade are determined from Longtoushi to Pubugou. The development of Zhentouba first grade, Zhentouba second grade, Shaping first grade and Shaping second grade are determined from Shenxigou to Shaping. The layout of the Dadu River after the completion of development is shown in Fig. 1. Through the research into harmonious development, the overall water-utilization index of the Dadu River has decreased slightly, the economic indicators have decreased, the reservoir submergence has been reduced, the difficulty of resettlement has been reduced and the adverse environmental impact has decreased significantly. The above development approach has solved the problem of planning, effectively avoided the sensitive factors and promoted the
development of hydropower development and economic and social development.

3.2 Normal water level and dam-site selection

3.2.1 Selection of the normal water level of Shuangjiangkou hydropower station

Shuangjiangkou hydropower station is a control reservoir in the upper reaches of the Dadu River, with an annual regulation capacity of 2 GW. After the completion of the power station, the compensation and regulation effect of the downstream cascade power station is obvious, which is of great significance to improve the power-supply structure of the Sichuan power grid. Due to the regulation of the Shuangjiang hydropower station, it is necessary to adjust the normal storage level. At the same time, because the power plant is located in the Sichuan Aba Jiarong Tibetan-inhabited areas, there are scarce land resources, limited resettlement environmental capacity and the reservoir flood is sensitive to power-plant construction. There is a need to decrease the normal dam-storage level. In view of the above factors, it is necessary to determine the normal water level of Shuangjiangkou hydropower station. To achieve a reasonable balance between the economic benefit and flood loss of the power station, the problem of multi-objective decision-making should be solved rationally. In the preliminary feasibility study stage, the primary choice of 2510-m elevation was the normal water level of Shuangjiangkou hydropower station. In the feasibility research stage, factors such as reservoir inundation, cascade connection, geological condition, damming technology, water-resource use, regulation capacity demand and the influence of south-to-north water transfer are considered. Several schemes have been proposed to carry out normal water-level selection. Due to the influence of the reservoir, it is a concentrated area of settlement for Tibetan people. It is also an industrial zone and tourist area, which plays an important role in local economic development. Therefore, the comprehensive comparison was made from the aspects of meeting the requirements of adjusting the storage capacity, controlling the technical difficulty of damming, reducing the inundation of the reservoir and the environmental impact, and promoting the development of the local economy. The normal water level of Shuangjiangkou hydropower station was selected as 2500 m, which is lower than the original scheme. This avoided the inundation of the important local towns, alleviated the impact on the local people and achieved the recognition and affirmation of all parties.

3.2.2 Dam-site selection of Houziyan hydropower station

The installation capacity of the Houziyan hydropower station is 1.7 GW, and a concrete-face rock-fill dam with the maximum height of 223 m will be used. From the perspective of water-energy use, the Houziyan dam site should be connected with the tailwater of the next cascade power station—that is, the lower dam site, which will flood Kongyu village above the lower dam site. From the perspective of reducing migration and reducing the influence on the surrounding environment, the dam site should be moved up and should avoid Kongyu village. Through a technical and economic comparison, the lower dam site was found to be 3.1 km away from the upper dam site, and the water head of the lower dam site is 6.78 m more than upper dam site, with a bigger capacity of 0.06 GW. Over the years, the average power-generation capacity will be 247 GWh, with more than 300 resettlements, an additional 3 km² of submerged land and an increase in investment of more than 280 million Yuan. From the economic indicators, the lower dam site is obviously superior to the upper dam site. But, taking all factors into account, especially the weighing of technical, economic, social and environmental factors, the lower dam site was abandoned, which improved economic benefits. The upper dam site was selected as the dam site of Houziyan hydropower station.

Fig. 1 Profile map of the hydropower cascade development plan of the Dadu River
3.3 Research on engineering construction technology

3.3.1 Key technical research on the Shuangjiangkou 300-m-level core-wall rock-fill dam

The dam site of Shuangjiangkou hydropower station is a steep ‘V’ river valley with a deep cover and a maximum width of 76 m [7]. The design intensity of the dam is VIII on the Modified Mercalli Intensity Scale. The maximum dam height is 312 m, which is beyond the current design standard in China. Even internationally, countries only have construction experience of 300-m core-wall rock-fill dams. Therefore, it is very necessary and urgent to carry out research on the key technology for a 300-m-level core-wall rock-fill dam. During the feasibility study stage, multiple topics and subtopics were examined, including: damming material properties; dam body and foundation deformation and stability analysis, theory and methods; structural style of the dam body and the partition design; dam dynamic response analysis and seismic measures; and analysis of seepage and seepage-control measures. A series of research outcomes for damming technology were achieved. This research has laid a technical foundation for the construction of a 300-m earth core-wall rock-fill dam project and will further promote the development of a world-class earth rock-fill dam. The typical transverse section of the rock-fill dam in Shuangjiangkou is shown in Fig. 2.

3.3.2 Research on the key damming technology of the Jinchuan concrete-face rock-fill dam

Jinchuan hydropower station is designed with an installed capacity of 0.88 GW. In the pre-feasibility study stage, Jinchuan hydropower station was to have a clay-core-wall rock-fill dam, which was 111.5 m high. Because Jinchuan hydropower station is in the Tibetan area, the cultivated-land resources are very limited. The clay-core-wall rock-fill dam needs more soil materials than other dam-construction methods and will occupy a large amount of cultivated land, so that more people will need to be resettled. To reduce the loss of farmland and the difficulty of resettlement, it was necessary to choose a more economical and applicable dam type [8]. In the feasibility study stage, therefore, the Dadu River Hydropower Development Institute and Design Institute made a scientific and technological breakthrough on a concrete-face rock-fill dam that is beneficial for the conservation of cultivated land and the economy. The maximum thickness of the deep layer of the riverbed in Jinchuan hydropower station is 65 m, and the material composition is complex and contains a sand-layer lens. At the same time, the unloading rock mass is strong. The rock material used for dam-wall filling is both soft and hard. There are no engineering examples of concrete-face rock-fill dams with a sand-gravel-layer lens body and unloading rock. Therefore, it is very difficult to build a dam with a concrete face. To this end, detailed research into using a thick overburden layer and strong unloading rock mass, dam material characteristics, stress deformation of the dam body, seepage control and other key technical problems of a concrete-face rock-fill dam was carried out. Many research results were obtained, and practical engineering measures have been proposed and applied to the engineering design. The merit of the solutions were recognized by the technical authority for hydropower engineering and solved the problem of building concrete-face rock-fill dams on deep riverbed layers.

3.3.3 Research on the key technology for earthquake resistance in the Dagangshan project

With a capacity of 2.6 GW, the Dagangshan hydropower station was designed with a concrete hyperbole arch dam with the maximum dam height of 210 m. The dam-site area design earthquake acceleration is 557.5 cm/s², seismic fortification intensity is IX on the Modified Mercalli Intensity Scale. Considering the dam height is above 200 m, the seismic fortification level is higher than the current seismic norm, and there is little experience with similar engineering designs. The safety of the dam in the event of a strong earthquake is very important. It was necessary to carry out a comprehensive system of engineering earthquake research in the feasibility study stage to ensure the safety and reliability of the project and assess whether earthquake resistance can be successfully solved as a controlling factor of engineering construction [9]. Scientific research was carried out into topics such as:

Fig. 2 A typical transverse section of the Shuangjiangkou core-wall rock-fill dam body
peripheral zone fracture and small fault activity evaluation in the dam area; the prediction of earthquake hazards induced by the reservoir; seismic safety analysis and seismic measures of dams; the nonlinear seismic response characteristics and seismic measures of the dam; the overall seismic analysis of the dam; dynamic model testing of the dam structure; and a seismic review of the double-curved arch dam under earthquake conditions. Through much research and many experiments, the problem of the seismic design of the project of the mountain-landscape hydropower station was clarified in the feasibility study stage. The schemes and measures adopted for earthquake resistance can meet the seismic requirements of the project, and the seismic design scheme was successfully carried out through technical review.

3.3.4 Research on key technology for gate-dam construction and soft-rock cavity formation in Danba

The installation capacity of Danba hydropower station is 1.196 GW, and the hybrid development was adopted. The length of the water-diversion tunnel is about 17 km. Because the maximum thickness of the riverbed cover in the dam site of Danba hydropower station is 127.66 m and the maximum dam height is about 42 m, this will be the highest sluice dam built on a deep overburden layer in China, and there is little relevant engineering experience. About 3 km of the water-diversion tunnel is in the soft rock of Eryunying schist, with the largest burial depth of 1220 m. There has been little study on the mechanical properties, cavitation conditions and the stability of surrounding rock in China or internationally. Research was carried out into the foundation treatment for the deep cover of the riverbed and the foundation treatment for the high gate dam, the stability of the deeply buried soft-rock diversion tunnel and the stability of the soft rock. These topics include: the creep characteristics of the deep cover layer of the river bed; liquefaction and dynamic parameters of sand; high-pressure jet-grouting test for dam foundation; foundation-consolidation grouting test; seepage analysis and seepage-stress coupling study of the sluice gate; gate-dam and gate 3D static and dynamic characteristics study; the change of strength and stability of the dam foundation; rheological properties of soft rock; deformation law of soft rock in caverns; geological characteristics of soft rock in underground caverns and geological classification of rock-mass engineering; the stability of the surrounding rock of a deeply buried soft-rock diversion tunnel; the surrounding rock stability of a large pressure-regulating chamber of soft rock; and 11 other subtopics. The research has moved to the next stage and will improve the progress of Chinese hydropower engineering technology.

3.4 Resettlement of inhabitants

The Pubugou hydropower station is a control reservoir in the middle of the Dadu River, with a capacity of 3.6 GW. It is the largest hydropower project in the Dadu River, which is a national key project and the landmark project for western development. The Pubugou hydropower station development needed to move about 105 000 people, and the number of resettlements was not only the largest in Dadu River, but also ranked second only to the Three Gorges (about 1.13 million people), Xiaolangdi (about 189 000). Most resettlements are concentrated in Hanyuan county (about 93 000) and they are very difficult to relocate [10]. Therefore, it is necessary to carry out in-depth research on the relevant topics before the relocation and resettlement. With the help of government departments, design institutes and other relevant units, Dadu River Hydropower Development Organization has systematically demonstrated and examined a scientific and reasonable compensation subsidy system and a strict and efficient immigration work-management system. In particular, it is the first organization to study the management mode of the owner’s active intervention in immigration. The standard and scope of compensation for the migrant workers in hydropower projects, the identification of physical indicators, the procedures and methods for the resettlements, the management of migration funds and other significant technical problems were improved. It has laid a solid technical foundation for the standardization and orderly implementation of relocation. It has been proved that the migration and resettlement work has been successful, and many successful practices and experiences have been extended to the relocation from other hydropower projects in China. These practices include: increasing the cultivated-land output-value compensation standard to 16 times, considering a house-decoration compensation fee, expanding the compensation scope to resettlements that cannot carry a physical index, the issuance of money directly to resettlements, owner participation in rebuilding engineering, setting up the enterprise and the place of the rotating coordinate system.

3.5 Environmental protection

The Dadu River valley is deep, the mountain slope is steep and the environmental capacity is limited. To protect the ecological environment, a number of studies were carried out during the trials and research in the early stage of Dadu River hydropower development [11]. First, to understand the impact of hydropower development on the environment, in the planning stage, the first hydropower-planning environmental assessment work was carried out in China. The second was the systematic study of the aquatic life protection scheme of the Dadu River, and the breeding and stocking measures for the Dadu River. It is the first to set up a fishway in the feasibility study of the Shaping-2 hydropower station and the Zhentouba-1 hydropower station (shown in Fig. 3). In the feasibility design of the Shuangjiangkou project, a scheme of stratified water intake, fish-habitat protection and a fish-feeding system was developed. Third, protection measures of rare plants were studied, and the protection measures of special rare plants were established in the feasibility study for the Shuangjiangkou hydropower station.
3.6 Economic and social benefits

3.6.1 Significant economic benefits

Large-scale hydroelectric developments are often contentious and controversial due to their social, environmental and financial impacts [12]. Research in the Dadu River basin, using as an example the Shuangjiangkou hydropower station project, which is the main reservoir power station of the Dadu River, shows that, during the construction period, its contribution to the GDP of Sichuan province will be 42.651–64.467 billion Yuan, which could increase the economic growth rate of the whole province by 0.17–0.33%. The contribution to the GDP of Aba prefecture is 8.53–12.893 billion Yuan, which can increase the economic growth rate by 2.57–3.89%. During the operation of the hydropower station, its annual contribution to the GDP of Sichuan province will be 4.01 billion Yuan, which can boost the economic growth of Sichuan province by 0.05%. The contribution to the GDP of Aba prefecture will be 1.727 billion Yuan, which will boost the economic growth rate of Aba prefecture by 1.0%.

3.6.2 Energy conservation and emission reduction

Renewable-energy optimization will reduce the reliance on fossil fuel as the predominant energy source in the power system [12]. After the completion of the Shuangjiangkou hydropower station, the newly added electricity will replace 2.96 million tons of standard coal per year, reduce carbon dioxide emissions by 7.18 million tons per year, reduce coal smoke and dust in the atmosphere by 11.82 million kg, and reduce sulphur dioxide emissions by 26.6 million kg, bringing huge benefits in energy conservation and emission reduction.

3.6.3 Other social benefits

During the construction of the Shuangjiangkou hydropower station, the total number of direct and indirect jobs will amount to 210,000. The flood-control capacity of the Shuangjiang project is 663 million m³, which can improve the flood-control standard of Yibin city for 50 years. At the same time, the Three Gorges and Gezhouba hydropower stations on the main stream of the Yangtze River will generate 198 GWh of electricity annually.

3.7 Hydropower complements other power sources

In general, the main supplies for the power grid include thermal power, hydropower, wind power, nuclear power, solar power and pumped storage. Multi-energy complementarity refers to the optimal combination and configuration of various power sources, such as hydropower, wind power, solar-power generation, pumped storage and thermal power, to operate within the power system to complement each other, so as to better meet the power-load demand and ensure the safe and stable operation of the power grid. Conventional hydropower stations with regulating capacity, especially large hydropower bases, are equipped with cascade hydropower stations with multiple regulating modes, such as multi-year, annual, seasonal, weekly, daily and run-off regulation, which can make use of reservoir-storage regulation and operate with wind power and photovoltaic to bring greater capacity benefits. The reaction speed of the hydropower unit is fast, and can adapt to fluctuations in wind power and photovoltaic output.

Taking the cascade hydropower base in the Dadu River basin as an example, the main stream of the Dadu River has three planned reservoirs with 28 cascade hydropower stations with a total installed capacity of about 27 GW and an average annual generating capacity of about 1,158,000 GWh. The three planned reservoirs are as follows: Xiaerxia (with multi-year regulation ability), Shuangjiangkou (with annual regulation ability) and Pubugou (with incomplete annual regulation ability). The other 25 cascade power stations will have seasonal, weekly and daily regulation abilities, respectively. Through unified basin operation and scientific forecasting of water supplies, the cascade hydropower base in the Dadu River basin will have the regulation ability of more than 1 year, meaning that it can completely replace the role of conventional hydropower and pumped storage power stations. It can be combined with thermal, wind, photovoltaics and even small hydropower in the basin to achieve complementary and energy-storage functions. Its complementary mode is very flexible and can adapt to a variety of types of power supply. Therefore, large-scale cascade hydropower bases in the basin will play a huge and irreplaceable positive role in the multi-energy complementary system.

4 Conclusion

(i) The water-resource areas of the Dadu River are rich in number, complicated in geological conditions, difficult to resettle and limited in environmental capacity. The key technical problems involved in the development of Dadu River hydropower are numerous and complicated. Therefore, it is necessary to use the concept
of harmonious hydropower development to guide the early trials of and research into these key technical problems using multi-objective scientific decision-making in hydropower development.

(ii) The concept of harmonious hydropower development has been widely applied to all aspects of the research into and trials of Dadu River hydropower development. It has solved the key technical problems faced by hydropower development and achieved remarkable results, which have promoted the development of Dadu River and even China’s hydropower development.

(iii) The concept of harmonious hydropower development conforms to the new development concept of innovation, coordination, green, openness and sharing in China, which will become the practical direction of hydropower development in the country. However, due to the reality of heavy engineering and light development, the outdated concept of heavy benefits and light protection still exists, which makes the concept of harmonious hydropower development worth promoting in the whole industry.

Conflict of Interest
None declared.

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