Hydropower and Sustainable Development in China

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1 Power Demand from China's Economic Development

At present, China is in a period with high-rate economic growth. Its GDP continuously keeps increasing at an annual rate of above 8%. The total volume of GDP in 2003 reached USD1400 billion, but the per capita GDP was only USD 1000. Therefore China is still a developing nation and maintaining its economic growth is an inexorable trend. The national economic growth is necessarily accompanied with an increasing demand for energy and electric power. By the end of 2003, the total installed capacity of power generation in the whole country reached 391GW with an annual power generation of 1900 billion kWh. Due to rapid economic growth, however, there is still a shortage of power in some regions where cutout of power distribution or other power-limiting measures have to be taken frequently. By prediction, the installation capacity of power generation will assume such increases as, exceeding 400GW in 2004, reaching 600GW in 2010 and 950GW in 2020, which is a considerable growth.

2 China's Primary Energy Reserves and the Assessment

Electric power in China mainly depends on traditional primary energy. And here is the statistic data from survey:

- Coal reserves (developable): 1390×10^8 tons;
- Crude oil reserves: 33×10^8 tons;
- Natural gas reserves: 1.7×10^{12} m^3;
- Water energy (developable) reserves: 24740×10^8 kWh/year.

2.1 China is relatively abundant in coal resources, but the per capita quantity is only 45% of that in the world. Coal is the major energy source for electric power in our country with 50% of the annual coal output used for power generation. The coal-fired generation makes up 74% of the total power generation of the country, so it is the main power source in China. However the issue of environmental pollution caused by coal combustion can hardly be resolved. Combustion of each ton of raw coal (equivalent to 0.7~0.8 tons of standard coal) will cause the emission of 2.49 tons of CO2 (accelerating greenhouse effect), 0.075 tons of SO2 and 0.037 tons of NO (contributing to acid rain), as well as 0.68 tons of flying ash. In addition, the coal mining will have an adverse effect on the ecologic environment, the cost of which can't be neglected. However it can be seen from the existing energy structure in China that the pattern with coal-fired power generation as the major force in power industry is difficult to be changed in the predictable future. Therefore we should promote the utilization of clean coal, improve the combustion technology in coal-fired generation, and expedite the use of circulating fluidized bed, supercritical and super-supercritical generation techniques so as to raise the utilization

efficiency of coal. But coal is not a renewable energy source and its total reserves will decrease year by year. Based on the current yearly mining output of 1.7 billion tons, it is estimated that coal will be depleted in over 80 years.

2.2 Petroleum is in shortage in China as an energy source with per capita quantity only accounting for 10.71% of that in the world. Petroleum is one kind of portable energy sources, so it is mainly used as fuel for airplanes, automobiles and ships and as raw materials of chemical industry. It is improper to use petroleum for power generation.

2.3 Natural gas is also in short supply in China with per capita quantity accounting for 4.99% of that in the world, so it is mainly used as chemical raw material and domestic energy. It is improper to use it in power generation either.

2.4 Water resource is relatively abundant in China with per capita quantity taking up 55.1% of that in the world. It is a clean and renewable energy, as well as a superior energy source for power generation. Hydropower generation is a kind of potential energy generation by using endless water flow of rivers and differences in water heads, and is a physical process of transforming primary energy to electricity. Hydropower is a clean energy without consuming a single cubic meter of water, causing a single cubic meter of pollution and producing a single cubic meter of hazard gas and a single kilogram of solid waste in its power generation process. Furthermore, water resource is a permanent and renewable energy source so long as water keeps circulating on the earth and rivers are not dried up. Quantity of electricity obtained from hydropower generation will never lead to any decrease in the total quantity of water resources. Therefore all countries in the world give high priority to the development of water energy. Statistics show that there are 24 countries that depend upon hydropower to deliver 90% of their total power supply, such as Brazil and Norway, and 55 countries with hydropower making up more than 50% of the total power supply, such as Canada, Switzerland and Sweden. In China, the hydropower installed capacity accounts for about 24% of the total power capacity with an annual generation making up 14.8% of the total. However the development of hydropower will inevitably change original conditions of rivers. More importantly, part of land will be submerged by reservoirs and local residents have to be relocated. The land area will be substituted by water area. The change of flow regime will have effect on fishes' living environment and sediment accumulated in reservoirs may bring about some unfavorable effects. For this reason, a scientific and complete assessment system must be established in the process of hydropower development, so as to make right decisions and take proper countermeasures.

2.5 Nuclear power is a superior and high-efficiency energy source. Through several decades of development, nuclear power has been recognized by the public in terms of both technology and safety. Today, the installed capacity of nuclear power in the world has taken up 16% of the total in power generation. With the progress of technology, the safe fission reactor has been further developed to neutron reactor and controlled nuclear fusion reactor, which is the development trend for human's future energy source. The nuclear power industry in China started late, so at present the installed capacity reaches only 6.364GW, making up 1.6% of the total power capacity of the country. We should

devote major efforts to developing nuclear power and it is predicted that the installation capacity will reach 36GW in 2020.

2.6 Wind, solar and biomass are clean and renewable energy sources. Due to their low density and efficiency in energy transformation, the utilization technology is still at the initial stage at the moment. Therefore we should speed up scientific research and development in this respect to substitute these for part of other energy sources. However they can't play a main role in power generation industry in the predictable future.

3 Hydropower Development and Current Situation in China

China is bestowed with a lot of rivers which, combined with the geographic and climate conditions, provide an abundant water energy source. Based on comprehensive investigation and assessment, the theoretical reserve of water resource in our country is 688GW with a possible annual generation of 5920 billion kWh. From latest overall economic, technical and environmental assessment and screening, water resources that can be developed and utilized reach 448GW, possibly producing an annual power output of 2470 billion kWh, equivalent to that produced by combustion of about 0.9 billion tons of coal each year. China is a country with the largest quantity of water energy source in the world, which is an important and precious resource for the economic development in China.

Although China built up its first hydropower station in 1912 (at Shilong Dam in Yunnan Province, with an installed capacity of 500kW), the actual development and utilization of hydropower started in the later half of the twentieth century due to the delay of industrialization process. After more than 50 years' construction, the hydropower installed capacity of the country reached 92.17GW in 2003, making up 24% of the total electric power, with an annual generation of 283 billion kWh, accounting for about 14.8 of the country's total. It can be seen from the reserves of water energy that the development level of China in hydropower is far behind those countries with relatively rich water resources. Tables 1 and 2 show respectively the development status of different nations in the world and the development course of China in hydropower industry.

Table 1 Development status of different nations in the world

Nation	Total reserve developable (GW)	Developed capacity (GW)	Development ratio (%)	Year of data
China	448	100	22.3	2004
USA	194.30	84.15	43.3	1986
Canada	152.90	65.67	42.9	1997
Brazil	213.00	54.51	25.6	1997
Russia	269.00	62.14	23.1	1986
India	84.00	22.01	26.2	1997
Japan	35.15	33.39	95.0	1986
France	22.80	21.00	92.1	1986

Norway	38.00	26.00	68.4	1997
Italy	19.20	17.86	93.0	1986
Spain	29.22	18.00	61.6	1997

Note: The data in 1986 come from "China River Hydropower Planning in the 20th Century" and the data in 1997 from "International Water Power and Dam Construction" in 1999.

Table 2 History and future prediction of hydropower development in China

Year	Installed capacity of hydropower (GW)	Year	Installed capacity of hydropower (GW)
1912	0.0005	1988	32.698
1949	0.163	1991	37.884
1955	0.498	1996	52.184
1960	1.941	1999	72.97
1965	3.02	2000	77.085
1970	6.235	2003	92.17
1975	13.428	2004	100.00 (predicted)
1978	17.277	2010	147.35 (predicted)
1980	20.318	2020	257.86 (predicted)
1985	26.415		

Of the installed capacity of 100GW that has been developed in China, More than 28GW is contributed by about 40000 small hydropower stations with an installation capacity below 50MW each, accounting for 33% of total hydropower capacity. There are abundant small hydropower resources, which can play an active and effective role in power supply to the rural and remote mountainous regions that power grids can hardly cover, and are also favorable to environmental protection by replacing coal-fired energy. Small hydropower stations can be invested in a decentralized way with most investors being individuals and collective groups. Thus the advantages of easy financing, relatively less-sophisticated technology and equipment and short construction period make small hydropower part of renewable energy sources that shouldn't be neglected. Therefore the Chinese government has listed small hydropower stations among the renewable energy sources supported by preferential policies.

The medium and large-sized hydropower stations with the installation capacity above 50MW constitute the main proportion of the hydropower in China. Through more than 50 years' construction and development, over 230 stations of such scale have been set up, among which 25 stations are above 1000MW and 40 are above 500MW. These medium- and large- sized stations demonstrate that China has the capability to build all types of hydropower stations, and have laid down a sound basis in professional personnel and teams specialized in survey, scientific researches, design and construction, as well as in specifications and standards, organizational structure and technologies. The successful construction of Yangtze Three Gorges Hydropower Station has symbolized that our development ability of super-huge stations has reached a new high level, being among the front rank in the world. So it can be said that the best opportunity for China to develop hydropower industry is coming now.

4 Experiences and Lessons in China's Development of Hydropower Industry

From over 50 years' history, China has accumulated rich experiences in successful hydropower development and also learnt a lot of valuable lessons from failures.

A well-established construction management system. Before 1980s, the construction of all the stations were controlled under national planning economy with funds allocated by the government and managed by relevant professional government departments in a centralized way. The construction enterprises did the construction and management by themselves and then turned over the station to the power authority for management after completion of the project. Although a lot of hydropower stations were successfully constructed, there were no clear division boundaries among investors, units responsible for projects, construction contractors and operation units with responsibilities either overlapped, disconnected or not clearly designated in the whole system. The investors were not obliged to recover the investment. There was no responsible person for the project with contracting determined by administrative authority, so that there was lack of effective supervision, lack of competition consciousness and the efficiency was rather low. With the reform of national economic system, the planning economy has been transformed to market-oriented economy. A complete set of brand-new management system has been implemented in hydropower development, that is, to execute project legal entity responsibility system and raise construction fund through multi-channel financing; to carry out bidding and contracting system for introducing competition mechanism; and to implement project supervision system for improving the mechanism of project supervision and management. The legal entity of the project organizes the constructors by means of contracts, thus establishing a comprehensive and scientific management system to accelerate the hydropower development and construction.

A good planning for river basin and project. In essence, project planning is a process of getting to know the nature, the river and the community in the river basin, during which a great deal of first-hand accurate data should be collected and necessity and feasibility study be carried out for the selected project in a scientific way. In the decision-making process, we must respect science and democracy and take into consideration of different opinions, and should never make decisions on the ground of subjective assumption. Only in such way can accurate and reasonable decisions be reached.

A quality design and technical management. Full knowledge of the natural conditions of the river in hydrology, geology and earthquake is one of the key elements for ensuring smooth and successful execution of the project. In the process of project construction, strict and scientific management must be exerted, as the construction of hydropower stations is highly subject to the effects of natural and human factors. And due to the complicated technology involved in the project, it is necessary to establish a strict technical management system. We should employ advanced technology and high-efficiency facilities as much as possible to achieve good performance in construction, and eradicate rashness and disorder in management, which is the key for assuring the prosterous construction of the project.

A sound resettlement policy and action. To do well the resettlement of residents in the reservoir area is also the key that determines the success or failure of a project. China has a large population but relatively small per capita land area, especially in eastern part of the country, where per capita area of cultivated land is only 1~1.5 mu (a Chinese unit, 1 mu=0.0667 hectare). For some medium and large-sized stations in southeast coastal areas, the capacity of an annual hydropower generation of 100 million kWh necessitates the relocation of more than 1000 people, and in the western region the figure is about 200 to 300 persons. Some of the stations built in earlier period did not provide sufficient compensation for relocated people, so the simple and ill-considered relocation resulted in a lot of remaining problems. Since 1980s, the Chinese government has improved the regulations and policies for resettlement of residents in reservoir areas, achieving remarkable achievements by combining resettlement with economic development and with poverty alleviation. A typical example is the Three Gorge Project (TGP). The total number of people relocated reaches 1.13 million. In addition to giving sufficient compensation as relocation funds, preferential policies have been implemented, such as nation-wide counterpart supports and relocation of part of residents to other provinces, which has been carried out simultaneously with the project construction since 1993. Up to June, 2004, we have fulfilled the relocation of about 900,000 residents, among which 165,000 have settled down outside at plain areas or the economically developed regions. The successful resettlement of TGP shows a good example and is well appraised by relevant UN organization.

A thorough ecologic and environmental assessment. The reservoir constructed for a hydropower station will inevitably change the original state of the river. The ecologic conditions in the submerged area will also be changed to some extent. There are a lot of issues that need to be carefully studied and analyzed, such as whether or not the water quality of the river will deteriorate due to decreased flow velocity, whether the change of aquatic animals' living habits caused will lead to an increase or decrease or even extinction of fishes and what is the mechanism of the river sediment movement, etc. The substitution of hydropower generation by using water potential energy for thermal power by fossil fuel mining and combustion is beneficial to reducing the environmental pollution and is, in general, favorable to eco-environmental protection and improvement. Generally speaking, hydropower development has its favorable side, but also has its unfavorable side. We must analyze its advantages and disadvantages in an objective manner with emphasis on how to make full use of its advantages and avoid its disadvantages and how to make it beneficial to human's sustainable development.

A good multi-channel financing and fund operating is the guarantee of funds for project construction. A hydropower project involves the construction of hydraulic structures to obtain primary energy, and manufacturing and installation of hydro electric equipment to obtain secondary energy. Therefore it necessitates larger amount of investment. In China, the cost for building a 1000MW station is about USD 1000~1200 per kW, with the total investment up to USD 1~1.2 billion. As an example, the total investment in TGP reaches USD 22 billion. The medium and large-sized stations will have a long construction period, normally 5 to 10 years. The price fluctuation and variation of bank interest rates

will affect the construction cost of a project, consequently exerting an effect on the competitiveness of its electricity tariff in the power market. For this reason, we must continuously make predictions on risks involved, intensify risk analysis so as to avoid and minimize risks, make necessary adjustment in financing patterns and reduce cost by means of “static investment control and dynamic capital operating”, thus ensuring the smooth progress of the project.

A rolling development mechanism for a river basin. In the development process, the project legal entity should establish rolling development conception that utilizing the revenue from power generation of the station completed for rolling development of new hydropower projects. The optimum development efficiency can be achieved by means of rolling development on the same river.

5 An Example——Yangtze Three Gorges Project

The Yangtze Three Gorges Project (TGP) is the largest hydropower station in the world at present. Its installed capacity is 18.20GW and the annual average generation reaches 84.7 billion kWh, equivalent to that generated by combustion of 40 million tons of coal. The project also plays an important role in flood prevention and navigation improvement on the Yangtze River. Going through 70 years’ course from initial envisage through planning, investigation, design, verification and decision-making, the TGP was eventually left off ground via voting by the National People’s Congress in 1992. The huge scale of the project necessitates RMB 90.09 billion at 1993 price (equivalent to USD 15.74 billion based on the exchange rate in 1993), of which RMB 40 billion (equivalent to USD 6.99 billion) is used as compensation for the resettlement of reservoir residents, accounting for 44.4% of the total investment. The whole construction period lasts up to 17 years. Taking into account of price factor and interest rate change of banks during this long period, it was predicted in 1994 that the total investment of the project would be RMB 203.9 billion (equivalent to USD 25 billion). The total population relocated reaches 1.13 million, and 12 new towns are to be rebuilt. Beginning from 1993, TGP has entered its implementation phase. The Chinese government decided to use market economic rules to organize the construction of TGP and established China Yangtze Three Gorges Project Corporation (CTGPC) as the legal entity of TGP to implement the project legal entity responsibility system. The TGP Construction Fund was set up for injecting capital into CTGPC. The Fund covers about 40% of the total investment, while the revenue from generation will cover 20% and the remaining 40% of capital will be raised from financial market through multi channels, such as bank loans, public issuance of bonds and corporate listing after restructuring.. After 11 years’ construction, we realized phase objectives like initial impoundment of the reservoir, opening to navigation of the ship lock and power generation of the first batch of units in June 2003 and the relocation of 0.9 million reservoir residents. Up to August 2004, ten hydro turbine-generator units each with a capacity of 700 thousand kW have been commissioned in the Three Gorges Power Plant with the total output reaching 7 GW and the total energy produced up to 32 billion kWh. It has been approved by the State Commission for Development and Restructuring that, the grid tariff for power generated by Three Gorges Hydropower Plant will be RMB 0.25/kWh, not taking into account of

40% allocated to non-profit investment items like flood prevention and navigation, of which cost for operating, depreciation, financing and taxation is about RMB 0.20 and net profit about RMB 0.05 for each kWh. CTGPC uses the revenue from generation into the construction of TGP during the construction period. By the end of 2003, RMB 100 billion of investment has been fulfilled for TGP. It is predicted that when the project is completed in 2009, the total investment will be controlled within RMB 180 billion (about USD 22 billion) without exceeding the budget, and in contrary, with some surplus. CTGPC has established via restructuring, China Yangtze Power Co., Ltd., a listed holding company. The "Yangtze Power" was successfully listed in 2003, utilizing the funds raised on capital market for rolling development of new hydropower projects. Now CTGPC has been granted the concession to develop four cascade hydropower stations on the Jinsha River, Wudongde, Baihetan, Xiluodu and Xiangjiaba. The total capacity of these four stations will be 38GW. The preparation and construction of Xiluodu and Xiangjiaba have already started. And CTGPC has entered a healthy rolling development period. The whole course of TGP development can be regarded as an example of hydropower development in China by establishing a set of mechanism favorable to accelerating hydropower development.

6 Suggestions about Power Policy for Sustainable Development

Hydropower is a renewable and clean energy source that can play an effective role in improving ecologic conditions and protecting environment. The proportion of fossil fuels for power generation should be reduced from the present 80% of the global total to about 25% in the coming half century, as is laid down in UN Convention on Global Climate Change. It is provided in Kyoto Protocol that the release of CO2 in industrialized countries should be curbed by 5.2% against that in 1990 in the period from 2002 to 2012. The amount of CO2 released in our country makes up 13.6% of the global total, ranking second only after USA. The status of environment requires that as long as hydropower resources are available, we should make the utmost use of this kind of energy and replace the non-renewable fossil fuel generation that aggravates environmental pollution as much as possible.

Scientific assessment should be made about the advantages and disadvantages of each hydropower station. There should be scientific data analysis being made on the impacts of land to be submerged and change of river conditions on environment and ecology so as to avoid conceptual judgment and to work out relevant feasible countermeasures. At the same time, comparisons should be made with other kinds of power generation with the same output and same quantity of electric generation to facilitate decision-making.

A sound market mechanism is a favorable factor for hydropower development, so we should speed up the reform of power system.

Small hydropower stations produce renewable and clean energy and are very important means for solving electricity issues in wide rural and remote mountainous regions. They should be supported by government policies. The random development, however, must be avoided to prevent law of water utilization and natural landscape from being damaged.

Small hydropower stations are relatively easy to construct, but have lower reliability, so it is improper to connect them with large power grids.

Taxation policy: The tax rate for those stations with flood prevention function should be treated differently from others. As they provide non-profiting public benefits, these stations should be levied at lower tax rate.

Within the future 30 years, it is reasonable to increase the proportion of the hydropower in the total power output of China from current 24% to more than 25%, which is an important measure favorable to sustainable development. To accommodate the high-speed growth in economy, China's power policy should still focus on coal-fired generation, but gradually reduce its proportion in the whole power output. We should exert great efforts to develop hydropower and make full use of water energy resources; we should accelerate nuclear power construction and actively make commercialized development of new energy sources like wind, solar and biomass energies.