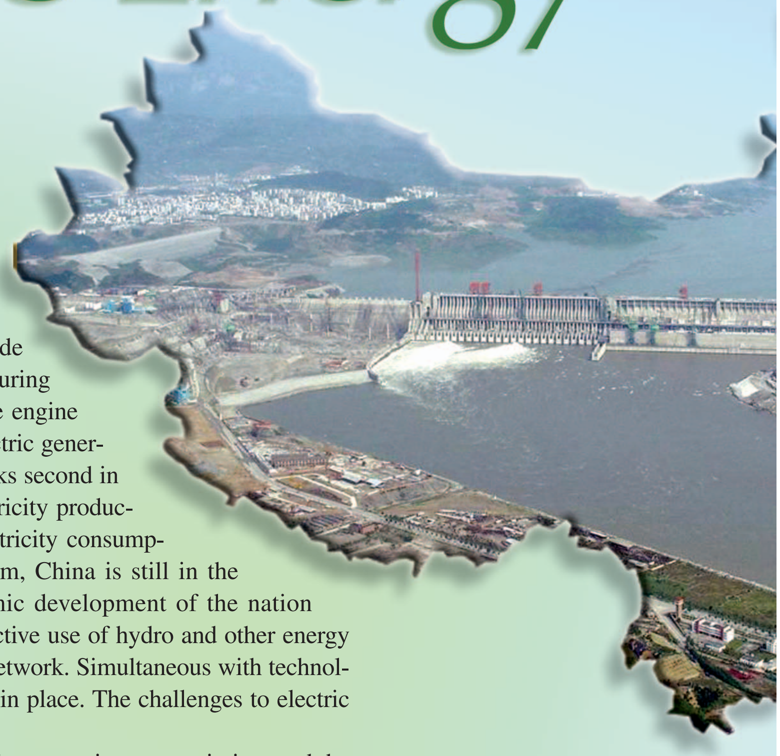
China's Future in Electric Energy



IN JUST A QUARTER CENTURY, CHINA'S ECONOMY has transformed itself from a relatively closed agriculture-based system to a market-oriented system with World Trade Organization membership and a reputation as the manufacturing capital of the world. The electric energy infrastructure is the engine that drives economic developments. Recent expansion in electric generation and transmission has been phenomenal. China now ranks second in the world in terms of installed generation capacity and electricity production. However, it lags far behind in terms of per capita electricity consumption. Indeed, with roughly 1,000 kWh per capita per annum, China is still in the category of a developing country. The continuing economic development of the nation requires sustainability in electric energy supply, and the effective use of hydro and other energy sources necessitates an expansive and reliable transmission network. Simultaneous with technology solutions, institutional and economic structures must be in place. The challenges to electric energy supply in China are tremendous.

In this article, recent developments and future challenges in generation, transmission, and the market aspects of electric energy systems in China are described. For each of the subjects, the major challenges being faced and the measures and policies being taken are listed.

Electricity Supply in China

Since the economic reform in 1980, China has experienced unprecedented economic growth. Gross domestic product (GDP) has jumped more than 800%. However, the corresponding growth in primary energy consumption has increased only 278%. The energy intensity, measured in terms of energy consumption in kilogram of coal equivalent (kgce) per economic output in dollar of Chinese yuan, dropped from 1.33 to 0.46. There are many factors contributing to this improvement in the more efficient usage of energy. A major one may be attributed to the fact that the share of electricity utilization (a more efficient means of energy usage in most cases) in the total energy consumption has more than doubled, up from 20.6% to 43.8%. As a result, the growth in electricity has surged 634% since 1980. Figure 1 shows the growth in the economy, and Figure 2 shows the increase in the share of electricity in total energy consumption.

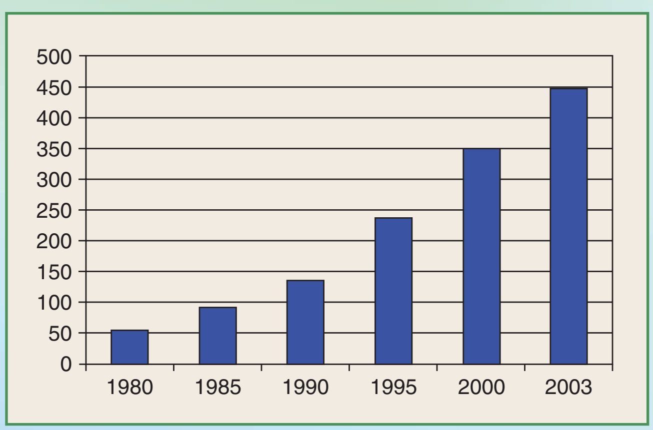


figure 1. GDP in billions of U.S. dollars, indexed at 1980.

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Fast-Growing China's Power System Developments and Challenges

by Felix F. Wu and Shuti Fu

The installed generation capacity in China has reached 440.7 GW at the end of 2004, with annual production of 2,187 trillion Wh, making it the second highest in the world. At present, about 75% of generation is from thermal power plants, 25% from hydro power plants, and a very small percentage (0.4%) from nuclear. Figure 3 depicts the trend in annual installed generation capacity and production since 1980. The average growth rate of installed capacity during this period is over 7.8%. The growth in electricity consumption in the last two years has been particularly noteworthy. In 2003, the electricity consumption increased 15.3% over the previous year, a growth, as expected, that is largely due to an increase in industrial and urban residential usage (consumption in the agriculture sector has in fact declined slightly).

Part of China experienced a more than a 20% increase in electricity consumption in 2003, causing 21 out of 29 provinces to suffer power shortages. The situation worsened further in 2004; 26 provinces had to shed load, especially in the highly developed industrial regions of Jiansu and Zhejiang, where factories had to be shut down part of the week, resulting in a loss of GDP worth tens of billions of U.S. dollars. The shortage in 2004 was estimated at around 35 GW. The immediate response from the government and the private sectors was to expedite the approval of the construction of new power plants. More than 68 GW of capacity are planned to be added in 2005 and 79 GW in 2006. After 2007, the power shortage problem should be eased.

Challenges in Electricity Supply

Per capita annual electricity consumption in China today is roughly 1,000 kWh, compared with more than 5,000 kWh in Hong Kong and over 12,000 kWh in the United States. The number will definitely rise as China's economy continues to grow and people's standard of living further improves. Some forecasts put the installed generating capacity at a level of 950 to 1,000 GW by the year 2020, or 250% of today. Such growth imposes tremendous challenges to the sustainability of power system developments in a multitude of dimensions for the next decade. The resources for electricity generation must be diversified, the environmental issues must be adequately addressed, efficiency improvement and conservation must be encouraged, and, above all, sources for capital investment must be ensured.

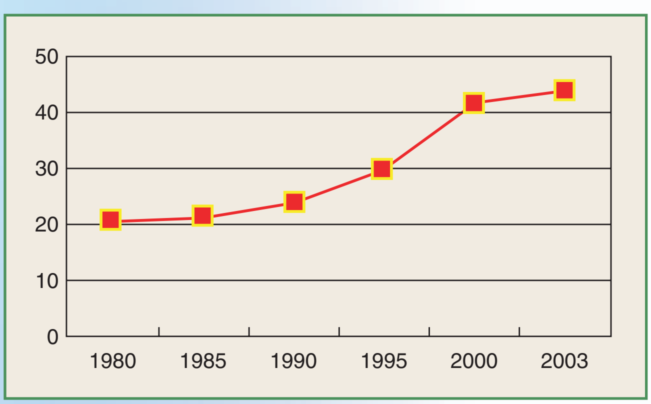

figure 2. Percentage share of electricity in total energy consumption.

The government's diversification plan calls for a reduction in the dependency on coal generation, which has a significant adverse environmental impact, from 75% today to 65% by 2020, upholding hydro generation

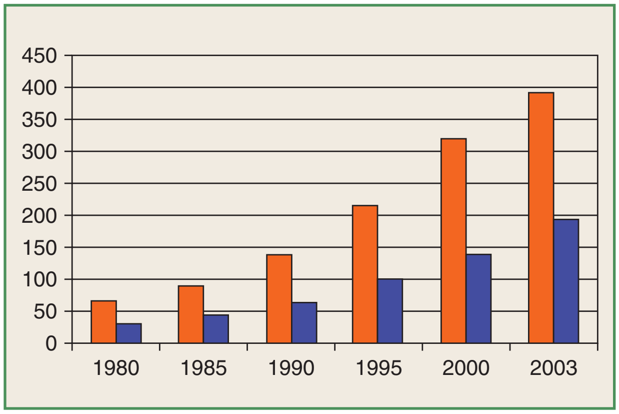

figure 3. Total installed generation capacity in GW (red columns) and annual electricity production in 10 trillion Wh (blue columns).

figure 4. Geographic map of six regional power systems (NC: North China; EC: East China; CC: Central China; SC: South China; NW: Northwest China; NE: Northeast China).

at around the present percentage level and increasing more environmentally benign gas generation to 6%, nuclear to 3–4%, and renewables to 2%.

China is endowed with large hydro potential; it is estimated that the exploitable hydro capacity is 378 GW, ranked first in the world. The government has an aggressive plan to develop hydro generation from the present 108 GW to 260 GW by 2020 (thus upholding hydro at 25% of the total generation capacity). The most famous hydro power project under construction, which will become the largest such plant in the world, is the Three Gorges. Three Gorges, due for completion in 2009, will consist of 26 generators of 700 MW each, or a total of 18.2 GW. After these units are commissioned, six more generators will be installed in an underground power house, and the total capacity of the plant will then become 22.4 GW with an annual production of 84.7 trillion Wh. The year 2003 was a landmark year for the project; six units began to generate electricity. Three Gorges lies in the middle stream of the Yangtze River. The upper stream of the Yangtze River, called *Jinshajiang*, has exploitable hydro of more than 18 GW and is being developed. In Yunnan, Southwest China, the Lancang River (called *Mekong River* in Southeast Asia) also has significant hydro potential.

The first nuclear power plant in China was a 300-MW unit constructed in 1991. Today, there are eight units with a total capacity of 6,840 MW. The government is planning to build 36-GW nuclear generation by 2020. The deployment of nuclear power plants is not without controversy, notably the issues of safety, security, and waste disposal. The government in recent years has also started to encourage renewable power generation with the enactment of preferential regulation. The China Meteorology Research Institute estimated that the exploitable wind energy potential in China is as high as 1,000 GW: 250 GW on land and 750 GW offshore. Currently, there are 40 wind farms, with a total of 1,042 units and a total capacity of 567 MW. Wind and other renewable energy sources are expected to reach 20 GW capacity, or 2% of the total capacity, by the year 2020.

Beginning in 2002, China intensified legal construction on environment protection and resources conservation and launched a series of rules and regulations for levying pollutant discharge fees, emission standards of air pollution for thermal power plants, standards on water extraction quotas, etc. Power plants are beginning to use clean coal technology to reduce SO_2 and NO_X. Newer power plants must comply with the air pollution protection standards. Several flue gas desulfuration techniques are used in China. The first 450 t/h circulating fluidized bed boiler was installed in 2003. By the end of 2003, the capacity equipped with desulfuration equipment constructed and under construction amounted to 20 GW.

In terms of conservation of resources, from 1980 to 2003 the net coal consumption rate decreased from 448 gce/kWh to 380 gce/kWh, and the line losses decreased from 8.93% to 7.71%. According to some statistics, the average cost of products per kWh of energy in China is still three times higher than the world average and ten times higher than in the United States. There is a lot of room for energy conservation. For example, air-conditioning load constitutes about 30% of the summer load in Beijing; considerable energy may be saved by improving air-conditioning efficiency. China has recently conducted several demand-side management (DSM) studies, all with positive conclusions. Experimental peak load pricing is being conducted. The government has successfully promoted DSM to alleviate somewhat the pain of power shortages in 2003 and 2004.

In addition to the challenge to the environment, China's continued appetite for electricity also imposes tremendous demand for capital to fund the power projects. The state-owned industry has to be restructured in order to attract private funding for generation projects, as discussed later in this article. The first step has been the corporatization of the state-owned enterprise.

Electric Transmission

China has more than 900 billion tons of coal reserve. However, the coal reserve is unevenly distributed in this vast country; about 82% of coal deposits are concentrated in the north and southwest regions. The same uneven distribution is true for hydro resources; 67% of the 378 GW hydro resources are in the southwest region. The majority of electricity consumption, indeed 70% of it, is consumed in the coastal regions of the east and the south as well as some part of the central region. Long-distance electric power transmission is necessary for effective utilization of the resources.

At the end of 2003, the total length of high-voltage transmission lines of 220 kV and above reached 207,563 km, of which 44,676 km were 500-kV lines. The transmission system consists of six regional power networks, excluding Xinjiang, Xizan, and Taiwan, as shown in Figure 4. The plan for interconnecting the six regional grids by way of a combination of 500-kV high-voltage ac (HVAC) and ± 500 kV high-voltage dc (HVDC) lines was achieved at the end of 2004 (Figure 5) as a result of significant progress being made in the last couple of years in transmission projects (Table 1). Central to the National Grid project is the Three Gorges power grid, consisting of 12-GW HVAC from the Three Gorges to the Central China grid and 7.2-GW HVDC to the East China grid.

The first HVDC project in China dates back to 1987 in Zhejiang province with a 100-MW ± 100-kV underwater cable that spans 54 km. The first HVDC line from Gezhouba (Three Gorges) to Shanghai was completed in 1991, and a number of other HVDC and HVAC lines linking regional grids have been completed in the last few years as listed in Table 1 below.

Additional planned HVDC and HVAC transmission projects for the 2006–2010 period include

- ✔ second 3G-Shanghai HVDC link
- ✔ second Guizhou-Guangdong HVDC link
- ✔ NC-NE back-to-back HVDC link
- ✔ NC-CC back-to-back HVDC link
- ✔ Guangdong-Hainan underwater HVDC link
- ✔ Yunnan-Guangdong HVDC link
- ✔ NC-NE HVAC link
- ✔ NW-NC HVAC link.

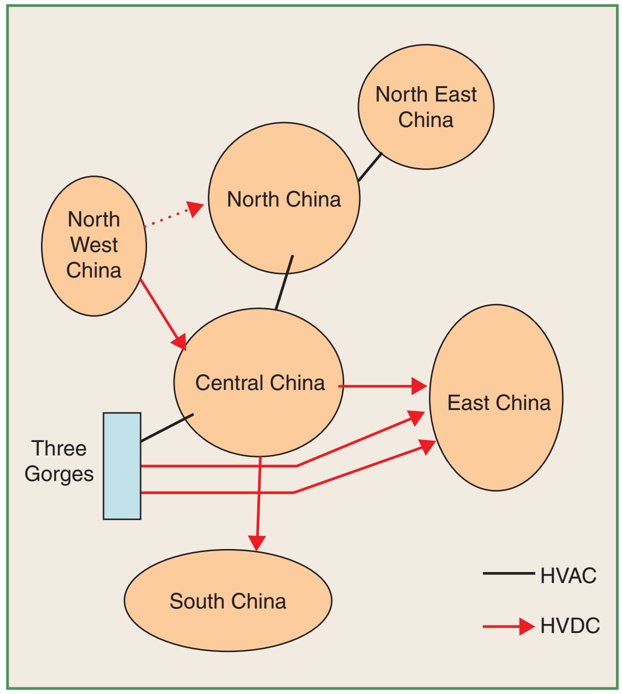

figure 5. Interconnection of six regional grids in 2005.

The two major strategies in transmission projects are for power flow from west to east and from north to south, since most of the energy resources are in the west and north. There will be three transmission corridors from west to east. The northern corridor will tap the thermal energy using ac lines and the hydro energy from the upper reaches of the Yellow River with dc lines. The middle corridor will transmit power from hydro stations along Jinshajiang to Central and East China via both ac and dc lines. The southern corridor will make hydro resources available along the Lancang River and the Hongshuihe River as well as hydro and thermal resources in Guizhou to Guangdong in South China. The transmission from North China to Central China will be strengthened by ac tie-lines. The design philosophy is to isolate western China from eastern China with dc links to prevent stability problems.

Challenges in Electric Transmission

China is constructing a colossal transmission network to

Table 1. A list of recently completed hvac/hvdc projects.

Grid	Location	Type	Capacity	Length	Completion
CC-EC	3G Gezhouba-Shanghai	±500 kV DC	1,200 MW	1,045 km	1991
SC-SC	Guangxi-Guangdong	±500 kV DC	1.800 MW	980 km	2001
CC-EC	3G Longquan-Shanghai	±500 kV DC	3,000 MW	900 km	2002
CC-SC	3G Jingzhou-Guangdong	±500 kV DC	3,000 MW	950 km	2004
CC-NW	Henan-Henan	±120 kV DC	360 MW	Back-to-back	2004
SC-SC	Guizhou-Guangdong	±500 kV DC	3,000 MW	1,000 km	2004
NC-NE	Hebei-Liaoning	500 kV AC	800 MW	167 km	2001
CC-NC	Henan-Hebei	500 kV AC	600 MW	210 km	2003

transport a massive amount of electricity over the geographic span of a huge country, and this is just the beginning. The challenges are to squeeze even more electricity into such a network, to manage this complex ac/dc network, and to maintain a high level of reliability for electricity supply.

The current backbone of 500-kV ac and ± 500-kV dc transmission systems is considered too weak for transmitting large blocks of power over a long distance for the future power systems in China. The first 750-kV transmission project was commissioned in 2003 in the northwest region of China. China's transmission system could be strengthened further by the deployment of ultrahigh-voltage (UHV) transmission, e.g., a voltage level higher than 1,000-kV ac and ± 800-kV dc transmission lines. Studies and plans are under way for incorporating UHV transmission into the existing power grid of China. Since an operating experience of 1,000 kV transmission is scant and manufacturing is lacking, a lot more research and development (R&D) must be accomplished in a short period of time before ambitious plans can be realized.

To enhance transmission capability and system dynamic performance of the ac networks, flexible ac transmission system (FACTS) devices are employed throughout China. There are six SVC (static var compensators) installed on 500-kV transmission systems. A ±20 Mvar STATCOM (static compensator) developed by Tsinghua University was installed on the 220-kV network in Henan Province. A TCSC (thyristor-controlled series compensator) was installed at a 500-kV substation in the southwest province of Guangxi in 2003, successfully increasing the power transfer capability from west to east by 300 MW. Another TCSC was installed on a 220-kV system. There are immediate plans for two more TCSC projects, one in the northeast and one at Three Gorges. Research into the deployment and manufacturing of FACTS devices is very active in China.

Since the mid-1980s, control centers with supervisory control and data acquisition (SCADA) or energy management systems (EMS) have been employed extensively to control and manage the transmission networks. Digital relays and substation automation are widely used. The control centers in China are structured in a three-tier hierarchical architecture. On the top is the National Control Center and underneath are six regional control centers. Each regional control center covers three to six provincial or municipal control centers. Control centers are all equipped with advanced application software that includes static security monitoring and control. As the network becomes more and more complex and the demand for higher reliability becomes more stringent, PMU (phasor measurement units) and WAMS (wide-area measurement system) are beginning to be employed in earnest in China. The first PMU was introduced in 1996 on the South China grid. Currently there are over 30 PMUs installed: five on Three Gorges transmission system, six on the north grid, nine on the northeast grid, nine on the east grid, and six on the south grid. The objective of using PMUs and WAMS is to enhance wide-area system protection and dynamic security monitoring and control for the future transmission systems in China and ultimately improve reliability of electricity supply.

Electricity Market

The pace towards reform and restructuring of the electricity industry in China is deliberate and cautious. Part of the Ministry of Electric Power was first transformed into the State Power Company of China (SPC) in 1997 to separate the enterprises from the administrative functions. Independent power producers (IPPs) are encouraged to ease the burden of capital expenditure from the state for power plant construction. Six experimental provincial or municipal electricity markets were established in 1999–2000. In 2002, major steps were taken towards industrial reform and restructuring: generation and transmission are unbundled and corporatized, and a regulatory commission was formed. The generation is carefully regrouped into five group companies (Huaneng, Datang, Huadian, Guodian, and Zhongdian) with the incorporation of IPPs and publicly listed companies. Each of the five companies has a similar composition in terms of the scale of assets, the makeup of installed capacity, etc., and none has more than 20% of any local market share. All generating companies have to compete in the market indiscriminately to supply power. Other participants in the market include local generating companies, additional small generating companies, and IPPs with foreign investment.

The grids are grouped into two companies: the South China Grid Company covers the south grid consisting of five south and southwest provinces, and the State Power Grid Company covers the rest of the five regional grids. Enough generating capacity (around 10–20%) is kept by the grid companies to ensure reliable operation, frequency modulation, and peak load following. Each regional grid operates an electricity market. More than 80% of the demand based on long-term (i.e., annual) bilateral contracts. The remaining demand is traded in the monthly and day-ahead markets operated by an Electricity Dispatch and Trading Center (EDTC) of the region. Northeast and East China regional grids are the first to set up their markets in 2004. The size of a regional market facilitates efficient competition. However, due to differences in economic development, significant parity exists today in neighboring provinces, which necessitates the adoption of different tariffs. Therefore, the provincial electricity market is allowed in some instances as an interim measure. In such a case, there will be a hierarchical market structure in which several provincial EDTCs are coordinated under a regional EDTC. But the goal is that eventually there is one EDTC per region. The EDTC is, in general, responsible for generation scheduling, contingency analysis, and congestion management. It also handles settlement and ancillary services (either self-provision or purchase).

The State Electricity Regulatory Commission was established in 2002 to ensure fair competition in the market. The commission is charged with the responsibilities to develop

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market rules, to monitor and to regulate market operation, and to maintain market efficiency. This is the first time in the history of China's electric power industry a regulatory body has been set up.

Under the one-country-two-system rule, the special administrative regions of Hong Kong and Macau have their own power industry structures. The power companies in Hong Kong and Macau are privately owned and they operate like a regulated monopoly with franchised service territory: Hong Kong Electric in Hong Kong Island, China Light and Power in the rest of Hong Kong, and Companhia de Electricidade de Macau in Macau. The regulatory compact is a contract, called a *scheme of control* (SOC) in Hong Kong, between the government and the utility company. The terms of the SOC are pretty similar to a regulated monopoly, e.g., vertically integrated monopoly with an obligation to serve and guaranteed rate of return. The SOC in Hong Kong will not come up for renewal until 2008. But public consultations are already underway to discuss the shape of the future power industry in Hong Kong.

Electricity Market Challenges

The driving force behind deregulation in many Western countries is the belief that competitive markets make the industry more efficient, leading to lower costs. In particular, under the rate-of-return regulation, electric utilities tend to overbuild causing higher cost to consumers. In the case of China, like other developing countries, the push for restructuring comes more from the needs for opening the electric generation market for private investment and to provide a leveled playing field for all participants. Of course, there is also the belief that the efficiency of a state-owned enterprise can be improved by private management.

From the beginning of its economic reform, China has been very mindful of the need for attracting nonstate capital to build the necessary power generation sector. A BOT (build-operate-transfer) scheme was adopted for power plant contracts. Long-term take-or-pay contracts with guaranteed price and minimum quantity of electricity on an annual basis were signed between the state or local governments and the builders of the power plants. These contracts tend to be very generous, and the annual return on investment generally exceeds 15%. A large number of IPPs were built with domestic or foreign capital from 1985–2000. During the excess-capacity period of the mid-1990s, some local governments were hard-pressed to honor these contracts. A proper balance between attractiveness to investors and affordability to consumers in the electricity business needs to be found as the economy matures.

In an ideal competitive electricity market, there is no central planning for generation expansion and market price signals are supposed to be enough to induce investors to build power plants. There is no more guarantee on investment return, and it is up to the investors to assess expected profit and risks. However, in the initial stage of market development, it is too risky to rely on this untested theoretical approach to ensure adequate generation that is so essential for the well-being of the society. Various forms of capacity payment have been added in different countries as incentives for generation investment. Large swings between excess capacity and undercapacity have to be avoided for any power systems, especially so for fast-developing countries like China. The greatest challenge in the restructuring of China's power industry is to ensure that the market rules send the right signals to ensure a proper level of generation investment.

As a fast-developing country, China can ill-afford the economic consequences of the inadequate or oversupply of electricity. The official data indicates that the power shortage in the coast province of Zhejiang alone for the first half of 2004 cost billions of dollars as a result from the direct loss in GDP. On the other hand, the market response to the power shortage is swift. It is reported that there is as much as 80 GW of *unplanned* capacity under construction from factories and other sources and, if true, that might result in oversupply in a few years' time and cause significant financial losses to investors.

In China, a two-part tariff is used, for example, in the northeast city of Liaoning The cost of electricity for residential customers is around US 5.4 cents/kWh. For commercial and lighting it is around US 9.5 cents, and for industrial customers, in addition to the energy charge (between US 3.7–5.3 cents/kWh), there is the capacity charge, consisting of two parts, one is based on maximum demand (around US$2.68/kW per month) and the other is based on transformer capacity (around US$1.83/kVA per month). Under the restructured system, the price of the energy will be determined by the electricity markets (contracts and spot) described previously; the price of capacity payment is determined through a unique market mechanism at the planning stage. First of all, generation planning will be conducted by the grid companies, who determine the optimal timing, size, location, and type of generation addition. Investors of power plants then bid for the capacity payment. In other words, the generator of the winning bid will then have the guaranteed income from the capacity payment plus the (uncertain) revenue for energy production that comes from contracts or the spot market. In this way, part of the risk of investment return is shifted from investors to consumers (capacity payment). At the same time, the competitive drive for efficiency improvement (competitive contract and spot markets) is still maintained.

Foreign investment in China's power generation reached its peak in 1997 at 14.5% of the total fixed asset, from around 9.5% in previous years. As stated previously, generous risk-free long-term contracts were no longer signed with the introduction of competitive markets. The foreign investment has steadily declined to 7.5% in 2002. The latest indication from unofficial data seems to suggest that foreign investment is crawling back again as market rules are finally specified and become transparent.

Transmission planning in China is solely the responsibility of the grid companies. Traditional transmission planning practices have been followed; therefore, many new issues in transmission planning in the restructured environment do not seem to have surfaced.

Conclusion

In the last few years, China has reached several milestones in the development of electric energy systems: the Three Gorges project has started generating power, an interconnected national grid has formed, new environmental regulations have been enacted, and the industry has been fundamentally restructured. The scale, speed, and complexity of the developments in both generation and transmission systems are breathtaking. And this promises to be just the beginning of a long and arduous endeavor.

The building of the electric energy supply infrastructure to power China's economic developments is a colossal undertaking. Until now, China's electric energy system has basically emulated the West. Technologies and solutions evolved gradually in the West over decades of developments. In an industry with a large base of legacy facilities, a fast-growing system in China has emerged from a modest beginning. Continuing along the current path does not seem viable. If current fossil fuel generation technologies are used when the generation capacity doubles or triples, the cost to the environment and society will be hardly affordable. High-voltage transmission technology is hitting the limit. The applications of power electronics and information technologies are not fast enough. China must develop its future electric energy system in a more efficient, more intelligent, and more sustainable manner than what has been done historically anywhere in the world. As the largest developer of an electric energy system, China has to take a leadership role in future technology R&D in all aspects, including clean energy development and efficient energy utilization with state-of-the-art power electronics and information technologies. Hopefully, China will be able to lead, not just in the deployment and utilization of electric energy systems but also in the development of new technologies in the coming decade to benefit the nation and the world.

Acknowledgments

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Biographies

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Shuti Fu received his B.S. degree from the electrical engineering department at Tsinghua University, Beijing, China, in 1948. From 1949 to 1950 he took a graduate training course at the Allis-Chalmers Manufacturing Co., Milwaukee, Wisconsin. He returned to China in 1951 and worked for the Central Laboratory of China, Electric Power Bureau, from 1951–1953, the North China Electric Power Design Institute from 1953–1971, and Hebei Electric Power Design Institute from 1972–1977. He was engaged in power system analysis and programming from 1962–1978. Since 1978, he joined China Electric Power Research Institute (CEPRI), Beijing, China, as a computer application engineer, specializing in power system online applications. From 1983–1985 he was the deputy chief engineer in CEPRI. Now he is presently a consultant (officially retired since 1994). p&e