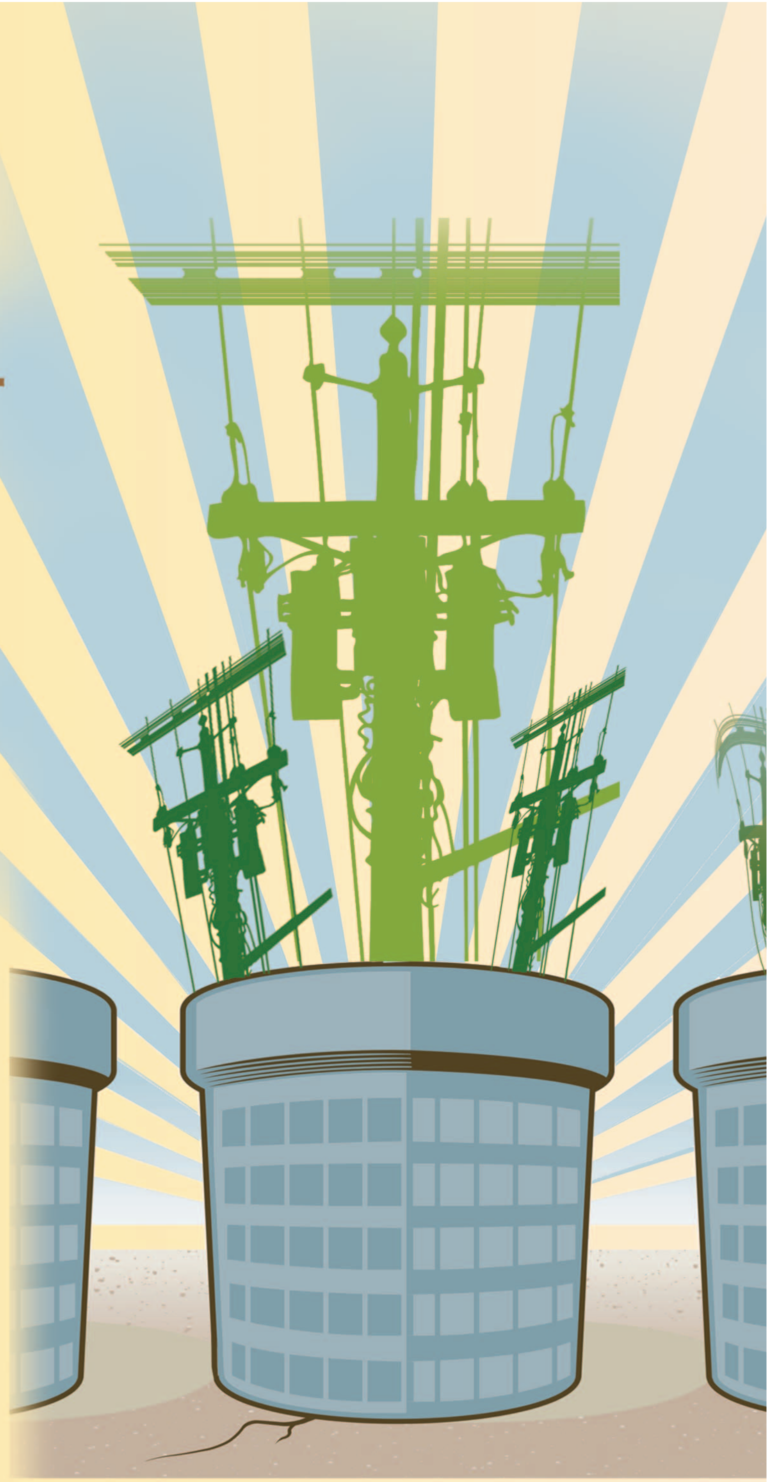
Chinese Growing Pains

The Need to Upgrade China's Distribution System to Keep Up with Its Growing Urban Population

by Jin Zhong, Chengshan Wang, and Yiping Wang



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IN THE PAST DECADES, CHINA'S ECONOMY has increased significantly. the annual average increase in gross domestic product (GDP) is more than 8% since 1978. With the sustained economic growth, the living standards of most people have improved, and more and more people have moved from rural areas to urban areas. In the long term, the extraordinarily high GDP growth drives China's increasing consumption of electricity. The urbanization requires high-quality and more reliable electric power supply.

China's current population of 1.3 billion people makes it the most populated country in the world. About 26.31% of the population lives in several metropolitan areas and the city centers or the surrounding rural areas of 268 prefecture-level cities. In 2004, the share of the urban areas in GDP reached 47.66%, which is CNY 7,620 billion (US$1 = CNY 7.74); the electricity consumption in the urban areas is 1,046 TWh, about 48.0% of the whole country. Figure 1 shows the share of the urban areas in population, GDP, and electricity consumption. The rapid economic growth in the urban areas and the concentrated loads require the enlargement in distribution capability and the improvement of distribution automation technologies in primary distribution systems.

In China, the discussions on distribution systems are mainly about the power distribution systems for urban

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areas (called an urban distribution network in Chinese). Here, we will focus on the distribution systems in urban areas in China.

The Past and Present

In the era of the centrally planned economy, the Chinese government put much more effort into power plant construction than transmission and distribution (T&D) system construction. Before 1978, the year that Chinese economic reform started, about only 20% of the investment in power sectors was for power grid constructions, while the other 80% was invested in generation sources. In the 1980s and the beginning of the 1990s, electric power supplies to large industry customers were strictly scheduled. Residential customers often suffered unexpected electricity outages. The capacities of secondary distribution lines would be inadequate if more customers turned on air conditioners on a warm summer day. T&D networks used to be the bottlenecks of electric power supply. Since the 1990s, more and more efforts and investment have been put in power grid construction.

Since 2002, some parts of China, especially the highly developed industrial regions, have experienced a rapid increase in electricity consumption. One third of all provinces have been suffering from power shortages. The generation shortages facilitated the rapid development and construction not only in generation expansion but also in T&D expansion. The total installed generation capacity by 2005 was 508.4 GW, and the number reached 622 GW in 2006. New T&D capacities and substation transformer capacities have increased about 80% from 2001 to 2005, while generation installed capacities increased about 50%, as shown in Figure 2.

Now, the distribution systems in China can satisfy the power supply requirement of economic growth. However, the reliability and power quality of current distribution systems are still lower than that of world levels. Most of the blackouts are caused by the failures in distribution systems.

Subtransmission and Distribution System Configurations

The voltage levels of T&D systems differ in various regions in China. In most areas, the voltage levels are 500/220/110/10/0.4 kV, while the voltage levels in the regions of Northeast China and Northwest China are 500/220/66/10/0.4 kV and 330/110/35/10/0.4 kV, respectively. In China, the systems with voltage levels equal to or higher than 220 kV are classified as transmission systems. Those equal to or lower than 110 kV are classified as distribution systems. In the distribution systems, the 110-kV, 66-kV, and 35-kV systems are called high-voltage (HV) distribution systems (or subtransmission systems); the 10-kV systems are called medium-voltage (MV) distribution systems (or primary distribution systems); and the 380/220 V

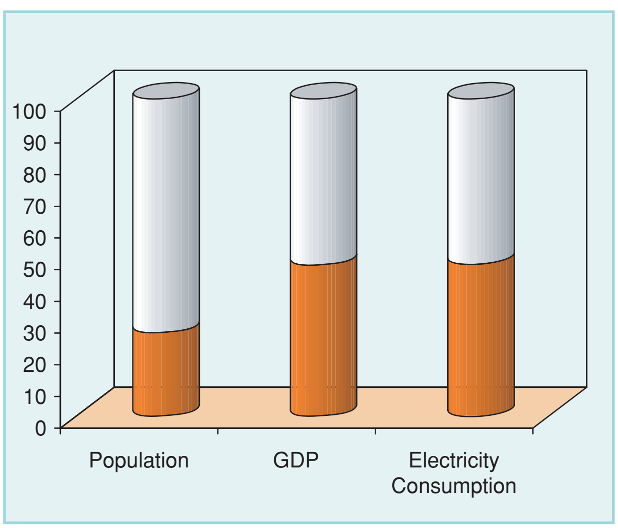

figure 1. The shares of urban areas in population, GDP, and electricity consumption.

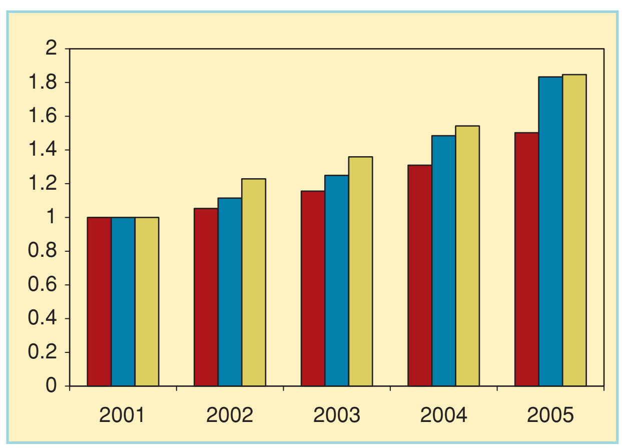

figure 2. Capacity increase of generation, transmission, and distribution from 2001 to 2005 (compared to the levels of 2001). Installed capacity (red column), 220-500-kV transmission capability (blue column), and 10-kV distribution capability (yellow column).

table 1. Transformer capacities of substations and lengths of lines in 2005.

	220–500 kV	35–110 kV	10 kV	0.4 kV
Transformer (GVA)	866.8	928.3	1,268.7	—
Length of lines (physical km)	251,900	746,200	5,074,400	12,822,800

systems are low-voltage (LV) distribution systems (or secondary distribution systems). In China, the loads are usually supplied by 10-kV feeders or 380-V/220-V power lines. The one-line diagrams for the typical 500/220/110-kV transmission system and 110/10/0.4-kV distribution system are shown in Figure 3 and Figure 4, respectively.

The designs of subtransmission systems are mainly based on three arrangements: *loop, radial*, or *T-type*. These three arrangements are shown in Figure 5. The designs of primary distribution systems are mainly radial or loop (also called as "hand in hand circuit" in the distribution systems in China). The typical circuit arrangements for the 10-kV overhead distribution feeders and underground cables are shown in Figure 6.

Development of Distribution Systems

The scale of T&D systems has grown rapidly in recent years. The transformer capacities of substations and the lengths of lines for various voltage levels in 2005 are given in Table 1. The data of the primary distribution feeders are shown in Figure 7, which shows that the situations of distribution systems have been improved in the past eight years.

The load growth in China is uneven in different regions. In some commercial districts of big cities and the economic development areas, the load densities have reached 30–40 MW/km^2. The capacity-load-ratio (the ratio of the substation transformer capacity and the load it supplies), which indicates the capability of a distribution system, is around 1.6 to 1.9 in most of the urban areas. A ratio larger than 1.6 means the capacity of the distribution system is enough to serve the current loads. However, in some cities the ratio is lower than 1.6. Due to the insufficient investment in distribution facilities and distribution automation systems, the current distribution networks and equipment need to be upgraded to improve the reliability and quality of power supply. There are some issues that need to be addressed in the present distribution systems: reliability, network configurations, and losses.

Reliability

About 75% of the electricity sold to urban customers is served through the primary distribution feeders and secondary service circuits, but the end users often complain about the electricity supply of the distribution systems. The complaints are mainly about frequent and long-duration electricity interruptions. Three of the standard reliability indices defined in China are: reliability on service in total (RS-1), reliability on service except scheduled interruptions (RS-3), and the average interruption hours per customer (AIHC-1). The definition of RS-1 is the same as the average service availability index (ASAI) defined in the IEEE standards,

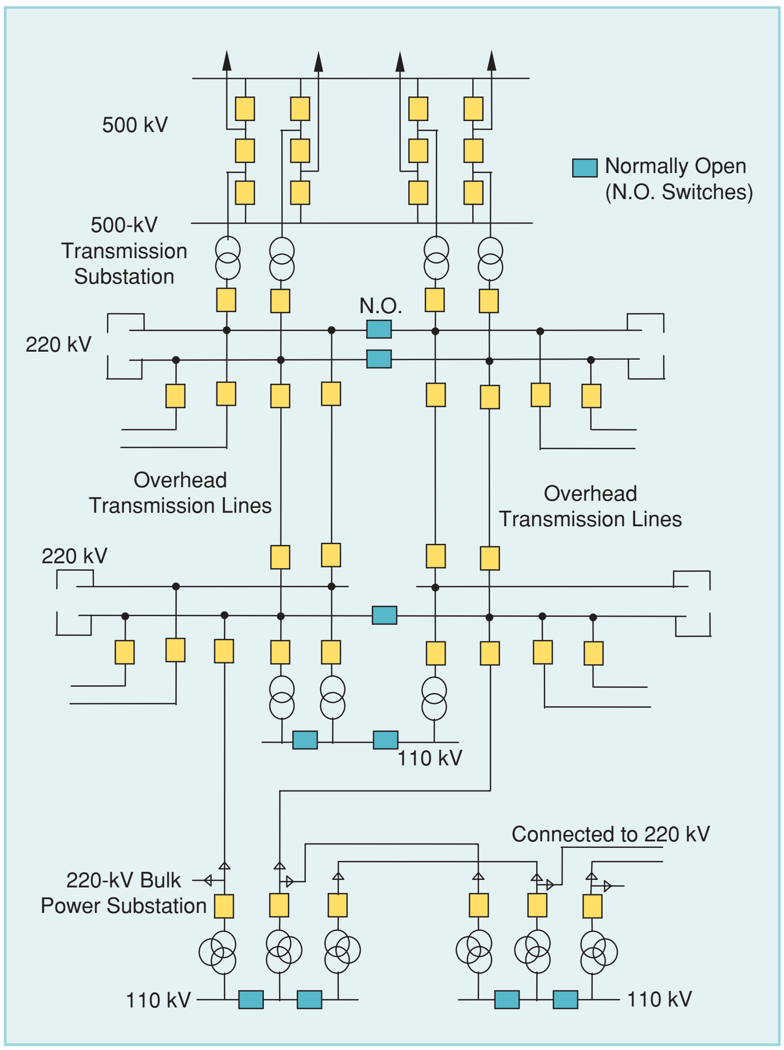

figure 3. A typical 500/220/110-kV transmission system.

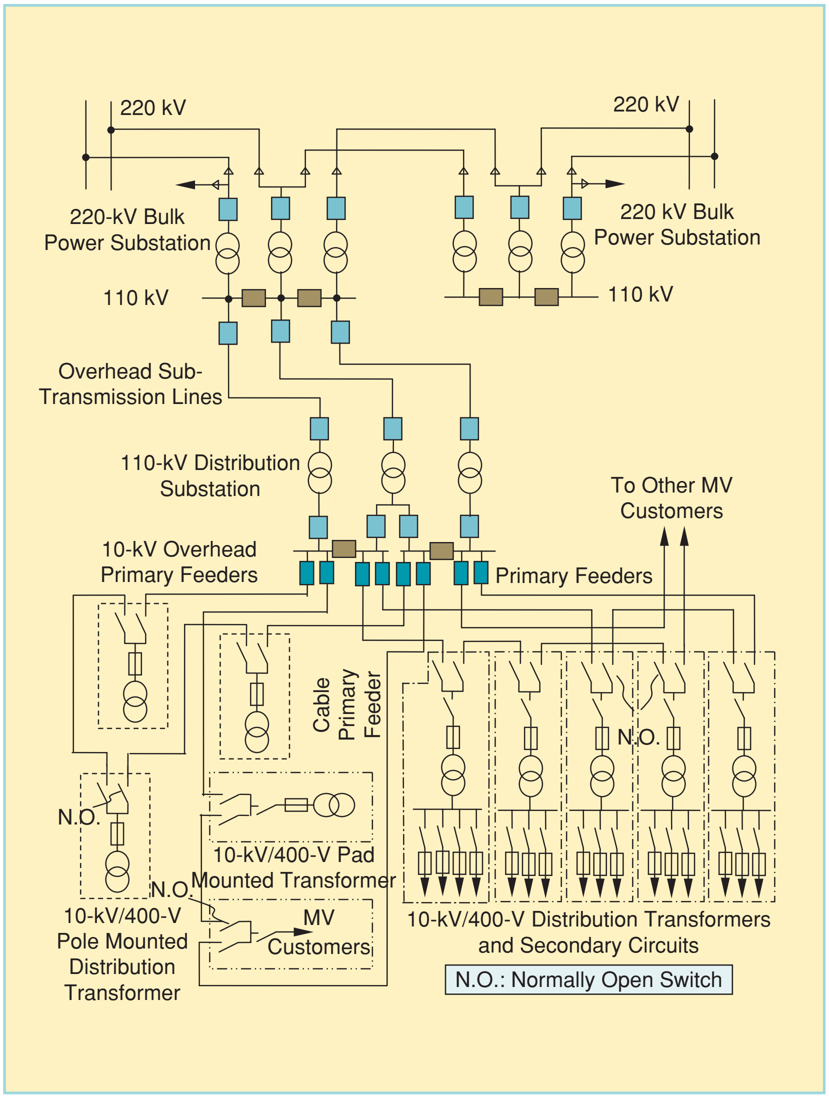

figure 4. A typical 110/10/0.4-kV distribution system.

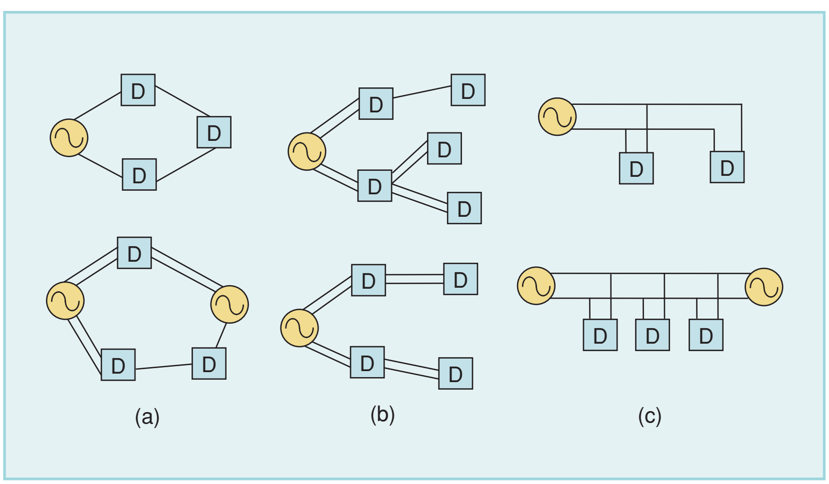

figure 5. The arrangements for subtransmission and primary distribution systems: (a) loop, (b) radial, and (c) T-type. The symbol D represents the distribution transformer.

which refers to the percentage of time power is available; the definition of AIHC-1 is the same as the customer average interruption duration index (CAIDI) defined in the IEEE standards, which describes the average number of hours per interruption. The index RS-3 refers to the average service availability excluding scheduled interruptions.

In 2005, the index RS-1 (or ASAI) for the customers of primary and secondary distribution systems was 99.766%; the index RS-3 was 99.845%, and the index AIHC-1 (or CAIDI) was 20.491 hours. The RS-1 and AIHC-1 for the customers of 35-kV and 66-kV subtransmission systems was 99.681% and 27.905 hours, respectively. The reliability level in China is still low compare to the ASAIs of the United Kingdom (99.988%), United States (99.984%), France (99.991%), Japan (99.999%) and other systems in developed countries. The indices RS-1, RS-3, and AIHC-1 of the 10-kV primary distribution systems from 1992 to 2005 are shown in Figure 8. Although the reliability of distribution systems is still low compared to developed countries, it has been improving rapidly since 1996.

In China, power system interruptions are divided into two groups: scheduled interruptions and interruptions caused by failures (for example, faults, weather, accidents, etc.). In 2005, the number of failure-caused interruptions in the distribution systems was 47,043, which is 23.5% of all interruptions; the other 76.5% of interruptions were scheduled interruptions, in which 15.8% were scheduled interruptions caused by generation shortages, as shown in Figure 9. The average duration of interruptions caused by failures is 3.3 hours. The frequency and duration of failure-caused interruptions from 2001–2005 are given in Table 2. It shows that the situations of power interruptions (both frequency and duration) became worse in the past five years. One of the reasons might be the electric power shortages that started in 2002. A quick response to a fault can reduce the impacts of the fault on customers and reduce the interruption duration. The distribution of fault interruption

table 2. Frequency and duration of the interruptions caused by failures (2001–2005).

	2001	2002	2003	2004	2005
Number of the interruptions	24,169	26,598	23,197	26,666	47,043
Duration of the interruptions (hr)	2.588	2.827	2.655	2.977	3.299

table 3. Facility failure rates of 10-kV primary distribution systems (2000–2005).

	Overhead Line*	Cable*	Transformer#	Circuit Breaker#
2000	18.126	11.119	0.85	6.1
2001	8.932	4.744	0.511	2.852
2002	9.674	4.447	0.640	3.077
2003	8.343	4.059	0.485	2.237
2004	9.408	4.148	0.468	2.535
2005	9.61	4.27	0.562	2.67

Note: * = the average numbers of failures per 100 km per year; # = the average failure rate per year (%).

duration for the 10-kV primary distribution systems in 2005 is shown in Figure 10. It shows that 75.89% of the faults can be cleared within 3 hours, whereas 5.39% of the faults need more than nine hours to be cleared.

Within all the facility failures of the 10-kV primary distribution systems, about 80% of them occur on the four types of distribution facilities: overhead lines, underground cables, transformers, and circuit breakers. The failure rates of the facilities for 2000–2005 are given in Table 3.

Distribution Automation in Urban Systems

The technologies of distribution automation and distribution management system (DA/DMS) are applied only in a few systems in China. According to an investigation on 33 urban and prefecture-level distribution companies in China, about 87.9% of the distribution companies have begun to study the possibilities of applying DA/DMS in their distribution systems. About 45.5% have started the demonstration projects of DA/DMS. However, the numbers of demonstrated lines are only 3% of all lines of the distribution companies that started DA/DMS demonstrations. From the investigations, we do not see the incentives for the distribution companies to introduce DA/DMS in their systems. However, some distribution companies have showed their interests in feeder automation and geographic information systems (GIS).

At present, about 75.5% of the customer interruptions are scheduled interruptions (see Figure 9), and only 23.5% of the interruptions are caused by failures. To a certain extent, the reliability is related more to the numbers of scheduled interruptions. If the numbers of scheduled interruptions can be reduced by one half, the RS-3 can be improved by 0.05 to 0.07%. If the DA/DMS can reduce the number of failures by one half, the RS-3 can be improved by 0.016 to 0.025%, which is only one third of that by reducing scheduled interruptions. For the systems with the reliability of 99.999%, the percentage of scheduled interruptions is usually lower than 25%; in Japan, the number is close to zero. Later on, with the improvement of distribution management, when the scheduled interruptions are reduced to a reasonable level, the impacts of DA/DMS on distribution reliability will be more obviously.

On the other hand, in China the investment in distribution automation is very low compared to other investments in T&D grid construction. According to past experiences, only 1% of T&D investment is used in distribution automation.

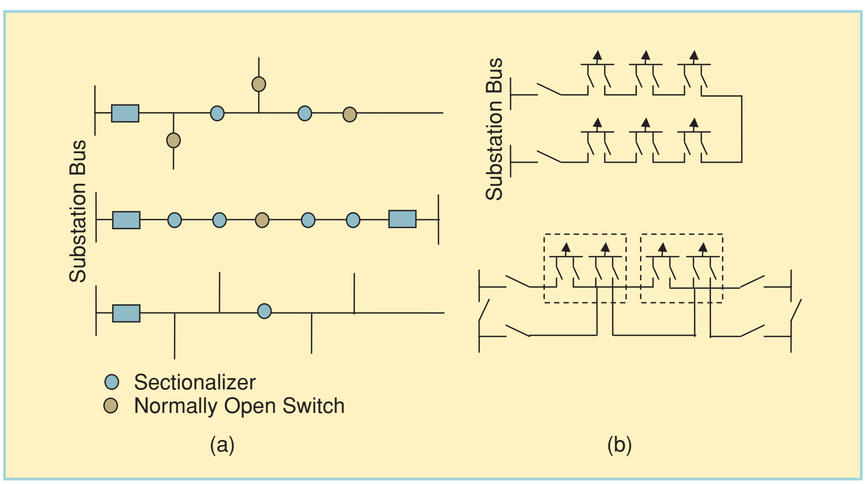

figure 6. The typical designs for the 10-kV primary distribution feeders: (a) overhead lines and (b) underground cables.

> The reliability and power quality of current distribution systems are still lower than that of world levels. Most of the blackouts are caused by the failures in distribution systems.

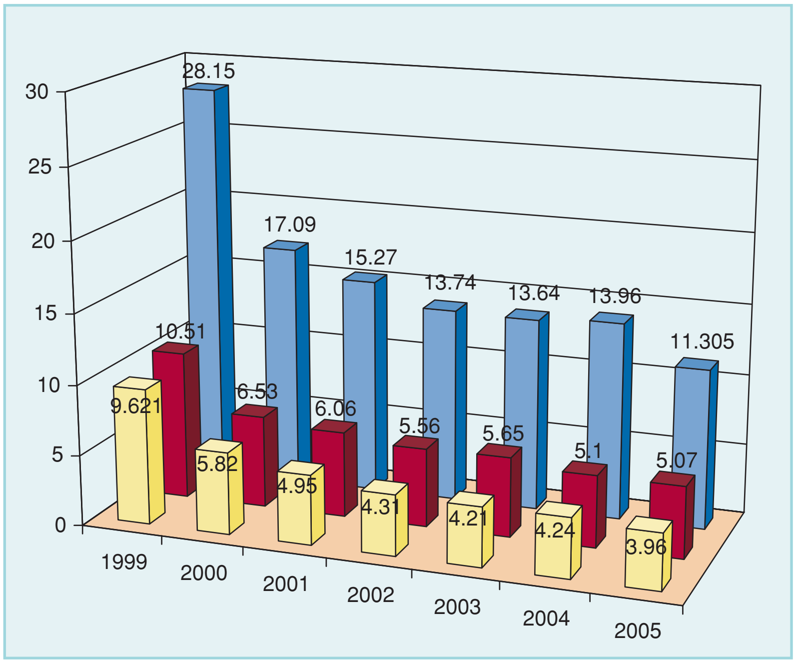

figure 7. 10-kV primary distribution systems from 1999–2005. Average length of line (km/line, yellow column), average transfer capability per line (MVA/line, red column), and average numbers of customers per line (blue column).

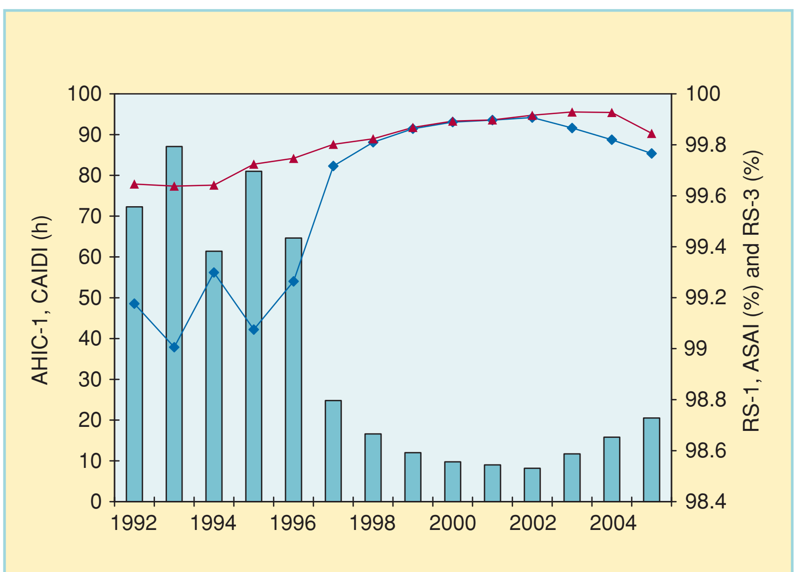

figure 8. The RS-1/ASAI (blue line), RS-3 (red line), and AIHC-1/CAIDI (column) for the 10-kV primary distribution systems (1992–2005).

Issues and Challenges

One of the issues in power transmission and distribution in China is the unbalanced development of transmission systems and distribution systems. The investment ratio on generation, transmission, and distribution is 1:0.23:0.2, while the average ratio in the world is 1:0.5:0.7. The technology development of distribution facilities lags the load growth and the development of transmission facilities. On the other hand, the coordination of different voltage levels is not well designed. For example, the 110-kV distribution substations are usually designed with big capacities. This means more primary feeders are connected to the substation in limited distribution corridors. In the heavy load density areas, it may result in substation siting problems or energy loss problems in primary feeders. Moreover, the connections from the primary distribution substations to the high-voltage (500 kV or 220 kV) bulk power substations are fragile in most cities; an outage of a 500-kV substation may result in system stability problems or even a large-scale blackout.

The high operation costs of primary and secondary distribution systems in China are mainly resulted from the high distribution energy losses and high maintenance costs. About 50% of the T&D wire losses (7.21% in 2005) occur on the primary and secondary power lines. The reasons for this situation can be traced back to the lack of planning in the early stages of distribution system constructions as well as the irrational distribution patterns; for example, the lengths of secondary service lines are too long. The old facilities designed around 30 years ago are the main reasons for high maintenance costs. In China, the overhead lines are still the dominant wires in distribution systems. In 2000, about 84% of the primary and secondary distribution wires were overhead lines; the other 16% were under-

> In China the investment in distribution automation is very low compared to other investments in transmission and distribution grid construction.

ground cables. After years of reconstruction of urban distribution systems, the percentage of underground cables reached 31.9% in 2005.

To improve the reliability and quality of power supply and reduce the losses in distribution systems, distribution companies need to plan and reconstruct the current distribution systems on a large scale as well as to upgrade the distribution facilities and improve the distribution automation technologies.

Being a developing country, China's urban areas develop very fast; more and more new cities and industrial areas are built up in a short term. Urban planning may conflict with the distribution system expansion planning. It is becoming difficult to keep some of the existing substations and distribution corridors in city centers. How to fit the future developments of cities and their surrounding areas is one of the challenges of the distribution system expansion planning. The increase of construction cost and the lack of capital investment is another challenge for distribution system reconstruction. The increasing land prices and the huge amounts of compensation fees to land users are the barriers for distribution system development. According to the investigations of 31 urban areas, the construction costs of urban distribution systems have increased by 30% in two years from 2003 to 2005.

The Future

T&D networks have been the bottlenecks of power transmission for a long time in China. From the technical viewpoints, the reasonable ratio of installed generation capacity and transforming capability is around 1:12. Although China has put a lot of effort on T&D expansions since 2000, the development of T&D still cannot follow the fast generation expansion. The ratio (installed capacity/transforming capability) was only 1:8.5 in 2005. The installed capacity in 2005 was 504 GW and the transforming capability was 4,300 GVA. The latest data shows that the target installed generation capacities will be 600 GW, 650 GW and 720GW in 2006, 2007, and 2008, respectively. The average increase rate of installed capacity will be around 14%. Following this increased rate of generation, the transforming capability needs to reach 10 TVA by

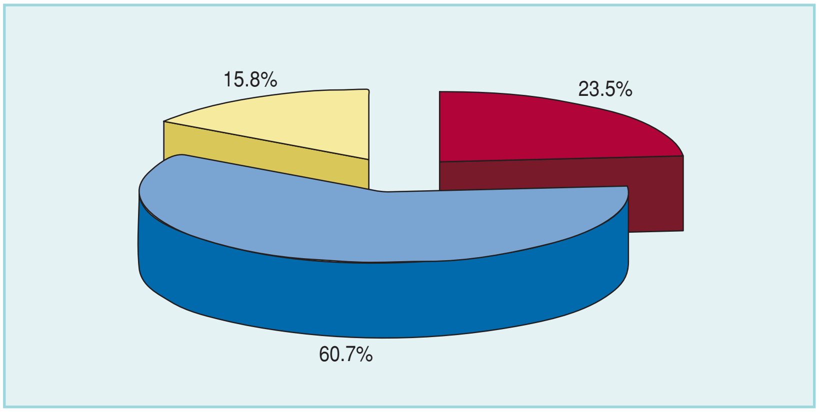

figure 9. Percentages of interruptions caused by failures (red column), scheduled interruptions due to generation shortages (yellow column), and scheduled interruptions due to other reasons (blue column) in 2005.

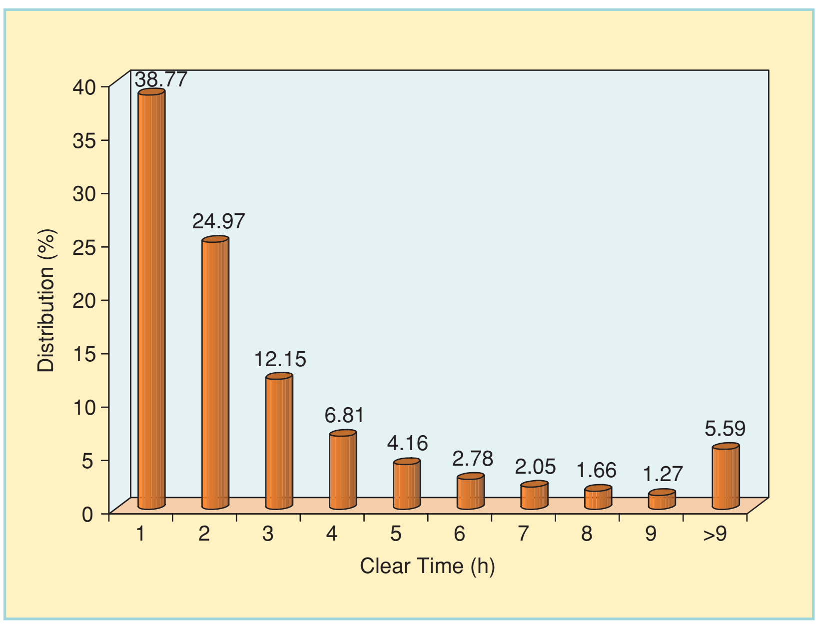

figure 10. The distribution of fault clear time for 10-kV primary distribution systems in 2005.

> Although the distribution systems have been reconstructed in the past decades, the reliability, power quality, and distribution automation levels are still lower than developed countries.

2010 to avoid T&D bottlenecks. That means an average increase rate of 23% is required for T&D systems.

China's two power grid companies, the State Power Grid and the China Southern Power Grid, have scheduled the T&D investment of CNY 996 billion and CNY 200 billion, respectively, for the Eleventh Five Year Plan (2006–2010). The sum of the investment is CNY 1,200 billion. The average increase rate of T&D investment will be 20%. But, how much of the investment can go to distribution systems? The data of 2006 already show that the two grid companies prefer to invest in high-voltage (and ultra-high voltage) transmission systems. In 2006, more than 60% of the T&D investment were spent at the 220-kV and higher voltage levels. The provincial power companies have scheduled T&D investment from CNY 10 billion to CNY 60 billion for the Eleventh Five Year Plan. Similarly, a large portion of the investment will be used for 220-kV and 500-kV high-voltage transmission networks. Probably, one day, when generators and transmission lines are well developed, the distribution bottlenecks will stimulate the development and investment in distribution systems.

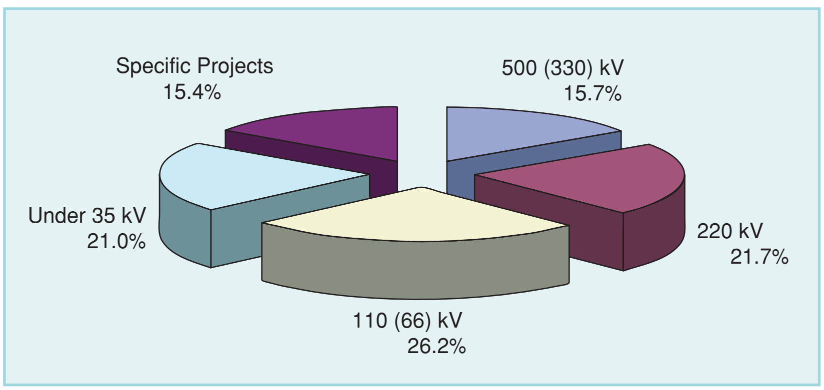

figure 11. Shares of the investment in various voltage levels in urban areas.

In the Eleventh Five Year Plan, the total electrical network investment in the 31 major urban areas will be CNY 420 billion. The shares of the investment in various voltage levels are shown in Figure 11.

Conclusions

China has achieved sustained high economic growth in the past two decades. The high-speed economic development drives the increasing consumption of electricity. The installed generation capacity has increased by eight times. However, the efforts and investment on T&D networks are less than that in generation systems. T&D systems are the bottlenecks of power transfer. Although the distribution systems have been reconstructed in the past decades, the reliability, power quality, and distribution automation levels are still lower than developed countries. The grid companies have scheduled a big investment in high-voltage transmission systems in the coming five years, but the situation of distribution systems has not improved.

For Further Reading

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Biographies

Jin Zhong is a Member of the IEEE. She received the B.Sc. (Eng.) from Tsinghua University, China, in 1995; the M.Sc. (Eng.) from the Electric Power Research Institute, Beijing, in 1998; and the Ph.D. from Chalmers University of Technology, Gothenburg, Sweden, in 2003. She is an assistant professor in the Department of Electrical and Electronic Engineering at the University of Hong Kong.

Chengshan Wang received the B.Sc. (Eng.), the M.Sc. (Eng.), and the Ph.D. from Tianjin University, Tianjin, China, in 1983, 1985, and 1991, respectively. He is the winner of National Science Fund for Distinguished Young Scholars of China. He is currently a professor in the School of Electrical Engineering and Automation at Tianjin University.

Yiping Wang received the B.Sc. (Eng.) and the M.Sc. (Eng.) from Tianjin University, China, in 1984 and 1987, respectively. She is currently a senior engineer at the State Power Grid Company, Beijing, China.