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HVDC transmission

Special Project Collection


华人民共和国万岁

HVDC: Going the distance

Commissioning of the second of China's longest and largest power links is scheduled for completion in June 2004. Using HVDC technology, the links built by ABB will transport power from central China to the fast-developing industrialized areas around Shanghai in the east and Guangdong in the south.

As China's economy continues to grow at an extraordinary rate, so does its need for power. Currently the greatest need is bringing power to the fast-developing industrialized areas around Shanghai and Guangdong.

To address this need, a project has been undertaken by ABB to build two of the world's most powerful and longest high voltage direct current (HVDC) transmission links each with a nominal rating of 3000 MW. The links, one of which came into operation in May 2003, will transport power from the massive Three Gorges hydropower plant to the eastern coastal region and the southern region.

"The contract to build China's first 3000 MW link was awarded in April 1999"

HVDC DEVELOPMENTS

The power generated by Three Gorges will be transmitted to regional grids via the Three Gorges transmission system, which will form the basis of a new national network. However, a major portion of the power will be transmitted to China's industrialized coastal areas in Shanghai and Shenzen via four HVDC links:

- Gezhouba-Shanghai 1200 MW bipole; in operation since 1991
- Three Gorges-Changzhou (3GC) 3000 MW bipole; commissioned in May 2003
- Three Gorges-Guangdong (3GG); currently being commissioned
- Three Gorges-Shanghai 3000 MW; scheduled to start up in 2007.

The contract to build China's first 3000 MW link (3GC) was awarded to ABB by the China Power Grid (CPG) in April 1999. Under this contract, ABB had the responsibility to design, build and supply the converter stations at each end of the line as well as 39 breaker-bay gas insulated switchgear (GIS) equipment at the Three Gorges dam site. This 890 km, +/-500 kV link which runs from Three Gorges to Changzhou near Shanghai in the east, formed part of the internationally financed portion of the project. The order was valued at Yuan 2.79 billion ($340 million). ABB arranged financing for the project through a group of international banks including Société Général, ANZ Banking Group; Crédit Agricole Indosuez, and the Nordic Investment Bank. The loans were partially guaranteed by the Swedish Export Agency.

The contract for the second order was awarded by the State Power Corporation in October 2001. This 975 km link runs from Three Gorges to Guangdong in the south. This contract was 100 per cent funded by China and no financing was required. Under the $360 million contract ABB is providing a turnkey system including converter valves, power transformers and the smoothing reactors for both the sending and

receiving ends of the link. In total, 28 power transformers and six smoothing reactors are being supplied jointly by ABB's transformer factory in Ludvika, Sweden and the Chinese state-owned Xi'an transformer works, an ABB licensee.

HVDC has a number of advantages over HVAC. The technology is particularly suited to transmitting power over long distances because losses are low. It is also ideal for connecting separate networks since it obviates the need for network synchronization.

At the heart of the HVDC station is the converter valve for rectifying or inverting electric current. This consists of a large number of thyristors connected in series to cope with the high voltages. The thyristors are mounted in modules of six. Each valve level can house 24 thyristors. The valve is normally suspended from the ceiling of the valve hall for protection against earthquakes. The valves have to be controlled in order to transmit the required current and power. The valve must also be cooled and the cooling water cleaned. Each valve hall has a surge arrester to protect the thyristor bridges against abnormally high voltages.

An HVDC station comprises much more than a converter for rectifying or inverting electric current. In a large outdoor switching station, it must be possible to isolate the station. On the AC side, filters are needed to smooth the current from the HVDC valves and the AC line has to be compensated for the reactive power.

HVDC plants are also provided with transformers on the AC side. The most important reasons for having a transformer are:

- To optimize the level of direct voltage in HVDC transmission and to have a sufficiently low voltage in back-to-back operation
- To be able to use tap changers for rough setting of the voltage
- To obtain more even direct current and more sinusoidal alternating current (12-pulse connection)
- The transformer limits the short circuit current into the valve.

On the DC side, the current must be made smooth and the return through ground or water secured through an electrode arrangement.

The high voltages call for large distances between converter-converter, and between converter-earth. This means the HVDC station has to be spread over a large area.

THE 3GC PROJECT

ABB had the overall responsibility for the two 3GC converter stations and supplied all the equipment except the converter transformers and smoothing reactors at Zhenping (the receiving end converter station). Although most equipment was imported into China, some transformer units, capacitors, and relay protections were produced locally. CPG was responsible for building the overhead line and the ground electrode stations. It also carried out civil works and installation of the converter stations.

THE CONVERTER VALVE IS AT THE HEART OF THE HVDC STATION

The sending end HVDC converter station is located at Longquan, about 50 km from the power plant. This converter station is connected to the main network of the interconnected AC power pool which comprises the Central China Power System and Sichuan-Chonqing Power System.

The receiving end station is located 890 km to the east at Zhenping, about 80 km northwest of Shanghai. This is connected to the East China Power System which covers Shanghai, Jiangsu, Zhejiang and Anhui. Longquan is connected to the Three Gorges plant by three 500 kV AC lines. Zhengping has two 500 kV AC outgoing lines.

"HVDC is particularly suited to transmitting power over long distances"

HVDC was chosen to transmit power from the Three Gorges plant for several reasons. Since the central and east China/Guangdong AC networks are not synchronized, an AC transmission scheme would have required coordination, and it would have been difficult to ensure adequate stability margins. HVDC allows controlled transmission of power between the networks, which retain their independence.

It would also have been difficult to build an AC transmission line in stages i.e. one link after another, as a very strong inter-tie would have been needed from the outset in order to keep the generators of the two grids synchronized.

DC is also more economic in terms of construction

costs and losses. Five series compensated, 500 kV AC lines would have been necessary to transmit the same amount of power and each line would require a larger right-of-way than one HVDC line of 3000 MW.

The bipolar transmission also means that half of the power can be transmitted even during an outage of one pole. The nominal DC voltage is +/- 500 kV but the operating voltage can be reduced down to +/- 350 kV to enable continued operation even when the DC withstand strength is reduced due to insulator contamination or adverse weather conditions.

The line overhead capacity of the DC transmission is about 10 per cent for two hours. A unique feature of the receiving end station is that all 500 kV DC equipment (except smoothing reactors) are located indoors. The control and protection system is ABB's Mach-2 system.

The converter station losses at rated operation is just 0.7 per cent. All critical subsystems are duplicated to ensure high availability and reliability.

The first pole (1500 MW) began commercial operation in July 2002 and the entire bipole was completed, on time, in May 2003.

THE 3GG PROJECT

While this was a short time schedule, the second project, 3GG, called for 30 per cent to be shaved off the normal lead time. This means that the first pole will be commissioned just 28 months after signing of the contract. ABB is achieving this by what it calls re-use of design engineering and the lessons learned from the first project. This was possible since both projects were similar. Indeed the tight project schedule was a major challenge.

The converter station at the sending end is located in Jingzhou, close to Yichang. At the peak time of construction there were nearly 1000 workers on site. The Jingzhou site was chosen for a number of reasons. The load distribution of the local network was a prime consideration. Jingzhou is the site of an existing substation and the AC yard is an important node in the future development of the network, together with other 500 kV substations. In addition, it has a good supply of water, good land availability and road access for heavy equipment.

When the HVDC link becomes operational, the substation will have the capacity to deliver 3000 MW to Guangdong plus 2250 MW from the existing AC substation. Testing of the system is well underway, with a list of items being tested to assure system reliability and functionality. The system will be tested under different operating scenarios. One important test will be the mode of transmission under increasing load. This is related to the power rating during transmission and will be done mutually at the sending and receiving end.

Despite the short time schedule for building the project 3GG link, construction of pole 1 was achieved by January 2004 and testing took just one month. Full load testing took place in February when the additional two units at 3G came on line. The entire system and line are due to be commissioned by June 2004, however ABB will manage to put the system into operation two months ahead of schedule. According to the CPG, this is the shortest time required for testing any project in China. All in all, the 3GG project will be completed one year faster than its sister project 3GC – a new record.

According to the project engineers at the Jingzhou substation, the biggest technical challenge was spanning the Yangtze River. But despite this, the project went smoothly and it is hoped that the experience gained at Jingzhou will be applied to future projects.

HVDC HIGHLIGHTS

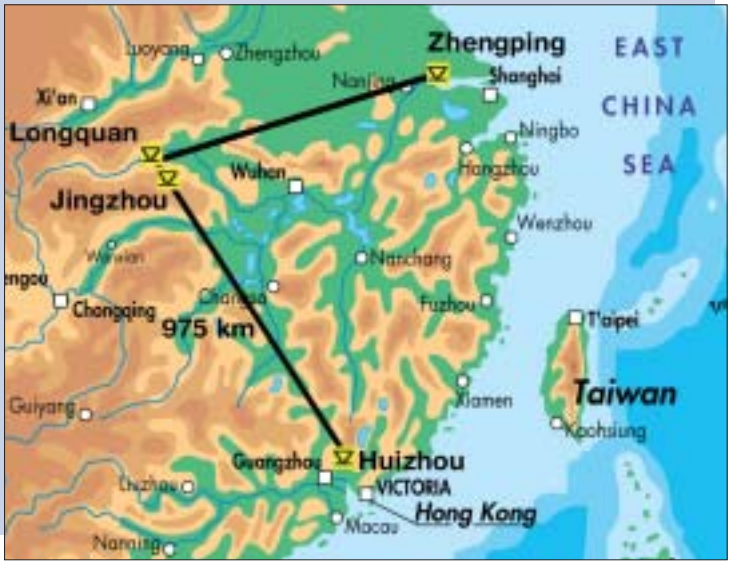
ABB's Three Gorges HVDC links set a number of records. They have the highest power flow per pole i.e. 1650 MW. The previous record was at Itaipu (1575 MW). The execution time of 32 months for the first link was shortest for its class. Itaipu took more than 60 months. At 975 km, the Three Gorges-Guangdong link is the longest DC line in its class – Itaipu is 805 km. The link uses one of the most advanced control and protection systems, ABB's state- of-the-art Mach 2 system

Project benefits

The project has both economic and technical benefits. Economic benefits include: lower investment cost; lower power losses, less impact on the environment; and high reliability and availability.

Technical benefits include: precise and fast controllability of power flow; prevention and cure of blackouts; asynchronous interconnection; limitation of short-circuit currents; no limit on the length of cable (due to absence of charging current).

From a social aspect one link provides power supply to about 6 million households; lower on-grid tariff of renewable hydro resources; avoids emissions from 3000 MW of fossil-fuel power plants in a densely populated area; saves about 16 720 hectares of farmland and forestation; saves about 78 MW through avoidance of losses – equivalent to supply for 156 000 households.



Building a grid for a nation

The Three Gorges project is at the heart of China's power sector restructuring plans. Once complete, the project will add 18.2 GW to China's generation capacity but perhaps more importantly, it will form the backbone of China's plan for a strong national grid.

On April 3, 1992, the Fifth Session of the Seventh National People's Congress passed the Resolution on Construction of the Three Gorges Project on the Yangtze River. The project is a key project for the treatment and development of water resources on the Yangtze River. The dam will facilitate the diversion of water from the south to the north and provide flood control. But perhaps more importantly, the power project will also be at the heart of the country's national power interconnection programme.

Supported by new trunk power transmission systems, the Three Gorges power transmission project will be central to China's plans to build an integrated national grid. Power generated from the plant will be transmitted to grids in central China, east China, Sichuan and Guangdong province. With more than 10 000 km of HVAC and HVDC lines, this system will form the basis for a new national grid which will combine the seven regional networks and five independent provincial networks to create two new interconnected regional networks.

HUGE HYDRO

The Three Gorges project will be the largest hydropower plant in the world. Construction began in 1993 and upon completion in 2009 it will have a generating capacity of 18.2 GW. Power will be generated from a total of 26 generators – 14 on the left bank and 12 on the right bank – each with a capacity of 700 MW. In addition, sufficient space has been set aside on the right bank for a future underground powerhouse for six turbine generators with a total capacity of 4200 MW. The intakes of these units are being constructed simultaneously with the project.

The dam is of a concrete gravity type, with a length of 2309 m. It has a crest elevation at 185 m and a maximum height of 181 m.

Construction of the project is scheduled to last 17 years. This includes the five-year (1993-97) first phase of preparations and construction ending with the damming of the Yangtze River; the six-year (1998-2003) second phase ending when the water level of the reservoir reached 135 m; and the six-year (2004-09) third phase which ends with completion of the whole project.

The main financial challenge was funding the project during the first 11 years of construction. But with the project beginning to generate income in 2003, money from electricity sales can now be used to fund the project during the latter part of the construction period.

Indeed, the year 2003 was a historic year in the construction of the project. The pivotal works began to store water on June 1, the storage went up to the elevation of 135 m on June 10 and the permanent ship locks opened on June 16. The first six units began to consecutively generate electricity in August (two went

TWO CONDUCTORS CARRY 3000 MW TO EASTERN AND SOUTHERN CHINA

into operation in August, two in October, and two before the year-end). The pivotal works entered the third phase at the beginning of 2004. An additional four units will begin commercial operation this year and a further four in 2005.

When all units are fully operational, Three Gorges will have an annual output of 84.7 TWh. A large portion of its electricity will be supplied to east China, central China and a small portion to the Chongqing municipality.

SECTOR REFORM

In the past, it has been said that what has most hindered the marketing of electricity has been the country's poor power management and limited power transmission capacity. However, information from the China National Power Corporation showed that by treating Three Gorges as an opportunity, China could restructure its power industry, reform the existing power management and operation mechanisms, and speed up the construction of transmission facilities in rural and urban areas.

China has experienced an annual growth rate in installed generating capacity of more than 8 per cent for the last 52 years. At the end of 2002, installed capacity stood at 357 GW. About 50 per cent of this capacity was controlled by the State Power Corporation (SPC). The remaining 50 per cent was owned by independent power producers, large generators like Three Gorges and Guangdong Nuclear, as well as provincial or local governments.

In October 2002 the government passed the Electricity Sector Reform Act to promote competition, increase efficiency and generally streamline the industry. A regulatory body was created to supervise the electricity market. The SPC was split into five competing generating companies and two non-competing regional network companies.

The five generating companies are Huaneng Group (37 970 MW); Datang Electric Power (32 250 MW); China Huadian Group (31 090 MW); SP Electric Power (30 430 MW) and China Electric Power Investment (29 890 MW). Transmission and distribution is to remain a monopoly, under the control of the State Grid Corporation and China Southern Power Grid Co. Ltd.

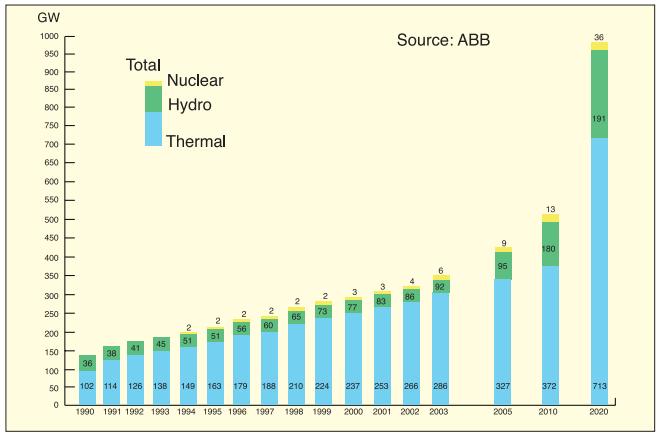
"China plans to create a modern power market in which plants sell power to the grid at market prices"

China's intention is to eventually create a unified grid, and have a modern power market in which plants sell power to the grid at market-determined prices. Initially it planned to introduce competitive pricing in six areas – Zhejiang, Shanghai, Shandong, Liaoning, Jilin and Heilongjiang – on a trial basis, with each free to employ its own method of competitive pricing. These six trial regional markets were expected to be merged or expanded for a more integrated competitive market but the expansion has been temporarily stalled because of severe power shortages experienced in 2003.

TRANSMISSION ISSUES

A key issue in the development of this integrated competitive market is the development of an integrated network.

Altogether, there are seven provincial or regional



CHINA'S TOTAL INSTALLED GENERATING CAPACITY

HVDC IS THE BACKBONE OF CHINA'S POWER GRID

grids and five independent grids which are not connected. The regional networks – North China, Northeast, East China, Central China, Northwest, Sichuan and Chongqing and the Southern Network – operate at 500 kV; with the exception of the Northwest Network which has a 300 kV backbone. The five independent grids are Shandong, Fujian, Hainan, Xinjiang and Tibet.

The southern provinces plus Hainan are viewed as the south grid and is operated by the Southern Network Corporation. The remainder is known as the north grid and is operated by the State Network Corporation (North Company). These network companies still also have their own generating plants, primarily pumped storage.

While network accessibility has reached 96.4 per cent, according to ABB there are still transmission opportunities. Already, Three Gorges is providing a significant portion of these transmission opportunities. Power from the plant will be distributed via 15 transmission lines, with 500 kV AC lines to central China and Chongqing City and +/- 500 kV DC lines to east China and south China. Overall, the project will require the construction of 6519 km of AC lines, with a converting capacity of 22.75 million kVA; and some 2965 km of DC lines with the capacity of the DC converter stations reaching 18 000 MW.

While Three Gorges will go some way to meeting the power demands in the east, there will be a continuing need for transmitting power from west to east. This is expected to be achieved via three routes:

- South lines: 10 000 MW from Guizhou/Yunnan/Guangxi to Guangdong
- North lines: 5000 MW from Shaanxi/Shanxi/Inner Mongolia to JinJingTang area
- Central lines: 9000 MW from Sichuan/Hubei to east China (including the second bipole HVDC link from Three Gorges to Shanghai).

There is also a need to interconnect the regional and independent grids using both AC and DC systems.

There are plans to step up the voltage level in the 330 kV northwest network to 750 kV. The plan is to build a 146 km, 750 kV AC line from Manping to Lanzhou. This will be one of only a few 750 kV transmission lines operational in the world. Construction of this line has begun and ABB is bidding on the transformers and reactors for the project.

There are also substantial requirements on the distribution side. According to ABB in the 10th Five Year Plan (2005-2010) the country plans to invest $24 billion in transmission and distribution. In addition to higher voltage HVDC systems, China will need large transformers – larger than today's 1000 MVA transformers which are available for single-phase. China predicts that in the next 15 years, transforming capacity will be about 20 GVA.

Technology such as FACTS (Flexible AC Transmission) will be needed to provide voltage regulation and compensation.

FUTURE HVDC

Last year was an important year in the Chinese power sector. Some 21 provinces/regions encountered power shortages. To counter this, some $24 million was invested in generation, with 37 GW being put into operation. At the same time, 8500 km of transmission lines were also put into operation.

"In the 10th Five Year Plan (2005-2010) the country plans to invest $24 billion in transmission and distribution"

By the end of this year some 144 plants will have been constructed and a further 10 000 km of both AC and DC lines will have come into operation.

Looking ahead, ABB sees more opportunities for the use of HVDC technology. China has scheduled several HVDC projects for both the near term and the longer term (e.g. up to 2015). There are plans for 16 sets of DC transmission lines between 2006 and 2020.

Interestingly, some of these projects may stretch over greater distances and operate at higher voltages than links built to date. Most 'long' transmission distances in China are currently around 1000 km but the country is looking at ways of sending power over distances of around 1800-2000 km.

Commenting on the future of HVDC in China, Peter Leupp, Chairman and President of ABB in China noted: "When you look at the amount of power and distances, you may see a need to step up voltages from 500 kV DC to 600 kV DC. China is now studying our experiences at Itaipu where we built a 600 kV DC link, which is still the highest DC voltage level after 20 years in operation. They are seeing how they can apply this technology to transmit power to locations which are further away."

The Chinese way

ABB's involvement in the power transmission from the Three Gorges area to the load centres at the pacific coast demonstrates the company's strong local presence in the Chinese market and its strategy of working in direct partnership with local businesses.

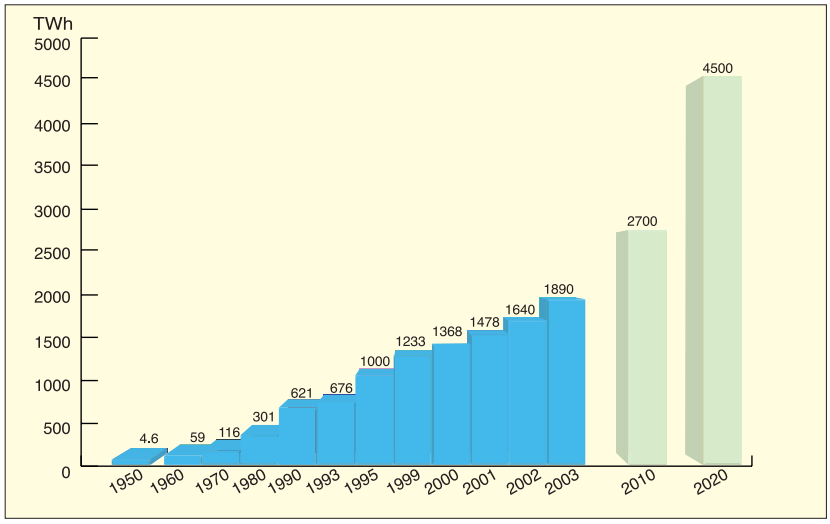
The impact of the Three Gorges project is huge on both a local and national scale. The project is located in Hubei Province. The main industries in the surrounding area are agriculture and fishing and one of the key goals of the project is to provide flood control in the middle and lower reaches of the Yangtze River. After completion of the project, the flood control standards in the Jingjiang reach of the Yangtze River will be raised from the present less than 10-year frequency flood to 100-year frequency flood.

The project called for the undertaking of a huge relocation programme. But although resettlement has been a difficult task, the project is being seen as a good opportunity to develop the local economy. The reservoir region of the project is in an under-developed region of China where people living in the area have a per capita income far below the national average. Since the project's implementation, thousands of hectares of farmland have been developed as well as thousands of square metres of new housing.

The project site is located 30 km from Yichang city, which is the home of the project owners – China Yangtze Three Gorges Project Development Corporation. Yichang has a population of 400 000 and construction of the project and its surrounding infrastructure is providing jobs for some 30 000 workers from the city.

At the national level, the project will supply China with cheap, reliable and clean energy. When it is complete in 2009 the plant will account for about four per cent of China's installed generating capacity and replace some 40-50 million tonnes of raw coal each year.

ANNUAL POWER CONSUMPTION GROWTH RATE OF MORE THAN 7 PER CENT IN THE PAST 50 YEARS



TECHNOLOGY TRANSFER

China has a policy of exchanging market share for technology; a policy which was adopted for the Three Gorges left bank power plant and its transmission links where HVDC technology was used for the transmission of power to Changzhou in east China and to Guangdong.

International manufacturers had to transfer technology to designated state-owned companies and use these companies as local sub-contractors – but take responsibility for the quality of performance and delivery of these local companies. International manufacturers were also asked to take full responsibility for the performance of the project including the performance their local partners.

THE CHINESE WAY

ABB is no stranger to doing business in China. It began selling into China almost a century ago but the turning point came about 10 years ago. Peter Leupp, Chairman and President of ABB in China, explained: "We decided to relocate our China headquarters from Hong Kong to Beijing. At this time we began to: set up more businesses in [mainland] China; manufacture locally; and develop our people. This has made us more of a fully fledged company within the country as opposed to just a sales

company here." Today ABB has 6500 people in more than 20 companies spread across 23 major cities.

Understanding China's current approach to building projects is key to being successful. China has many design institutions which carry out detailed engineering for power technology projects. It also has installation companies; testing companies, for commissioning; and construction companies to build plant.

Leupp commented: "The only thing they lack is products. Even for large power plants, China has very few turnkey power plants. In the past China has been a 'product market'. They would buy the turbines, the generators, boilers, auxiliaries and then build the plant themselves."

ABB has established a strong manufacturing base in China. For example, it has three companies established for building power transformers and owns some 20 per cent of the market for large-sized power transformers. Leupp noted: "These companies are at maximum capacity and we would have to consider setting up a fourth company if we want a bigger share of the market."

These companies were set up to overcome barriers to import. "We had a lot of customers wanting to buy our products but didn't have US dollars. At that time import was also more difficult. The customer would have to go through an evaluation and debate as to why a local product could not meet his needs."

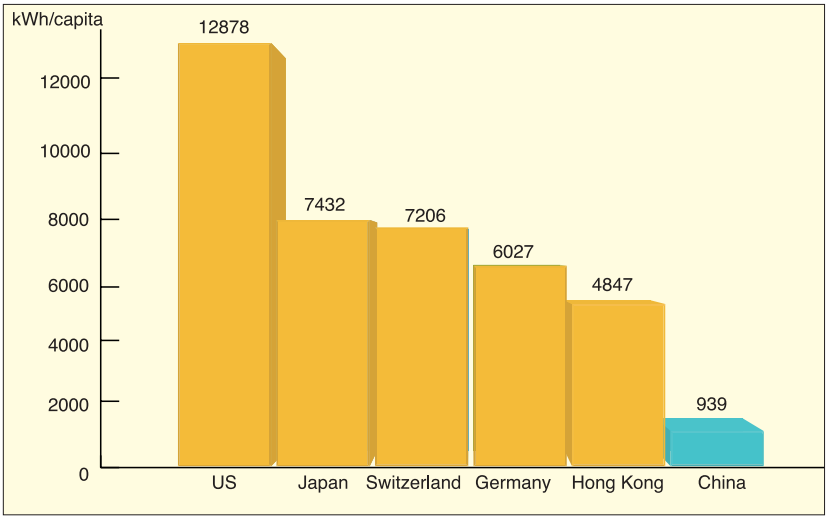
CHANGING TIMES

Certainly doing business in China has not been straightforward in the past. But with a fast growing economy and its entry to the World Trade Organization (WTO), the government is being forced to make changes.

China has one of the world's fastest growing economies and is now the world's fourth largest economy. At the 16th Party Congress in November 2002 the government set the objective to quadruple its GDP per capita (in the year 2000) by 2020. This will require a yearly growth rate of around eight per cent. This is a high growth to maintain but is necessary in order to keep down unemployment and maintain social stability.

The huge economic growth is accompanied by an increased power demand. Power consumption is expected to increase from 1890 TWh in 2003 to 4500 TWh in the year 2020. In the past 50 years already, there has been an average annual growth rate of seven per cent.

Unemployment is one of the main political challenges. There are an estimated 20-25 million job seekers each year. The state can, however, only provide some 10 million jobs each year through capital investments in infrastructure developments. China therefore has to rely on the service sector to provide the remaining jobs. This, however, requires the opening up of the service sector – a process which is being facilitated by the country's entry into the WTO in 2002.



CHINA: ELECTRIC POWER CONSUMPTION PER CAPITA

The country has a five-year grace period to become WTO compliant. The National People's Congress appointed a new government in March 2003 which will oversee a series of changes related to China's accession to the WTO. This government will serve for a five-year term.

The last two years have seen changes in legislation to make China more WTO compliant and this will be an ongoing process.

China is also opening its doors to foreign direct investment (FDI) and international events such as the 2008 Olympics and the World Expo in 2010 will promote further FDI and help lift the international image of the country.

China's economy is showing no signs of a near term recession. FDI is still strong – the actual utilization was about $50 billion in 2002 and is forecast at $60 billion in 2003. With the economy continuing to grow with no sign of a slowdown, there has been pressure to appreciate the Yuan.

WELL PLACED

China is well placed for continued growth and continuing changes in legislation will continue to encourage an influx of foreign capital and expertise. According to ABB, foreign investment accounts for more than 50 per cent of China's exports. "Foreign investment is the key behind the country's exports and its continuing growth," said Leupp.

The private sector will be China's engine for job creation. It accounts for more than 30 per cent of GDP. Today, the country has more than 1.7 million private enterprises with an investment of RMB1.1 trillion. In 2000, 75 per cent of industrial output came from non-state sectors.

Basing a company in China certainly provides competitive advantages. The country has a huge, educated labour force at low cost. With these fundamentals in place and a rapidly growing electricity market, ABB believes it is well positioned to increase business as China goes through its changes.

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Special Project Collection

Three Gorges

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The links from Three Gorges are a key part of China's goal to build an integrated national grid. Power generated from the plant will be transmitted to grids in central China, east China, Sichuan and Guangdong province. With more than 10 000 km of HVAC and HVDC lines, this system will form the basis for a new national grid which will combine the seven regional networks and five independent provincial networks to create two new interconnected regional networks. China's intention is to eventually create a unified grid, and have a modern power market in which plants sell power to the grid at market-determined prices.