

RECENT TRENDS OF POWER ELECTRONIC INDUSTRY IN CHINA

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Abstract.- Recent trends of the power electronic industry in China have been summarized in this paper. Based on the applications of the power electronic products in the chinese industries the production trends of power semiconductor devices, drives, power supplies, power electronic industry used in power systems in China have been briefly reviewed.

1. INTRODUCTION

Electrical energy is a most important element in modern industrial civilization. Per capita consumption of electricity has been a key measuring stick of a nation's prosperity. In order to use this energy efficiently with high quality, an increasing significant portion of the generated electrical energy has to be processed through power electronics for various applications in industrial, and military environments.

Power electronics plays a very important role both in renovating traditional industries and in building modern automation industries. Moreover, it is of great significance to save energy, reduce environmental pollution, improve work conditions, save raw material, reduce production cost and increase productivity.

Power electronics has established itself as a strong technological discipline that will seriously influence industrial development and economic competition of nations in the near future. In highly automated industrial environment of the future, possibly the computer, power electronics, and motion control will emerge as the most important technologies[1].

China is a developing country and it is still in the pre-industrialization stage. The traditional industries remain to be main force in chinese economy. Therefore the development of chinese economics will to a large extent depend on the renovation and the development of the traditional industries of China, even in a considerable period of time in the future.

To speed up its own economic growth, chinese government has put power electronics at one of the key technologies which will be developed in China with emphasized efforts in this century, even in the next century.

Table 1 gives some economic data of China before the year 2010.

Table 1. Economic Data of China Before The Year 2010

year data item	1993	1995	2000	2010
total output (¥ 100 million)	19.3	20	40	140
power devices (million units)	35	35	70	70
power electronic equipments (MkWs)	2.31	2.60	5.0	7.0

This paper will briefly introduce the developments and technical trends of power electronic industries in China.

II. INDUSTRY OF POWER SEMICONDUCTOR DEVICES

Historically, the evolution of power electronics generally follows the evolution of power devices. As a heart of modern power electronic apparatus, the power device always plays a significant role in the power electronic industry.

Up to now, thyristors still act as a main workhorse in power electronic industry in China. Today, China can produce 6kV/3000A power diode and 5.5kV/2500A thyristors with 100mm dies in batches. The thyristor and its applied technology have been mature and can basically satisfy the requirements of chinese industries.

At the end of 1980's, China transfered the gate turn-off thyristor technology from UK and Sweden respectively. At present, the reverse-blocking gate turn-off thyristor (GTO) of 1000 - 2000A/1600- 2500V and the shorted-anode GTO of 600-1000A / 2500-4000V can be made in China, but the products of high voltage large current GTOs are only fabricated on some transfered production lines with a small quantity.

The novelized field-controlled power devices, such as power MOSFETs, insulated gate bipolar transistors (IGBTs), static induction transistors (SITs), static

induction thyristors (SITHs), MOS-Controlled thyristors (MCTs), and the intelligent power modules (IPMS) are all at a research stage. Some factories are working on packaging the chips of those new power devices in China.

Table 2 shows production and research levels of power devices made in China. The yield of power devices made in China in 1995 is given in Table 3.

The main objectives for device production in the chinese " 9th Five-Year Plan " period (1996-2000) are developing 100-125mm dies, 6-8kV SCRs, 1600-2500A / 2500-4500V GTOs, and 800-1500A / 1500-4500V fast recovery diodes with $t_r < 1-3\mu s$, as well as high power IGBT modules etc..

Table 2 Power Semiconductor in China [2]

DEVICES	PRODUCTION LEVEL	RESEARCH LEVEL
Phase Control Thyristor	2kA, 4.5kV, di/dt = 200A/us dv/dt = 4kV/us toff = 400us	2.5kA, 6kV, di/dt = 200A/us, dv/dt = 200A/us, toff = 400us
Fast Switching Thyristor	1.2kA, 2.2kV, V _{tm} < 2.1V, toff < 25us	1.5kA, 2.2kV V _{tm} < 2.1V, toff < 25us
Triac	500A, 1.6kV	800A, 1.6kV
GTO	2kA, 2.5kV, V _{tm} = 3.0V, toff < 20us	2.5kA, 4.5kV, V _{tm} = 3.4V, toff < 20us
GTO module	2.5kA, 2.5kV	2.5kA, 4.5kV
BJT module	200A, 1.2kV	400A, 1.2kV
IGBT module	50A-200A, 1.2kV	200-400A, 1.2kV
MOSFET	10-35A, 1kV	
MCT		50A, 600V
BSIT	20A, 800V	30A, 800V
SITH	50A, 800V	60A, 1.2kV
LTT	500A, 4kV	1.2kA, 4kV
Rectifier Diode	3kA, 6kV	4kA, 6.5kV

Table 3 The Yield of Power Devices Made in China in 1995

device type	yield (unit)
power rectify diode	18,400,900
rectify modules & components	2,455,926
phase control thyristors	7,274,032
fast swiching thyristors	1,346,082
thyristor modules & components	44,939
hybrid modules	4,112
GTO	337
high voltage Si modules	6158
triac	76,067

III. INDUSTRIES OF POWER ELECTRONIC APPARATUS

Power electronic equipments are fundamentally based on the applications of power converters. Power converters convert electrical energy from AC-to-DC, DC-to-AC, DC-to-DC, and AC-to AC at the same frequency (AC voltage regulator) or at a different frequency (natural commutation cycloconverter, and forced commutation cycloconverter so called PWM controlled venturing or matrix converter). Power converters have technologically evolved three generations. The first generation exclusively uses devices such as rectifier diodes, thyristors, and triacs, which are commutated by a segment of inverse line voltage. The second generation mainly uses self-controlled devices, such as GTOs, BJTs, Power MOSFETs, IGBTs, SITs, SITHs, which are controlled by PWM technique. The third generation of power converters is featured by soft-switching, Active power factor correction, and harmonic elimination etc.

The applications of power converters applied in chinese industries, according to their main functions, can be catalogued into : drives, power supplies, and converters applied in the power systems.

A. The Drive Industry

The total per year yield of electrical motors made in China is about 350 - 450 million kW, among which 90% are AC motors, they consume roughly 60 - 70% of total electricity energy generated in China. For example, there are 4.2 million sets of blowers, pumps and compressors with total installed capacity of 130 million kW operated in chinese industries. However, up to now the motors controlled by variable speed drives in chinese industries are only about 8%. The equipment with a total installed capacity of 125 million kW in the chinese traditional industries should be renovated by using variable speed drives.

Based on the data of the total electricity production of 905 billion kWh in 1994, after adopting variable speed drives, the potential of the energy saving is about 40 billion kWh and the investment saving for electricity construction more than 40 billion RMBs. Therefore, the variable speed drive industry, particularly the AC drive industry, has very big potential market in the industries of steel, mineral coal, metallurgy, hydroelectricity, and lift manufacture etc. in China.

The drive industry in China was established in 1954. since DC motors have been still primarily using in steel, metallurgical, textile industries in China, up to now, 90% of variable-speed drives operated in industries still remains DC ones[3]. During 1985-1995, the power

density of the DC drives manufactured in China has been increased by 5 times due to transferring some advanced technologies from abroad. The accuracy of speed stability reaches to 0.05%, and the adjustable speed range is 1:100. But the control strategy adopted in those equipments is of analogues and their performance is not good enough. The replacement of analogue controllers with digital ones will be a main trends in chinese DC drive industries.

A largest 13MW DC drive with an analogy controller has been put into operation. Since 1992, full digital controlled DC drives could now be made in China, and widely used in industries. It is predicted that 25,000 sets of DC drives will be needed per year in China at the end of the year 2000.

It is no doubt that a clear trend indicates the supremacy of AC drive over DC drive which will be eventually pushed out of the market because of the troublesomeness from commutations and brushes specially needed for a DC motor.

China started to develop AC drives in 1970s, but the progress was very slow due to the difficulties from both the limited project budgets and lack of advanced technologies. Since 1980s, China has been opening its door to the outside and its economy has been growing up very fast. In late 1980s chinese iron and steel industry imported eleven AC drives with total capacity of 50MVA. Among them, nine are the cycloconverter-fed AC drives. The maximum one is operating as a main drive for a hot strip mill in Baogang, Shanghai. It is rated a power of 9MVA, output voltage of 1650V, maximum speed of 150 / 578 rpm, and 8.33 / 19.3 Hz of frequency range. Up to now the maximum AC drive operated in China was imported from ABB Co. and installed in Panjiakou Pumped-Storage Hydropower Plant with an inverter power of 60MVA. At the same period, a large number of general purpose BJT / IGBT PWM inverter-fed AC drives with a power range up to 200kVA rushed into chinese market several years ago.

These above mentioned transferred technologies and open door policy have certainly stimulated the development of AC drive in China. A home-made 1.25MVA, 10kV high power cycloconverter for an induction motor was put into operation in 1992. After that, a 2.5MVA cycloconverter-fed AC drive for a synchronous motor was successfully developed in 1993. A 2*1.4MVA, 3KV DC linked AC drive for an induction motor for blower application and a 2*5MVA fully digital-controlled cycloconverter-fed AC drive for a synchronous motor are under developing. China is capable of producing 3000 - 5000 kW, ≤ 600 rpm cycloconverters with vector control, and of developing a variable speed drive for synchronous motors with a capacity up to 12 MW, a speed regulation ratio of 1:10,

and an accuracy of 0.5%. A contract on importing 12 sets of main drives for a hot strip rolling mill plant in Baogang from a joint cooperation between Mitsubishi Co. and Habin machine manufacturer, was signed in 1993. The 6000A, 6000V GTOs will be used in the inverters. When these drives are put into operation, they will be one of the largest GTO inverters installed in the world.

Concerning the servo drive system, China can produce a servo drive system with an extra wide adjustable speed ratio of 1:48000, a lowest speed up to 1rev/day, and a speed accuracy of 0.005%. Another fast response servo-system with a range of tracking speed over 1:3000 can be made in China too.

Moreover, for transportation applications, a 4MVA AC drive for an electric locomotive is also under developing.

Table 4 shows the yield of drives made in China in 1995 and the maximum rating of drives. Table 5 summarizes the progress of drives in China.

During 1996-2000, China will put emphasis on the development and production of the 100 - 500 KW IGBT AC drives, 500 - 1000 KW GTO and/or SCR high power AC drives.

Table 4 The Yield Of 1995 And The Maximum Rating Of Drives Developed In China

Drives	Yield(kVA)	Maximum rating
DC Drives	64296	13MVA
AC Drives	20667	2.5MVA
Mine Tractors	6293.4	

Table 5 Summary Of The Development Of Drives In China

year	1970s '75	1980s '85	1990s '95
Developed Drives	①		②③④ ⑤ (R&D)
Speed Accuracy	DC drives	$\pm 0.5\%$	$\pm 0.5\%$ $\pm 0.25\%$ $\pm 0.1\%$ $\pm 0.05\%$
Adjustable speed range	1:40		1:100 1:40 AC drives

- 1.-Analog Controlled Thyristor DC Drives
- 2.-Digital Controlled Thyristor DC Drives
- 3.-Analog Controlled thyristor AC Drives
- 4.-Digital Controlled Thyristor AC Drives
- 5.-Vector Controlled BJT, IGBT, AC Drives (R & D)

B. The Power Supply Industries

In China various power supplies are routinely used in electrochemical processes, such as electroplating, metal refining, anodizing and production of chemical gases. They are also widely used for induction heating, DC and AC regulated power supplies, electrical welding, high voltage high frequency power supplies and lighting etc..

Table 6 shows the yields and the maximum rating of various power supplies made in China in 1995. Most of them still belong to first generation using power diodes and thyristors. Recent years IGBT modules and power MOSFETs emerge in large number into the chinese market, the power supplies applying these novel devices have been developed very fast recently.

Table 6 The Yield And The Maximum Rating Of Power Supplies Made In China In 1995

Power Supplies	Yield (kVA)	Maximum Rating
Electronical Processes	1,388,000	160kA / 920V
Induction Heating	345,195	3000kW, 1kHz 250kW, 8kHz 80kW, 100kHz 20kW, 300kHz
UPS	5031	BJT 150kVA
Electrical Welding	912,384	350A
High Frequency High Power	42,741	
PE Equipment for Power System		

The present situation and the trends of the industrial applications of power supplies are outlined as followings:

★ Supplies For Applications In Electrochemistry, Metallurgy, Electrolysis, Electroplate

All power supplies applied in these industries have been being the main power electronic products in China for a rather long term. Such kind of power supplies with a total capacity of 1.388 million kws were made in China in 1995, which is 74% of the total yield of power electronic products that year. Amonge them the diode rectifier with an efficiency of 97% were made in China, but most of the SCR rectifiers with a efficiency more than 98.6% are mainly imported because of their high reliability and anti-corrosion.

Before 80's, the electrolysis equipments used in the industries with a per year yield of 100,000 tons were imported from abroad. For example, two rectifiers of 56kA/920V used in Gwei-zhou aluminum factory were imported from Japan in the end of 70's. 8 sets of

56kA/1150V used in Jihai aluminum factory were imported from BBC and Siemens in the end of 80's. During 1996 - 2000 several large aluminum factories will be built in China. Certainly they need many this kind of power supplies.

Concerning the power supplies for metallurgic heating, such as the DC power supplies for the electric-arc furnace and the power supplies for the graphitizing furnace, many steel factories in China are still using the rotating blast furnace and the AC electric-arc furnace. These furnaces have many disadvantages, such as, the power factor is low, the three phase net power aren't symmetric, the electrode damage is serious, and the lifetime of the furnace is very short. The DC electric-arc furnace can overcome these problems. Some steel factories will be built in China during 1996-2000. They are planing to build some 70,000 kg DC electric-arc furnaces and the graphitizing furnaces, which need many DC power supplies with several to tens thousands amperes with an output voltage of 300V-400V.

★ Power Supplies For Induction Heating

Since 1970, the first 100kW, 1kHz power supply for induction heating with a parallel resonant inverter was developed by Zhejiang University in China, the induction heating power supply industry has been built up in China. The frequency range of the supply can cover up to 8kHz, the power rating up to 2000kWs.

In 90's the high frequency supplies for induction heating by using power MOSFETs and IGBT modules has been developed. The present per year yield of medium frequency induction heating supplies applied in melting applications is the highest. The power supplies used for holding furnaces need a power rating of more than 2000kW per unit. And a production line for ten thousands Ton forging press requires 2500kW/2kHz induction heating supplies. China is capable of producing the induction heating supplies of 250kW/8kHz applied for chilling treatment..

According to the 1996-2000 plan the emphasis will be put on the development of high frequency and / or large power induction heating power supplies.

★ Power Supplies For Electrowelding

With the fast development of chinese economics, the requirements for electrowelding machines increase rapidly with a growth rate of 20-30%. The yield of electrowelding machines have been up to 150,000 sets in 1995. But most of them are AC electrowelding machines. There were more than one hundred manufacturers in China to make the SCR rectifier electrowelding machines with a yield of 10 thousands sets in 1993. Amonge them only 6000 sets were the inverter welding machines with the frequency of 1-4kHz in 1994. Most of this kind of welding machines used in China now are from abroad with a total cost of 270

million USDs. In the 1996-2000 plan China decides to develop the IGBT inverter welding machines with a rating of 400A, 630A by own.

★ High Frequency High Voltage Power Supplies

The high frequency high voltage power supplies have been widely applied in power stations, cement mills, wastewater processing factories etc., which are related to the environment protection. The main objectives of using this kind of supplies are to trap dusts and to generate ozone. From 1985, the yield of the static electric dust traps products have increased by 4-5% per year in China. In 80's China transferred technologies of manufacturing, microcomputer controlled rectifiers, and the pulse supply equipments from Fida Co. of Sweden and GE of USA. In 1993 an intelligent electrical dust trap with high DC voltage of 62-72kV and efficiency of 98% was made in China. This trap was designed for a 300,000 kW generator set. Developments of intelligent static electric dust traps operating with following features, such as : high operating temperature, high output voltage, high power density, explosion-proof, and corrosion resistance have been listed as one of the main projects in China environment protection industry in the 1996-2000 plan. By estimation there will be 600-700 sets of such machines will be needed by China power ministry in that period.

C. Power Electronic Industry For Power Systems

China started to develop HVDC transmission system in 1970. Since 1990, Xi'an Power Rectifier Factory transferred thyristor based SVC technology, China can produce its own Static VAR Compensatory in the form of thyristor-controlled reactor (TCR) in conjunction with thyristor-switched capacitors (TSC) and harmonic rejection resonant filters . The maximum SVC produced in China is 220kV, 42.5MVA used for a substation. Nevertheless, because of the extremely high reliability requirements to the SVC, the active filter used in utility systems for harmonic elimination, and reactive power compensation, applications of converters in power system were developed rather slowly and less popular in China.

Most of them operated at main stations were imported from abroad. With growing phase control applications of power converters, utility systems are facing serious power quality problems. Recently proposed standards IEEE 519 and IEC 555 tend to severely restrict harmonic injection into power line by this type of nonlinear load. However, at present, bulky and expensive passive filters are still been popular used to combat the enharmonic problem in China. It is the key period for chinese economic developments from 1996 to 2000. With the rapid growth of the chinese power industry, there will have a strong demand to this industry, such as the demand to the generator exciter, the static VAR compensators, harmonics

suppressors, and to the power electronic equipment for power systems etc. The maximum transmission line with $\pm 500\text{kV}$, 1800MW capacity will be put into operation soon. It is predicted that about 300,000 km $\pm 500\text{kV}$ HVDC transmission line will be built up in China in the beginning of next century.

In 2000, the total installed capacity of the generation sets in China will reach 300 million kW and it will be 600 million kW in 2010. And the technical and economic specifications should approach the international standard. The total length of the transmission lines with a voltage over 220 kV will reach 171.200 kms in 2000. As an example, the Yantze Gorges Hydroelectric Station will install largest generation sets in the world with a transmission capacity of 6000MW by 500kV HVDC and AC transmission lines next century. The installed capacity for each generator will be 700MWs. 26 generator exciters with capacity of 680,000 kW are required in that project. Chinese government will adopt a form of international public bidding with three different modes : know, home-made, and cooperations.

Therefore the potential for the power electronic equipments applied for the power systems will strongly stimulate its growth in the near future.

The great demand to the power industry forces chinese engineers to make great efforts to generate electricity with high efficiency and high quality.

IV. CONCLUSION

The paper gives a brief introduction on the power electronic industries in China. It is clear that China has made great effort to develop power electronic industries in the past, but there seems to be a very large gap both in its technological level and in its industrial applications in comparison with advanced countries in the world. Therefore it is no doubt that China has to do its utmost to develop power electronics at a great pace in the future. Concerning the trend of power electronic industry in China, it can be concluded as follows:

- (1) China will put emphasis on developing field-controlled power devices, such as power MOSFETs, IGBTs, MCTs and intelligent power modules (IPMs).
- (2) The second generation of power converters using self-switching power devices will gradually replace most of the traditional phase controlled converters, and it will be more widely adopted by chinese industries. Especially AC drives will gradually replace the dc drives in the future.
- (3) As growing applications of power electronics in China, power quality problems will become more serious

So called "Green Power Electronics", free of harmonic contamination with unity power factor, will become more attractive. To improve the existing utility power quality, development of novel static VAR compensatory, PWM type active power line conditioners (APLC), and flexible AC transmission system (FACTS) will draw strong scientific interest in China.

Nevertheless, all those efforts have to be focused on one point: to obtain good compromises between the economical price and reasonable performance.

Chinese scientists and engineers working on power electronics will go forward hand in hand with ones around the globe, to develop this technology for the benefit of our society in the future.

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