

Technology of Photovoltaic Conversion in Japan and Its Enlightenment for China

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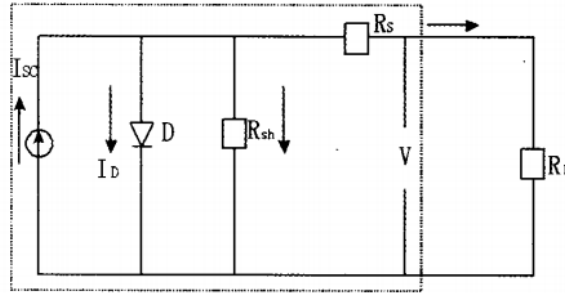
Abstract. As a country whose resources are deficient, Japan is being positive in exploring new energy and ahead of other countries. Electric power, as an important form of energy, is both primary energy consumption and secondary energy production industry, and Japan has made enormous efforts in new energy application in electric power industry. From the technology of photovoltaic conversion, the principle of technology of photovoltaic conversion and the current situation of its development in Japan are analyzed in this paper. The factors that affect the photovoltaic conversion efficiency are discussed and the ways that improve the photovoltaic conversion efficiency are proposed, which provide valuable experiences for the rapid development of photovoltaic industry in China.

Introduction

Since human being entered into industrial society, electric power has become the main primary energy consumption industry and the most important secondary energy production industry. Currently, electric power energy includes oil, natural gas, coal, water and other conventional energy, as well as new energy covering nuclear, solar, wind and biomass. Solar energy, as an inexhaustible supply of clean energy, has become a top priority of the world, which has driven the upsurge of photovoltaic power generation. According to statistical review of world energy 2011, at the end of 2010, the world's photovoltaic power installed capacity reached 39777 MW. Germany, which is the world's largest photovoltaic power country, the installed capacity in 2010 was 17320 MW, accounting for 43.5% of the world, while Japan ranked third place in the world after Germany and Spanish, the installed capacity was 3617 MW, took 9.1% of the world share. This paper focused on the research and application of technology of photovoltaic conversion in Japan, and how to improve the photovoltaic conversion efficiency to make a contribution to Japan's power energy. Meanwhile, combined with the current application of the photovoltaic conversion in Japan, we think about the enlightenment for the development of China's power resources.

The present of technology of photovoltaic conversion and the principle analysis

The solar cells used this effect are the devices made of semiconductor silicon, selenium and other materials, and they can absorb solar energy efficiently and convert it into electrical energy. These devices have the advantage of high reliability, long life, no pollution and high conversion efficiency, can be used as power source of artificial satellites, lanterns and transistor radios. The working principle is that sun light spreads on the PN junction and creates new pairs of electrons and holes. In the effect of PN junction electric field, holes flow from N to P, while electrons flow from P to N, which creates potential differences around PN junction and produces photovoltaic effect. When circuits connected, conversion from luminous energy to electrical energy is done. Single battery size is from 1×1cm to 15.6×15.6cm with several mill watts to watts of output power. Its theoretical conversion efficiency is over 25% while the practical efficiency is more than 22%. Among many solar cells, there are four kinds of them who are common and practical; they are single crystal silicon, polycrystalline silicon, amorphous silicon, and multiple compound solar cells.



Picture 1 sketch map of common silicon solar cell Picture 2 electric current sketch map of ideal solar cells

Current situation analysis of technology of photovoltaic conversion in Japan

Solar energy is inexhaustible clean energy, sum of global energy consumption equivalent to only 40 minutes' energy projected from sun onto the earth's surface. According to Japanese experts, the energy produced by the sun is about 42 trillion kilocalories per second. Except a part is reflected into space, the rest is equal to 60 millions of one million KW nuclear power reactors operating at the same time. If this part of energy can be used as electrical energy, electric quantity in one hour is enough for all human beings for one year. Till 2013, solar power only account for 0.2% in Japanese energy structure. Under the severe energy situation, Japan has stepped up the research and development of large-scale photovoltaic equipments to improve the efficiency of solar cells, at the same time, Japan also constantly study new technology of solar cells and application styles.

Japanese Kyocera Corp recently started to produce a batch of the highest levels of polycrystalline solar modules whose photovoltaic conversion efficiency is 17.8%, while the Panasonic Corp will use the new material and new structure of the battery modules in order to increase the photovoltaic conversion efficiency to 24%. Thus, Japan has increased its strength on the research of solar cells in order to effectively improve photovoltaic conversion efficiency and had achieved good results.

Chart 1 Analytical statement on types and characteristics of solar cells in Japan

types	materials	structure	measured photovoltaic conversion efficiency(%)	Cost advantages	advantages	disadvantages
silicon	monocrystalline silicon	p type monocrystalline silicon layer with n type silicon layers	25.0	poor	high conversion efficiency, high reliability	it's not appropriate for scale production; high costs; conversion efficiency close to the limit
	polycrystalline silicon	p type polycrystalline silicon layer with n type silicon layers	20.4	general	lower cost than monocrystalline silicon, high conversion efficiency, high reliability	conversion efficiency is lower than monocrystalline silicon; uncertainty price of raw material
	A-Si(amorphous silicon)	product p, i, n film with CVD technology	9.5	general	little silicon use level; lower cost than	conversion efficiency is lower than

					monocrystalline silicon	monocrystalline silicon; light leads to ageing
compound	GaAs	organic metal vapor phase method	26.1	poor	high efficiency, good tolerance to radiation in space	low film-forming rate; As is highly toxic; high cost
	CdTe	N type cadmium sulfide with p type CdTe cadmium telluride polycrystalline silicon	16.7	general	varies manufacture methods; wave band difference is used to generate; lower cost than monocrystalline silicon	Cd is toxic; rely on Te
	CIS/CIGS	CIS/CIGS plating into films	19.4	general	high light absorption rate	rely on Te
dye-sensitized	pigment, semiconductor, electrolyte	put titanium dioxide electrodes into electrolyte to absorb pigment	10.4	better	can be produced in general air condition; can be colored or hyalinized; can be generated with internal light	ultraviolet rays lead to ageing
Organic thin-film	fullerene, polymer	mix p type polymer with n type fullerene to coat	5.2	better	can be produced by the slimmest and cheapest spraying technology	ultraviolet rays lead to ageing; low conversion efficiency

The factors affect photovoltaic conversion efficiency

Light loss

According to optical theory, when the light illuminate on the battery, the positive and negative side of the cells will have refraction and reflection effect, plus the blocking effect of electrodes and grid lines, therefore battery pieces cannot absorb all photons and short circuit current is decreased.

Compound of pairs of electrons and holes

The existence of compound affects electric current collection, and compound includes three kinds, they are internal compound, surface compound and depletion region compound. The internal compound is the major one.

Loss in electric current transport

The solar cells can be analyzed as a current source, like picture 2.

In the picture, D refers to two-electrode valve, R_{sh} 、 R_s 、 R_L separately indicate parallel resistance, series resistance and load. From equivalent circuit we can see that if the parallel resistance is small and the series resistance is large, then the output current is small, that is, the current has large loss in the output process. In practice, ideal solar cells do not exist, so we should consider the parallel and series resistances. When the load is short, $V = 0$ now I_D is very small, and the short circuit current can be expressed as:

$$I_{SC} = \frac{I_L}{[1 + R_s / R_{sh}]} \quad (1)$$

According to (1) we can see that short circuit current I_{SC} is connected with R_s 、 R_{sh} , when $V = 0$, I_{SC} is in direct proportion to area of the solar cells and irradiance of incident light. The

expression of solar cells conversion efficiency is:

$$\eta = \frac{P_M}{P_{in}} = \frac{I_m V_m}{P_{in}} = \frac{FF I_{sc} V_{oc}}{P_{in}} \quad (2)$$

In the above formula, P_{in} 、 P_m 、 FF 、 I_{sc} 、 V_{oc} separately represent solar incidence power, maximum output power, filling factor, short current and open circuit voltage. According to the expression, the greater the filling factor, the more helpful to improve conversion efficiency.

The methods of improving photovoltaic conversion efficiency

The establishment and utilization of photovoltaic system

Japan use two plastic lens structure of tatami-large area has the highest photovoltaic conversion efficiency in the world right now. The main principle is that a light panel of 7.2mm area is set up in the lens. High intensity of sunlight is used to generate electric which makes the photovoltaic conversion efficiency up to 37.4% that is twice of general solar cells. At the same time, light panels can track the sun automatically; each piece of light panel can generate electric 800w.h, and only 8 tatami-large areas can provide a household of four people. And the key point of the high photovoltaic conversion efficiency is the use of the compound semiconductor material with 3 layers structure, which can absorb a greater wave length of light compare with single silicon cell panel. The establishment of photovoltaic system is to use the vacant space areas such as the roof of city apartments and public facilities or the space area that can get light in order to build a small power station for nearby residents.

Research and development of high concentrator solar cells with wide spectrum

Concentrator solar cells are battery pieces of multi-junction series based on GaAs, which has high photovoltaic conversion efficiency, good resistance ability to high temperature, small performance degradation after long working time little semiconductor material consumption, and covers 50% area less than silicon. The key to improve the conversion efficiency is to improving material structure and increasing the concentration ratio. In order to solve the problems of cells material, the technology "quantum dot" was introduced. The optical absorption character of quantum dot depends on the size of quantum dot, which not only increases the absorption spectra of the solar light, but also reduces the internal stress caused by the lattice mismatch. Arakawa Yasuhiko, a professor at University of Tokyo, plans to use the new "quantum dots" technology, which can increase three times of the photovoltaic conversion efficiency compare with current situation. Through the computer calculation, he believes that the photovoltaic conversion efficiency of solar cells can reach 75% in theory, and the most practical conversion rate can be up to 60% according to conservative estimate, that is, from 2013, photovoltaic conversion efficiency can be increased 30% within five years, and then within another five years it can reach 60%.

To increase the solar cells concentration rate, an optical splitter can be used to reflect 98% of light from 400nm to 900nm to the receiver, and then solar energy can be converted into electric, while the infrared light from 900nm to 2.7um can heat working liquid directly through infrared window. The optical splitter with high performance and low cost will directly influence the use of hybrid solar receiver. If the reflector is processed a slight curved, it can further assemble the reflect light and the transmitted infrared light is divergent, which is not only good for photovoltaic conversion, but also good for the heating efficiency of the working liquid. The total energy of photo thermal conversion accounts more than 70% for utilization of solar energy. While in the concentration photovoltaic system, the cost of photovoltaic receiver is 35% of the total cost, and the concentrator system including lens, support and tracking mechanism covers 46%, so the very important way to decrease cost is to improve the concentration system.

The enlightenment for China's electrical generation industry

Compared with the successful experience in the development of solar energy industry in Japan, China's current photovoltaic industry is still not getting rid of the essence of raw materials processing. The huge production capacity mainly concentrated in the steps of low cost of PV modules, and we didn't form a complete and mature industrial chain, so there is a lack of core

technology competitiveness. Besides, 90% of the market is over the seas, and the development of the industry and the market is not balanced. Once the industrial policies in major consumer countries had adjustments, China's PV companies will face certain risks. What's more, some proper incentive and supportive policies from are still missing; refinement and implementation of these policies are still not in place, and protection and support of laws are not enough. In order to promote the steady and healthy development of solar energy industry in China, we should draw lessons from the successful experience of Japan's solar energy industry. (1) To complete incentive policies from the government and build photovoltaic technology research institutions; (2) To fully explore the potential of domestic market, in accordance with the long-term development of renewable energy planning, the total PV market is expected to 1800 MW in 2020. (3) To create a complete industrial chain and improve the international competitiveness.

Conclusion

The photoelectric conversion technology in Japan is in the world's leading level, and changing the structure of the solar cell materials can continuously improve the photovoltaic conversion efficiency and make great contribution to the development of Japan's power resource. As one of the most rapidly developing economies in the world, China is only in the lower reaches of the world in technology and applications of photovoltaic power generation. In order to improve the development of China's solar energy industry effectively and promote the development of electric power resources, to create an industrial chain of mature, complete and with our own core technology is essential to focus.

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