Asia-Pacific
Economic Cooperation

APEC Photovoltaic Application Roadmap and Model Study

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APEC Photovoltaic Application Roadmap and Model Study (PVARM)

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1 Overview of PV Industry Development

As a common goal for APEC economies, sustainable development of energy and the environment can be effectively achieved by popularizing renewable energy sources vigorously. Of all the renewable energy sources, solar energy, as a clean, safe and widespread alternative energy source of high potential, plays a significant role in satisfying global energy demand with less reliance on traditional fossil energy.

However, cost has been the major obstacle for large-scale application of solar photovoltaic. PV power generation, as an emerging clean energy technique, still accounts for a low ratio in the whole energy consumption among APEC economies. Yet with advancing technologies and lower cost during recent years, more and more APEC economies start to realize the broad development space of solar photovoltaic industry. As a result, by the end of 2015, at least 2,000 GHW power will be generated by PV power generation, accounting for about 1% global power demand.

Figure 1-1 serious pollution by fossil fuel

The rapid development of PV power stations in the APEC region not only stimulates the healthy growth of PV industry, but also brings a series of problems.

Therefore, this report tries to bring up discussions on PV power station industry chain, technology application, PV power station accidents and issues and other aspects so as to come up with suitable circuit diagram and development mode for the APEC region.

1.1 Solar PV Global Capacity Statistics 2014

According to the latest IEA report, the global PV installed capacity reached 177GW by the end of 2014, which is more than 50 times increase than 3.7GW of 2004.

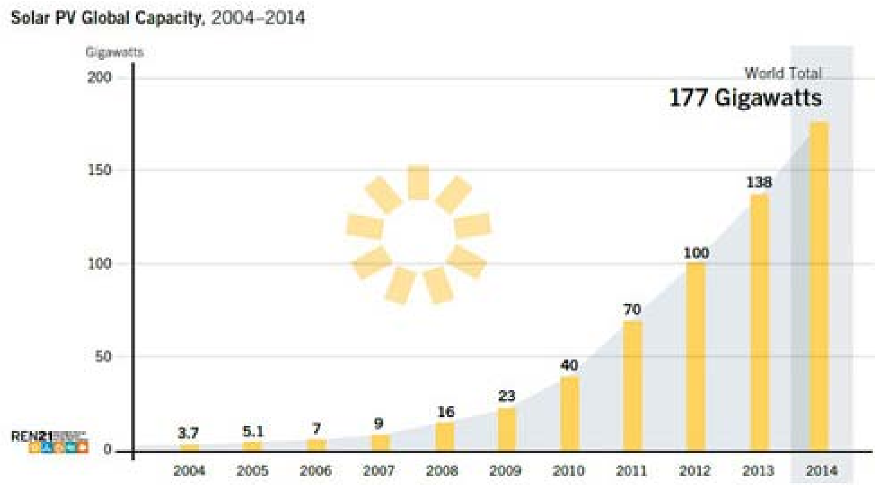


Figure 1-2 Solar PV Global Capacity Statistics

(source: REN21 Renewable Energy World White Paper 2015, 20150618)

The newly increased global installed capacity in 2014 stays at 38.7GW (IEA data) with China, Japan and the US keeping their leading roles as 2013, enjoying installed capacity of 10.6GW, 9.7GW and 6.2GW respectively. The installed capacity of European market has dropped for three years consecutively due to further slump of German and Italian market despite of the strong growth of PV installed capacity of the UK, keeping an overall installed capacity of about 7GW. Moreover, Indian, South Africa, Chile and some other emerging markets developed vigorously in 2014.

From the aspect of installed gross capacity, Germany comes the first with an installed capacity of 38.2GW, followed by China and Japan with 28.1GW and 23.3GW respectively. According to statistics, more than 20 economies by now have more than 1GW PV installed capacity, marking a great increase compared to only 9 economies in 2013.

Regarding the ratio of PV power generation in energy structure, more than 1% of the national power demand of 19 economies across the world is satisfied by PV power generation, among which Italy enjoys the highest portion of 7.9%, Greece 7.96%, and Germany 7.0%, all exceeding 7%. In Europe, about 3.5% power comes from PV generation. In addition, the portion of PV power generation in energy structure of Japan, Australia and Thailand, etc all goes beyond 1%.

According to the annual installed capacity 2014 data, the APEC region enjoys the highest speed in developing PV power stations. In addition to economies including China, Japan, the US, Australia, Korea, etc ranking top 10 in newly increased installed capacity, economies as Canada, Chile, Malaysia, Thailand and Mexico, etc also witnessed rapid increase in PV installed capacity. Preliminary estimate shows that the installed capacity of the APEC region in 2014 stays at 29.8GW, accounting for about 76% of the newly increased; and the overall installed capacity is about 80GW, about 44.9% of cumulative installed capacity. The rapid development can be attributed to government support for PV industry as well as related supportive policies implemented in the APEC member economies.

1.2 PV Development in Major Economies and Regions

1.2.1 Australia

With the illumination intensity of more than 80% land exceeding 2000kWh/m2, Australia makes one of APEC economies with best light resources. As a result, the cost for Australia PV power generation only accounts for half that of Germany with the same PV system cost.

Thanks to all the governmental supportive policies such as new national renewable energy resources objective, solar family and community plan, solar city and solar school program, solar energy flagship project (establishment of two large-scale PV power generation system) as well as the feed-in tariff subsidy policy implemented by state and regional governments, together with strongly high exchange rate of Australian dollar, Australian PV market grows vigorously with PV power generation gradually accepted and supported by the public. In addition, if its cost decreases with the international trend, PV power generation will become more popular in the coming ten years even without government subsidy. Therefore, Australia has the potential to develop into a major global PV market.

Australia ranks the 7^{th} in global annual installed capacity 2014 with 910GW, which is mainly made up of small-scale systems less than 100KW.

1.2.2 China

By the end of 2014, the cumulative PV power generation installed capacity of China reached 28.05GW with a year-on-year growth of 60%. Among all the installed capacity, large-scale ground PV power stations accounts for 23.38GW and distributed 4.67GW, generating a year-on-year growth of more than 200%.

China’s annual installed capacity in 2014 stays at 10.6GW, including 8.55GW from large-scale ground PV power stations and 2.05GW from distributed PV power stations. This is nearly one fifth of global newly increased and one third of China’s PV battery pack production, thus realizing the governmental goal of 10GW average annual increase.

In March 2015, National Energy Administration of China issued *PV Power Generation Construction and Implementation Project 2015*, increasing the PV construction scale in 2015 to 17.8GW. In June, National Energy Administration of China, Ministry of Industry and Information and Certification and Accreditation Administration jointly issued *Advice on Promotion of Advanced PV Technical Products Application and Industrial Upgrade* to implement the pilot project, which brought an exponential growth to the PV market. By the end of August 2015, China’s newly increased grid-connected PV installed capacity reached 7.73GW with a cumulative installed capacity of 35.7GW. During the first half year, the poly-crystalline silicon production was 74,000 tons, 15.6% increase on year-on-year basis; import volume stayed at 60,000 tons, increased a little over the same period of last year; the battery pack production reached 19.6GW, which marks 26.4% year-on-year increase; and the export value of major PV products such as silicon wafer, battery and modules reached $7.7 billion. According to preliminary statistics, the gross output of PV production industry in China during the first half of 2015 exceeded $200 billion.

It is predicted that by the year 2020, the PV Installed capacity of China will go beyond 100GW and by 2050 reach 2,200GW, acting as one of the major energy sources of China.

1.2.3 Japan

As one of the first group of APEC economies stimulating their national PV market, Japan has once been the biggest PV application market across the world. The priority of Japan's PV application lies in the roof system, which occupies as high as 90% of its market. However, due to Fukushima nuclear accident, it began to put emphasis on the development of large-scale ground power station. By now, the cumulative PV installed capacity of Japan ranks the 3rd globally following Germany and China, accounting for 17.4% of the world's total.

The Japanese government has long been promoting solar roof installation among common people by FIT subsidy policy. In March 2014, the government reduced the FIT subsidy rate as 32 yen (including tax) to commercial power generation project (installed capacity ≥10kW) for 20 years and 37 yen (including tax) to commercial power generation project (installed capacity ≤10kW) for 10 years. Though the Japanese government further reduced FIY subsidy in 2014, Japan FIT still leads the world, which is two times that of Germany. In addition, 80% of distributed PV systems in Japan are installed in personal houses, which also take the lead in the world. Besides, several important events including the Fukushima nuclear leak event and the Summer Olympic Games 2020 also accelerate solar energy development in Japan.

1.2.4 Korea

The Korean government spares no effort in facilitating PV industry development and has already carried out renewable energy sources combination standard program, which came into effect last year as a substitute for the original FIT subsidy policy. According to the program, Korea aims to increase its PV installed capacity to 1.2GW by 2015. In 2014, the annual installed capacity of Korea was 909GW, making its cumulative installed capacity reach 2,384GW.

1.2.5 United States

In 2004, Obama administration issued ARRA (American Recovery and Reinvestment Act), in which $4 billion is invested to projects related to energy efficiency and renewable energy.

In last two years, BAPV stands out in American PV industry development thanks to the political guidance and the massive innovation of new-type financial mode in PV industry. As for policy, instead of the popular nationwide FIT subsidy mode, the US adopted a series of policies including preliminary investment subsidy, electricity price subsidy, PV investment tax deduction and exemption, accelerated depreciation, REC, net metering power price and RPS, etc, which is more conductive to the development of distributed PV compared to FIT.

As is announced by GTM Research and SEIA on March 10th, the annual installed capacity of the US in 2014 reached unprecedented 6.201GW, of which 3.934GW from utility, 1.231GW from residential and 1.036GW from non-residential/commercial, marking a more than 30% growth compared to that of 2013. Together with 736GW from CSP, PV power generation accounts for 32% of the newly increased generating capacity of the US in 2014, ranking the second place after natural gas thermal power generation with two years consecutively surpassing wind power generation and coal thermal power generation. In addition, the PV application market scale of the US in 2014 reached $13.4 billion, .which is a substantial growth to $3 billion in 2009 thanks to a series of reasons including lower solar module price, new business mode, more liberal regulations and lower financing cost, etc.

With the ITC program implemented since 2006, the US has invested a total of $66 billion on PV power generation system setup, creating more than 150 thousand working opportunities, which are more than the total number of employees of Google, Apple, Facebook and Twitter.

The installed PV power generation system is able to generate a total of 20GW power output, which can satisfy at least 4 million families. GTM Research predicts that the market scale of PV power generation device of the US in 2015 will reach 8.1GW with a year-on-year growth of 31%.

2 PV Power Station and PV Industry Chain

2.1 Major PV Application Method

2.1.1 Large-scale Ground Power Station

Large-scale ground PV power station refers to PV power generation systems that are installed above ground and connected to the public grid with electricity transmission tasks. It is preferred by large-scale power station developer with the features of large scale, high investment and convenient management (from the aspect of economical efficiency of scale).

Large-scale PV ground power stations are preferred in economies with comparable lower electricity price as China. From the market segment of China's PV application, the newly increased PV installed capacity and cumulative installed capacity come mainly from large-scale ground power station. Whereas in the meantime, rapid development of large-scale ground PV power station is stranded due to difficult grid connection as well as delayed and inadequate subsidy.

Figure 2-1 Large-scale Ground Power Station

2.1.2 CPV

CPV is the technology that directly converts concentrated sunlight into electric power via high conversion efficiency PV cells. As is predicted by IHS, CPV will keep a 37% growth rate from the beginning of 2015 to accomplish 250GW installed capacity by the end of 2015.

a) High Concentration

High concentration cells are mainly made of gallium arsenide with optical condensers, secondary optical devices, triple-junction solar cells and tracking systems as their major system unit. The most outstanding advantage of high concentration technology lies in its high photoelectric conversion rate, which can reach 36% to 40% with 500 times concentrated sunlight, as is compared to 16% to 18% for crystalline silicon cells and 9% to 10% for thin film PV cells.

The disadvantages of high concentration cells should also be taken into consideration. Arsenic in gallium arsenide is too highly toxic to be used heavily. Moreover, the cost of concentration cells production is far higher than the previous two generation solar cells (crystalline silicon cells and thin film cells) due to lack of raw materials.

Figure 2-2 High Concentration

b) Low Concentration

As a kind of CPV, low concentration increases efficiency by concentrating sunlight via mirror. Different from high concentration (usually dozens to hundreds times), low concentration requires less in solar tracking accuracy, battery performance and module heat dissipation effect and is more reliable.

Figure 2-3 Low Concentration

2.1.3 Fishing and PV Hybrid

Since large-scale PV power stations demands large floor space, large-scale PV power station development in economically advanced regions is faced with scarce land resources though it is easy for them to be connected to the grid. The fishing and PV hybrid mode provides a new way to develop large-sale PV power stations in economically advanced regions with land shortage.

Fishing and PV hybrid power station means to utilize abundant fish ponds and reed marshlands to develop PV power generation projects, enjoying the potential of developing tourist industry with the mode of power generation above water and aquaculture under water. This mode makes the best of land efficiency and will play as an exemplary role in combining comprehensive utilization of land and new energy industry.

Figure 2-4 Fishing and PV Hybrid

2.1.4 PV Agricultural Greenhouse

The power generation module of PV agricultural greenhouse makes use of the roof of the greenhouse instead of ground, thus saving land resources without changing the nature and main goal of land utilization. The power generated can not only cater to the power demand of the greenhouse in temperature control, irrigation, lighting and fill-in light, etc, but also can be sold to the grid company once connected to the grid so as to bring benefits to the investor.

PV agricultural greenhouse combines solar PV power generation, smart temperature control and modern high-tech cultivation. With steel framework, it is covered on the top with solar PV modules without affecting solar PV power generation and the lighting demand of the crops inside. The power generated can support its irrigation system, provide supplementary lighting to the crops, satisfy heating demand in winter and increase greenhouse temperature so as to accelerate crop growth.

Power generated by PV greenhouse can be consumed in two ways: for small-scale distributed PV power stations (such as less than 6MW), power will be used by themselves with surplus power connected to the grid; and for large-scale ones, power generated will be connected to the grid directly.

Figure 2-5 PV Agricultural Greenhouse

2.1.5 Self-provided Commercial and Industrial Power Plant

Self-provided commercial and industrial power plant is one form of distributed PV power generation, especially referring to PV power generation devices that features power distribution system balancing adjustment near commercial and industrial user site with self-sufficient operating method. Since the electricity price for commercial and industrial users is comparatively high, particularly for manufacturing enterprises that have strong demand for power, self-provided commercial and industrial power plant can save energy, protect environment and cut electricity cost in the meantime by installing PV devices on their roofs. Altogether, it is a kind distributed PV power station mode of great prospect.

Figure 2-6 Self-provided Commercial and Industrial Power Plant (Distributed)

2.2 PV Industry Chain

The complete PV industry chain covers all aspects related to PV manufacturing products and services, including upstream raw materials, midstream module manufacturing, downstream system application and power station development as well as operation, maintenance and financial services, etc.

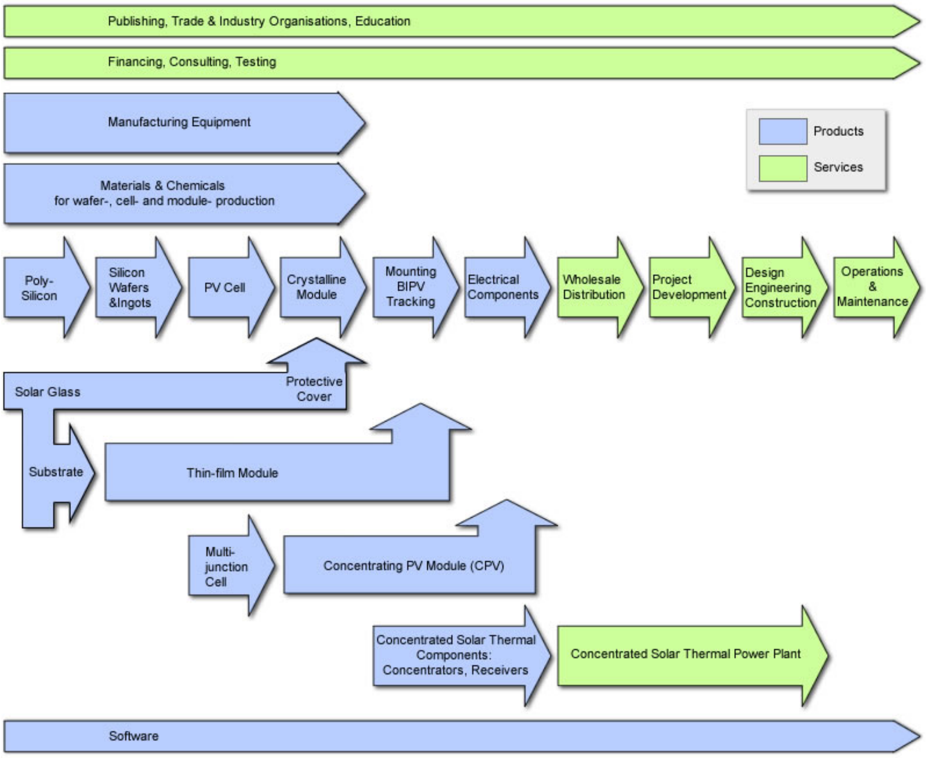


Figure 2-7 PV Industry Chain

From the perspective of manufacturing, the PV industry chain mainly includes 5 links: silicon mixture and silicon wafer as the upstream, solar cell and battery module midstream and the solar system downstream.

Figure 2-8 PV Manufacturing Industry Chain

2.2.1 Poly-crystalline Silicon

In 2013, global poly-crystalline silicon industry scale continued to increase with the capacity reaching 387 thousand tons and output staying at 246 thousand tons, marking a 5.1% year-on-year growth with the increment mainly from solar grade poly-crystalline silicon. The demand of electronic grade poly-silicon approximates 25 thousand tons while the output stays at about 26 thousand tons, which are mainly produced by a few poly-crystalline silicon enterprises in China, the US, Germany and Korea, etc.

In 2013, China ranks 1st with an output of 84 thousand tons across the world, followed by the US with 59 thousands tons, then Germany, Korea and Japan with 46 thousands tons, 41 thousands tons and 13 thousands tons respectively. Moreover, global poly-crystalline silicon industry highly concentrate with the top ten poly-crystalline enterprises producing a total of 278 thousand tons capacity and 215 thousand tons output, accounting for 87% of the global total output.

Tablet 2-1 Major Manufacturers and Respective Output (2013)

Manufacturer	Economy	Capacity (ton)	Output (ton)
GCL Silicon	China	65000	50400
Wacker	Germany	52000	46000
Hemlock	US	42500	33000
OCI	Korea	42000	35000
REC	Norway	25000	20500
TBEA	China	17000	7900
Tokuyama	Japan	15400	7500
MEMC(SunEdison)	US	8000	6000
Daqo New Energy	China	6000	4800
AsiaSilicon	China	5000	4000

Data source: OFweek

2.2.2 Silicon Wafer

In 2013, global silicon wafer industry scale continued to increase with the capacity exceeding 57GW, of which Mainland China produced 40GW, Chinese Taipei 4.5GW and Europe 4GW. Global annual output reached 39GW with a 8.3% year-on-year growth, including 29.5GW from Mainland China and 4GW from Chinese Taipei, as well as 1.6GW and 1.2GW from Korea and Europe respectively. From the perspective of developing region, global silicon wafer output gradually concentrates in Asia with 52GW capacity, which is 91% of global silicon wafer capacity and 37.7GW output, accounting for 97% of global total. As for the manufacturer, top 10 global silicon wafer manufacturer is able to produce 26GW capacity and 23.1GW output, which is 60% of the world total, marking an increasing industrial concentration.

Tablet 2-2 Global silicon wafer industry

Manufacturer	Economy (Region)	Capacity (GW)	Output (GW)
GCL	China	10	8.6
Yingli Solar	China	2.8	2.3
Renesola	China	2.2	2.1
Green Energy Technology	Chinese Taipei	2	1.9
Sornid	China	1.8	1.6
LDK	China	3.3	1.5
Jinko Solar	China	1.8	1.5
Nexolon	Korea	1.7	1.3
Longy	China	1.3	1.2
Trina Solar	China	1.4	1.2

Data source: CPIA, OFweek

2.2.3 PV Cell

In 2013, global PV cell production scale maintained its momentum of growth with the capacity exceeding 63GW (excluding thin film cell) and output staying at 40.3GW, a 7.5% increase compared to that of 2012. The ratio of poly-crystalline PV cell to mono-crystalline PV cell is about 3 to 1 in 2013. However, PV cell development becomes flat during recent years regardless of its growth momentum maintained year by year. From the aspect of developing region, Mainland China ranks the 1st across the world with an output of 25.1GW, which is 63% of the world total. The crystalline silicon cell output of Chinese Taipei and other regions increased 55% over the same period of last year with 8.5GW, ranking the 2nd globally. As for the manufacturer, capacity and output by major 10 PV cell manufacturers can reach 20GW and 16.3GW, accounting for 33.3% and 40.7% of the world total respectively, which increased 2 percentage points over the same period of last year.

2.2.4 Battery Module

Global battery module production scale also maintained its momentum of growth, increasing 11.3% over the same period of 2012 with 65GW capacity and 41.4GW output in 2013. Regionally, China is still the biggest Solar PV cell manufacturer in the world with an output of 27.4GW, which mainly comes from crystalline silicon cells. It is followed by Europe and Japan regarding the output with 3.8GW and 3.5GW respectively. From the aspect of industrial concentration, 10 biggest module manufacturer is able to provide an output of 16.3GW, accounting for 41.6% of the world total with a tear-on-year growth of 2.5 percentage points. Moreover, the output of top 9 biggest manufacturers all go beyond 1.1GW. It is worth to mention that almost all 10 biggest PV module manufacturers are located in the APEC region, including 5 in China, 2 in the US, 2 in Japan and 1 in Korea.

Tablet 2-3 Global battery module industry

Manufacturer	Economy (Region)	Capacity (GW)	Output (GW)
Trina Solar	China	2800	3100
Yingli Solar	China	2450	2471
Artes	China	2600	1800
Jinko Solar	China	2000	1700
First Solar	US	2560	1628
Hanwha	Korea	1620	1300
JA Solar	China	1800	1218
SunPower	US	1270	1134
Kyocera	Japan	1200	1100
Solar Frontier	Japan	980	920

Data Source: OFweek

2.2.5 PV System

The PV power station development industry chain consists of feasibility study, engineering design, procurement, project execution, erection & commissioning and operation & maintenance.

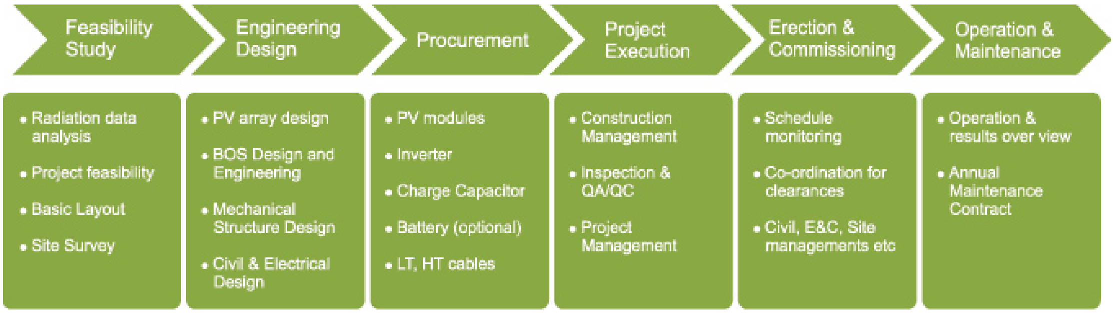


Figure 2-9 PV Power Station Development Industry Chain

As is stated in the IHS report, the general installed capacity of solar PV system in 2014 by top ten EPC manufacturers is expected to reach 8GW, which can satisfy 20% non-residential PV demand of the global PV market.

World PV Integrator Rankings (based on installed capacity)

	2014 (estimated)	2013
1	First Solar	First Solar
2	TBEA Sun Oasis	TBEA Sun Oasis
3	SunEdison	GD Solar
4	SunPower	Shanghai Solar Energy
5	GD Solar	SunEdison

Source: IHS ©2014IHS

Figure 2-10 World PV Integrator Rankings(based on installed capacity)

Source: IHS

According to the latest ranking list 2014, the installed capacity in 2014 of two companies including First Solar of Arizona, the US and TBEA of Xinjiang, China is expected to increase more than 1GW. These two companies, focusing on the internal development projects of their national markets, is followed by SunEdison headquartered in Missouri, the US, SunPower headquartered in the Silicon Valley as well as GD Solar of China.

With the enthusiasm of PV investment shifting from manufacturing link in previous years to PV application link, a lot of traditional industry and enterprises also enter into PV investment sector apart from financial institutions. In addition, PV application shows a diversified development trend as combination with poverty alleviation, agriculture, environment and climate, etc.

2.2.6 Micro-grid Application combining PV and Energy Storage

Micro-grid, as a small-scale power generation and distribution system made up of distributed power supply, energy storage device, energy conversion device, related load and monitoring and protecting device, is an autonomous system of self control, protection and management which can operate by being connected to the power grid or by itself.

PV power generation system is stimulating traditional large-scale regular power generators depending on PTD system to evolve from simple method of uni-direction to a hybrid power supply mode that is more complex and smaller in scale. The micro-grid combining PV and energy storage can be widely used in remote areas, army and national defense, industrial plants, industrial and commercial buildings as well as residential communities and buildings, etc.

Advantages of micro-grid:

- Environmentally friendly PV Generation reduces carbon emission
- Better self control and adjustment performance requires less technical input during operation
- Isolation from the bulk power system lowers risks brought by grid outage and disturbance
- Increased users autonomy

Since micro-grid is able to enhance power supply safety and reliability of the power grid as well as power utilization efficiency, it is bond to develop vigorously with increasingly mature technology, lower renewable energy sources cost, energy storage industry development and increasing fossil energy prices.

2.2.6.1 PV Application in Smart Grid

Smart grid, intellectualization of the power grid, is also called “Power Grid 2.0”, aiming to make the power grid reliable, safe, economic, highly-efficient, environmentally friendly with application of advanced sensing and measuring techniques, device technology, controlling method as well as decision support system based on an integrated and high-speed bilateral communication network. It mainly features self-healing, user encourage and protection, power quality satisfying under demand of the 21st century, access for various power generating methods, power market initiation as well as optimal and high-efficient operation of assets.

Smart grid enjoys the following advantages:

（1）promoting development and utilization of clean energy, reducing green gas emission and stimulating low-carbon economy development;

（2）optimizing energy structure, realizing complementary of various energy forms, guaranteeing safe and stable energy supply;

（3）enhancing energy transmission and utilization efficiency, improving safety, reliability and flexibility of power grid operation;

（4）advancing technological innovation of related sector, promoting technical upgrade of equipment manufacturing, information communication and other industries; increasing employment opportunities, stimulating sustainable development of social economy.

Once intellectualized, distributed PV will be equipped with sensing, information interaction, comprehensive judgment and decision functions to be integrated to the entire system with adaptive control. However, compared with the mature technology of bulk power system, distributed PV power generation is still at its preliminary stage, still requiring time and practice to solve various problems confronted and optimize technological projects.

2.2.6.2 PV and the Energy Internet

Enterprises enjoying high market share in distributed PV industry in the US are all equipped with IT management platform of independent intellectual property, via which 8 links of PV projects including market exploitation, resources evaluation, project design, project construction, operation management, assets disposal, device manufacturing and financing are organically integrated to establish an ecological system with resource integration capabilities.

The energy internet not only supplies power as traditional power grid, but also provides a public energy exchange and sharing platform for various customers. The Energy Internet has the following 5 characteristics:

Renewable: renewable energy sources play as the major energy supply for the Energy Internet. Large-scale access of renewable energy power generation which is intermittent and volatile will harm the stability of the power grid, thus stimulating traditional energy network to transform into the Energy Internet.

Distributed: considering the distributed feature of renewable energy sources, networks for collecting, storing and utilizing energy sources is required to be established. Being small in scale and distributed in wide range, all these micro energy networks can act as nodes of the Energy Internet.

Interacting: micro energy networks that are distributed in wide range can only balance energy supply and demand by combining for energy exchange. The Energy Internet focuses on establishing interconnections between micro energy networks made up of distributed power generation devices, energy storage devices and load, while traditional power grid concentrates on how to "bring in" all these elements.

Open: the Energy Internet should be a reciprocal and flat energy sharing network with bilateral energy flow, enabling plug and play of power generation devices, energy storage devices and load. As long as interoperability standard is satisfied, this access will be autonomous with equal importance for all network nodes from the perspective of energy exchange.

Smart: energy production, transmission, conversion and utilization in the Energy Internet should be smart to some extent.

Compared to power system of other forms, the Energy Internet has 4 key technical features:

（1）High Concentration Rate of Renewable Energy: with a large number of distributed renewable energy power generation system being placed into the Energy Internet, the controlling management of the Energy Internet, under the situation of high renewable energy concentration rate, is far different from that of traditional grid, requiring research of a series of new scientific and technological issues.

（2）Nonlinear randomness: despite of its major role in the future Energy Internet, distributed renewable energy sources is uncertain and uncontrollable. In the meantime, considering random features such as the real time electricity price, operation mode change, user side response, load change and other elements, the control, optimization and dispatch of the Energy Internet is confronted with greater challenges.

（3）Multi-source big data: with implementation of distributed power supply grid connection, energy storage and user side response, the Energy Internet is required to deal with mass information including weather information, user power consumption features, energy storage status and other sources. In addition, the quantity of smart terminal with measuring functions in the Energy Internet will increase dramatically with the popularization of application of advanced measuring technologies, which will trigger rapid increase of data size.

（4）Multi-scale dynamic property: the Energy Internet is a system of high interaction of substance, energy and information, a poly-domain of physical space, energy space, information space and even social space, and a complicated system including continuous dynamic behavior, disperse dynamic behavior and ignorant conscious behavior. As a super large compound network with mutual dependence between society, information and physics, the Energy Internet enjoys broader openness and greater complexity compared to traditional grid, presenting complicated dynamic characteristics of different scales.

2.2.6.3 New Opportunity of PV Industry: Internet + Finance

With the outstanding financial feature of energy assets, each step of PV power station development requires strong support from finance industry.

However, the conservative and prudent attitude of financial assets due to various reasons as well as unbalanced resources provide an opportunity for “Internet + Finance”, thus resulting in a new transformation chance for the PV industry within the APEC region. Large-scale power station is reluctant to publish its operation data on account of different reasons. As a result, data demand from the financial industry together with reluctance of large-scale power stations will result in difficult PV industry financing with data conflict or unbalanced data information.

“Internet + Finance” is able to provide both financing and maintenance assistance to power stations, therefore, some enterprises start to transform from “Internet + Finance” to management and control as well as industry chain systematic service. With big data support, it is convenient for users to know the operation status of his power station and communicate with operation and maintenance service provider once problems appear. In this sense, “Internet + Finance” at present is a communication platform of multi-party cooperation that locate and solve problems as well as provide lasting stable services instead of simple combination of data and financial capital.

3 PV Technological Innovation

3.1 PV Power Station Modularization and Standardization

3.1.1 PV Power Station Modularization

The matching issue of PV system can be solved with refined and modularized design so as to achieve best combination of PV system, thus realizing its modularized application. Refined design enables design plan optimization, takes differentiated application into consideration and compares project design (including comparison of cost, generated capacity, yield rate and individual demand); while modularized design makes it easier to install, dismantle, manage and match standard products (color steel title roof, civil roof and commercial roof). The modularization of PV system application is expected to stimulate large-scale popularization and application of PV system with optimal power station efficiency.

3.1.2 PV Power Station Standardization

Standardization of PV system application can mainly be reflected in two aspects: on the one hand modularized products used in key devices of PV power generation system, on the other the standardization of technical process, document system and project management during all links of PV power station construction management.,

a) Modularized Products Affiliated to Key Devices

- Large-scale PV power generation system installed on flat ground is applied in two technical means: the first is application of concentrated inverter, which is realized with fixed-type components , combiner box and inverter as well as AC/DC power distribution cabinet; the second is serial type inverter, which works with the direct current of each series directly converted into alternative current instead of DC combination, so as to realize long distance transmission with higher electric-pneumatic conversion efficiency.
- Large-scale PV power generation system installed on complex ground is

applied with modularization of some key devices in accordance with the terrain. The major units of modularization are components, combiner box, inverter and holder, etc.

- There are also different types of industrial and commercial roofs for distributed industrial and commercial plants of large floor space. Corresponding modularized techniques including integrated modularized design of micro-inverter, DC optimizer and folding bracket, etc., can be utilized for mainstream roof forms at present.
- Modularized design of distributed user system, which caters to buildings of different forms in line with the differences between villa and other buildings, is easy to install, secure and reliable.

b) Standardization of PV Power Station Construction Management

- Technical Process Standardization: standardization of all personnel, department and unit frameworks involved in each link demanded for site testing, scientific research, material submission, approval, construction and operation and maintenance.
- Document System Standardization: standardization of texts, materials as well as the depth of description required for each link is demanded.
- Project Management Standardization: standardization of management layer and departmental coordination involved in the project is required.

3.1.3 PV Power Station Serialization

Serialization of PV system application domain, scale and territorial environment can be realized with further modularized design based on modularization and standardization of PV system application, helping the PV system to cater to modularized demands of different sectors as industry, agriculture, commerce, civil use and architecture, etc, modularized demands of different installed capacity as well as modularized demands of different territory, irradiation and climate respectively.

3.2 PV Cell Technical Innovation

3.2.1 Solar PV Cell Technical Classification

Solar PV cells are mainly classified as crystalline silicon solar cells, thin film solar cells and concentrating solar cells.

The first generation is crystalline silicon PV power generation, including poly-crystalline silicon and mono-crystalline silicon.

The second generation is thin film cells of wide varieties which require less materials yet provide lower electric pneumatic efficiency. Thin film cells mainly cover the following kinds: amorphous, crystallite and other silicon thin film, CIGS thin film, CdTe thin film and gallium arsenide thin film cells. With improved conversion efficiency and working life, thin film technology will have specific application market and even enjoy certain advantages especially for regional specific market as building integration.

The third generation lies in PV power generation technology with condensation as the key technique, which will increase the cell conversion rate by large margin.

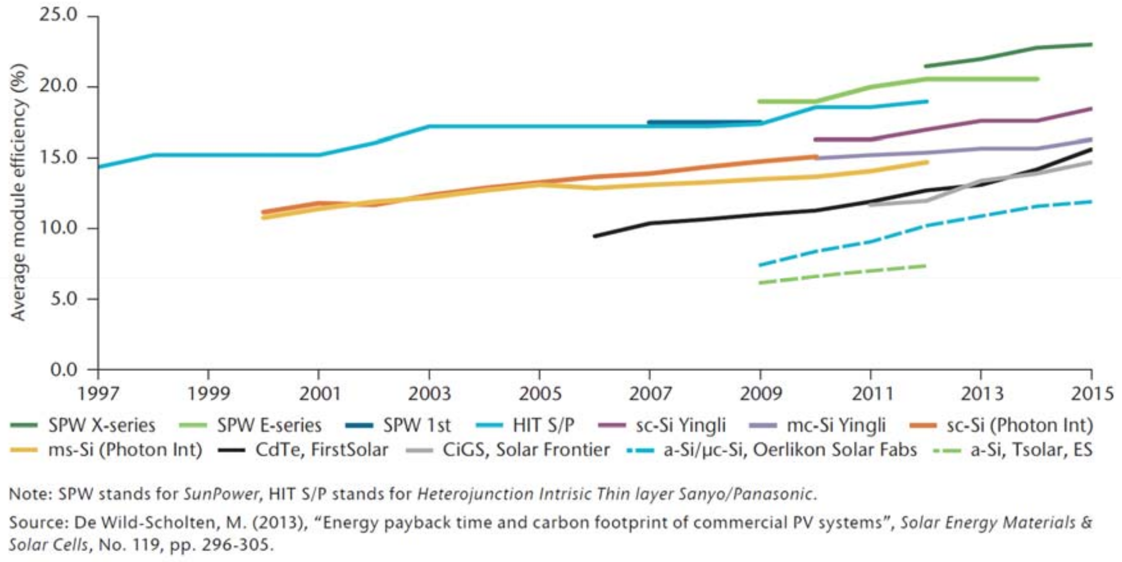


Figure 3-1 PV Component Conversion Rate

When it comes to PV power generation technologies for commercial employment, crystalline silicon solar cells are still the market mainstream with comprehensive measurement of PV cell conversion efficiency, reliability and cost. According to the ITRPV data, crystalline technology occupies 90% PV application market while thin film 10% in 2014. Although mono-crystalline cell technology can hardly threaten poly-crystalline solar cell market in short terms, it will maintain a stable growth thanks to greater demand on high-efficient solar energy products out of rapid development of rooftop solar energy installation market. As is predicted by IHS, the market share of mono-crystalline silicon will increase to 27% by 2015, marking a 24% growth compared to that of 2014.

3.2.2 High-efficient PV Cell

Since the core objectives of silicon solar cell at present lie in high efficiency and low cost, high-efficient PV cell has drawn high attention from researchers of all industries. The following will present several innovation technologies for high-efficient cells, including Passivated Emitter and Rear Contact (PERC), Passivated Emitter and Rear Locally Diffused (PERL), Passivated Emitter and Rear Totally-diffused (PERT), Pluto, PANDA, Interdigitated Back-Contacted (IBC), Heterojunction with Intrinsic Thin-layer (HIT).

3.2.2.1 PERC

As a development and improved design of industrial standard screen-printed p-type Si solar cells, the detailed fabrication process High-efficiency PERC is slightly different from the industrial standard Al-BSF cells.

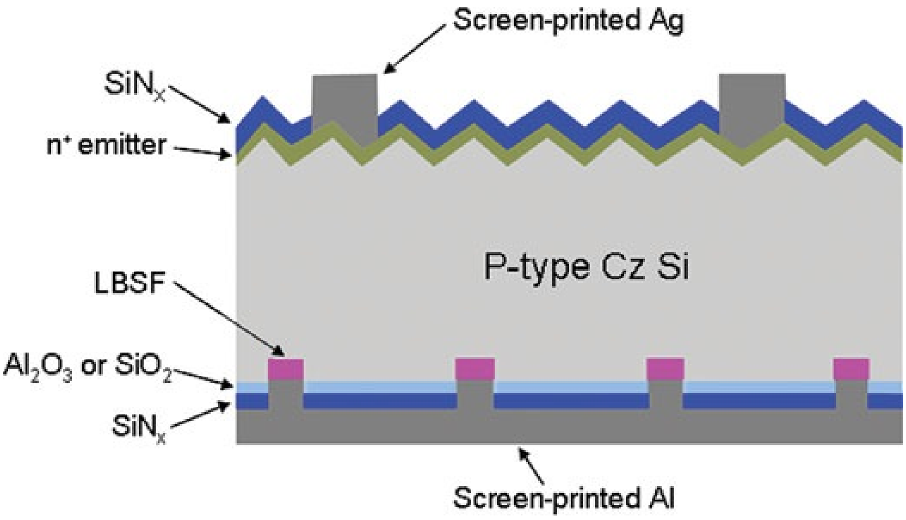


Figure 0-2 Screen-printed Al

3.2.2.2 PERL

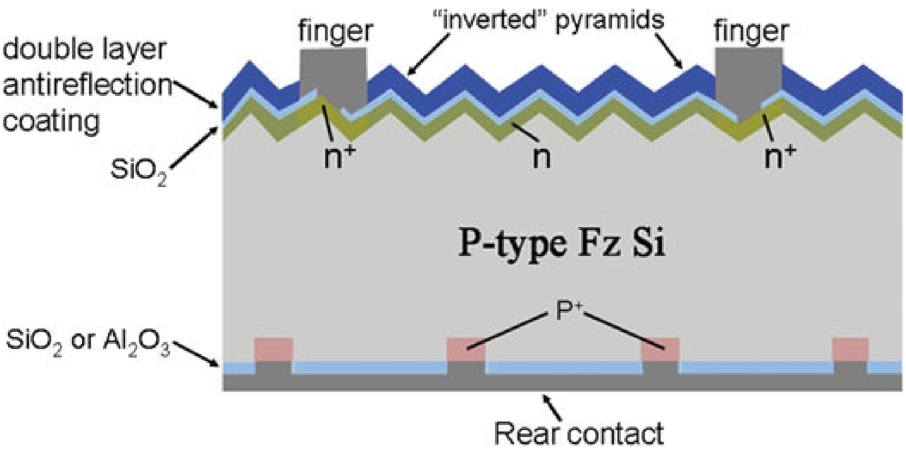


Figure 0-3 A schematic structure of the passivatd emitter, rear locally-diffused (PERL) cells

The passivated emitter cell series, particularly the PERL cells, developed at the University of New South Wales, have made major contributions to the development of high-efficiency silicon solar cells. Fig. 3-2 shows the schematic structure of PERL cells.

3.2.2.3 PERT

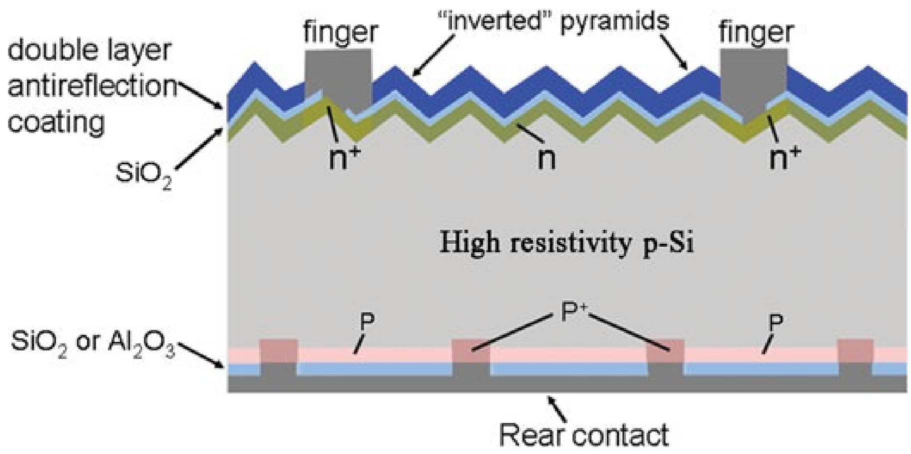


Figure 0-4 Passivated Emitter Rear Totally-diffused(PERT) cell structure

As shown in Fig. 3-3, the PERT cell has added one more processing step to diffuse a light boron layer along the entire rear surface of the cell, while all the other features of the PERL cells remain.

P3.2.2.4 luto-PERC, Pluto-PERL Cells

Pluto achieves an average cell efficiency of 19% in a 0.5 GW production, with highest efficiency of 19.6% independently confirmed. Earlier in 2011, a new record of 19.7% was independently confirmed by Solar Energy Research Institute for a Pluto cell using the Pluto-PERC cell structure and the same commercial p-type CZ mono-Si wafers. More recently, an efficiency of 20.3% has again been independently confirmed by SERIS on similar commercial-grade CZ mono-Si wafers, this time using the Pluto-PERL structure.

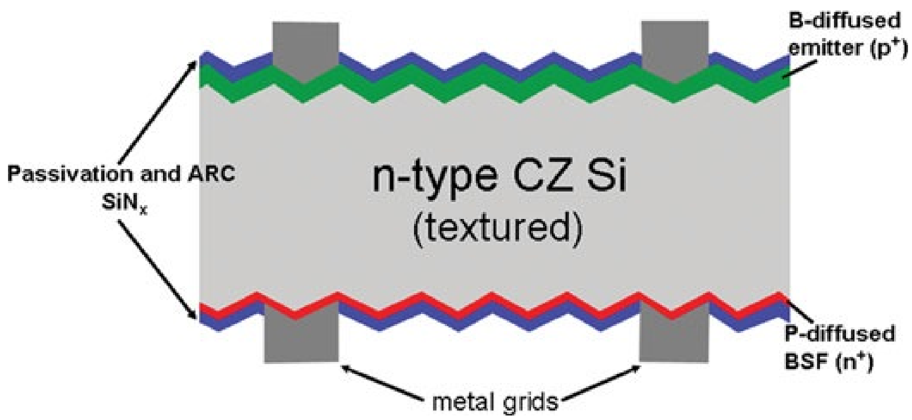


Figure 0-5 Schematic sketch of Yingli's PANDA solar cell

3.2.2.5 IBC

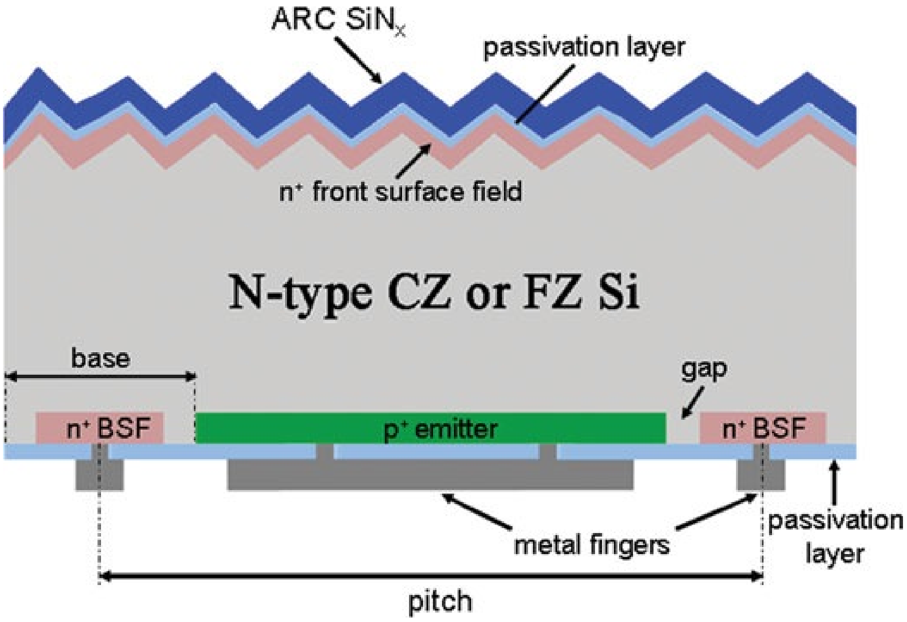


Figure 0-6 Schematic of an IBC cell

IBC silicon solar cells become more and more attractive for the industry mass production because of its high-efficiency potential and simple cell interconnection in modules. As shown in Fig. 3-5, the main structure differences are the location of the emitter and its contact. The most prominent advantage of IBC solar cell is the adoption of all rear contacts, which eliminates optical shading losses at the front side. Therefore, this cell type has an increased absorption and short circuit current density.

3.2.2.6 HIT

Sanyo Co. Ltd. developed a new a-Si/c-Si heterojunction structure called HIT, which features a very thin intrinsic a-Si layer inserted between the doped a-Si layer and the c-Si substrate. A typical scheme of the n-type Si HIT solar cell developed by Sanyo is shown in Fig. 3-6.

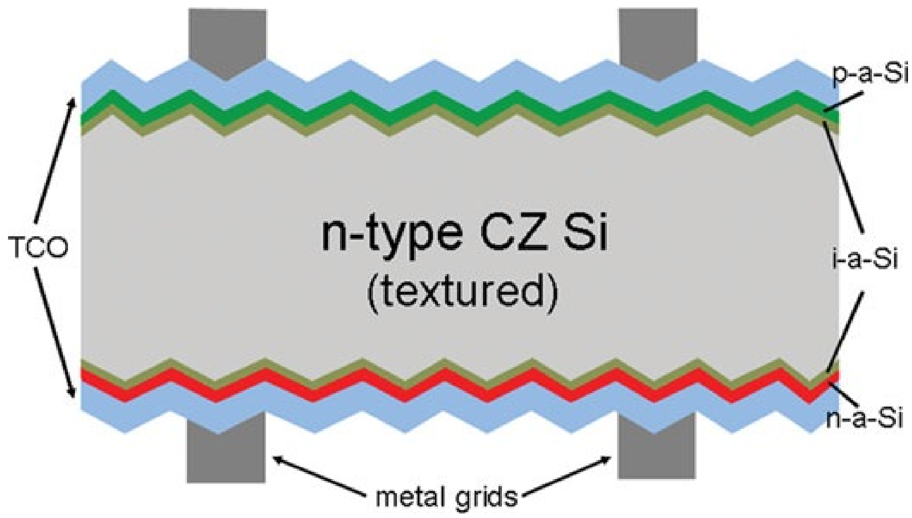


Figure 0-7 A schematic structure of the n-type CZ-Si HIT solar cells developed by Sanyo and Panasonic Corporation

4 PV Power Generation System Accidents and Problems

4.1 PV module Accident and Problem Analysis

As the core and most important part of solar energy power generation system, PV module acts to convert solar energy into electric energy, transmit the electric energy to storage battery or drive load working. By now, frequent PV module accidents and problems has resulted in great loss for solar energy power generation system owners since the safety of PV module is closely related to that of solar energy power generation system. The reasons contributing to PV module accidents and problems mainly include: defective cell/raw materials, unreasonable manufacturing process, unprofessional operation, inappropriate transporting, non-conforming installation process and specific environment, etc.

4.1.1 Cell/Raw Material Quality

4.1.1.1 PV cell Fissuration

PV cell cracking (fissuration) is likely to happen during each link including the cell itself, module lamination, transporting, operation and installation, etc.

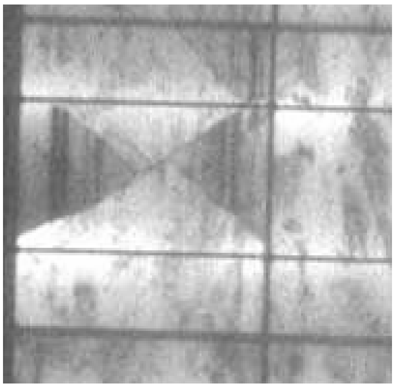


Figure 4-1 PV Cell Cracking (Fissuration)

4.1.1.2 PV Cell Lighting Line

Figure 4-2 PV Cell Lighting Line

4.1.2.3 Hybrid Application of Cells of Different Property

Hybrid application of cells of different property is mainly caused by unsatisfying cell material, manufacturing process and selection, resulting in PV hot spot due to great differences between cells. It will lead to lower module efficiency or even irreparable losses.

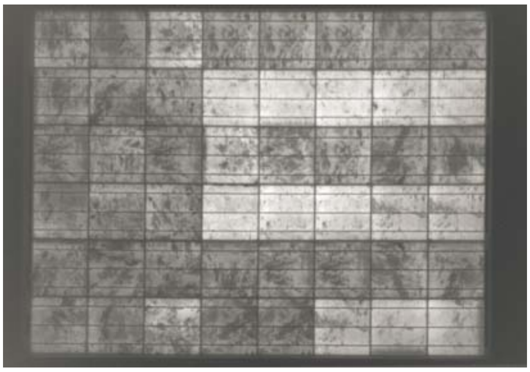


Figure 4-3 Hybrid Application of Cells of Different Property

4.1.1.4 Raw Material Quality

EVA leafing and flavescence, which is caused by too much scaling powder, non-conforming laminating technique and deficient EVA material, etc., will result in decreased light transmittance rate and lower generated energy,

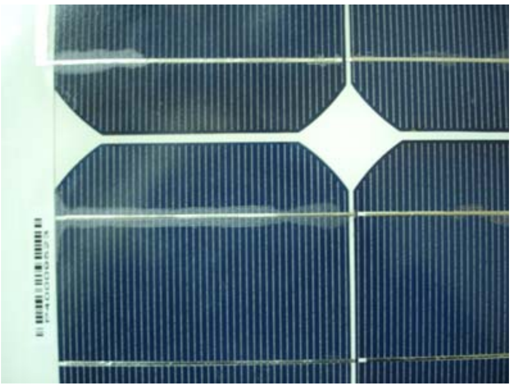


Figure 4-4 EVA leafing

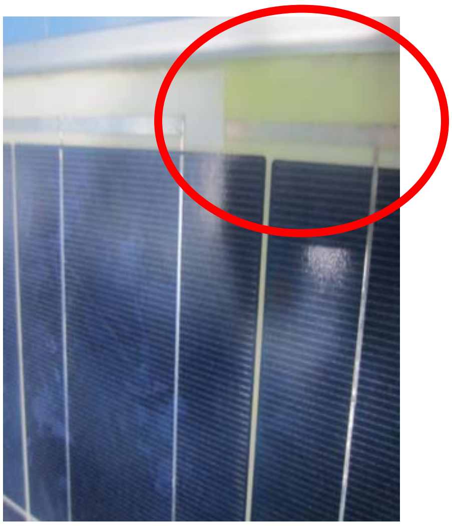


Figure 4-5 EVA Flavescence

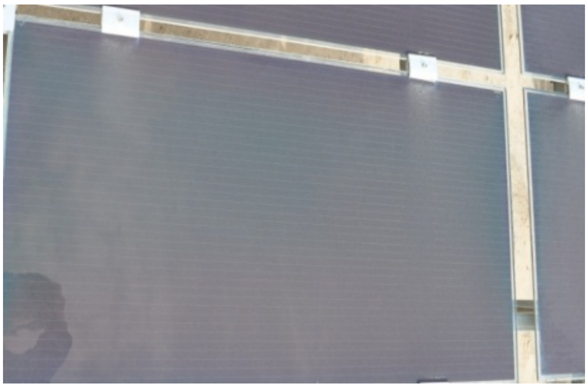


Figure 4-6 A-Si Layer Color Fading

4.1.2 PV Module Quality

4.1.2.1 Dry Joint and Sealing-off

Dry joint and sealing-off of PV modules is mainly caused by non-conforming welding process (insufficient temperature or instability of searing iron, excessive local welding speed and solder strip oxidation and bend) and silver electrode vulcanization due to excessive cell exposure, etc, which invalidate the internal connection of PV module and make part of the module to work inefficiently or even stop working. As a result, current of other cells are restricted with surplus current flow back to the inefficient part, causing high back-swing voltage. The surplus energy will then be converted into thermal energy, increasing the temperature of that part dramatically, which will finally fuse the module or even cause a fire disaster.

Figure 4-7 PV Module Dry Joint Causing Local Module Fusing

Figure 4-8 PV Module Sealing-off

4.1.2.2 PV Module Short Circuit

PV module short circuit is mainly caused by foreign materials and inflow caused by edge leafing, etc, which impedes some cells to contribute current with power coast-down.

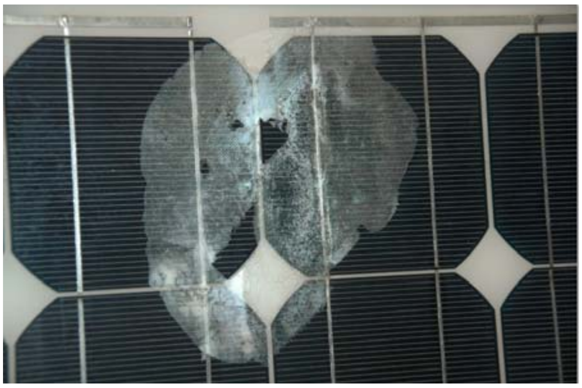


Figure 4-9 PV Module Short Circuit

4.1.2.3 PV Module Rear Panel Bump

PV module rear panel bump is mainly caused by material (low EVA peal strength, insufficient binding power and self leafing) hot spot effect and incompatibility with certain cell due to recessive tape, etc. It leads to weakened performance with bump-caused thinner part, which is likely to crack under external influence, thus resulting in module performance failure.

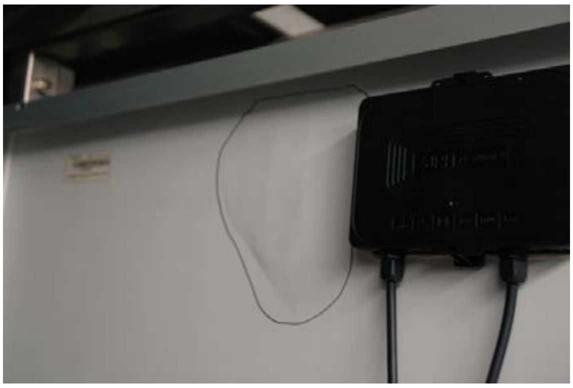


Figure 4-10 PV Module Rear Panel Bump

4.1.2.4 Highly Humidity Environment PID

PID is regularly seen under highly hot and humid environment with decreased FF, Jsc, Voc due to deteriorated cell surface passivation effect caused by mass electric charge aggregation. PID is mainly caused by ionic migration inside semiconductor active layer, PN junction performance degradation and shunt as well as ionization erosion, etc. Currently, this problem can be solved by cell and module manufacturing technique improvement, module frame ground connection and inverter DC side negative pole ground connection, etc.

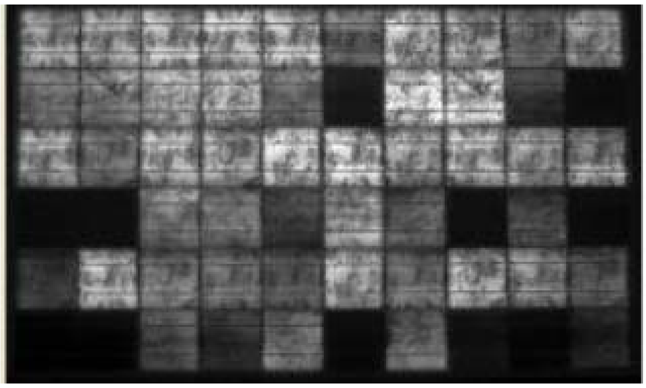


Figure 4-11 PID

4.1.2.5 Other PV Module Problems and Accidents

Occasional accidents including falling stone or quality issue will lead to glass panel fracture.

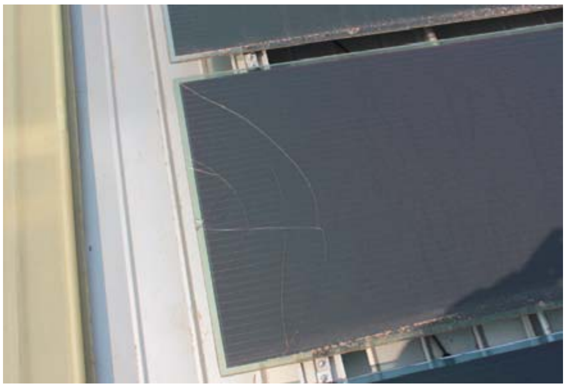


Figure 4-12 Glass Panel Fracture

The module performance may be decreased with solar energy cell laminated board deformation of different levels, which is caused by mechanical load during transportation and utilization of PV modules.

Figure 4-13 Light Mechanical Deformation

Serious chromatic aberration due to careless omissions during film coating and manufacturing of raw materials will cause power decay.

Figure 4-14 Serious Chromatic Aberration

Regional conditions and climate will also cast influences. PV module installed in coastal regions and highly saline and alkaline areas are under high risk of salt mist erosion, while that installed in agricultural districts with more farms and stock farming is likely to be eroded by ammonia gas.

Figure 4-15 Module Problems Caused by Salt Mist and Ammonia Gas

4.2 Combiner Box Malfunction and Problems Analysis

Main reasons for frequent PV DC combiner box malfunction are: design flaws of some PV DC combiner boxes, misunderstanding for the basic requirements of PV DC system, hasty manufacture of unverified components due to underestimation of PV DC products market demand by existing components and parts manufacturers, ambiguous definition of DC product usage occasion and environment by component manufacturers, and the fact that low voltage device manufacturers of all economies are still at their initial stage of development in general for products of DC1000V or more.

4.2.1 Combiner Box Design Flaw

The design flaws triggering frequent PV DC combiner box malfunction include burnout caused by insufficient electric clearance and creep age distance, short circuit burnout due to unreasonable structural layout and short circuit burnout caused by short flash-over distance, etc.

Figure 4-16 Burnout Caused by Insufficient High Voltage Creep Age Distance

Figure 4-17 Short Circuit Burnout Due to Unreasonable Structural Layout

Insufficient flash over distance leads to unduly short distance between the breaker and shell, which will decrease thermal exchange surface between the combiner box and external environment, thus resulting in extremely high temperature inside the box. Besides, unduly short flash over distance of the breaker may cause short circuit burnout easily.

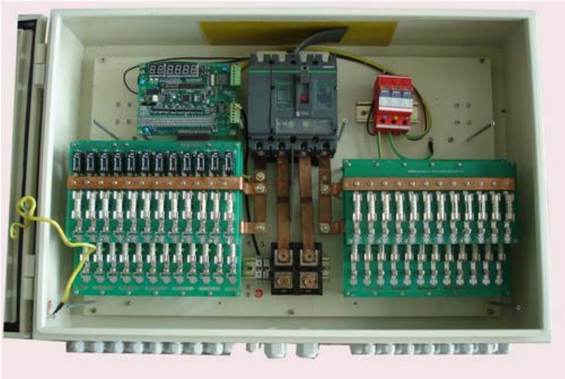


Figure 4-18 Insufficient flash over Distance

4.2.2 Combiner Box Quality Problem

Frequent PV DC combiner box malfunction includes fuse rupture due to bad wire quality, excessive high temperature of the whole box since aluminum strip bus-bawire offers higher specific resistance than copper and the specific resistance may further increase due to aluminum material oxidation, and protective shell coating quality problems, etc.

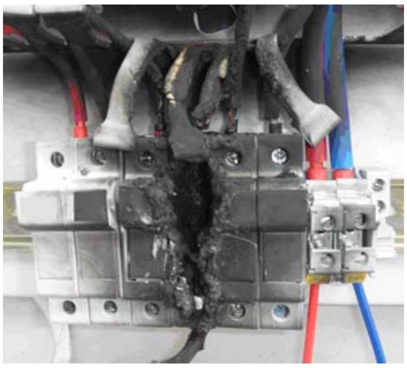


Figure 4-19 Fuse Rupture By Wire Quality Problem

Figure 4-20 Protective Shell Coating Quality Problem

4.2.3 Combiner Box Installation

Failure to install protective door for the combiner box may cause dust and water inflow easily, which will lead to short circuit accident.

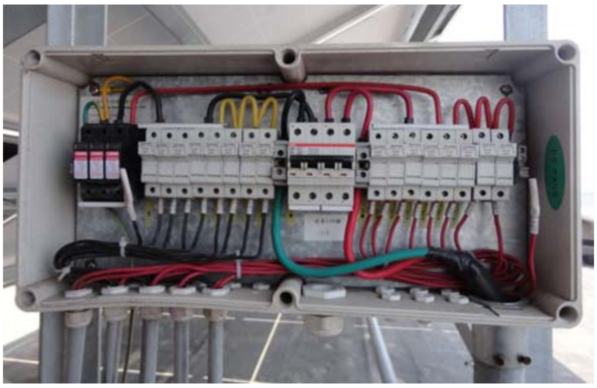


Figure 4-21 Failure to Install Protective Door

Nonconforming installation of inlet wire results in easy falling off with low protective degree, which is hard to overhaul.

Figure 4-22 Nonconforming Inlet Wire Installation

The breaker may fail to protect the circuit without breaker phase partition once short circuit happened on the inlet wire.

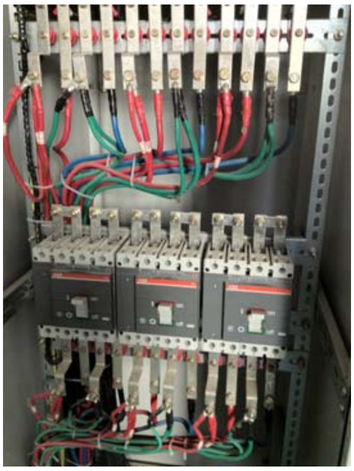


Figure 4-23 Failure to Install Breaker Phase Partition

4.3 Power Station Design Stage Accident and Problem Analysis

4.3.1 Unreasonable Dip Angle Design

Unreasonable dip angle design will reduce power generation efficiency. As is shown in the following figure, the south and north slop of the color steel tile roof is designed with different dip angle, resulting in efficiency loss of the module array.

Figure 4-24 Unreasonable Dip Angle Design

4.3.2 Design Blocking

Some components are blocked by barriers due to inappropriate design, which will do harm to current of the entire string with a cask effect, cutting down on power generation efficiency in the end.

Figure 4-25 Design Blocking

4.4 Construction Stage Accident and Problems Analysis

4.41 Inadequate Preliminary Preparation

Nonconforming concrete foundation size and depth, which is caused by failure of geological prospecting during the preliminary preparation of power station holder design, will create hidden danger for long-term safe operation of the power station.

Figure 4-26 Inadequate Preliminary Preparation

4.4.2 Wire Connection Disorder

Inlet and outlet wire connection disorder may cause potential safety hazard and even increase difficulties for maintenance. Therefore, electrical circuit connection is required to be standardized.

Figure 4-27 Wire Connection Disorder

4.4.3 Unreliable Equipotential Connection Welding

Unreliable equipotential connection welding, especially big potential difference is under danger of electrical accident and even lightning stroke.

Figure 4-28 Unreliable Equipotential Connection Welding

4.4.4 Unduly Low Insulation Resistance

Unduly low insulation resistance may cause arc discharge and even trigger fire disaster, which threats not only safe operation of PV power generation system but also personal safety.

Figure 4-29 PV String

Table 4-1 Insulation Resistance Value

	String 1	String 2	String 3	String 4	String 5
Positive to Ground / Ω	0.004	0.006	0.005	56	210
Negative to Ground / Ω	159	0.35	35.1	67	40

4.4.5 Inappropriate Connection

Insecure string connection and dry joint may cause zero string voltage.

Figure 4-30 Inappropriate Connection

4.4.6 Poor ID Durability

Poor durability causes potential danger with difficulties for future maintenance.

Figure 4-31 Poor ID Durability

4.4.7 Cable Casting Protection

Problems related to cable casting protection include unduly shallow cable casting, inappropriate cable protection, no cable protection and trunking opening quality, etc, which may bring systematic safety risks.

Figure 4-32 Unduly Shallow Cable

Figure 4-33 Inappropriate Cable Protection

Figure 4-34 No Cable Protection

Figure 4-35 Trunking opening quality

4.5 Operation and Maintenance Stage Accident and Problem

Accidents and problems frequently seen during operation and maintenance period include inappropriate fault handling, maintenance inefficiency, lack of maintenance tools, severe environment challenge, inadequate safety protection and poor monitoring data analysis capability, etc.

4.5.1 Inappropriate Fault Handling

Major problems for PV power station operation and maintenance period include inappropriate fault handling, excessive breakdowns and large deviation of power station output, etc.

4.5.2 Maintenance Inefficiency

The operation and maintenance of large-scale power stations require systematic and effective maintenance methods. However, a series of factors may lead to maintenance inefficiency of PV power stations, including geographical environment restriction, lack of professional technicians and difficult site management of scattered power stations due to lack of professional operation and maintenance system.

4.5.3 Occasional Blocking of PV Module

Too much obstructions around the square array such as weeds which requires timely cleaning up may threat power generation safety.

Figure 4-36 Weeds Blocking

Occasional obstruction of PV module by snow should be cleaned up timely to prevent potential influence on power generation.

Figure 4-37 Blocking by Snow

4.5.4 Lack of Maintenance Tools

Lack of maintenance tools, out-dated PV power station maintenance detection method, and lack of on-site test and maintenance tools are too be solved. With the out-dated PV power station maintenance detection method, ordinary malfunctions requires on-site test and maintenance while daily maintenance calls for 7×24 shifts by several staff. Problems will not be effectively and timely found without enough on-site testing and maintenance tools.

4.5.5 Severe Environment

Insufficient maintenance measures, maintenance impeded by on-site environmental conditions as well as temperature and dust pollution, etc. should be taken into consideration.

4.5.6 Inadequate Safety Protection

Inadequate safety protection including lack of effective measures for fire disaster, theft and electricity shock accidents.

4.5.7 Fire Disaster

Researches show that most fire disasters took place in the PV module (component junction box and shunt diode) and combiner box, while on-site test shows that corresponding fire prevention devices are equipped in the inverter room instead of on the PV square array site.

Figure 4-38 Fire Disaster

4.5.8 Poor Monitoring and Data Analysis Capabilities

Lack of power station data is caused by data collection scope deficiency, larger data error, inadequate data storage space and sever data modification. Besides, incomplete power station monitoring system and poor monitoring and data analysis capability will lead to delayed judgment and handling of related accidents and problems during the operation and maintenance stage.

4.5.9 Data Monitoring System Problems Analysis

Related data monitoring system problems include bad data transmission quality, irradiator related problems, inadequate environment monitoring holder strength and temperature sensor.

a) Poor Data Transmission Quality

Insufficient data coverage, PV square array operation status monitoring deficiency;

Unstable data transmission, civil-use data transmission devices exposure to the external environment, short service life, poor transmission quality;

Wrong communication method, ill judgment of on-site electromagnetic environment leads to failure of data collection and communication for some devices;

Poor construction quality: insufficient self protection level of communication cables result in poor cable protection;

Environment monitoring absence: environment monitoring devices fail to collect accurate and key parameter;

False data: transmission of false data via pre-wrote programs set in the server.

b) Irradiator

Several problems may come up during the systematic design and installation of irradiator, including different irradiator, early burn-in of irradiator wire connection, irradiator blocked by shade and lack of temperature sensor, which can lead to irradiance measuring error with unreliable monitoring data.

c) Different Irradiator

Figure 4-39 Different Irradiator

d) Early Burn-in of Irradiator Wiring

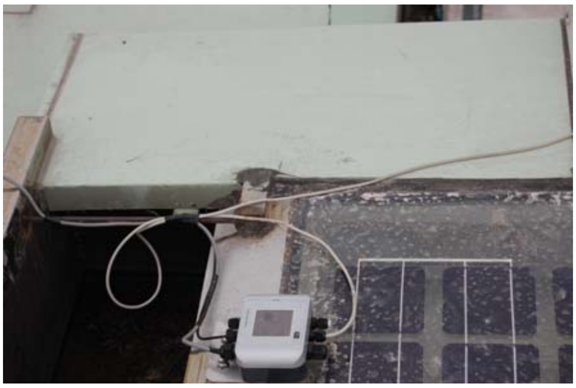


Figure 4-40 Early Burn-in of Irradiator Wiring

e) Irradiator Blocked By Shade

Figure 4-41 Irradiator Blocked By Shade

f) Irradiator Lacks Temperature Sensor

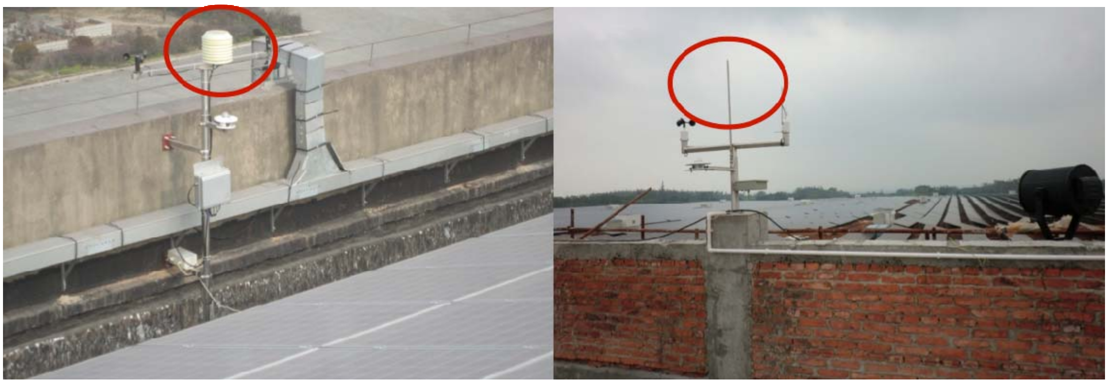


Figure 4-42 Irradiator Lacks Temperature Sensor

g) Environment Monitoring Instrument

The environment monitoring instrument holder inclines due to inadequate strength, which leads to monitoring data errors.

Figure 4-43 Inclined Environment Monitoring Instrument Holder

h) Temperature Sensor

The temperature sensor should be attached to the rear panel;

Failure of sticking the temperature sensor to the rear panel may cause inaccurate temperature collection point, which will invalidate the temperature data.

Figure 4-44 Failure of Sticking the Temperature Sensor to the Rear Panel

i) Sticking Position Fault of Rear Panel Temperature Sensor

Sticking position fault of rear panel temperature sensor leads to inaccurate temperature.

Figure 4-45 Sticking Position Fault of Rear Panel Temperature Sensor

5 PV Industry Development Roadmap Suggestion

5.1 Basic Objective

5.1.1 Installation

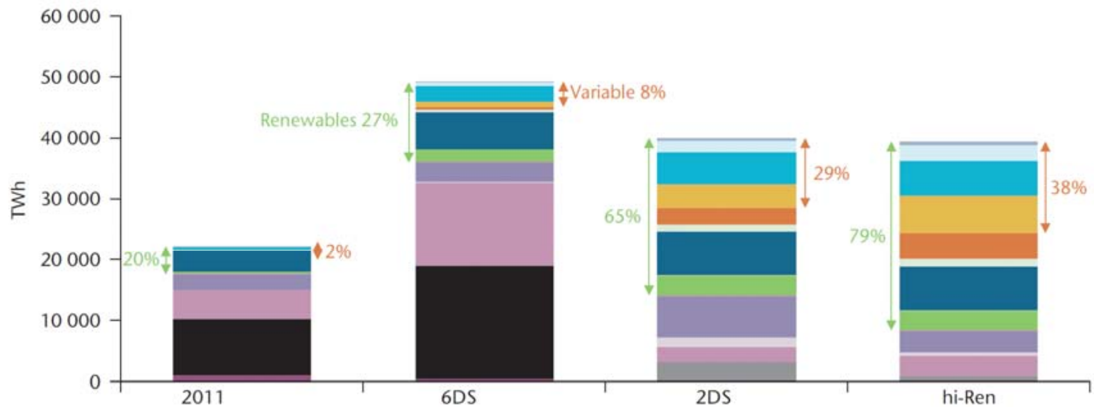
IEA PVPS statistics 2014 shows that global PV installed capacity in 2014 increased by 38.7GW in total with an accumulative installed capacity of 177GW. According to the statistical data, the annual PV installed capacity in the APEC region approximates 29.8GW, accounting for 76% of the increased total; and the total installed capacity in the APEC region stays at about 80GW, which is 4.9% of the accumulative total, marking the major role of the APEC region in global PV development in the future.

Table 5-1 Annual and Accumulative Installed Capacity statistics 2014

Economy	Annual Installed Capacity (MW)	Accumulative Installed Capacity (MW)
China	10560	28199
Japan	9700	23300
US	6201	18280
UK	2273	5104
Germany	1900	38200
France	927	5660
Australia	910	4136

Economy	Annual Installed Capacity (MW)	Accumulative Installed Capacity (MW)
Korea	909	2384
South Africa	800	922
India	616	2936
Canada	500	1710
Thailand	475	1299
Chinese Taipei	400	776
Netherlanders	400	1123
Italy	385	18460
Chile	365	368
Switzerland	320	1076
Israel	250	731
Austria	140	767
Portugal	110	391
Malaysia	87	160
Romania	69	1219
Paraguay	65	3074
Mexico	64	176
Turkey	40	58
Denmark	39.4	603
Sweden	36	79
Spain	22	5358
Greece	16	2595
Norway	2.2	13
Czech	1.7	2134
Bulgaria	1.6	1022
Slovakia	0.4	533

APEC Economies Marked in Red



Year	US	Other OECD Americas	EU	Other OECD	China	India	Africa	Middle East	Other developing Asia	Eastern Europe and former Soviet Union	Non-OECD Americas	World
2013	12.5	1.3	78	18	18	2.3	0.3	0.1	1.4	3	0.2	135
2030	246	29	192	157	634	142	85	94	93	12	38	1721
2050	599	62	229	292	1738	575	169	268	526	67	149	4674

by IEA, 79% of global electricity in 2050 is expected to be supplied by renewable energy sources, 38% of which is realized by renewable fluctuating power supply that includes 16% PV power generation.

Table 5-2 PV capacities by region in 2030 and 2050 in the hi-ren scenario(GW)

Year	US	Other OECD Americas	EU	Other OECD	China	India	Africa	Middle East	Other developing Asia	Eastern Europe and former Soviet Union	Non-OECD Americas	World
2013	12.5	1.3	78	18	18	2.3	0.3	0.1	1.4	3	0.2	135
2030	246	29	192	157	634	142	85	94	93	12	38	1721
2050	599	62	229	292	1738	575	169	268	526	67	149	4674

As for the detailed installation, global PV installed capacity is expected to reach 1700GW by 2030 and 4674GW by 2050. China and the US are expected to accomplish 1738GW and 599GW installed capacity by 2050, accounting for 37.2% and 12.8% of the world total respectively. The two economies together will fulfill 50% of the PV installation objective.

According to the above-mentioned PV installation objective, the basic goal of PV power station installation in the APEC region are as follows:

1. By 2030, 1130GW will be installed in the APEC region with China, the US, Japan, Australia and other the APEC region accomplishing 634GW, 246GW, 140GW, 30GW and 80GW respectively;

2. by 2050, 2787GW will be installed in the APEC region with China, the US, Japan, Australia and other APEC economies accomplishing 1738GW, 599GW, 230GW, 70GW and 150GW respectively;

Table 5-3 The basic goal of PV power station installation in APEC region

Economy	2030	2050
China	634	1738
US	246	599
Japan	140	230
Australia	30	70
Others	80	150
Total	1130	2787

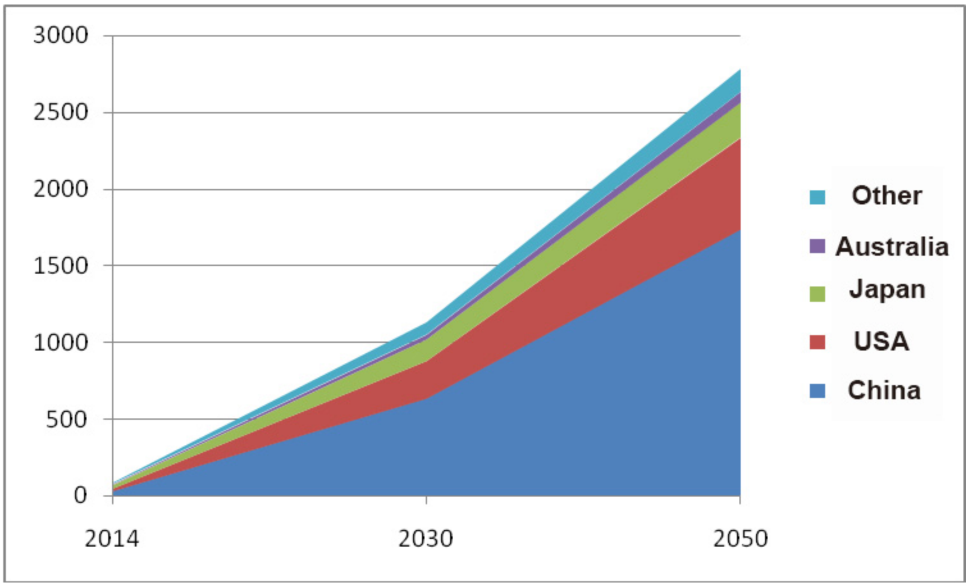


Figure 5-2 Installation Objective of APEC Region

5.1.2 PV Installation Cost

Significant PV installation cost in the past few years is one the major reasons contributing to rapid development and large-scale application of PV power station installation. During last 7 years, PV module and system price have decreased by 86.4% and 86.7% respectively while PV electricity prices fell by 76.2%.

Presently, the PV installation cost in China stays at $1.26/W (RMB8/W) while that of the US is $2.66/W, which is expected to be reduced to $1.77/W by the year 2017. The reason of higher cost in the US than China mainly lies on some soft cost.

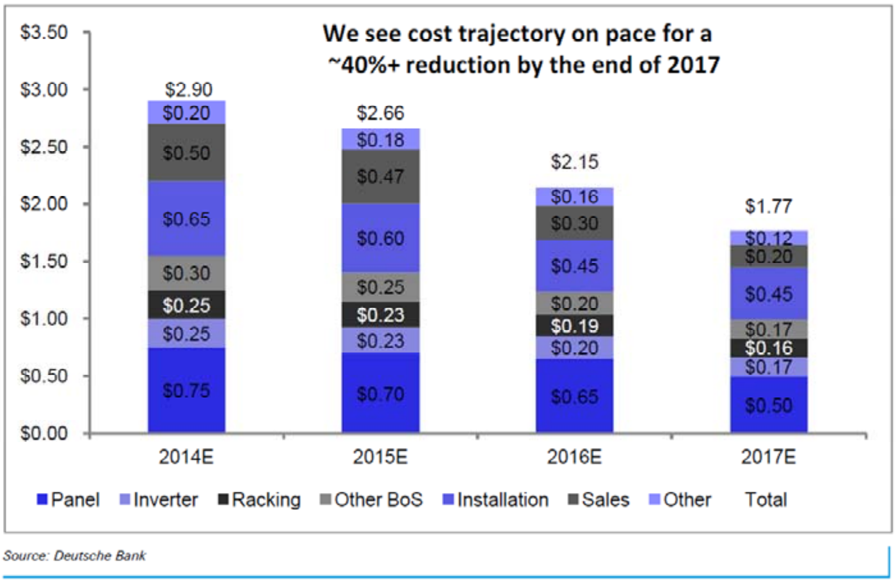


Figure 5-3 PV Installation Cost in the US (Source: Deutsche Bank Research Report)

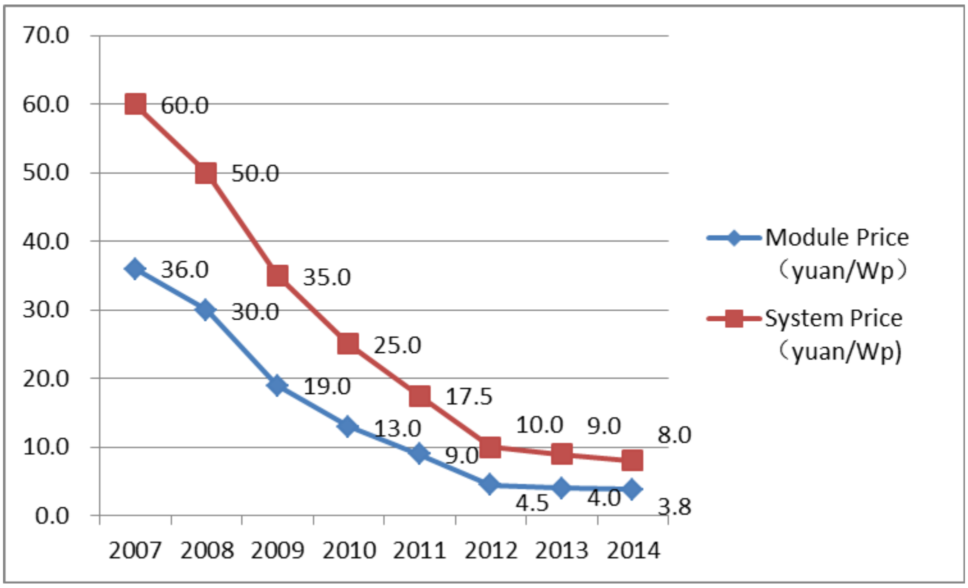


Figure 5-4 PV Installation Cost in China (Source: Professor Wang Sicheng)

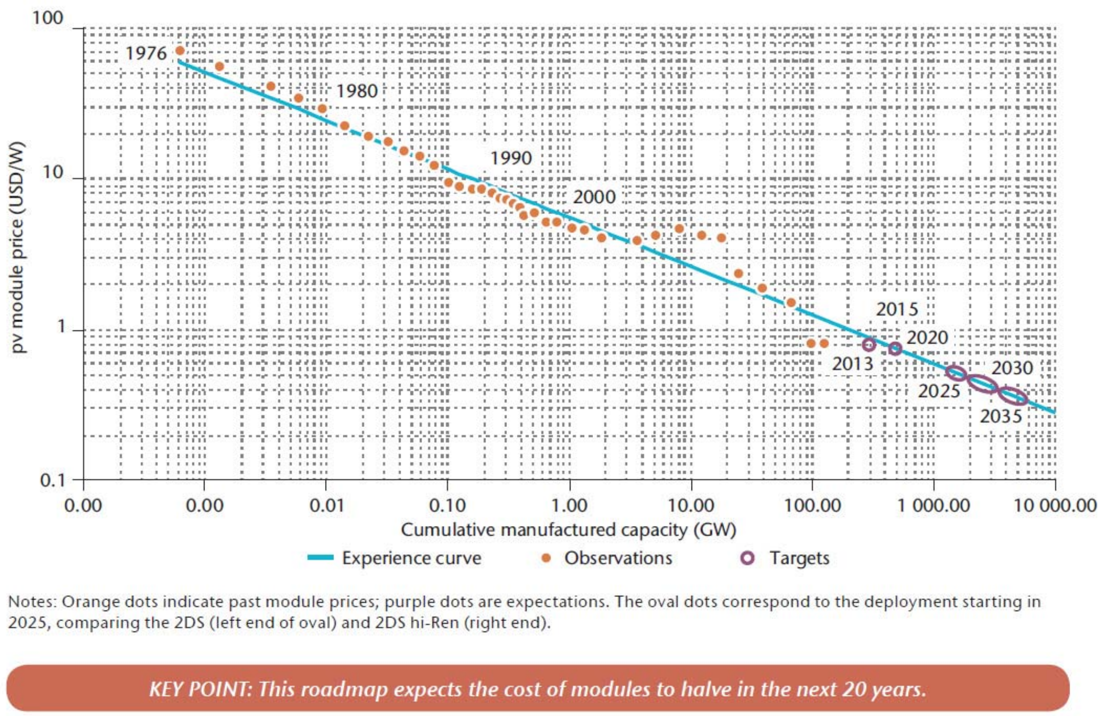


Figure 5-5 PV Modules Prices in the US (Source: IEA roadmap 2014)

Historical price fluctuations shows that PV modules cost in the US is expected to be reduced to \$0.7/W by 2015, \$0.5/W by 2020 and \$0.3/W by 2030.

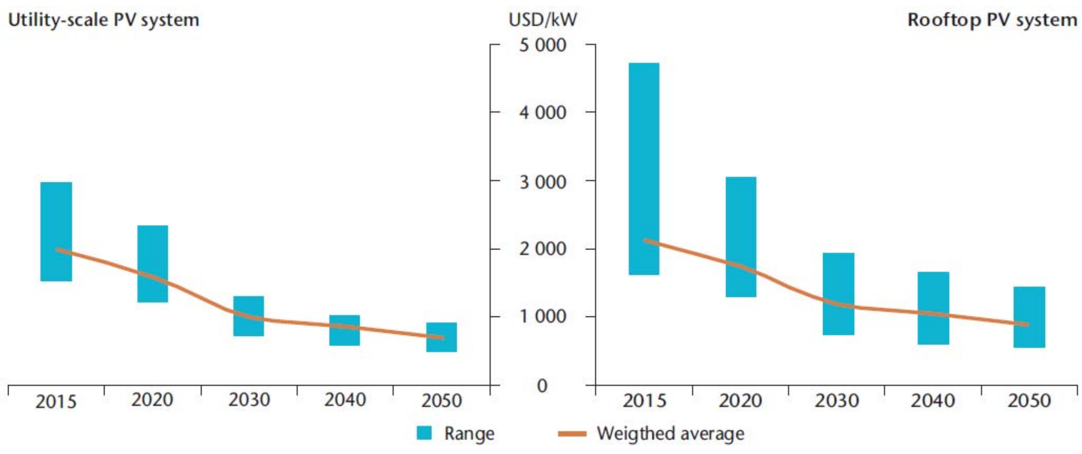


Figure 5-6 Prediction shows that PV installation cost in the US is expected to reach $1/W by 2030 and $0.8/W by 2050.

5.1.3 PV Installation in the Total Electricity in APEC Region

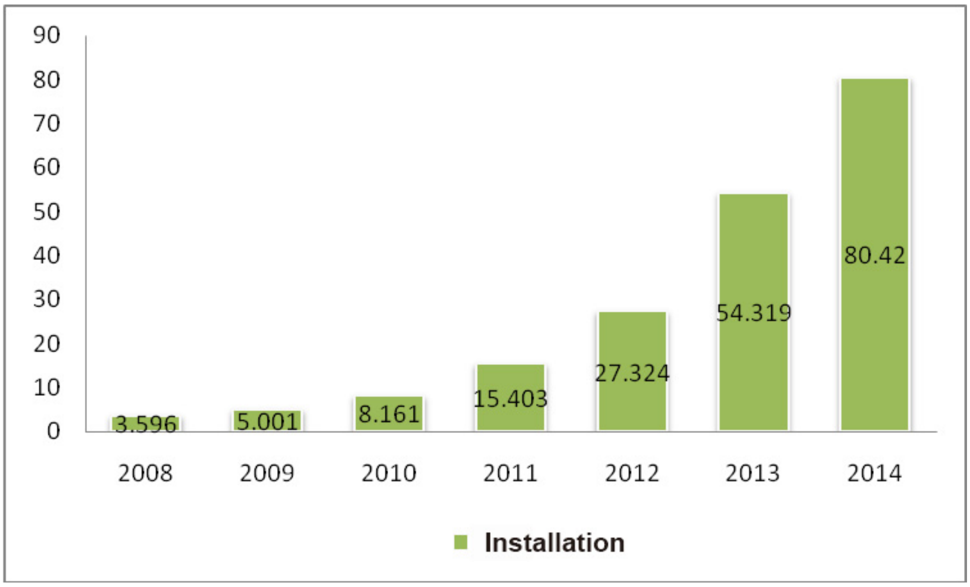
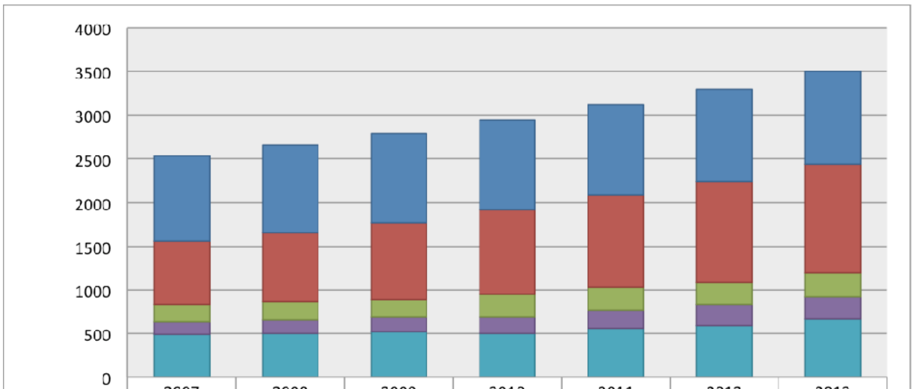


Figure 5-7 PV Installation Statistics 2008-2014 in APEC Region (GW)



	2007	2008	2009	2010	2011	2012	2013
America	981.1	1001.1	1017.8	1032.1	1045	1057.5	1061
China	718.3	792.9	874.1	966.4	1056	1146.8	1247.4
Japan	204	207	210	263.6	258.8	259.3	269.4
India	146.8	153.8	164.6	180.6	208.2	240.3	251
others	485.9	503.4	518.3	502.4	556.9	591.5	669.1
Total	2536. 1	2658. 2	2784. 8	2945. 1	3124. 9	3295. 4	3497. 7

Figure 5-8 Total Electricity Installation Statistic 2007-2013 in APEC Region (GW)

Source: Global New Energy Development Report 2014

With comprehensive consideration of the PV installation, total electricity installation and predictions on future PV installation objectives of APEC economies from 2008 to 2014, the ratio of PV installation in the total electricity installation of APEC region in 2020, 2030 and 2050 is projected as follows:

The objectives are:

1. the ratio of PV installation reaches 5% by 2020;
2. the ratio of PV installation reaches 10% by 2030;
3. the ratio of PV installation reaches 18.5% by 2050.

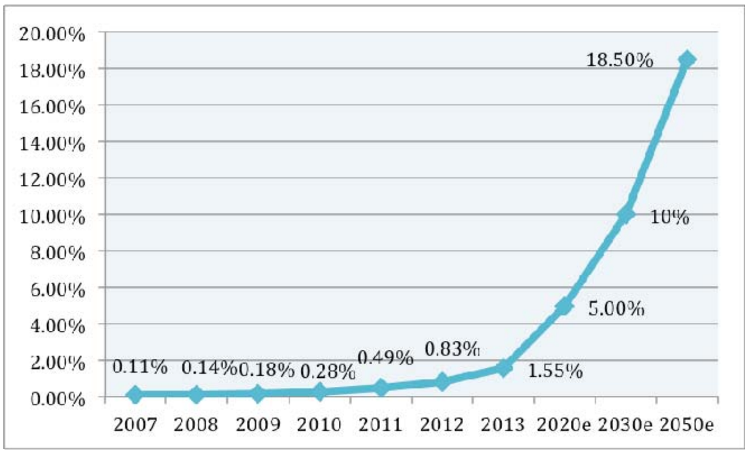


Figure 5-9 Predicted Ratio of PV Installation in the Total Electricity Installation of APEC Region in 2020, 2030 and 2050

5.1.4 Gross Investment

In accordance with above-mentioned prediction, the gross PV installed capacity in APEC region will reach 1130GW in 2030 and 2787GW in 2050. Presume PV power station cost stays at $1 per watt in 2030, the gross investment will be $1,130 million in 2030; and a total of $2,229.6 is required in 2050 if the cost is $0.8 per watt by then. Therefore, the gross investment for PV power stations in APEC region will bring great opportunity and challenge in the meantime to PV power station financing.

By now, the financing status of PV power station varies in APEC economies. Major financing methods used include stock equity financing, debt financing and other financing means as finance lease, trust and YieldCo, etc.

5.1.5 Fair Price Grid Connection – Example of China

The research and development of Solar PV power generation cell technology will remain vibrant with the major orientation of increased conversion efficiency and reduced manufacturing cost. Overall fair price grid connection is expected to be realized with decreasing PV power generation cost. Moreover, solar PV power generation will become one of the major alternative power supplies after 2030 and even one of the dominant power supplies after 2050.

Main calculation points of fair price grid connection roadmap are as follows:

1) average grid connection electricity price of China's large-scale PV power stations in 2013 is RMB1.0/kWh;

2) average distributed PV electricity price in China in 2013 is RMB1.2/kWh;

3) PV model grid connection electricity price and distributed electricity price decreases 5% per year from 2013 to 2032;

4) Desulfuration coal fire model electricity price in 2013 stays at RMB0.42/kWh with 2% increase per year in average before 2020 and 3.5% increase per year in average after 2020;

5) the average electricity price consumed by industrial and commercial, large-scale industry and low electricity price users is RMB0.95, 0.71 and 0.42

per kWh in 2013 with 2% increase per year in average before 2020 and 3.5% increase per year in average after 2020.

Based on the above-mentioned conditions, PV fair price grid connection roadmap of China is as follows:

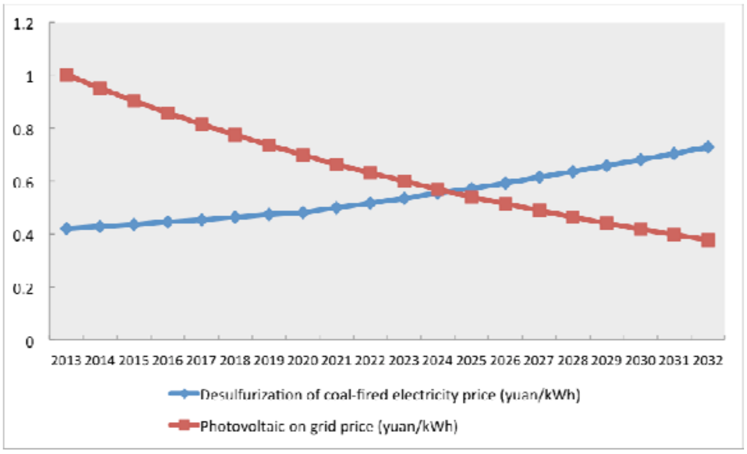


Figure 5-10 PV Fair Price Grid Connection Roadmap of China (Power Generation Side)

The figure shows that fair price at power generation side for large-scale PV power generation project will be realized in 2025 with equal grid connection price as desulfuration coal fire unit.

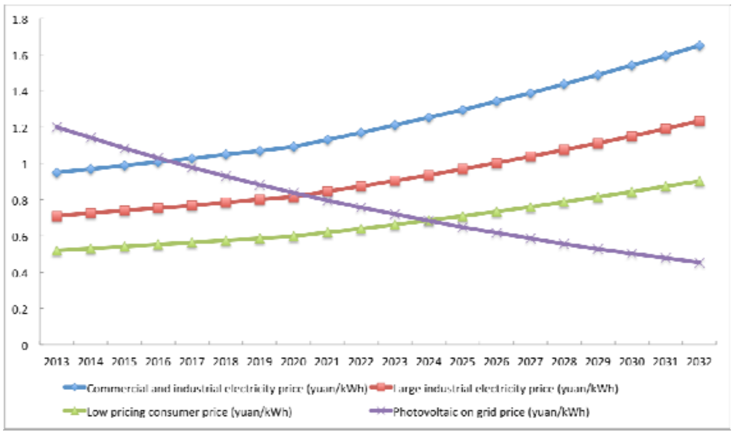


Figure 5-11 PV Fair Price Grid Connection Roadmap of China (Power Consumption Side)

As is shown in the figure, fair PV price will be realized at different power consumption side (industrial and commercial power consumption, large-scale industrial power consumption and low electricity price power consumption) in2017, 2021 and 2024 in eastern China.

As for PV installation in other economies, fair price grid connection has been realized in Germany, Australia, Chile, Hawaii of the US and Japan, etc. in addition, fair price grid connection has also been primarily achieved in some places in China with higher electricity price as well as better lighting.

5.1.6 Policy Support

The above-mentioned figure also shows that fair price grid connection is still out of reach for some APEC economies since PV power station is of higher cost than traditional energy sources and electricity technology. Therefore, in order to speed up energy strategy transformation, a lot of governments of APEC economies has issued strong PV encouragement policies including subsidy, taxation and quota system, etc. With national policy support and stimulation of PV industry, which is a policy-oriented industry, PV power generation technology can be developed continually with decreasing PV power station system construction cost.

In addition, PV policies requires constant adjustment and optimization in line with different industry development phase and policy efficiency. Due to rapid development of PV application and comparatively short history, each APEC economy should not only carry out rigorous economic calculation to ensure accuracy of their policies, but also optimize them constantly by combining policy and experiences of other economies according to effects received after implementation of policies as well as feed-backs from the industry. Effective PV policies is able to stimulate the establishment of effective PV investment commercial mode and financing mode in short term to reduce financing cost for PV power stations and make use of market guidance to allocate resources reasonably, thus realizing healthy development of PV industry.

5.2 PV Power Station Development

Full life circle supervision plan of PV power station is required to be established in order to prevent PV power generation accidents and problems, keep away accidents and problems during design, transportation, construction, operation and maintenance of PV products and power station and enhance safety, quality and efficiency of PB power generation projects, thus providing triple management control on products quality, engineering construction quality and power station operation and maintenance quality to ensure PV power station quality and security, stable operational earnings and controllable risk in the APEC region.

5.2.1 PV Products Quality Assurance System

PV power stations operate in different outdoor environments including severe environments as direct sunlight exposure, high operating temperature, high environment temperature (hot area/dessert), high humidity, wind pressure/snow pressure, low environment temperature, thermal cycle and high salinity environment in coastal areas, etc. the following PV products quality assurance system is able to reduce PV products early failure frequency and prolong PV products life span.

5.2.2 PV Power Station Construction Management System

PV power station construction management system plays a significant role in realizing standardization of PV power station construction management, including standardization of construction process, document system and engineering management. Construction process standardization refers to standardization of personnel, departments and units related in each link of site testing, scientific research, declaration, official reply, design, construction and operation; document system standardization requires standardization of texts, materials and depth of description related to each link; and engineering management standardization involves standardization of management level and department coordination during the project.

5.2.3 PV Power Station Operation and Maintenance System

PV power station operation and maintenance aims to protect safety of PV power station, prevent personnel from being harmed and maintain the maximum power generation capacity in the meantime.

a) Elements of Power Station Operation and Maintenance Management System

b) Core of Power Station Operation and Maintenance Management System

The core to establish PV power station operation and maintenance system lies in realization of MTBF and MTTR.

The advantage of power station operation and maintenance management system lies in constant optimal and large-scale operation of power station, which will further bring a series of favorable factors:

Stable and Immediate collection of real-time data provides owners and investors detailed information of power generation;

Real-time analysis and alarm of potential faults with preventive maintenance philosophy to prevent potential risks and realize maintenance and appreciation of assets value;

Statistical analysis of power station to constantly optimize operation and management, maintain and increase power generation efficiency and output of its full life circle for the benefit of assets appraisal;

Accurate generating capacity prediction that enables the state electric power dispatch system to flexibly deal with power deployment during peak and slack hours;

PV power station fire disaster tele-control pre-warning system that reduces fire risk by large margin to protective power station safety comprehensively;

Intensified centralized control center operation and management enables unattended operation or less on duty for remote power stations, reducing the number of maintenance technicians to reduce labor cost; real-time grasp of power generation, device operation, operation and maintenance status, unusual conditions to prevent device faults, thus reducing device maintenance cost. All these is expected to reduce maintenance cost of the full life circle and prolong operation cycle of the power station to as long as 25 years.

c) Establishing Third-party Quality Assurance System

The third-party PV quality assurance system is required to cover PV power station solutions including design-end quality hidden danger identification, customized key equipment selection requirements based on application environment, key equipment quality monitoring, knowledge and skill as well as on-site installation specifications training for installation personnel, quality conformance supervision and on-site polling and sample test based on statistics and risk probability and more rigorous and accurate on-site testing methods, etc. with reference of UL, LEC and existing PV related regulations as well as analysis of common PV system issues, pointed and valid solutions to safe, sustainable and reliable operation of power stations can be provided to ensure lasting and stable benefit of PV power stations.

5.3 PV Grid Connection

PV industry has developed dramatically during recent years with increased PV installed capacity every year. As is projected, the total installed capacity of APEC region will reach 1300GW by 2030 and 2787GW by 2050. Such large-scale PV grid connection is bound to bring new challenges for safe and stable operation of the grid.

5.3.1 Problems Brought by PV Grid Connection

a) Output and Consumption

At present, most large-scale PV power stations are located in areas with good sunshine condition, low population density and small electricity consumption pressure. Therefore, electricity produced requires long distance transmission. With increased quantity of PV power station, line voltage overrun phenomenon due to short-term fluctuation and periodical change of illumination intensity will take place frequently. As a result, output and consumption problem caused by opposing distribution of resources and load will be one of the major constraints for large-scale PV power station construction and development.

b) Outstanding Operation Control Problem

Operation control problem is hard to ignore due to the volatility and randomness of irradiation intensity. The outstanding volatile and random feature of PV power supply together with active power step change due to lack of inertial element of PV power station requires adjustment by increasing the spinning reserve capacity of the grid. Besides, there are also technical problems for various operation control measures including power supply reliability index analysis, voltage and reactive power control, electric power measuring and billing as well as information interaction of grid automatic system, etc.

c) Grid Security

Distributed PV grid connection brings unplanned isolated island operation, which will threaten personal safety of line maintenance personnel, harm the power supply quality for users connected to the isolated island, and cause switching over-voltage due to non-synchronous reclosure. Moreover, mono-phase distributed power generation system will result in default phase power supply of three-phase load while non-detection zone exists in all anti-islanding detecting algorithm.

d) Protective Relaying

Protective relaying and reclosure behavior will be affected by PV power generation system once line malfunction happens. Three-stop current protection based on the breaker is under the greatest influence, resulting in lower line protection flexibility and instantaneous quick-break protection malfunction of adjacent lines as well as loss of selectivity.

e) Electric Energy Quality

PV grid connection inverter adopts high-frequency modulation which may generate harmonics easily; amplifying harmonics generated by parallel connection is hard to predict and manage; uncertain power output may cause grid voltage fluctuation and flickering; all these requires the grid to be equipped with related power energy quality governance devices .

f) Solutions

Reasonable Planning of PV Power Station Construction

PV power station construction should be advanced systematically to solve the output and consumption problem. Sticking to the general thought of “reasonable layout, nearby access, local consumption and systematic development” , construction of PV power station of various kind is to be advanced in an orderly way with the premise of market consumption in accordance with requirements of local electricity market development and energy restructuring. It is encouraged to construct PV power station with multi-energy complement method by utilizing existing electric facilities. Moreover, PV power station and supporting grid planning and construction should be coordinated to ensure timely grid connection and high-efficient employment of power generated by the power station.

5.3.2 Smart Grid Construction

Grid connection is limited to some extent due to above-mentioned problems. Therefore, several technologies can be used to avoid security problems of PV power generation grid connection and realize smart grid construction, including PV generated output prediction technique, integrated planning and coordinated control of PV and other power supply as well as smart control technique that increases the controllability of PV power station power. Butt joint of PV power generation system and smart grid will be achieved in the end to advance grid connection and high-efficient utilization of PV power generation.

5.3.3 Energy Management System Construction

Construction of smart grid requires high integration of information technology, communication technology, computer technology and existing power transmission and distribution infrastructure. The reliability of the new-type power distribution network established will be confronted with challenges. Therefore, strong energy management system should be established so as to realize the butt joint of PV system, smart grid and energy management system and enhance grid connection and efficient utilization of PV power generation.

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