Recent Development of Grid-connected PV Systems in China

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***Abstract*-- The exhaustion of fossil fuels and environmental degradation has aroused worldwide attention for renewables as alternative clean energy sources. Benefiting from the rapid development of photovoltaic (PV) technology, solar energy generation, as an important component of renewable energy exploitation, has been witnessing an exponential increase since the past decade. Based on the characteristics of energy distribution and electricity supply status in China, this paper summarizes the current development trends of PV implementations. The state-of-the-art PV technology, specifically the grid-connected photovoltaic system applications is discussed as well. Finally, future challenges and suggestions for PV industry are analyzed and presented.**

***Index Terms*—Renewable Integration, photovoltaic, grid-connected photovoltaic systems**

I. Introduction

THE excessive use of fossil fuels brings about two serious problems: the exhaustion of conventional fossil fuels and grave environmental degradation. Both problems threaten the sustainability of future development. In order to sustain rapid social and economic growth, governments worldwide are promoting renewable energy exploitation to cut down on the emission of greenhouse gases, which causes global warming. According to the United Nations Framework Convention on Climate Change (UNFCC), twelve countries have submitted their pledges to reduce the rate of greenhouse gas emission by 2020. The world's biggest greenhouse gas emitter, the US, claims that its greenhouse gas emissions will fall 17% by 2020, while China, the second-biggest emitter, assures that it will reduce carbon dioxide emissions per unit of GDP in 2020 by 40% to 45% compared to 2005.

To reach these targets, inexhaustible solar energy is a promising alternative to conventional energy consumption. Naturally, all forms of energy on earth come from the sun. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 EJ per year [1], which is thousands of times the global primary energy consumption in 2005, which is 485EJ [2]. However, the extremely low efficiency of energy conversion devices has limited large scale exploitation of solar energy until this century. Since the beginning of 21st century, PV industry witnessed a dramatic growth. There are two major features: (1) the reduced cost of photovoltaic (PV) power generations, especially grid-connected applications (2) the breakthrough of the core techniques for grid-connected PV power system. Lower cost and better quality of PV applications justifies large-scale PV installation as an alternative power source. According to an estimation made by European Commission Joint Research Centre (JRC) in 2004, the share of solar energy among all the primary energy sources will continuously rise to a dominating proportion compared to other forms of energy.

Compared to the rest of the world, the energy crisis in China is even more severe because of the deficiency in conventional energy reserves. Table I illustrates the current status of energy shortage in China. Also, the increasing demand for energy resources by the fast developing economy intensifies the market panic for energy shortage. To address this pressing energy problem, Chinese government has promulgated a series of promotion policies for renewable energy implementation [3].

TABLE I
THE ESTIMATED YEARS LEFT FOR CONVENTIONAL ENERGY RESERVE (STARTING FROM 2000) [3]

The type of energy	The World	China
Oil	45	15
Natural Gas	61	30
Coal	230	81
Mined Uranium	71	50

To get a better understanding of PV power, this paper focuses on grid-connected PV implementation in China. Based on up-to-date PV analysis reports, the current status of worldwide PV development is briefly introduced and the development in China be carefully discussed. The reason for integrating PV generation into power grid is justified. The state-of-the-art technology relevant to grid-connected PV system applications is then discussed. Finally, future challenges for PV industry, especially grid-connected PV applications, in China are analyzed and several suggestions for future development are proposed.

II. Recent Status of PV System Implementation

A. International Development Trend of PV System

The past decade has seen an exponential increase in the

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global PV market; this growing trend will continue in the coming decade. According to European Photovoltaic Industry Association(EPIA), a global PV market outlook updated in May,2010, the world's cumulative PV power installed approached 22.9GW in 2009, increased by 45% compared to 2008 (16GW) and today almost 23GW is installed globally. This produces about 25 TWh of electricity on a yearly basis. Fig. 1 shows the market share of the world's in 2009 and Fig. 2 shows the historical development of World cumulative PV power installed in main geographic regions [4].

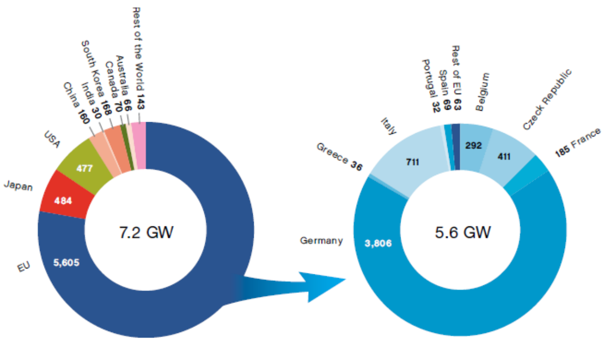
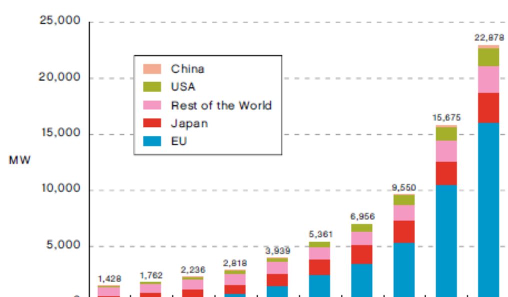


Fig. 1. World and European PV markets in 2009 in MW [4]



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
China	19	30	45	55	64	68	80	100	145	305
USA	139	168	212	275	365	479	624	831	1,173	1,650
ROW	763	825	913	1,000	1,044	1,051	1,235	1,422	1,870	2,347
Japan	318	452	637	860	1,132	1,422	1,708	1,919	2,149	2,633
EU	189	286	429	628	1,334	2,341	3,309	5,279	10,338	15,943
Total	1,428	1,762	2,236	2,818	3,939	5,361	6,956	9,550	15,675	22,878

Fig. 2. Historical development of world cumulative PV power installed in main geographies [4]

The Europe maintains its lead with installed capacity of 5.605GW in 2009, which accounts for 78% of the world total capacity. Germany remains the world's largest PV market with a cumulative PV power installed of almost 10 GW, including around 3.8 GW installed in 2009. Outside Europe, Japan and USA are the leading markets with 484MW and 475MW installed in 2009. The market in China increased significantly with 160MW installed in 2009, although the market share is still slight compared to the world [4].

Because of the much higher cost of PV power than that of grid power, promotion policies adopted by the national government play an important role in global PV application deployment. As public funds encourage the investment of grid-connected PV markets, grid-connected applications dominate the market, accounting for 99% of the market share in IEA-PVPS countries in 2009 [5]. Feed-in-Tariff (FIT) is currently the prime incentive adopted worldwide. The FIT provides a premium price for electricity generated by renewable power installation. For instance, the FIT price for solar power in Germany is ten times that of the thermal power and is paid for a time period of 20 years [6-7].

B. *Classification of Modern PV System*

With the rapid growth in PV technology, modern PV systems can be categorized into two major types: off-grid and grid-connected.

Off-grid systems, also known as the stand-alone plants, are used to supply electricity to isolated users with no access to electricity grid.

Grid-connected systems are usually connected to a typical public electric grid and feed power into the grid. They can be further classified into grid-connected distributed PV system and grid-connected centralized system. Distributed PV systems are installed on the demand side to provide power primarily to a particular grid-connected customer. Building-integrated PV (BIPV) is a prevailing application of this kind. Centralized grid-connected systems function as centralized power station. They are directly connected to an electricity transmission grid to provide supply of bulk grid power instead of an electricity network feeding a specific customer. Such systems are usually located in spacious open areas with abundant solar irradiation [5].

To enhance the performance of these PV generation systems, there are hybrid PV systems using multiple energy sources. The combined use of renewable energies can increase both capacity and reliability due to their complementary features. The distribution feature of local resources should be analyzed in the hybrid system design. The key technical concern in such application is the control strategies [8-10].

In China, large-scale grid-connected applications are the growing trend because electricity distribution suffers from regional imbalance between prime energy resources and economic development [11].

III. Grid-Connected PV Systems Development in China

In order to help balance the mismatching of solar radiation distribution in the west and load centre of power grid in the east, grid-connected PV system has been developed rapidly in China.

A. *Distribution of Solar Resource in China*

China is rich in solar resources compared to the world average. The total capacity of annual solar radiation in China is between 930 and 2330 kWh/m2, which equal 2.5 to 6.4 kWh/m^2 daily solar radiation. On the whole, the daily solar radiation in more than two thirds areas in China is higher than 4 kWh/m^2, which is favorable for solar deployment. Fig. 3 shows the distribution feature of solar resource in China [12].

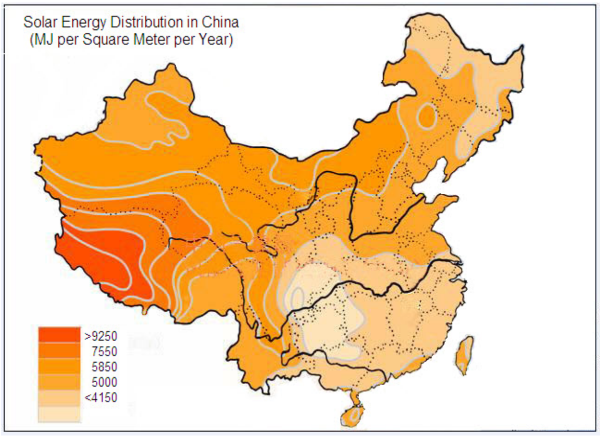


Fig. 3. Solar Energy Distribution in China [12]
(Center for Wind and Solar Energy Resources Assessment, China Meteorological Adiministration)

From Fig. 3, the distribution of solar resource in China bears three characteristics:

(1) Solar radiation in the western part of Tibet is the most abundant in China. Its annual solar radiation is up to 9250 MJ/m2·year, which is only second to the Sahara desert in the world [13] .

(2) Annual solar radiation in the western part is higher than that of the eastern part and the southern part higher than that of the northern part, except in the Tibet and Xinjiang provinces.

(3) Annual solar radiation increases as the latitude increases because lower geographic regions enjoy more precipitation.

The annual surface absorption of solar energy is equal to 280 times the total reserves of coal in China, which well justifies the inexhaustible solar energy as a promising alternative energy source to address long-term energy shortage [3], [14].

B. Development of PV Market in China

The beginning of the 21th century saw a rapid growth in the PV market in China. From Fig. 4, the cumulative installed capacity has increased by seven-fold in 2008 since 2000 and the annual installed capacity has increased by thirteen-fold [3]. However, the market share of solar power is still negligible compared to thermal power and hydro-power in 2010. Fig. 5 shows the installed power capacity in China in 2010 [15].

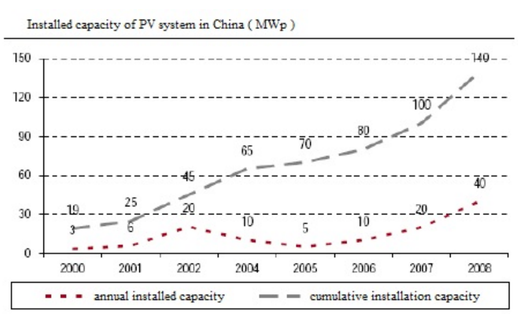


Fig. 4. Installed capacity of PV system in China

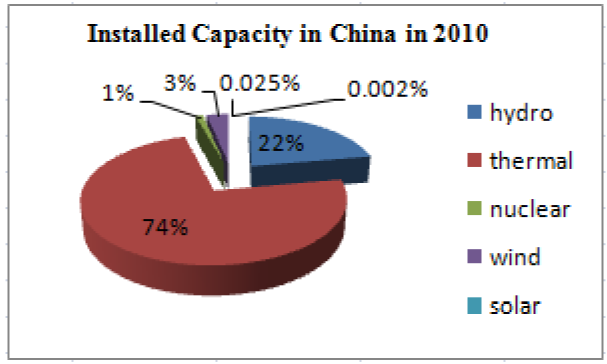


Fig. 5. Installed capacity in China in 2010 [15]
(China Electricity Council)

The PV industry in China is export-dominated and the demand in domestic market is insufficient. China ranked the first in PV cell production since 2008, accounting for 44% of the global market share, while only 2% of the capacity is for domestic application. The cumulative installed capacity of PV only accounts for 1% of the world total and the annual installed capacity only accounts for 2% of the world total. From the aspect of PV application distribution, grid-connected PV system only account for 5% of the total PV installation capacity in 2006 [3].

The situation is changing and the domestic market of grid-connected PV is expanding since the launch of the golden sun program in 2009 initiated by The Chinese Ministry of Finance (MOF), the Ministry of Science and Technology (MOST) and the National Energy Administration (NEA). This program aims to install more than 500MW PV modules, including Feed-in-Tariff for building material integrated PV (BIPV) and large scale grid-connected PV station as well as a support fund for research and development (R&D) in PV industry. Up till now, 294 projects of 642 MW have been approved, indicating the success of the domestic grid-connected PV market in China [3], [6].

IV. DISCUSSION ON KEY TECHNOLOGIES IN PV SYSTEM DEVELOPMENT

A. Photovoltaic Cells

Photovoltaic cells are key components of PV applications. They are basic units that convert solar energy into electricity. Cost and efficiency are the two major concerns in evaluating the PV cells production. At present, there are three generations of PV cells: (1) wafer-based crystalline (2) thin-film technology (3) concentration PV cells (CPV).

The traditional wafer-based crystalline cells still dominate the market of PV cells. The module conversion efficiency of this type is between 15% and 18% for commercial products [4]. Nevertheless, the market share of the first generation is slowing taken over by the second generation thin film cells because of the reduced cost in using much thinner layers of material and less expensive process. However, the consequential low efficiency which results from the reduced use of material requires larger installed space and more labor to generate the same amount of electricity using thin-film cells. To further retrench the costs without decreasing efficiency, concentration PV (CPV) is a rising technology, which reduces the amount of PV material needed by concentrating sunlight onto photovoltaic surfaces. The smaller number of PV modules required and the reduced installation cost justifies the use of more costly cells with higher conversion efficiency. The current typical commercial device efficiency is 39%. In 2010, a 30MW grid-connect PV plant in Yixin, China has achieved 42% efficiency using CPV cells. The on-going research on CPV focuses on developing cost effective tracking devices to track the sun [6], [16], [17].

B. Grid-connected Inverter and Control Strategy

Grid-connected inverter, also known as the synchronized inverter, converts direct current electricity (DC) generated by PV cells into alternate current electricity (AC) and feeds it into existing electricity grid. There are three main concerns for grid-connected inverter control: (1) maximum power point tracking (MPPT) (2) grid-connected synchronization (3) islanding effect dealing.

Maximum power point tracking aims at achieving the greatest possible power output by adjusting electrical load due to the variations of irradiation level and ambient temperature. By adopting a specific algorithm to control the output of inverter, PV system can be operated at its maximum power point (MPP) in order to improve the efficiency of the overall system. The available algorithms include constant voltage tracking (CVT), incremental conductance method (INC) and fuzzy control. However, the optimal solution is still difficult to obtain because photovoltaic cells exhibit a nonlinear current-voltage characteristic. Up to now, no algorithm is capable of providing the best performance for all environmental conditions, especially when a large fluctuation of ambient occurs. There is still MPPT research that focuses on searching for cost-effective ways to get better responses under complex environmental conditions [18].

Grid-connected synchronization ensures that the output power has the same voltage and frequency of the power grid. Also, sine wave with small distortion is considered in control strategies in order to eliminate the impact of integration to the power grid. With the development of the digital signal processer (DSP), lots of methods appear, for example, neural network control, adaptive control, sliding model variable structure control and fuzzy control, competing with traditional PWM current control strategies [19].

Islanding effect dealing is important because islanding effect may bring potential safety hazards. Islanding effect happens when a distributed generator continues to power a location even through the grid power is interrupted and no longer exists. This may cause personal injury to maintenance personnel or unpredictable damage to electrical equipment. Dealing with islanding effect includes detection and judgment. Detection methods include passively monitoring voltage or voltage frequency to detect if there is any deviation from the normal and actively send some smaller disturbance signal in to the system to see the voltage or frequency response of a particular testing point. Judgment follows to decide whether a real islanding occurs and whether to make wise decisions to cut down the generator [19].

Currently, the market of grid-connected inverter is dominated by Solar Technology AG (SMA), which takes over one-third of the global market share. Domestic products in China still lag far behind in apparatus efficiency and dependability, compared to European ones [20].

C. High Levels of PV Penetration Issues

As the grid-connected PV capacity increases to a signal proportion of the power grid in the near future, high levels of PV penetration issues rise because of the impact of large-scale PV generation on the grid. To enhance the electricity quality and system security, harmonics cancellation and low-voltage tolerance are two main issues. Also, for better energy management, storage is introduced to balance the load.

Harmonics may exceed internationally accepted IEEE 519 standards at the point of coupling a large scale connection of several converters in a realistic solar farm. A certain mechanism for harmonic cancellation/minimization is needed in order to improve the quality of electricity output [21]. Group control technology, which involves a group of inverters, may be the remedy. Such a harmonics compensation method can also be adopted to improve the quality of grid electricity [22-23].

Low-voltage tolerance is essential when a fault happens in a power grid and the grid voltage drops all of a sudden. Detection algorithm is implemented to identify the instantaneous voltage sag and notify the controller of PV inverters to alter output in accordance with the standard low-voltage tolerance demands [22].

Storage capacity is introduced into a large-scale PV system to enable both active and reactive power output of PV system so that the system can be integrated into the automatic control system for economic dispatch. Storage can also be used to perform peak shaving, load shifting, demand response, outage protection and power quality control, contributing to better reliability, security, and electricity service [22] ,[24].

With larger PV system capacity connected into a power grid, more integration issues may occur. Integration technology of high levels of PV penetration will be the heated research topic in the following decade [25].

V. Challenges of Grid-connected PV in China

A. Government Policy

Since the advent of PV technology, Government policy has been the conclusive factor in the development of PV industry because of the high costs of PV application investment. In Spain, dramatic changes to the support scheme in late 2008 resulted in a total collapse of PV market in 2009. The installed capacity of PV plummeted from 27GW in 2008 to 60MW in 2009. On the contrary, in Germany, favorable FIT guaranteed by Renewable Energy Sources Act (EEG) contributes to a steady growing trend in PV market [5].

In order to achieve the goal of renewable energy stratagem, the Chinese government should implement active promotion policy for PV application investment, especially large-scale grid-connected PV plant projects. In China's 12th Five-Year plan, renewable energy development is labeled as the first among the five major concerns of national energy stratagem and solar energy is one of the critical components of renewable energy. In order to maintain the fast growing trend in cumulative PV capacity, the Chinese government should make wise decisions to provide reasonable price for feed-in-tariff and subsidies.

Government should also take responsibilities in guiding the restructuring of the domestic PV industry. Currently, domestic PV manufacture displays a pyramid-structure industrial distribution with relatively a small number of large enterprises upstream and a larger number of small companies close to the downstream. Besides, the proportion of domestic consumption compared with total PV cells production is scant. To reverse the situation, governments should take several measures to reshape the PV industry: (1) establish special fund for research and development of core technology in PV industry to speed up industrial upgrading (2) set up entry threshold and encourage large international competitive enterprises (3) increase domestic demand by promoting large-scale PV installation [26].

B. Project Planning Issues

Several factors should be considered in PV project planning, including solar irradiation level, regional electricity consumption and space available for installation.

Western parts of China, especially the west of Tibet, are sparsely populated and enjoy abundant solar irradiation. Large-scale grid-connected PV system should thus be invested and the electricity can be transmitted to the load centre in the east. In developed regions, especially the coastal cities in the east, building integrated PV (BIPV) should be encouraged because BIPV technology replaces conventional materials with PV materials and consequently, does not require extra space for PV installation. Since the electricity demand of buildings accounts for a remarkable proportion of electric load in the city during the daytime, BIPV can help to shave the peak load. In southwest China, hydro and solar energy resources have complimentary feature because of the alternate climate pattern between wet and dry seasons. Implementation of hydro/PV hybrid power system will contribute to a comprehensive use of renewable energy and provides better system stability [10].

Research and development for core PV technology are also important for the sake of the sustainability of PV industry. Only when the cost of PV power is reduced to a market-competitive level can the PV industry turn from being policy-driven to being market-driven, which is ultimately sustainable in the long run. Researches on the promising technology, such as CPV, should be led by government policies in order to obtain lower cost and higher efficiency for PV power generation. Also, the control and management methods for large-scale PV integration should be emphasized.

VI. Conclusions

With abundant solar resources and rapid technology development, PV generation in China will enjoy great prospects in the following decades. To accelerate sustainable PV industrial development, governments should make more effective policies to support sensible PV investment and set up special fund for research and development of key technologies for large-scale PV integration in the future. According to the characteristics of power grid and solar energy distribution in China, it is believed that high efficiency and market-competitive grid-connected technology is critical.

VII. References

[1] Advanced Power & Energy Inc. “Energy from the Sun”, p2 [Online]. Available: http://www.anenergy.com/solar_energy.pdf

[2] Energy Information Administration, "World Consumption of Primary Energy by Energy Type and Selected Country Groups, 1980-2004". [Online]. Available: http://www.eia.doe.gov/pub/international/iealf/table18.xls

[3] “Development Report on China and Abroad PV Industry”, 2011 [Online]. Available: http://www.all4report.com/simple/?t10274.html

[4] EPIA, Global Market Outlook for Photovoltaics until 2014, May 2010 Update. [Online]. Available: http://www.epia.org/fileadmin/EPIA_docs/public/Global_Market_Outlook_for_Photovoltaics_until_2014.pdf

[5] IEA-PVPS, Trends in photovoltaic applications Survey Report of Selected IEA Countries between 1992 and 2009. T1-19:2010. [Online]. Available: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/tr_2009_neu.pdf

[6] Thilo Grau, Molin Huo, Karsten Neuhoff, Climate Policy Initiative, DIW Berlin and Tsinghua University. (2010, Mar.). “Survey of Photovoltaic Industry and Policy in Germany and China” [Online]. Available: http://www.climatepolicyinitiative.org/files/attachments/112.pdf

[7] “Supporting polices on PV industry by various countries”. 2007 [Online]. Available: http://www.chd.com.cn/news.do?cmd=show&id=27686

[8] Osawa, H.; Miyazaki, T.; , "Wave-PV hybrid generation system carried in the offshore floating type wave power device "Mighty Whale"," *OCEANS '04. MTTS/IEEE TECHNO-OCEAN '04* , vol.4, no., pp.1860-1866 Vol.4, 9-12 Nov. 2004

[9] Seul-Ki Kim; Eung-Sang Kim; Jong-Bo Ahn; , "Modeling and Control of a Grid-connected Wind/PV Hybrid Generation System," *Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES* , vol., no., pp.1202-1207, 21-24 May 2006

[10] Wu Chun Sheng; Liao Hua; Yang Zi Long; Wang Yi Bo; Peng Yan Chang; Xu Hong Hua; , "Research on control strategies of small-hydro/PV hybrid power system," *Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on* , vol., no., pp.1-5, 6-7 April 2009

[11] Zhang Ruihua; Du Yumei; Yuhong Liu; , "New challenges to power system planning and operation of smart grid development in China," *Power System Technology (POWERCON), 2010 International Conference on* , vol., no., pp.1-8, 24-28 Oct. 2010

[12] Centre Center for Wind and Solar Energy Resources Assessment, China Meteorological Adiministration [Online]. Available: http://cwera.cma.gov.cn/cn/

[13] Zhong Yang; Sumei Gao; , "On Selecting the Locations of 60MW Grid-Connected Photovoltaic Power Plant," *Photonics and Optoelectronic (SOPO), 2010 Symposium on* , vol., no., pp.1-4, 19-21 June 2010

[14] Xiangshuo Li; Chun Wang; Jiaolong Gong; Ning Hua; , "Photovoltaic technology research and prospects," *Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on* , vol.8, no., pp.328-330, 9-11 July 2010

[15] China Electricity Council. (2011, Feb.). Statistics Report for National Electric Power Industry in 2010. [Online]. Available: http://www.cec.org.cn/tongjixinxibu/tongji/niandushuju/2011-02-23/44236.html

[16] Seshan, C.; , "CPV: Not just for hot deserts!," *Photovoltaic Specialists Conference (PVSC), 2010 35th IEEE* , vol., no., pp.003075-003080, 20-25 June 2010

[17] "The Breakthrough of Solar Generation Technology in Yixins" Oct, 2009 [Online]. Available: http://istock.jrj.com.cn/article, 600095,2492677.html

[18] Jiyong Li; Honghua Wang; , "Maximum power point tracking of photovoltaic generation based on the fuzzy control method," *Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on* , vol., no., pp.1-6, 6-7 April 2009

[19] Zhou Xue-song; Liang Fang; Ma You-jie; Song Dai-chun; , "Research of control technology in grid-connected photovoltaic power system," *Computer, Mechatronics, Control and Electronic Engineering (CMCE), 2010 International Conference on* , vol.3, no., pp.5-8, 24-26 Aug. 2010

[20] "Current Status and Prospects of PV Inverter Development" (2010, Dec) [C]. [Online]. Available: http://solar.ofweek.com/2010-12/ART-260002-8500-28433029.html

[21] Varma, R.K.; Salama, M.; Seethapathy, R.; Champion, C.; , "Large-scale photovoltaic solar power integration in transmission and distribution networks," *Power & Energy Society General Meeting, 2009. PES '09. IEEE* , vol., no., pp.1-4, 26-30 July 2009

[22] Huan Wang; Yanchang Peng; Zilong Yang; , "Analyzing the key technologies of large-scale application of PV grid-connected systems," *Power System Technology (POWERCON), 2010 International Conference on* , vol., no., pp.1-4, 24-28 Oct. 2010

[23] Xu Jin; , "Photovoltaic Grid-Connected Inverter Harmonic Compensation and Grid-Connected Unified Control," *Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific* , vol., no., pp.1-4, 27-31 March 2009

[24] Hanley, C.; Peek, G.; Boyes, J.; Klise, G.; Stein, J.; Dan Ton; Tien Duong; , "Technology development needs for integrated grid-connected PV systems and electric energy storage," *Photovoltaic Specialists Conference (PVSC), 2009 34th IEEE* , vol., no., pp.001832-001837, 7-12 June 2009

[25] Sinke, W.C.; Montoro, D.F.; Despotou, E.; Nowak, S.; Perezagua, E.; , "The Solar Europe Industry Initiative: Research, technology development and demonstration in support of 2020 and long-term targets," *Photovoltaic Specialists Conference (PVSC), 2010 35th IEEE* , vol., no., pp.000424-000429, 20-25 June 2010

[26] Tao Chun-Hai; , "Research on China's Photovoltaic Industrial Restructuring," *Computer Technology and Development, 2009. ICCTD '09. International Conference on* , vol.1, no., pp.606-610, 13-15 Nov. 2009

VIII. Biographies

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