ISESCO Science and Technology Vision
Volume 6 - Number 9 - May 2010 (50-53)

# Establishment of One MW HCPV System at Taiwan

**I-Tao Lung, Cherng-Tsong Kuo, Hwa-Yuh Shin, Hwen-Fen Hong, Cheng-Dar Lee, and Tsung-Te Lin**

Institute of Nuclear Energy Research, #1000 Wenhua Rd., Jiaan Village, Longtan, Taoyuan, Taiwan,
886-3-4711400 Ext. 6412,
itlung@iner.gov.tw

## Abstract

*Despite the sharp economic downturn in 2008, one MW high concentration photovoltaic (HCPV) system designed by Institute of Nuclear Energy Research (INER), Atomic Energy Council, Executive Yuan, Taiwan, is still constructed as planned, at Lujhu township of Kaohsiung county, the southern part of Taiwan. At the end of 2009, ad hoc system has been established, and which for now is the largest HCPV power plant in Asia. To demonstrate characteristics of different systems elements (such as solar cell, module, etc.), one MW HCPV system is categorized into 5 regions. Purposes of building one MW HCPV system are not only to integrate technologies of upper-, mid-, and down-stream of Taiwan HCPV industry, but to conduct the field test to verify the different figures of cells to validate the different modules against outdoor environment. To conform with IEC standard, and to have a certified laboratory qualifying the required tests of CPV module, INER has made lots of efforts on the establishment of module qualification lab, and won the certificate of accreditation from Taiwan Accreditation Foundation, and was granted the IECEE Witnessed Manufacturer's Testing laboratory by UL to provide services with test and qualification on CPV modules for domestic companies. This paper depicts the MW HCPV system configuration, tracking strategy, advanced central control and monitoring system, project goals, comparison test on module, and experiences learned from this project.*

***Keywords:*** *High Concentration Photovoltaic (HCPV), Solar Cell, Module, Tracker, DNI.*

## 1. Introduction

The statute for Taiwan's renewable energy development containing 23 articles was promulgated on July 8, 2009, in expectation of effectively bringing out the demands on solar market, and driving a new era in renewable energy of Taiwan. INER has been developing HCPV technologies of, such as solar cell, concentration module, tracker, and central control system, etc. since 2003. Establishments of HCPV system in past three years include 100 kW HCPV system in Oct. 2007, a demonstration system with three sets of 1.5 kW, 5 kW, and 7.5kW HCPV system at the HCPV Qualification Center of INER in May 2009, and one MW HCPV demonstration power plant (shown as ***Figure 1***), which covers an installation area of 2 hectares, at Lujhu in December 2009, anticipating generating over 1 million kWh per year, reducing carbon dioxide emissions approximately of 660 tons annually. It is a milestone for Taiwan's government to put the policy of energy saving and carbon reduction into practice. For assisting the Kaohsiung Science Park, inviting related companies to join HCPV business, forming a CPV industrial cluster, and achieving the most valuable synergy, the HCPV Qualification Center of INER at Kaohsiung Science Park was starting to operate in May 2009. This center is also set up for enhancing multi-junction solar cell epitaxy technologies, sharing knowledge and expertise, and for expediting the module qualification service.

***Figure 1.*** *One MW HCPV Demo System at Lujhu, Taiwan*

## 2. One MW HCPV Demonstration System

The opening ceremony of one MW HCPV demo system was held at Lujhu on Dec. 22, 2009. Industrial tycoons of CPV sector and guests from all walks of life were gathered to celebrate INER setting up the largest HCPV power plant in Asia, second to the one in Spain. In terms of HCPV techs, INER has kept pace with international, and led Taiwan to a new era of photovoltaic industry.

Current unbalance of three-phase distribution systems induced by grid-connection of many distributed single-phase solar generators was solved by an algorithm making three-phase current unbalance rate lower than 5 percent [1]. As to the electrical power system engineering, it includes installation of power transmission system, switch yard, lightning protection system, and on-grid enabled equipment. Generated power is boosted to 11.4 kV to connect to on-grid of Taiwan Power Corp.

To demonstrate the performance of different sources of cells and various processed modules, one MW HCPV system is categorized into 5 regions. Four regions (A-D) are composed of 120 sets of 7.5 kW pillar-stand subsystems. The fifth region (E) consists of 21 sets of 5 kW pillar-stand subsystems. Average cell conversion efficiency is above 35%, and module efficiency is 25% in average, surpassing the average module efficiency 23% with a geometrical concentration ratio of 476x under 850 W/m$^2$ and passive cooling conditions for INER's 100 kW HCPV system [2]. Subsystem efficiency is about 21% in maximum. Site features of one MW HCPV system are shown as in ***Table 1***; Debut performance leaves something to be desired; however, the field ground is still dusty and pollution may drop the efficiency about 2% [3]. This situation will be solved by growing grass in May this year.

**TABLE 1. Site Features of One MW HCPV System**

| Item | Description |
|---|---|
| 7.5 kW HCPV Subsystem | 120 |
| 5 kW HCPV Subsystem | 21 |
| Cell No. | 321600 |
| Cell Conversion Efficiency | 35% in average |
| Modules No. | 8040 |
| Module Efficiency | 25% in average |
| Inverter | 201 |
| Subsystem Efficiency | 21% in max |

### *Tracking Strategy*

Comparing with the conventional PV system, solar trackers used in HCPV system need more accurate in order to guide sunlight onto the cell surface, through the secondary collimator. Generated power will be dramatically decreased if the HCPV tracker goes off the axis of the sun. To have a maximum power and reduce unnecessary power consumption, a robust tracking strategy has been achieved for the one MW demonstration system, eluding either sophisticated installation, or weather influences, or intermittent recalibration. The strategy is a combination of an open loop tracking, based on sun ephemeris, and close loop tracking, using a sun position sensor with a dynamic feedback controller. The hybrid tracking controller is in which strategy depends on the illumination of sunlight, detected by the sun position sensor; bright enough, the close loop strategy will dominate the tracking. Otherwise, the open loop strategy will take over [4]. However, to have a precise tracking, imprecision caused by tracking precision and weather should be compensated [5].

### *Advanced Central Monitoring and Control System*

The Structure of Advanced Central Monitoring and Control System (ACCS) is shown as ***Figure 2***. To cut down the cost of establishment, the ring topology takes the place of the star network within each region. To maintain a snap monitor, multi-threading and advanced networking technologies are utilized. Monitoring function applies to the web to provide data for management purposes. Various colors of the solar tracker icon on screen symbolize different states, i.e., communication or generated power in normal or abnormal, etc. Monitoring function also demonstrates the information of DC/AC output power, system efficiency, DNI and so on. Functions of ACCS can be divided into the following parts: (1) to extract azimuth or elevation value for the offset adjustment during maintenance; (2) to compare the azimuth or elevation value of each solar tracker with solar trajectory information to move solar trackers to the predetermined position if needed; (3) to force the solar tracker elevation to horizontal position if wind speed is greater than the predetermined value; (4) to identify abnormal conditions whenever DNI is greater than the predetermined value but no power generated.

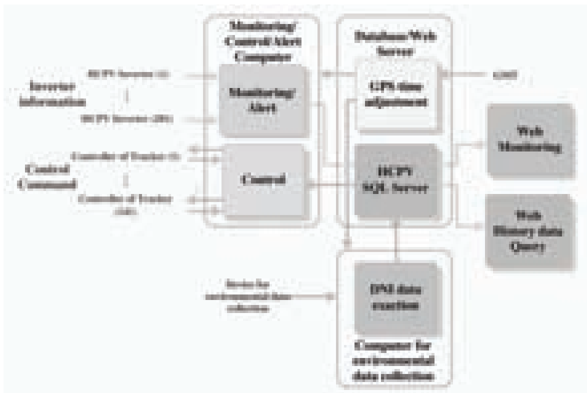


***Figure 2.*** *Structure of ACCS*

The meteorology station located at the HCPV demonstration power plant can manifest the prompt information of the DNI. The environmental information acquired from the pyranometer, pyrheliometer, UV irradiation meter, anemometer, thermometer and hygrometer, etc., was sent to ACCS, providing automatic tracking strategy to avoid the damage from high wind speed. The information of power generation and meteorology is collected by terminal server to analyze and calculate every parameter [6].

## 3. Project Goals

In 2009, with the short-circuit current ratio of 133, the energy conversion efficiency of InGaP/GaAs/Ge tandem solar cell under concentration reaches 37.1%. Meanwhile, INER has captured HCPV technologies needed for solar module, tracker, and monitoring and control system. Concentrating lenses taking the mold-injection process is in place for the advantage of low manufacturing cost and throughput in terms of the mass production [7]. The uppermost record of module efficiency under 476 geometric concentration ratios is 27.1% [8]. The tracking accuracy is improved to 0.2 degree, and multi-thread programming is used for data fetching and commands distributing in order to expedite the processing and enhance the management efficiency. Establishing the MW grade HCPV demonstration system, promoting the performance, industrializing relevant tech of HCPV, and cutting down cost of production are the essential goals. However, integrating the technologies of upper-, mid-, and down-stream, expediting systematic installation process, collaborating with corporations to make HCPV commodified, popularized are the additional commissions.

## 4. HCPV Industrial Status in Taiwan

Some solar cells used in one MW HCPV demo system are foreign products, and the rest of them are from domestic. Up to 2009, there are 22 vendors in total involved in HCPV industry, which can be categorized into four groups [9] (some are versatile, shown as *Table 2*), eight in cell, eight in module, eight in tracker, and six in system integration.

**TABLE 2. Taiwan HCPV Industrial Current Status**

| Group | Upper- | Mid- | Down-stream |
|---|---|---|---|
| III-V Solar Cell | NTU NTHU, NCTU,CYCU, DYU | INER, CSIST ITRI | *VPEC, *AOC, *EPISTAR, *WIN, Solapoint, TRANSCOM, M-com, CompSolar |
| CPV Module | NTU, NTHU, NCTU, NCU, CYCU | INER | *DELTA, *BROWAVE, *EVERPHOTON, HOKUANG, ArimaEco, RODAN, *CMS, Higher Way |
| Solar Tracker | NCKU, NCU, NDHU, TNU, NYU | INER | *DELTA, *GREEN SOURCE, *LIH KANG, *Mirle, *Spirox, EVERPHOTON, ArimaEco, TRANERGY |
| HCPV System | WFIT, VNU, CGU | INER | DELTA, EVERPHOTON, Spirox, AREi, ArimaEco, TRANERGY |

Remark: *stands for the company providing product to INER, or receiving technology transfer, or technical service from INER

## 5. Comparison Test on Module

Besides establishing the test capacity for IEC 62108, INER's module qualification lab has the outdoor comparison test (effective exposure area: 0.576 $m^2$) on CPV module with Fraunhofer ISE and UL San Jose laboratory, in 2008 and 2009 respectively. The slightly different results are less than 1%, within the tolerance caused by the different climatic environment. In Germany, the module efficiency is 21.4%, while the maximum DNI is 830 $W/m^2$, and in the U.S.A., it is 22.4% at 920 $W/m^2$, while is 21.9% at 850 $W/m^2$ in Taiwan, showing the test capability and credibility of INER matches with international labs'. And test modules are referred as samples for the subsequent CPV module test.

## Conclusions

During the establishment of MW grade HCPV system, several complex situations are occurred, such as land acquisition, approval of enterprise plan and developing plan, removal of trees, reimbursement for the tenant, enforcement of evacuation of illegal inhabitants, change in category of land, and separation of the land ownership, etc. With helps from local government, all the difficulties were conquered item by item, allowing works of installation and test are fulfilled within three months. The application process takes time but is reasonable if it compares with the world-wide approval processing time, ranging from the fastest one month to the slowest 15 months. Experiences learned: well-prepared documents, professional officials, right contactors, and cooperation can expedite the approval process greatly.

To fortify local HCPV related industries in the field of epitaxy, solar cell, concentration module, solar tracker, power system, module qualification, and central monitoring and control, etc., INER has applied for patents since 2005, either in invention or in utility, and 32 patents are granted, 93 invents are undertaken the patent application procedures. In addition, nine items of technology transfer and authorization have been completed, and 11 cases of technical service had been provided. Moreover, INER is aggressively pushing HCPV industrialized, and roots relevant tech locally by helping domestic vendors promote their skills and cultivate their capabilities. Besides, INER has set off establishing the HCPV module qualification, incubation and promotion of HCPV technologies to have the HCPV system extended its application, and forming an HCPV circle in the southern part of Taiwan. The major efforts recently are centered on two topics; one is increasing the magnification of the lens, and the other is enhancing the accuracy of the tracker. For the former one, a new style of 900x concentration photovoltaic module is manufactured with the technologies of high performance lens, vacuum welding, and the energy conversion efficiency reached 26.6% under outdoor test with 795 W/m$^2$ DNI. For the latter, the tracker is designed by adapting digital signal technology to filter the false signal from solar position sensor, making the tracking accuracy improved.

By the tech transfer, patent deployment, and establishment of the demo system, not only would the HCPV tech have been industrialized, but expertise also has been spurred; in addition, energy conservation and carbon reduction policy fulfilled, working opportunities created, practical skills via training conveyed, and tourism flourished. To keep track of Taiwan governmental policy of “Green Energy Industry Program,” in the future INER will work with HCPV industries side by side to push forward the mass production progress, get more synergy at industrialization, and stride into international solar market, which is recovering from 2008-09 recession and getting its second wind due to new technologies, falling price for solar materials, and raised solar feed-in tariffs, even though the German government is expected to cut feed-in tariffs for PV solar panels by 16 percent from July this year; but general speaking, demands for solar PV across Japan, China, and the US are expected to rise in 2010 so to speak.

## Acknowledgements

Thanks to all the contributions and efforts from team members, one MW HCPV system has been established in 2009. Special thanks to Ms. Ying-Ling Wang for her supportive information and editorial peer review.

## *References*

[1] Hao-Wu Huang, Kai-Shun Yu, A Study of Three-Phase Power Balance of Distributed Solar Generators, Monthly Journal of Taipower's Engineering, Vol. 733 PP 77, September 2009.

[2] Cherng-Tsong Kuo, Hwa-Yuh Shin, Hwen-Fen Hong, Chih-Hung Wu, Cheng-Dar Lee, I-Tao Lung, Yao-Tung Hsu, Development of the high concentration III-V photovoltaic system at INER, Taiwan, 2007 World Renewable Energy Conference - Pacific Rim Region, Taipei, Taiwan, October 30, 2007.

[3] Cherng-Tsong Kuo, Hwa-Yuh Shin, Hwen-Fen Hong, Chih-Hung Wu, Cheng-Dar Lee, I-Tao Lung, Yao-Tung Hsu, Development of the high concentration III-V photovoltaic system at INER, Taiwan, Renewable Energy, Vol. 34, No. 8, pp. 1932, 2009.

[4] Hong-Yih Yeh, Cheng-Dar Lee, I-Tao Lung, Cherng-Tsong Kuo, A Hybrid Control Strategy for HCPV Solar Trackers, INER Report 6329R, 2009.

[5] Chih-Chieh Ma, Shang-Lee Chyou, I-Tao Lung, Hung-Ju Lin, A smart central control system of on-grid HCPV, 17th International Photovoltaic Science and Engineering Conference, Fukuoka, Japan, December 4th, 2007.

[6] Cherng-Tsong Kuo, Ying-Ling Wang, Establishment of HCPV Demonstration Power Plant at Lujhu, Yearbook of INER, 2009.

[7] Hwa-Yuh Shin, Hwen-Fen Hong, Chih-Hung Wu, Chieh Cheng, and Yen-Chang Tzeng, The development of a 5 kW HCPV system at INER, 4th International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, EL ESCORIAL, March 15, 2007.

[8] I-Tao Lung, Cherng-Tsong Kuo, Hwa-Yuh Shin, Cheng-Dar Lee, Hwen-Fen Hong, HCPV Gets a Boost, INTERPV pp.70-73 June, 2009.

[9] Cherng-Tsong Kuo, I-Tao Lung, Hwan-Li Hsu, Current status and future outlook of HCPV, Electronics Industrial Yearbook of Taiwan, ROC, pp.140-143, Oct. 2009.