Prediction on Energy Yields of PV Systems

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Abstract - The China Central Government is determined to promote the use of solar PV in providing electricity to rural areas as well as supplementing power in cities; the installed PV capacity is predicted to be over 4.2GW by year 2015. To attend such a target, the annual expansion rate of PV installations in China and nearby regions has to be over 40%. At the same time, in May 2005, the Hong Kong local government also established its target in alternative energy, which is 1 to 2% by 2012. With such a rapidly expanding market, the capability in accurately predicting the real performance of a PV system to be installed; together with the proper monitoring and evaluation of its performance are thus of crucial importance to designing of these systems. The HKU & HK PolyU PV research teams are collocating together to introduce a methodology in prediction of PV system performance by considering intelligently the local environmental data into an efficiency model of the PV systems for accurate prediction of power output. Other parameters including orientation, tilt angle, shading factor, panel temperature, wiring configuration, and inverter efficiency are also fed into the prediction algorithm for a year-round energy yield.

INTRODUCTION

16th February 2005 marked the Kyoto protocol coming into effect with 141 countries pledged to cut their emissions by 5.2% of 1990 level by 2012. China as a responsible country also ratified the protocol. On 28th Feb 2005, China's renewable energy law was approved by the Standing Committee of the National People's Congress (NPC). It is scheduled to take effect at the beginning of 2006 [1]. With the determination of the China Central Government to promote the use of solar Photovoltaic (PV) in providing electricity to rural areas as well as supplementing power in cities, the installed PV capacity is predicted to be over 4.2GW by year 2015 [2]. To attend such a target, the annual expansion rate of PV installation has to be over 40%. This rapidly expanding market necessitates the capability in accurately predicting the real performance of a PV system to be installed; together with the proper monitoring and evaluation of its performance. The University of Hong Kong (HKUPV) and HK PolyU PV research team is introducing a methodology in prediction of PV system performance by input of local environmental data of solar irradiance, module temperature and air mass into an efficiency model for accurate calculation of power output. Other parameters including orientation, tilt angle, shading factor, wiring configuration, and inverter efficiency can then be fed into the calculation for a year-round energy yield prediction. This methodology will be explained in details with Hong Kong meteorological data input as an example to illustrate the usefulness of the methodology. This will then be extended into the learning cycle of design – installation – monitoring – evaluation of PV systems intended to be installed. A case study of comparing various aspects of 3 different extensively monitored PV systems installed in summer 2004 in a primary school in Hong Kong will be adopted as an example to illustrate the learning cycle. When the PV systems are monitored and evaluated, we then can plan for the future and make suggestions to select of PV technology, installation method, wiring configuration, etc. This methodology is particularly useful in the fast growing PV market in China when deployment of PV systems is running at such a pace that the learning cycle might not be catching up. We therefore encourage the China Government / PV industry to implement similar approach to promote the proper installations of PV systems.

PREDICTION

To apply PV effectively, it is essential to formulate certain extent of prediction during the process of design stage. One of the most important parameters to predict is the energy yield the PV system is going to generate if installed in a particular manner. This prediction could be done by a simulation programme developed by the HKUPV team. Due to the research inclination of the team, this software programme is specially designed for grid-connecting Building Integrated PV (BIPV) system.

Input

There are quite a number of factors affecting the performance of a PV system [3]. The factors under investigation include:

a) weather profile;
b) PV efficiency model [4];
c) orientation;
d) tilt angle;
e) shading factor;
f) wiring loss;
g) inverters efficiency model.

All these input parameters will be fed into the simulation programme for energy yield prediction. Other performance indices (e.g. energy saving due to reduced heat gained by BIPV system) can also be calculated by the extended functions of this programme.

Output

The simulation programme would then generate the electrical energy yield according to the above input parameters. In varying the different input parameters, we then could foresee the influence of different design strategy to the PV systems. A sample of simulation output is shown below:

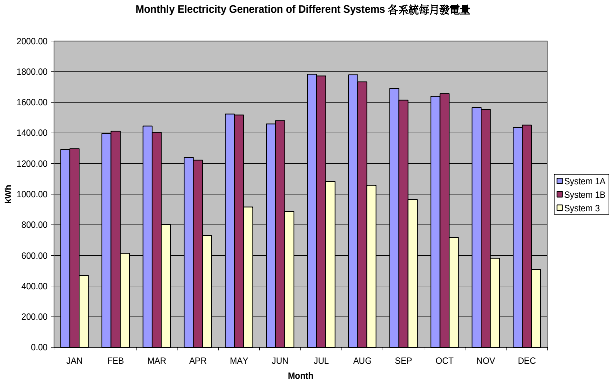

Figure 1. Simulation results of the monthly output.

MONITORING

The essence of the learning cycle of prediction, monitoring, evaluation lies in the accurate measurement of performance of the PV system at installed form. High accuracy sensors and sophisticated software were adopted by the HKUPV in monitoring the installed PV systems designed by the team in Hong Kong. Real operating data were then recorded automatically at different sites of PV installation for future evaluation. With the advancement of modern computing technology, massive data can be recorded and stored at frequent intervals for detailed analysis. Parameters to be monitored are set according to IEC Standard 61724 [5].

Hardware

To record the data of different PV systems at different locations (even within the same building complex), remote monitoring is necessary. Network modules of a famous brand of data acquisition solution provider were chosen for such purpose. Real time data are transferred back to the central monitoring station (CMS) through Local Area Network. To avoid data loss in event of power or network failure, the network modules were equipped with built-in CPU and RAM to store independent data-logging software. When it cannot communicate with the CMS, the software embedded can still operate and keep logging data for 2 weeks without interruption. Both the CMS and network modules were supported by UPS power.

Software

The computer programme developed by the HKUPV research team could monitor, store and publish the data acquired from the sensors through the network modules. Remote control of the system can also be done through the internet. To facilitate education purpose, together with the merit of easy routine checking, instantaneous data are published on website through the internet.

EVALUATION

After sufficient period of data have been collected, the results can then be evaluate according to prescribed criteria [5]. One of the most important parameters to be evaluated is the final PV system yield Y_f which is defined as the average daily energy output to the load normalized by the nominal power of the array:

$$Y_f = (\Sigma E_{PV}) \text{ / number of days / nominal power of array} \quad (1)$$

The unit for Y_f of small to medium size of arrays was $kWhd^{-1}/kW$. This is a commonly applied indicator of the overall PV system performance. Y_f indicated the final yield of the system as a result of the solar irradiance received and therefore it was site-specific. This indicator could therefore only be applied for comparison of arrays installed at the same physical conditions. Another useful indicator for evaluating the performance of a PV system was the Performance Ration PR defined as the ratio of Final Yield (as defined above) to the Reference Yield Y_r which was defined as:

$$Y_r = (\Sigma \text{ Esolar}) * \eta_{STC} / \text{number of days} \quad (2)$$

where η_{STC} is the nominal array efficiency at Standard Testing Conditions (STC). And it follows that Performance ratio Rp is defined as:

$$Rp = Y_f / Y_r \quad (3)$$

For any PV array installed on the same plane with identical orientation, array area, and structural design, we can compare only the Final Yields which would eliminate the influence of weather conditions, module temperatures (due to different structural constructions) and orientation on the system performance. It also provided a platform for accessing the influence of the power conditioning system on the system performance by changing the inverter which was the dominant component of the power conditioning sub-system for a grid-connecting PV system. Final Yield is therefore adopted as the key parameter for comparing performance of the sub-systems with the same design intent. Performance Ratio, on the other hand, would be adopted as the parameter for comparing different PV installations within the same location but of different design context or even systems at different locations. The overall data flow is shown below:

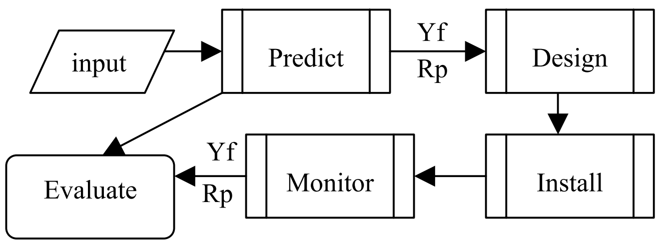

Figure 2. Data flow of the methodology.

CASE STUDY

The above detailed prediction-monitoring-evaluation methodology has itself evolved through a learning cycle. The HKUPV research team applied it to the Ma Wan primary School in Hong Kong as a case study for perfecting this methodology. In year 2001 the team successfully applied and then was granted an Innovation and Technology Fund (ITF) from the Hong Kong Government for installing 3 systems of BIPV in a Primary School on the Ma Wan Island. There are 3 PV systems designed for the Ma Wan Primary school. They utilize contemporary PV technology of Copper Indium Diselenide (CIS) modules, poly-crystalline (p-Si) silicon embedded in glass and tandem junction amorphous silicon (a-Si) modules. An aerial view of the installations can be referred to Fig.2. They all form part of the building envelop and were integrated to the school as

System 1. CIS Deck Shading
System 2. p-Si Rooflight
System 3. a-Si Canopy

This case study also provided the platform for comparing different BIPV approaches of utilizing standard and customized PV modules for system integration. All the performance indices of energy yield will be monitored and compared amongst the systems, technologies; and with that of the initial estimation from the model developed previously. To investigate the influence of the inverter configuration to the system yield, System 1 is further divided into two sub-systems. System details are shown below:

Table 1. Details of CIS sub-systems

System	**CIS**	
Sub-System No.	**1A**	**1B**
No. of panels per string	15	5
panel rating	40W	40W
No. of strings	24	12
String V_{DC}	249	83
Sub-System rated power	14.4kW	2.4 kW
No. of sub-system	1	6
Total no. of panels	360	360
System rated power	28.8kW	

Table 2. Details of p-Si and a-Si PV systems

System	**p-Si**	**a-Si**
System No.	**2**	**3**
No. of panels per string	24-28	3
String V_{DC}	294-319	136
No. of sub-system	2	3
No. of strings	1	7
Sub-System rated power	2.0kW	2.4kW
Total no. of panels	52	63
System rated power	4.0kW	7.2kW

The BIPV systems at Ma Wan Primary School were scheduled to be finished by summer 2003. However, due to the sub-contractors' "lack of familiarity", the school construction finished late (by 3 months) and the PV installations, in phases, later still (9 months) while the monitoring system for data acquisition was not fully completed until August 2004 with extra input from the HKUPV team. A table summarizing the recorded data is as follow:

Table 3. Summary of monitored data

	Sept	**Oct**	**Nov**	**Dec'04**
HKO Solar irradiance* (kWh/m^2)	125.750	140.878	101.083	106.089
System 1	2821.2	2831.2	1768.9	1315.9
System 2	354.14	370.05	193.78	150.35
System 3	768.626	497.09	333.71	315.41
Total PV	**3943.9**	**3698.4**	**2296.4**	**1781.6**
School Elec. bill	38,290	33,510	23,640	19,770
Total Elec Use	42,233	37,208	25,936	21,551
PV %	**9.34%**	**9.94%**	**8.85%**	**8.27%**

*all unites in kWh except marked

Due to the delay in project completion, the intended one-year period of monitoring is still ongoing. We can only discuss here basing on the one-quarter results. In general, the Final Yields from the respective BIPV systems are well in line with the prediction, when we take into consideration of the decline in solar radiation we received in recent years. Together with the less than expected school electricity consumption, the PV systems generated 9.2% of the total school electricity consumption during the last quarter of 2004. This is in excellent agreement with the prediction of PV providing 9.04% of the school energy load [6]. To evaluate the Performance Ratios of respective PV systems, a one-year data is necessary for meaningful comparison to eliminate seasonal effects. The final results will be published by end of 2005.

The monitoring system is also important to ensure efficient operation of the PV system. At the beginning of its operation we discovered a few loosely-connected strings through the help of the monitoring system which also monitors individual string currents. At the end of 2004 there were occasional failures of one of the inverters. With the help of the monitoring system the research team was able to identify the exact time when the inverter failed, relevant information were sent back to the manufacturer and the problem has been solved consequently.

CONCLUSIONS

It has been a long and difficult learning curve [7] for the introduction and development of new technologies. The HKUPV and HK PolyU research teams, in witnessing most of the process, gained much experience ourselves. Some of those experiences concerning electrical aspects were reported in a previous paper [8]. This paper outlines the methodology and initial results for an intelligent prediction process for energy yield of PV systems.

REFERENCES

[1] "Changing Views Change Climate," China Daily, March 6, 2005.

[2] 王斯成, 馬勝紅, "我國光伏發電的重要地位和展望" Proceeding of the 8th China Photovoltaic Conference, Shenzhen, China, November 15-19, 2004, pp.1-10.

[3] H. Pang, J. Close, K.H. Lam, "Factors Affecting the Performance of s Local Grid-connecting Façade BIPV System," Proceeding of the 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, May 11-18, 2003.

[4] K.H. Lam, J. Close and W. Durisch, "Modelling and Degradation Study on a Copper Indium Diselenide module", Journal of Solar Energy, vol. 77, Elsevier, pp. 121-127, 2004.

[5] IEC 61724, "Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis", International Electrotechnical Commission, 1998.

[6] J. Close, H. Pang, K.H. Lam, T. Li, "10% from renewables? The potential contribution from an HK Schools PV installation Programme" Proceeding of the World Renewable Energy Congress 2005, Aberdeen, UK, May 22-27, 2005.

[7] J. Close, K.H. Lam, H. Pang, F. Wong, "Building Integrated Photovoltaics in HK: Big Potential but a Long Learning Curve", Proceedings the 6th International Conference on Advances in Power System Control, Operation and Management, Vol. 1 Nov 3-5, 2003, pp. 80.

[8] K.H. Lam, J. Close, H. Pang, "Local experience in designing, testing and commissioning grid-connected PV systems in Hong Kong", Proceeding of the 8th China Photovoltaic Conference, Shenzhen, China, November 15-19, 2004, pp. 568-573.