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Thermal Model Based Power-Generated Prediction by Using Meteorological Data in BIPV System

C.Y. Huang[a*], H.J. Chen[a], C.C. Chan[a], C.P. Chou[b], C.M. Chiang[c]

[a] *Green Energy & Environment Research Laboratories, Industrial Technology Research Institute , Chung Hsing Rd. Chutung, Hsinchu, Taiwan*
[b] *Department of mechanical engineering, National Chiao Tung University No. 1001 University Road, Hsinchu, Taiwan*
[c] *Department of Architecture, National Cheng-Kung University, Tainan*

Abstract

Building integrated photovoltaic is an art and trend using PV module to replace building material on the outer wall. The semi-transparent c-Si PV module is installed to replace the tiled roof in this study. PV power generation prediction is follow with module performance, installation site and meteorological data. A simple model is created to simulate the power output using PV module thermal model. PV module thermal model is the relation of the module temperature, ambient temperature and solar radiation. In the present study, two parameter linearly regression model is to simulate the power generation in BIPV system. The monthly root-mean -square error (RMSE) is about 4.7%.

Keywords: photovoltaic; PV; simulation; Building Integrated Photovoltaic; BIPV

1. Introduction

Building Integrated Photovoltaic (BIPV) is an art and trend in the world, which is using renewable energy to replace the building material such as roof, wall and window by PV modules. It is a reverse ratio between the temperature and PV power output. Thus, solar radiation and temperature are the main issues to influence the electrical power output from PV modules, which are depended by the installation site of the BIPV study building.

PV module temperature is influent the power performance of PV modules. Under steady state conditions the electrical power output primarily depends on the module temperature T_{pv}, PV module efficiency η_{pv} at standard test condition, plane of array solar irradiance G_T and installation area A_{pv}. The

* Corresponding author. Tel.: 886-3-5914216; fax: +886-3-5820203.
E-mail address: masonhuang@itri.org.tw

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PV module temperature can be predict use the simple module as $T_{pv}=aT_a+bG_T+c$.

In the presented paper, the semi-transparent c-Si PV module is installed in tiled roof to replace the building material (see Fig.1). The BIPV system is local in Industrial Technology Research Institute campus where was the 23°18' North Latitude and 120°28' East Longitude in Taiwan. Using the thermal model based on the power generated prediction is investigated in this paper.

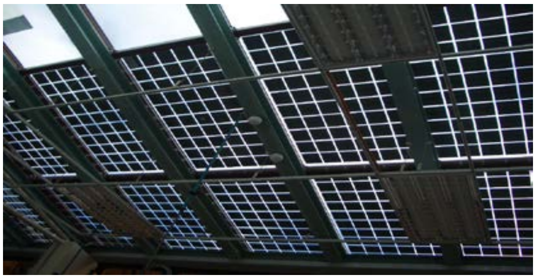

Fig. 1. The semi-transparent c-Si PV module in tiled roof has 4.2kW installation capacities.

The PV modules are semi-transparent pc-Si module and the specification is present in Table1.

Table 1. PV module/array specification

PV module	Specification
Type	Poly-crystalline Si
Module efficiency (η_{pv})	11.95%
Maximum power(P_{max})	210 W
Maximum power voltage(V_{mp})	28.84 V
Maximum power current(I_{mp})	7.33 A
Open circuit voltage(V_{oc})	36.73 V
Short circuit current(I_{sc})	7.71 A
Temperature coefficient of p_{max} (β)	-0.42%/℃
Module area (A_{pv})	1.88 m^2
Number of Modules	20
Array area(A_{array})	37.6 m^2

2. The Math of Thermal model in BIPV module

Thermal model approach is consists in local meteorological data including ambient temperature, wind speed and solar radiation. The meteorological data shows from January 2011 to May 2011 (see Fig.2). The weather station Davis Vantage Pro2 can be used in our experiment. Weather station installed in local site and can record the horizontal solar radiation wind speed environment air temperature wind direction.

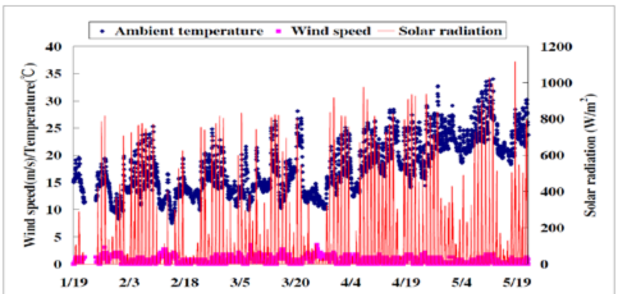

Fig. 2. Solar radiation and temperature of ambient and PV module backside are presented.

Several researcher have been developed the cell module temperature predict model [1]. The module temperature directly affects the PV performance. The simplest explicit equation for the operating temperature of a PV module is developed by R.G. Ross in 1976 as below [2] in (1).

$$T_{pv} = T_a + k\ G_T \tag{1}$$

Table 2. The Ross parameters for various mounting situation are present as below [3]

PV array mounting type	k (km²/W)
Free standing	0.021
Flat roof	0.026
Sloped roof Well cooled	0.020
Sloped roof not so well cooled	0.034
Sloped roof highly integrated, poorly ventilated	0.056
Façade integrated tansparent PV's	0.046
Façade integrated opaque PV's---narrow gap	0.054

In this expression, the module temperature is depended on the ambient temperature and solar radiation and k_T is 0.0434 in the experiment data (see Fig.3). The results are approach to Ross parameter in the façade integrated PV system.

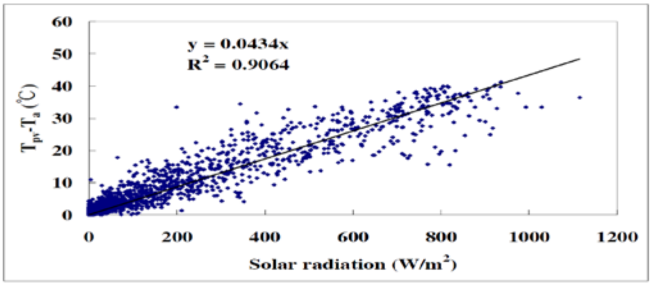

Fig. 3. Temperature difference (T_{pv}-T_a) with solar radiation using linearly regression.

The semi-empirical approach with local wind speed in PV module temperature models are developed by E.Skoplaki et al. the module temperature model as bellow [3] in (2):

$$T_{pv} = T_a + \left(\frac{0.25}{5.7 + 3.8V_w}\right) G_T \tag{2}$$

where V_w is the local wind speed.

The two parameters linearly regression model had developed in this paper. The module temperature model as bellow

$$T_{pv} = b \times G_T + a \times T_a + c \tag{3}$$

Linearly regression

$$\sum_1^n T_{pv,i} = c \cdot n + a \cdot \sum_1^n G_{T,i} + b \cdot \sum_1^n T_a \tag{4}$$

$$\sum_{1}^{n} T_{pv,i} \times G_{T,i} = c \cdot \sum_{1}^{n} G_{T,i} + a \cdot \sum_{1}^{n} G_{T,i}^{2} + b \cdot \sum_{1}^{n} G_{T,i} \times T \tag{5}$$

$$\sum_{1}^{n} T_{pv,i} \times T_{a} = c \cdot \sum_{1}^{n} G_{T,i}^{2} + a \cdot \sum_{1}^{n} G_{T,i} \times T_{a} + b \cdot \sum_{1}^{n} T_{a}^{2} \tag{6}$$

The matrix of values

$$\begin{bmatrix} 22476.5 \\ 4056954.2 \\ 349072.96 \end{bmatrix} = \begin{bmatrix} 12591 & 105068 & 17841 \\ 105068 & 47801823 & 1842138 \\ 17841 & 1842138 & 264499 \end{bmatrix} \begin{bmatrix} c \\ a \\ b \end{bmatrix}$$

The constants in (3) are $c=-3.931$, b=0.04433, and a=1.27615. However, in the experiment results, a, b, and c constants had been gotten as 1.27615, 0.04433, and –3.931.

The module temperature is measured in the middle of the PV module backside and sensed by K-type thermal couple.

The module temperature shows different prediction model. Present model and Ross model are better to predict the module temperature (see Fig.4).

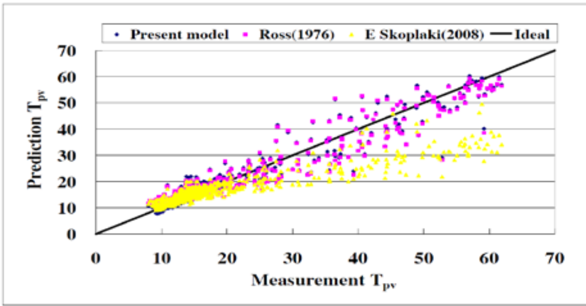

Fig. 4. Comparison hourly measured and predicted module temperature

3. Electrical performance in BIPV module

The electrical power can be predicted using thermal model. The electrical power is similar in form in (7), is

$$P = G_T \eta_{pv,ref} A\left(1-\beta\left(T_{pv}-T_{ref}\right)\right) \tag{7}$$

where

P: Power output for PV system

G_T: Instantaneous solar radiation of tilted surface W/m^2

$\eta_{pv,ref}$: PV efficiency at STC

A: PV array installation area m^2

B: Temperature coefficient of PV module

T_{ref}: Module temperature at STC (typical is 25 ℃)

T_{pv}: module temperature (℃)

Electrical power output of PV system is primary depends on the solar radiation (see fig.5). High solar radiation can produces the high electrical power. In present results, the maximum instantaneously power output is 3610.7kWh.

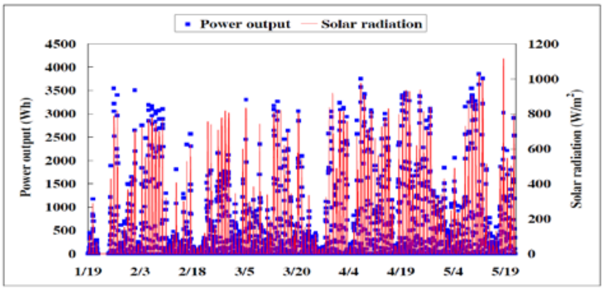

Fig. 5. Electrical power output is presented during in January-May 2011.

The electrical power output is linearly with solar radiation in prediction model and measured data (see Fig.6).

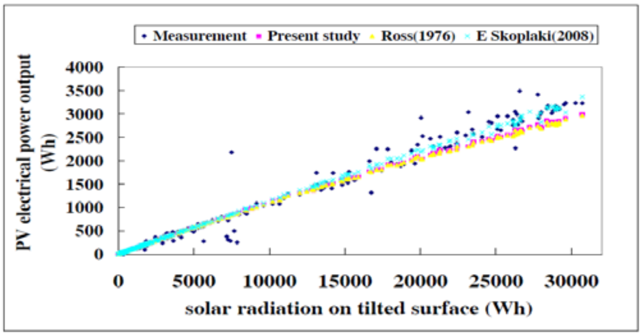

Fig. 6. Relation of the solar irradiation on tilted surface and energy power output with difference prediction model

The electrical power output with differential prediction model in the measurement period. Ross model and present model are similarly to close meet the measure data (see fig.7).

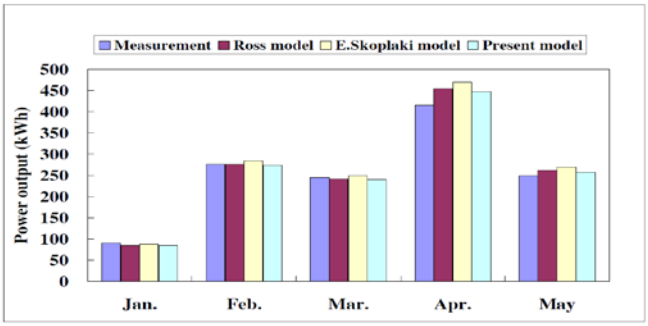

Fig. 7. Differential prediction model is simulating from January 2011 to May 2011.

It defines the RMSE root-meat-squared error to determine the accuracy of the measurement and prediction results. The RMSE is as bellow (8) and (9)

$$Error = \sum_{1}^{n} \left(\frac{S-M}{M}\right) * 100\% \tag{8}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{1}^{n} Error^2} \quad (9)$$

where M is the measurement data, S is the simulation data, n is the month.

In this paper, power output is important to calculate and compare. The hourly RMSE and monthly RMSE are separated calculation by hourly and monthly power output.

Table 3. Comparison of different prediction model in power output results in January-May 2011.

Month	Measurement	Ross model	Error (%)	E.Skoplaki model	Error (%)	Present model	Error (%)
Jan. (1/18~1/31)	89.9	85.0	-5.4	88.0	-2.1	84.7	-5.8
Feb.	275.5	276.4	0.3	284.8	3.4	274.0	-0.5
Mar.	244.9	241.3	-1.5	248.8	1.6	239.6	-2.1
Apr.	415.6	453.9	9.2	469.5	13.0	447.6	7.7
May (5/1~5/23)	248.5	262.0	5.4	269.4	8.4	257.1	3.5
RMSE(%)			5.4		7.2		4.7

4. Helpful Hints

In our study, to predict the module temperature precisely is difficult but the electrical power prediction is directly influence by module temperature. So, in the future, using high prediction model to predict the module temperature like Artificial Neural Network or Fuzzy Theory is very important to improve the prediction model.

Location of PV system is not considered in our study. The solar irradiance of tilt surface is difficult to get. So, future work can combine the tilted angle, longitude and latitude to predict the solar irradiance in the tilt surface.

5. Conclusion

Thermal model predicts the power output is one of the methods in the PV system. Using linearly regression to predict the module temperature with local meteorological data like ambient temperature, wind speed and solar radiation is very close with measure results.

In this paper, two parameter linearly regression approach is better than another method to predict the power output with thermal model and the monthly root-mean-square error (RMSE) is about 4.7%. Besides, the Ross parameter k in our BIPV system is 0.434. This parameter can offer designer apply in the BIPV system power prediction.

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