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Combine the thermal model to analyze the building integrated photovoltaic array performance

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Abstract. The solar cell temperature of BIPV module is higher than the free standing PV module at normal operating cell temperature condition. The thermal model had been built to predict the electrical power of BIPV and had taken into account the ambient temperature, solar radiation of tilted plane and wind speed to evaluate the solar cell temperature. The heat transfer approach can be applied in material design with different lamination material and evaluate to the electrical power performance. The results have shown that the RMSE of the predicted and experimented electrical power with monthly data has about 5%.

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

1. Introduction (Use “Header 1” Style)

Recent years have seen increased attention to the application with Building Integrated Photovoltaic (BIPV) replace the traditional building materials. Operating cell temperature is an important factor to influence the power output. Under steady state conditions the electrical power output primarily depends on the solar cell temperature T_c, PV module efficiency η_{pv} at standard test condition, plane of array solar radiation G and the installation area of PV array A_{pv}. The solar cell temperature can be predicted use differential correlation model with ambient temperature, solar radiation or wind speed [1-4].

In this study, the semi-transparent c-Si PV module is installed in tiled roof to replace the building material and the tilted angle is 10 degree (see Fig.1). The BIPV system is local in Industrial Technology Research Institute campus where was the 24^{o}8’ North Latitude and 121^{o}28’ East Longitude in Taiwan and the total installation capacity is 4.2kW. With the energy balance, the cell temperature can be predicted with heat transfer approach in presented paper, the cell temperature depends on the ambient temperature, the layer properties of PV module like thickness and thermal conductivity, wind speed and solar radiation. Using the different thermal conductivity of EVA film in PV module, the cell temperature and electrical energy can be evaluated in this paper.

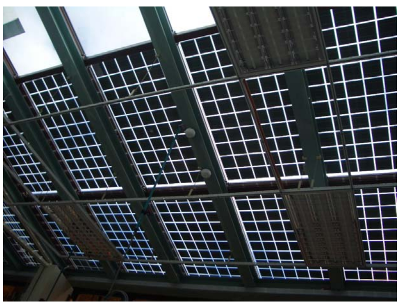


Fig.1 the semi-transparent c-Si PV module in tiled roof has 4.2kW installation capacities.

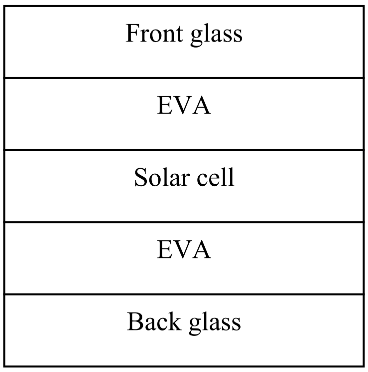
The PV modules are semi-transparent c-Si module and the specification is present in Table1.

Table 1: PV module/array specification

PV module	Specification
Type	Poly-crystalline Si
Module efficiency at STC (ηpv)	11.19%
Maximum power (Pmax)	210 W
Maximum power voltage (Vmp)	28.84 V
Maximum power current (Imp)	7.33 A
Open circuit voltage (Voc)	36.73 V
Short circuit current (Isc)	7.71 A
Temperature coefficient of pmax (β)	-0.42%/℃
Module area (Apv)	1.88 m^2
Number of Modules	20
NOCT (℃)	47±2
Array area (Aarray)	37.6m^2

2. Thermal model of BIPV module

Typical photovoltaic module is consist the front glass, EVA, solar cell, tedlar and BIPV module sometimes apply the glass to replace the tedlar to be a transparent module. Fig.2 has shown the structure of the BIPV module.



(b)

Fig.2 BIPV structure

From the energy balance of solar cell, the solar cell temperature is heated from solar radiation and cooled from ambient temperature and wind speed.

Energy balance from solar cell

$$\dot{Q}_{in} = \dot{Q}_{out} \tag{1}$$

$$(\tau\alpha)G-\eta_{stc}G(1-\beta(T_c-25))=\frac{T_c-T_a}{R_{th}} \tag{2}$$

The thermal resistance is shown bellow

$$R_{th}=\frac{R_1\times R_2}{R_1+R_2} \tag{3}$$

$$R_1=\frac{1}{h}+\frac{L_{glass}}{k_{glass}}+\frac{L_{eva}}{k_{eva}} \tag{4}$$

$$R_2=\frac{1}{h}+\frac{L_{cell}}{k_{cell}}+\frac{L_{eva}}{k_{eva}}+\frac{L_{glass}}{k_{glass}} \tag{5}$$

Then,

T_c : The solar cell temperature ℃

T_a : The ambient temperature ℃

R_{th} : The overall heat transfer coefficient ℃-m^2/W

η_{stc} : Efficiency of PV module in STC

β : Temperature coefficient of Efficiency

τ : Transparent of front glass (~0.9)

α : Absorptance of solar cell (~0.95)

L : Thickness (m)

k : Thermal conductivity of material (W/m-℃)

h : Convective heat transfer coefficient of air (W/m^2-℃)

Table 1 is the physical properties of typical single glass photovoltaic module. The convective heat transfer coefficient is given as below by [7]:

$$h=8.91+2.0\times V \tag{6}$$

Where, V is the wind speed.

Table 2 the dimension and properties of each layer in Si based BIPV module

Layer	Thickness (mm)	Thermal conductivity coefficient k (W/m-℃)	Convective heat transfer coefficient h (W/m^2-℃)
Outside air			8.91+2.0V
Front Glass	3	0.98	
EVA	0.5	0.23	
Solar cell	0.25	148	
EVA	0.5	0.23	
Back Glass	3	0.98	
Outside air			8.91+2.0V

The maximum power output from a PV panel at STC which is usually labelled on the panel nameplate. The actual power output can be estimated:

$$P_{real}=G\times A\times\eta_{stc}(1-\beta(T_c-25)) \tag{7}$$

3. Validation analysis of simulation model

The simulation model of the PV array power output is verified with one year measured data for the BIPV system on the ITRI in Taiwan which has been working from 1 Jan. 2011 to 31 Oct. 2011. These data were caught and recorded for each hour. Fig 3 has shown the DC electrical power output between the simulation and measurement every month.

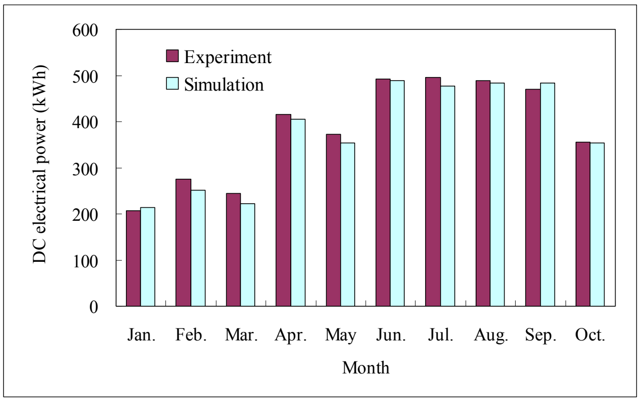


Fig 3 Comparison the simulated and measured results every month

It defines the RMSE root-meat-squared error to determine the accuracy of the measurement and prediction results. The RMSE can be estimated as bellow：

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

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

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

The monthly RMSE are calculated by monthly power output data as 5.0%.

4. Conclusion

Using Thermal modelling to predict the c-Si based PV array power output has best agreement in this paper. The PV array power output depends on the ambient temperature, wind speed, on the instantaneous plane of array solar irradiance. The Outside wind speed is the important parameter to influent the module temperature. The results have shown that the RMSE of the predicted and experimented electrical power with monthly data has about 5%.

In this paper, the thermal model used to predict the cell temperature and simulate the PV array electrical power output. The thermal model takes into account the ambient temperature, solar radiation of tilted plane and wind speed to evaluate the solar cell temperature. The thermal approach can be apply in material design with different lamination material and evaluate to the electrical power performance.

5. Acknowledgment

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