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Improvement of the Module Temperature Model in 1D5P Forecasting Power Output for Photovoltaic Systems

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Abstract
This paper presents the improvement of the existing module temperature model in forecasting power output for photovoltaic systems. The proposed module temperature model was developed by using a weight function technique. The weight function technique was created by using annual data on a module temperature and solar irradiance. Then the researchers adjusted the simulated graph trend to measure the weight function. The results showed the behavior of the proposed module temperature and confirmed accuracy by comparison of measured data. It was found that the root-mean-square error (RMSE) of the existing module temperature model ranged from 0.0257 to 0.0758 and the average RMSE was 0.0512, and the root-mean-square error (RMSE) of the proposed module temperature model adjusted by weight function ranged from 0.024 to 0.076, and the average RMSE was 0.0491.

Keywords: *Module Temperature Model, weight function, root-mean-square error*

1.Introduction

One part of the renewable energy technologies is photovoltaic energy. The Photovoltaic power has been rapidly growing worldwide as one of the lowest cost options for generating electricity (International Energy Agency, Trends 2015 in Photovoltaic Applications, 2015). The amount of power from photovoltaic energy depends on solar irradiance and module temperature (Garcia & Balenzategui, 2004).

The Module Temperature Model often works with the Forecasting Model of Power Output in Photovoltaic Systems. The Module Temperature is one part of the input for 1D5P Forecasting Model (Chouder et al., 2012; Ciulla et al., 2014). The 1D5P power output forecasting model was an essential factor for the design and installation of the photovoltaic systems. Generally, the 1D5P Forecasting Model of Power Output for Photovoltaic System uses two input parameters consisting of solar irradiance and module temperature. The temperature model was developed to integrate with the forecasting model 1; its input parameter was employed to simplify the model (Dawan et al., 2018).

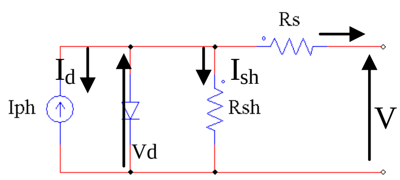
This research studied the improvement the Module Temperature Model in 1D5P Forecasting of Power Output for Photovoltaic Systems by a weight function technique. The power plants in Thailand have studied types of polycrystalline solar cells. The module is 245 Wp/module. The module temperature model was verified for the purpose model by comparison with measured data.

2.Mathematical Model

2.1. Photovoltaic Module (Abdulazeez & Iskender, 2011)

The basic equivalent circuit of the photovoltaic module is shown in Figure 1. The module consists of a current shunted through the intrinsic diode (I_d): I_{ph} as photocurrent, I_{sh} as current of the shunt resistance, V_d as the voltage across the diode, V as the terminal voltage, R_{sh} as shunt resistance, and R_s as series resistance (Abdulazeez & Iskender, 2011).

Figure 1: The basic equivalent circuit of the photovoltaic module



The output current I can find by

$$I = I_{ph} - I_d - I_r \tag{1}$$

The source current is

$$I_{ph} = I_{sc0} \cdot \frac{S}{S_0} + C_t \cdot (T - T_{ref}) \tag{2}$$

I_{sc0} is a short circuit current of each solar cell at the reference temperature
S is the solar irradiance on a plane W/m^2
S_0 is reference solar irradiance W/m^2(1000 W/m^2)
C_t is temperature coefficient, in A/C or A/K
T is the ambient temperature in °C
T_{ref} is temperature under the standard test conditions, in °C
The current through diode can find by

$$I_d = I_0 \cdot e^{\frac{qV_d}{AkT}} - 1 \tag{3}$$

q is the electron charge (q = 1.6 x 10^{-19})
k is the Boltzmann constant (k = 1.3806505 x 10^{-23})
A is ideality factor of each solar cell, also called emission coefficient. It is around 2 for crystalline silicon
V_d is the voltage across the diode
I_0 is reverse saturation current of the diode

$$I_0 = I_{s0} \cdot \left(\frac{T}{T_{ref}}\right)^3 \cdot e^{\frac{qE_g}{Ak}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)} \tag{4}$$

The current flows through the resistor defined as

$$I_r = \frac{V_d}{R_{sh}} \tag{5}$$

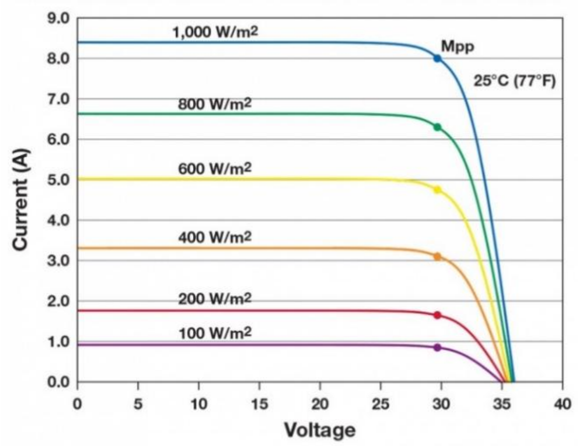
The output power is dependent on the solar irradiance and temperature. To get the maximum power, one has to control voltage and current to the maximum all time.

2.2. Module Temperature Model

Effect of Irradiance and Temperature (Rekioua & Matagne, 2012)

Significant variable solar irradiance contributes to the efficiency of solar cells in each area. This is an important point when it comes to application in each area as well as the calculation photovoltaic systems installation when calculating the number of solar panels to be used in each area, as shown below.

Figure 2.1: The effect of Irradiance on current and voltage of the photovoltaic module (Glaize, 2011)



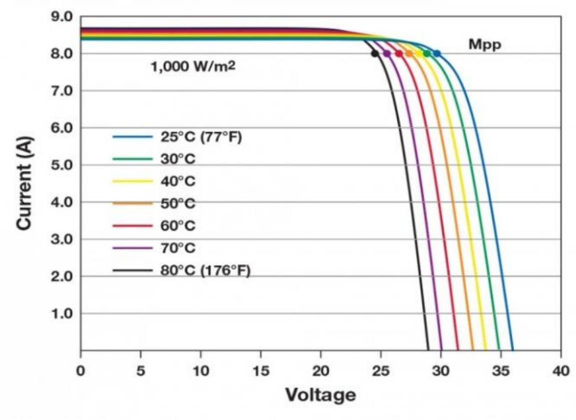
The intensity of *the current* is directly proportional to *the solar irradiance*, as shown in high solar irradiance and high photocurrent. However, the voltage is almost unchanged by the solar irradiance. The standard solar irradiance is the intensity of the light.

Light is measured on the earth in clear weather and measured at the sea level in the condition under which the sun is perpendicular to the Earth, with a light intensity of 100 milliwatts per square centimeter or 1,000 milliwatts per square meter. It is approximately 75 milliwatts per square centimeter 750 MW per square meter, which is equal to AM2; in the case of solar panels AM 1.5 will be used. It is the standard for measuring panel performance, as shown in Figure 2.1

The *current* will not change with changing temperature. However, the voltage (Volts) will decrease as the temperature rises. On an average, every 1-degree increases. This will reduce the voltage to 0.5%, and in the case of solar panels, the standard used to determine the efficiency of the solar panel is at 25 degrees Celsius; for example, the solar panel has an open circuit voltage (open-circuit voltage or V_{oc}) at 21 volts at 25 degrees Celsius.

A photovoltaic or PV module's voltage output is actually a variable value that is primarily affected by temperature. The relationship between module voltage and temperature is actually an inverse one. As the module's temperature increases, the voltage value decreases and vice versa. This can be seen in the correlation in Figure 2.2 below. The variable output voltage is an important factor for both cold temperatures and hot temperatures, and both types of temperature must be considered during the system design. When temperatures are cold, the PV module will increase in voltage. When it is hot, the module's voltage will drop. Both are simple and unavoidable facts in PV design. So as long as you account for both properly, you won't have any issues in the performance of your array — at least not due to the voltages (Glaize, 2011).

Figure 2.2: The effect of temperature module with current and voltage of the photovoltaic module (Glaize, 2011)



2.3. Weight Function Model

The weight function is a new technique for improving the accuracy of module temperature model which was used in this research. This function was created by using real data of focus area in a year data of that area was used to calculate in the model (Kittisontirak et al., 2016).

2.4. RMSE

The Root Mean Square Error (RMSE) is a frequently used measure of the difference between values predicted by a model and the values observed from the environment that is being modeled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

The RMSE of a model prediction concerning the estimated variable X_{model} and is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

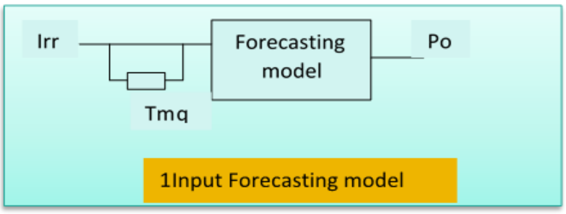
where X_{obs} is observed values, and X_{model} has modelled values at time/place i.

The calculated RMSE values will have units, and RMSE for phosphorus concentrations, for this reason, cannot be directly compared to RMSE values for a chlorophyll concentration. However, the RMSE values can be used to differentiate model performances in a calibration period within the validation period as well as to compare the individual model performance to that of other predictive models (Chai & Draxler, 2014).

3.Research Methodology

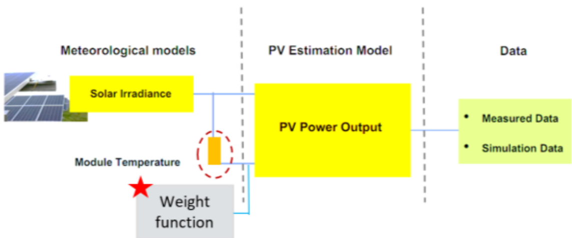
This research was to improve the efficiency of the module temperature model in forecasting power output for Photovoltaic System in the 1D5P model. Firstly, the module temperature model is created by the effect of solar irradiance and the temperature module as can be seen in block diagram in Figure 3.1 (Dawan et al., 2018).

Figure 3.1: Block Diagram 1D5P Model 1 input



The module temperature model in forecasting power output for Photovoltaic System to increase accuracy by using a weight function which was obtained from one-year measured data as shown in Figure 3.2. It was found that by using the weight function with the newly developed model, the accuracy was verified as very high by comparing with one-year measured data.

Figure 3.2: Structure of 1D5P Model 1 input with a weight function



The procedures implemented in improving the accuracy of the newly developed model are as follows:

Step 1: Calculate the average of the annual measured module temperature (T_{md}) and the average of the annual module temperature model ($T_{m(model)}$) at one value of solar irradiance (G) on the day d as follows:

$$\overline{T}_{my}(G) = \frac{1}{N_y}\sum_{d=1}^{N_y} T_{md} \qquad (1)$$

$$\overline{T}_{m(model)y}(G) = \frac{1}{N_y}\sum_{d=1}^{N_y} T_{m(model)d} \qquad (2)$$

where N_y, is the number of days during the one-year time period.

Step 2: Create an equation in relation to solar irradiance and the average of the annual measured module temperature (T_{md}) and the average of the annual module temperature model ($T_{m(model)}$). Then, use the polynomial equation for fitting the data as shown in Table 1:

Table 1: The data used in the newly developed model

	Parameter	Value
Measured	Intercept	-0.2001
	A_1	0.0219
	A_2	3.00e-6
	A_3	3.00e-9
Simulated	Intercept	-0.4266
	A_1	0.0292
	A_2	2.00e-6
	A_3	1.00e-9
Weight function	Intercept	2.27e-1
	A_1	7.30e-3
	A_2	-1.00e-6
	A_3	2.00e-9

$$\hat{\hat{T}}_{my}(G), \hat{\hat{T}}_{m(model)y}(G) = Intercept + A_1 G + A_2 G^2 + A_3 G^3 \qquad (3)$$

where T_{my}(G), $T_{m(model)}$ (G) is a function of annual module temperature from measured and simulated, respectively

Step 3: From (4), the weight function was generated, which was used to improve the accuracy of the model as follows:

Equation (5) shows that the simulated module temperature used in the newly developed model $T_{m(model)}$ improved the accuracy with the weight function:

$$T_{\psi} = \hat{\hat{T}}_{my}(G) - \hat{\hat{T}}_{m(model)y}(G) \qquad (4)$$

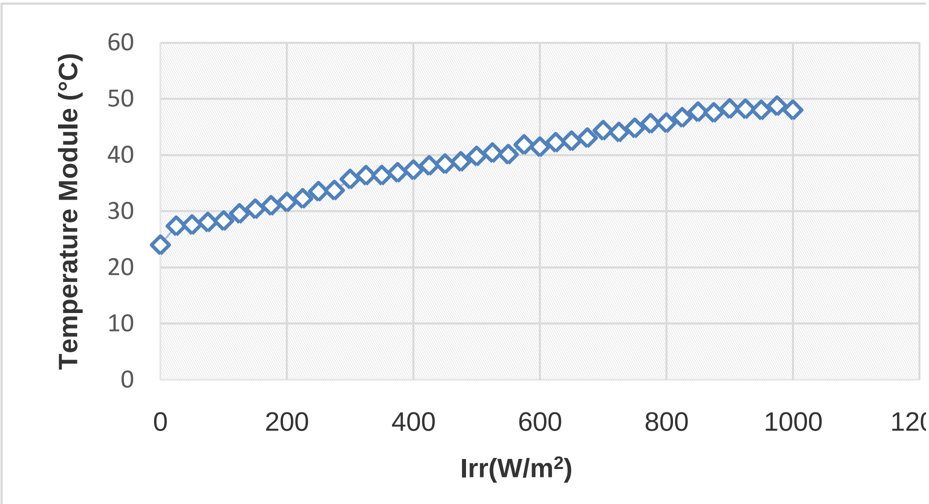
$$T_{m(model)} = \hat{\hat{T}}_{m(model)y}(G) + T_{\psi} \qquad (5)$$

where T_w is a weighted function.

4. Research Results

The module temperature model was created for the forecasting of photovoltaic systems with solar irradiance. The relations of solar irradiance (I_{rr}) and the module temperature (T_m) are shown in Figure 4.1.

Figure 4.1: The relationship between solar irradiance (Irr)and Tm



As seen, when solar irradiance increased, the temperature also increased in a straight relation.

Then the solar irradiance measurement data was sent to the module temperature model for temperature measurement before further sent to the output power-predicting model. The temperature was then graphed to compare the actual temperature measurement at the specific points of solar intensity, as shown in Figure 4.2.

Figure 4.2: The estimation values of module temperature model verses module temperature measurement at various solar irradiance

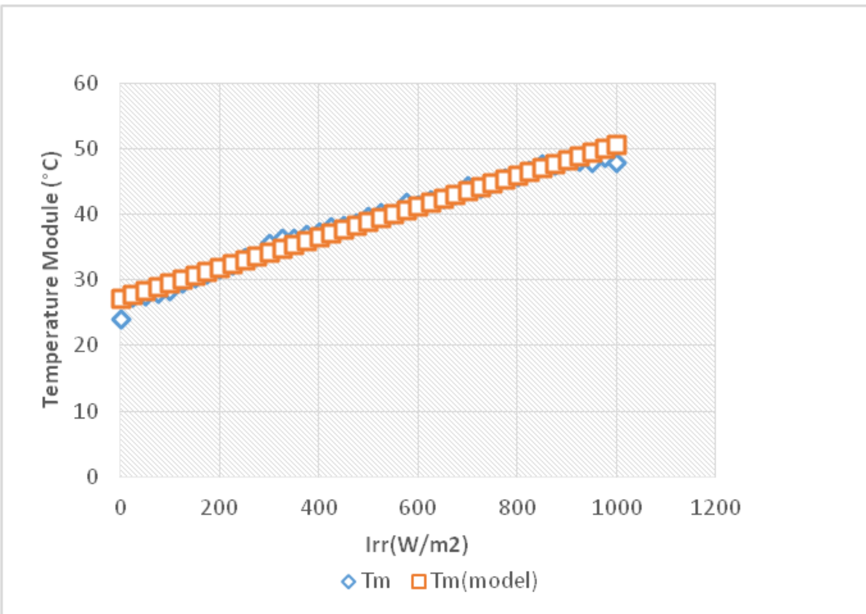
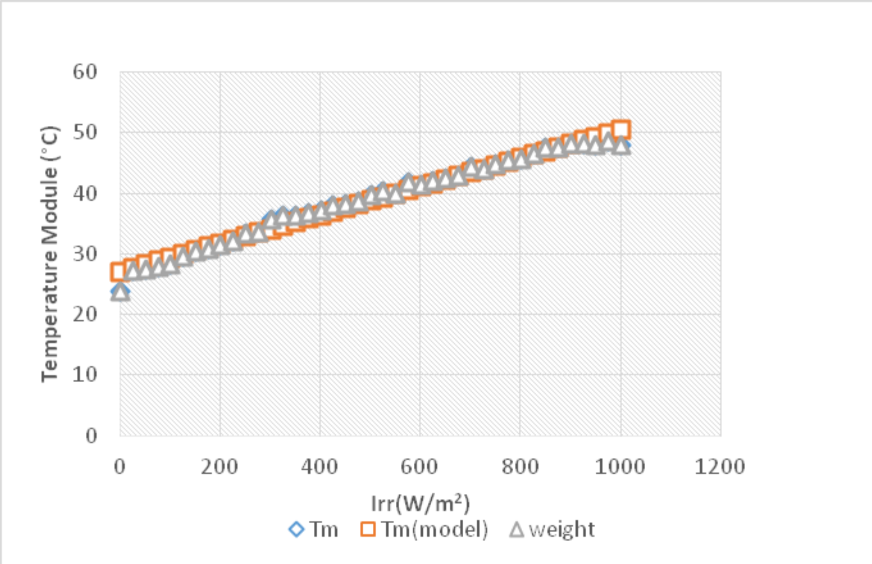
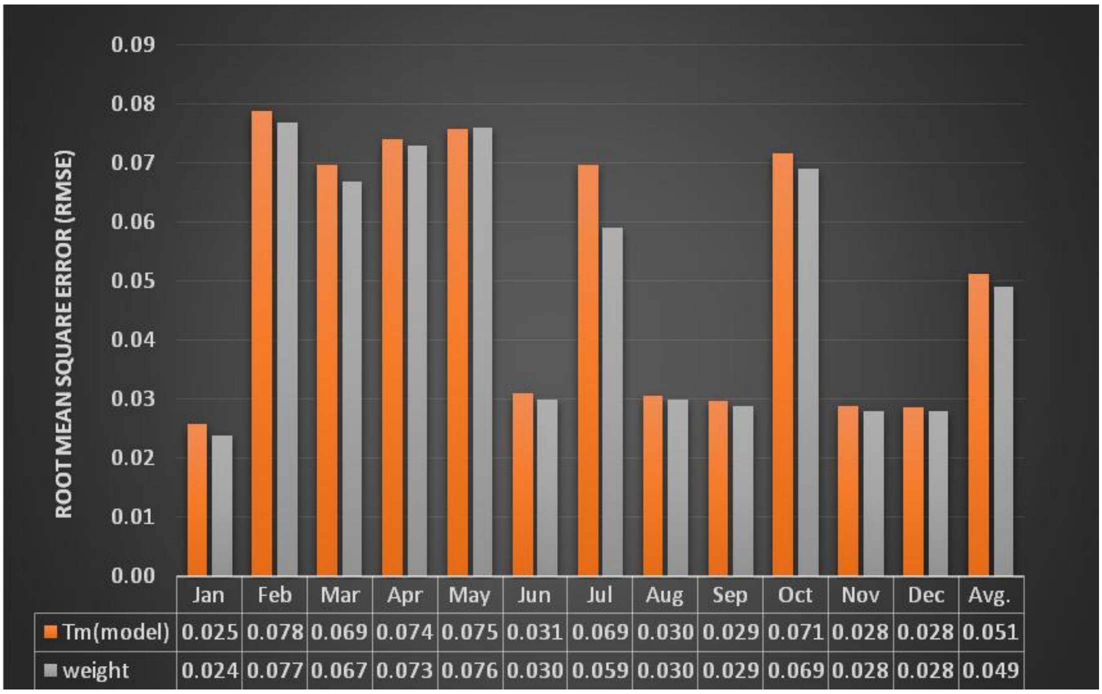


Figure 4.3: The estimated values of the module temperature model with module temperature measurement and module temperature model adjusted by a weight function at various levels of solar irradiance



The RMSE from *the module temperature model* compared with RMSE from *the module temperature model* adjusted by a weight function is shown in Figure 4.4.

Figure 4.4: The power output of the 1D5P model with 2 Inputs and 1 Input



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Tm(model)	0.025	0.078	0.069	0.074	0.075	0.031	0.069	0.030	0.029	0.071	0.028	0.028	0.051
weight	0.024	0.077	0.067	0.073	0.076	0.030	0.059	0.030	0.029	0.069	0.028	0.028	0.049

Figure 4.4 shows that *the module temperature model* compared with RMSE from *the module temperature model adjusted by a weight function*, had their values of the RMSE average for the entire year as 0.0512 and 0.0491, respectively. The results indicated that the proposed model adjusted by a weight function obtained higher accuracy in measurement.

5. Conclusion

The results of this study were the improvement the module temperature model in forecasting power output for photovoltaic systems by using a weight function technique. The results showed that *the module temperature model* was verified by comparing *with the module temperature model adjusted by a weight function*. It was found that the proposed model adjusted by a weight function obtained high accuracy in measurement. The newly developed module temperature model provided a root-mean-square error (RMSE) at 0.0491, which was greater in accuracy than the existing module temperature model that carried a RMSE at 0.0512.

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7.References

Abdulazeez, M. & Iskender, I. (2011). Simulation and Experimental Study of Shading Effect on Series and Parallel Connected Photovoltaic PV Modules. *ELECO*, I-28-I-32.

Chai, T., & Draxler, R.R. (2014). Root mean square error (RMSE) or mean absolute error (MAE) – Arguments against avoiding RMSE in the literature. *Geoscientific Model Development, 7,* 1247-1250.

Ciulla, G., Lo Brano, V., Di Dio, V., and Cipriani, G. (2014). A comparison of different one-diode models for the representation of I–V characteristic of a PV cell. *Renew Sustain Energy Rev, 32,* 684–696.

Chouder, A., Silvestre, S., Sadaoui, N., and Rahmani, L. (2012). Modeling and simulation of a grid-connected PV system based on the evaluation of main PV module parameters. *Simul Model Pract Theory, 20,* 46–58.

Dawan, P., Worranetsuttikul, K., Kittisontirak, S., Sripapha, K., and Titiroongruang, W. (2018). Performance of the Temperature Model in Forecasting the Power Output of Photovoltaic Systems. *International Electrical Engineering Congress, 1,* 209- 211.

Garcia, M.C.A. & Balenzategui, J.L. (2004). Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations. *Renewable Energy*, 29: 1997-2010.

Glaize, C. (2011). Caractéristiques d’un panneau photovoltaïque, recherche du point de puissance maximale, intérêt d’un convertisseur », data of the solar panel MSX-83 available on the website (reference of June 2011): http://www.geea.org/.

International Energy Agency, Trends 2015 in Photovoltaic Applications. (2015). *Report IEA-PVPS.* T1-27.

Kittisontirak, S., Bupi, A., Chinnavornrungsee, P., Sriprapha, K., Thajchayapong, P., and Titiroongruang, W. (2016). An Improved PV Output Forecasting Model by Using Weight Function: A Case Study in Cambodia. *International Journal of Photoenergy*, 1-10.

Rekioua, D., & Matagne, E. (2012). E.Optimization of Photovoltaic Power Systems, Green Energy and Technology, DOI: 10.1007/978-1-4471-2403-0_2,Springer-Verlag London Limited.