Multiple Linear Regression Photovoltaic Cell Temperature Model for PVSyst Simulation Software

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Abstract: In this paper, two multiple linear regression models for the determination of photovoltaic (PV) cell temperature and for selection of appropriate thermal loss factor values in PVSyst is presented. One of the linear models can determine the cell temperature with solar irradiation and ambient temperature alone while the second model requires the solar irradiation, ambient temperature and wind speed in order to determine cell temperature. The cell temperature determined from any of the two models can then be used to select the appropriate thermal loss factor for PVSyst simulation. Sample meteorological data extracted from PVSyst software meteo-file for Dakar, the capital of Senegal, in West Africa is used for the study. In agreement, the two models gave the same thermal loss factor $U = 30.255$. Essential, the approach presented in this paper can be used to effectively determine cell temperature, with and without wind speed.

Keywords: Thermal Loss, Cell Temperature, PVSyst, Photovoltaic Effect, Cell Temperature Model, Multiple Linear Regression

1. Introduction

Solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted through photovoltaic (PV) effect into electricity [1, 2, 3]. The PV cell efficiency is dependent on a number of intrinsic and extrinsic factors. Particularly increase in the cell temperature tends to reduce the cell efficiency [4, 5, 6]. During operation, the part of the solar energy falling on the cell is converted to electricity while some part are converted to heat which in turn increases the cell temperature above the ambient temperature. Among other things the solar irradiation, the ambient temperature and wind speed influence the extent to which the cell temperature can rise above the ambient temperature. In addition, the temperature coefficient and the nature of the PV installation also affect the cell temperature.

In PVSysts, cell temperature model is based on the Faiman module temperature model which utilizes ambient temperature, wind speed and solar irradiation in computing the cell temperature [7, 8, 9]. In the model, PVSysts includes some empirically determined parameters that reflects constant heat transfer component and the convective heat transfer component. The two parameters are used to compute the thermal loss factor ($U$) which is used in computing the cell temperature. However, the two heat transfer parameters are not well defined in PVSyst. Moreover, due to lack of hourly or appropriate wind speed data, PVSyst tends to ignore the convective heat transfer component which makes use of wind speed.

In practice, users are expected to set the value of the two parameters based on their specific PV installation. However, different published works have used or suggested different combinations of the values of two heat transfer parameters in PVSyst. In all, there is no known guide for appropriate selection of the right combination of the values of the two parameters. In view of this, a set of five different combinations of the values of the two parameters are considered in this paper. From the analysis of the resulting cell temperature for a given set of data, a multiple linear regression model is developed for estimating the cell temperature. The model will enable PV designers using PVSyst software to select the right value of the thermal loss factor for computing the cell temperature.
2. Theoretical Background

2.1. PVsyst Thermal Loss Factor

In PVsyst the thermal loss model is based on the single-diode mode while the PV module’s thermal behavior is based on the energy balance between ambient temperature and the cell temperature due to irradiance as follows [10]:

\[ U (T_c - T_a) = \alpha G (1 - \eta_{PV}) \]  

\[ U = \frac{\alpha G (1 - \eta_{STC})}{T_c - T_a} \]  

Where \( U \) is the thermal loss factor, \( \alpha \) is the absorptivity of the module (PVsyst default value is 0.9).

2.2. PVsyst Cell Temperature Model

Also, PVsyst, implements a cell temperature model based on the Faiman module temperature model given as [11]:

\[ T_c = T_a + \left( \frac{\alpha G (1 - \eta_{PV})}{U_0 + U_1 (V_{wind})} \right) \]  

where:
- \( T_c \) is cell temperature (°C)
- \( T_a \) is ambient air temperature (°C)
- \( \alpha \) is the absorptivity of the module (PVsyst default value is 0.9)
- \( G \) is the irradiation incident on the plane of the module or array (W/m²)
- \( \eta_{PV} \) is the efficiency of the PV module (PVsyst default value is 0.1)
- \( U_0 \) is the constant heat transfer component (W/m²K)
- \( U_1 \) is the convective heat transfer component (W/m²K)
- \( V_{wind} \) is wind speed (m/s)

PVsyst does not provide enough information on the value of \( U_0 \) and \( U_1 \). The current default values assume no dependence on wind speed. \( U_1 = 0 \). The following five different set of values are available from published literatures:

i. For free-standing arrays the current default is: \( U_0 = 29 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

ii. For fully insulated arrays (close roof mount) the current default is: \( U_0 = 15 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

iii. Some PVsyst users proposed, \( U_0 = 25 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

iv. SunEdison (SunEdison, 2015) proposed \( U_0 = 26 \) W/m²K, \( U_1 = 1.4 \) W/m²K / m/s

v. SunEdison (SunEdison, 2015) proposed \( U_0 = U = 26 \) W/m²K, \( U_1 = 1.4 \) W/m²K / m/s

By using \( U_0 = U \) and \( U_1 = 0 \), the value \( U \) and hence value of \( U_0 \) can be obtained from the knowledge of \( T_c \) and \( T_a \) and then using equation 2. In this paper, the approach adopted is to use a multiple linear regression model to determine the cell temperature (\( T_c \)) from the values of \( G, T_a \) and \( V_{wind} \) or \( G \) and \( T_a \) and then compute the value of \( U \) and hence the value of \( U_0 \) from equation 2.

3. The Simulation Process

The simulation is conducted with meteorological data extracted from PVsyst software meteor-file for Dakar which is the capital of Senegal, in West Africa. The site coordinate for the data is 14.5° N, 17.0° W and altitude of 5m. The PV used in the study is the monocrystalline silicon (m-Si) PV with module efficiency \( \eta_{STC} \% = 18.4 \% \); temperature coefficient of maximal power \( \beta_{STC} = -0.38 \%/\degree \)C; watt peak rating for PV=100Wp and; NOCT=45 ° [12, 13]. PVsyst default value for the adsorption coefficient of the module (\( \alpha \)) is 0.9.

The cell temperature are computed using the following five set of published combinations of values for \( U_0 \) and \( U_1 \):

i. For fully insulated arrays (close roof mount): \( U_0 = 15 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

ii. For free-standing arrays the current default: \( U_0 = 29 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

iii. Some PVsyst users proposed, \( U_0 = 25 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

iv. The default value in the old version of PVsyst \( U_0 = 20 \) W/m²K, \( U_1 = 6 \) W/m²K / m/s (PVsyst, 2016)

v. SunEdison (SunEdison, 2015) proposed \( U_0 = 26 \) W/m²K, \( U_1 = 1.4 \) W/m²K / m/s

4. Results and Discussion

Table 1 shows the cell temperature determined from the five different set of published combinations of values for \( U_0 \) and \( U_1 \). According to Table 1, the cell temperature obtained in Tcell2, Tcell4 and Tcell5 are very close.

i. Tcell2: is obtained from the current PVsyst default value

ii. Tcell4: is obtained from the current PVsyst default value

iii. Some PVsyst users proposed, \( U_0 = 25 \) W/m²K, \( U_1 = 0 \) W/m²K (PVsyst, 2016)

iv. The default value in the old version of PVsyst \( U_0 = 20 \) W/m²K, \( U_1 = 6 \) W/m²K / m/s (PVsyst, 2016)

v. SunEdison (SunEdison, 2015) proposed \( U_0 = 26 \) W/m²K, \( U_1 = 1.4 \) W/m²K / m/s

<table>
<thead>
<tr>
<th>Global Irradiation on the Tilted Plane (W/m² day)</th>
<th>Ambient Temperature, Ta (°C)</th>
<th>Wind Speed, Vwind (m/s)</th>
<th>Tcell2</th>
<th>Tcell4</th>
<th>Tcell5</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>11.4</td>
<td>5.6</td>
<td>34.1616</td>
<td>32.15255</td>
<td>31.8073</td>
</tr>
<tr>
<td>249</td>
<td>11.7</td>
<td>5.6</td>
<td>33.7904</td>
<td>32.64088</td>
<td>32.15255</td>
</tr>
<tr>
<td>59</td>
<td>29.2</td>
<td>3.1</td>
<td>32.0884</td>
<td>30.69412</td>
<td>30.62813</td>
</tr>
<tr>
<td>85</td>
<td>30</td>
<td>6.1</td>
<td>34.1616</td>
<td>32.15255</td>
<td>31.8073</td>
</tr>
</tbody>
</table>

v. SunEdison (SunEdison, 2015) proposed \( U_0 = 26 \) W/m²K, \( U_1 = 1.4 \) W/m²K / m/s
The average cell temperature obtained in Tcell2, Tcell4 and Tcell5 is computed, as shown in Table 2. Multiple linear regression model was fitted to predict the average cell temperature as a function of solar irradiation (G), ambient temperature (Ta) and wind speed ($V_{wind}$). The first multiple linear regression model (MLR Model 1) is given as;

$$T_c = 0.02431381049 G + 1.00086483\frac{1}{T_a} - 0.662692592$$

(4)

### Table 2. The Average Cell Temperature for the Three Best Set of Thermal Loss Factor Value Uo and U1 and the Predicted Average Cell Temperature.

<table>
<thead>
<tr>
<th>Global Irradiation on The Tilted Plane (W/m², day)</th>
<th>Ambient Temperature, Ta (°C)</th>
<th>Wind Speed, Vwind (m/s)</th>
<th>Average Tcell (°C)</th>
<th>Predicted Average Tcell (°C) (Using G, Ta and Vwind)</th>
<th>Predicted Average Tcell (°C) (Using G and Ta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>11.4</td>
<td>5.6</td>
<td>12.546</td>
<td>12.422</td>
<td>12.424</td>
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<tr>
<td>249</td>
<td>11.7</td>
<td>5.6</td>
<td>17.525</td>
<td>17.586</td>
<td>17.590</td>
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<tr>
<td>59</td>
<td>29.2</td>
<td>3.1</td>
<td>30.677</td>
<td>30.856</td>
<td>30.622</td>
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<tr>
<td>85</td>
<td>30</td>
<td>6.1</td>
<td>31.964</td>
<td>31.838</td>
<td>32.061</td>
</tr>
<tr>
<td>292</td>
<td>31.3</td>
<td>6.1</td>
<td>38.610</td>
<td>38.624</td>
<td>38.405</td>
</tr>
<tr>
<td>243</td>
<td>32</td>
<td>6.7</td>
<td>37.614</td>
<td>37.682</td>
<td>37.920</td>
</tr>
<tr>
<td>869</td>
<td>45</td>
<td>4.5</td>
<td>65.919</td>
<td>66.156</td>
<td>66.253</td>
</tr>
<tr>
<td>761</td>
<td>45.4</td>
<td>3.1</td>
<td>64.451</td>
<td>64.141</td>
<td>64.031</td>
</tr>
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<td>64.141</td>
<td>64.031</td>
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</tr>
</tbody>
</table>

In PVSyst, the argument is that there is no available hourly data on wind speed. As such, PVSyst tends to estimate the cell temperature without wind speed. In that case, a second multiple linear regression model is fitted to predict the average cell temperature as a function of solar irradiation (G) and ambient temperature (Ta). The second multiple linear regression model (MLR Model 2) is given as;

$$T_c = 0.02431381049 G + 1.00086483\frac{1}{T_a} - 0.662692592$$

(5)

In all, since G, Ta and $V_{wind}$ or G and $T_a$ are given, the cell temperature, $T_c$ is computed from the multiple linear regression model and then the thermal loss factor, U is computed using $U_0 = U = \frac{\alpha(G) (1 - \eta_{STC})}{T_c - T_a}$ and $U_1 = 0$. This set of value can then be used in PVSyst to estimate the cell temperature for PV system simulation. For instance, with $\alpha=0.9$, $\eta_{STC} = 18.4\%$ and from Table 2 row 3 column 1, G=49 W/m², then $\alpha(G) (1 - \eta_{STC}) = 0.9 * 49 * (1 - \frac{18.4}{100}) = 35.9856$. Also Average cell temperature from Table 2 row 3 column 4 is $T_c = 12.5462546$ °C while the ambient temperature from Table 2 row 3 column 2 is $T_a = 11.4$ °C. Then

$$T_c - T_a = 12.5462546 - 11.4 = 1.1462546$$

Therefore, $U_0 = U = \frac{\alpha(G) (1 - \eta_{STC})}{T_c - T_a} = \frac{35.9856}{1.1462546} = 31.39407248616494$.

However, in practice, $T_c$ and $\alpha(G) (1 - \eta_{STC})$ are computed for the given set of data, then the average of $\alpha(G) (1 - \eta_{STC})$ is divided by the average of $T_c - T_a$ in order to obtain the value of $U$. As shown in Table 3, for the given set of data in Table 2, the average of $\alpha(G) (1 - \eta_{STC}) = 239.3226$ and for the two models, the average of $T_c - T_a = 7.91321056$. Then,

$$U_0 = U = \frac{\alpha(G) (1 - \eta_{STC})}{T_c - T_a} = \frac{239.32}{7.91} = 30.255$$ and $U_1 = 0$.
5. Conclusion

Multiple linear regression model for determination of PV cell temperature and for selection of appropriate thermal loss factor values in PVSyst is presented. The linear model can determine the cell temperature with solar irradiation and ambient temperature alone. Another multiple linear regression model is presented which requires the solar irradiation, ambient temperature and wind speed in order to determine cell temperature. The cell temperature determined from the model can then be used to select the appropriate thermal loss factor for PVSysts simulation.

References


