OPTIMIZATION OF PV MODULE WITH SINGLE-DIODE MODEL FOR TOKAT REGION

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Abstract
In this study single diode model of photovoltaic cell is is simulated with using all cell parameters for Tokat Region in TURKEY. Retscreen software and matlab were used to determine model parameters. Simulation studies were carried out with different irradiations and temperatures in Tokat Region. The output power, voltage and current characteristics of PV model are analyzed especially with taking the effect of temperature and irradiance. Komaes 140W PV module is referenced to analyze the presented model. Also Euclidean distance, Manhattan distance and Minkowski distance methods are used to determine distance from maximum panel power.

Introduction
Over the last decades, renewable energy sources has been most popular and credible for humankind. Because fossil fuels cause pollution and limited sources [1]. So, solar energy, wind energy, biomass etc. become most popular in alternative energy sources. In that context, solar energy is inexhaustible, renewable and non-polluting. Therefore it can be used in different energy applications [2]. But solar energy has less energy contribution than other energy sources. Because it has low efficiency and high cost [3]. Our country has a position of having second highest potential of solar energy in Europe. However, Turkey is falling behind of many of European countries in terms using its potential. Nevertheless, due to the new regulations put in place in last years, benefiting from solar energy has begun to be chosen in Turkey as well, for producing electricity. That is why, today, Energy Ministry of Turkey encourages setting up Solar Power Plants and it is permitted to produce electricity up to 500kW without licence.

Solar cell is the main part of PV systems and these systems directly produce the electric from sun. Cells are suitable to be connected to power electronic systems and loads [4]. Efficiency is very important for photovoltaic systems. Thereby maximum power point tracking control is preferred in many PV systems. PV system parameters also have an important role and the circuit based model is needed for modelling for the PV cell [5]. Generally non-linear I-V curve is used for modeling of PV module. Many researchers used single-diode model to characterize the PV module as the current source in parallel to a diode [6-8]. The single diode model use a series resistance for good performance. These models are known as Rs-models [9-10]. Also many researchers have used this model that includes a shunt resistance (Rsh) for right approach [11-13]. On the other hand the second model is two-diode model of a solar cell. Difference between Rs model and two-diode model is a second diode. But especially Rs model is commonly preferred. Because this model is very simple and to determine parameters of cell is easy [14-17].

In literature; Celik et.al., have used analytical models that are used four- and five-parameter for current of photovoltaic module [9]. For PV panel behavior Neural network revised under realistic weather conditions [19]. Ghani et.al., have studied numerical solution about series and shunt resistances [20]. PV cell's dynamic resistance is calculated using I-V characteristics in Ref [21]. Zagrouba et.al., calculated the electrical parameters using genetic algorithms [22]. Ishibashi et.al., offered a new approach using a single I-V curve to derive cell parameters [23].
In this study; single diode model is preferenced to determine unknown parameters of solar cell and focused on distances from the maximum panel power according to meteorological data of Tokat. Numerical analysis showed a 40% loss of maximum panel power.

Mathematical Model of A Solar Cell
One-Diode model is shown in Fig.1 where represents series and parallel resistance, respectively. \( I_L \) light current (A), \( I_D \) ideal diode current (A), \( I_{sh} \) shunt resistance current, \( I_{cell} \)’s current.

![Figure 1 Electrical Device of Solar Cell with One-Diode](image)

Generally to calculate relation between the cell’s current and voltage is used following equation:

\[
I = I_L - I_0 \left( e^{\frac{V+R_s I}{a V_T}} - 1 \right) - \frac{V+R_s I}{R_{sh}}
\]  

(1)

Where:
- \( I_L \): Photocurrent (A)
- \( I_0 \): Diode Saturation Current (A)
- \( R_s \): Series Resistance (Ω)
- \( R_{sh} \): Shunt Resistance (Ω)
- \( a \): Diode Ideality Factor
- \( V_T \): Thermal Voltage equivalent (V)

Cell Parameters And Equations To Determine Cell Parameters
Photocurrent (\( I_L \))
The photocurrent can simply be calculated using Equation 2. This equation is a function of temperature and irradiance values. [24],

\[
I_L = \frac{l_{scref}}{G_{Tcref}} G_{Te} - a(T_c - T_{cref})
\]  

(2)

Where:
- \( G_{Te} \): Irradiance (W/m²)
- \( G_{Tcref} \): Reference irradiance (1000 W/m²)
- \( l_{scref} \): Reference condition’s short circuit current (A)
- \( a \): Curve Fitting Parameter
- \( T_c \): Condition Temperature
- \( T_{cref} \): Reference Temperature (25 °C)
\[ \alpha = \frac{T_{\text{ref}} + 273}{T_c + 273} \alpha_{\text{ref}} \quad (3) \]

\[ \alpha_{\text{ref}} : \text{The value of } \alpha \text{ the reference condition (1000W/m}^2 \text{ and 25}^{\circ}\text{C) [25],} \]

\[ \alpha_{\text{ref}} = \frac{2V_{\text{mpref}} - V_{\text{o cref}}}{I_{\text{sc ref}} + \text{ln} \left( \frac{I_{\text{mpref}}}{I_{\text{sc ref}}} \right)} \quad (4) \]

\[ V_{\text{mpref}} : \text{The Reference Condition’s Maximum Power Point Voltage (V)} \]

\[ V_{\text{o cref}} : \text{The Reference Condition’s Open Circuit Voltage (V)} \]

\[ I_{\text{mpref}} : \text{Maximum Power Point Current At The Reference Condition (A)} \]

**Diode Saturation Current (I_0)**

According to variations in cell temperature to calculate the diode saturation current (I_0) is used the following equation [26];

\[ I_0 = \frac{(R_{\text{sh}} + R_s)lm - V_{\text{o cref}}}{R_{\text{sh}} + \frac{V_{\text{o cref}}}{\text{mpref}}} \quad (5) \]

\[ V_T = \frac{n_s \text{k} T}{q} \quad (6) \]

q : Electron Charge (1.60217646 \times 10^{-19} \text{C})

n_s : Series Cells’s number

k : Boltzmann Constant (1.3806503 \times 10^{-23} \text{J/K})

T : P-N Junction’s temperature (K)

**Series (R_s) And Shunt Resistances (R_{sh})**

Both series and shunt resistances are calculated according to the following equations [26];

\[ R_s = \alpha_{\text{ref}} \text{ln} \left( 1 - \frac{I_{\text{mpref}}}{I_{\text{sc ref}}} \right) + V_{\text{o cref}} - V_{\text{mpref}} \quad (7) \]

\[ R_{\text{sh}} = \frac{(V_m - R_s)(V_m - R_s)(I_{\text{sc}} - I_m) - aV_T}{(V_m - R_s)(I_{\text{sc}} - I_m) - aV_T I_m} \quad (8) \]

Series resistance is small than parallel resistance. Also parallel resistance's value is generally high. Therefore both of them are negligible [27].

**Materials and Methods**

Komaes KM(P) 140 PV panel is referenced for modeling. Because it is most commonly used in PV technology. Electrical characteristics data of Komaes 140W pv module is shown in Table 1.
Table 1. Electrical characteristics data of Komaes 140W

<table>
<thead>
<tr>
<th>Electrical Characteristics</th>
<th>KM(P) 140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>KM(P) 140</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>Pmax (W) 140</td>
</tr>
<tr>
<td>Voltage</td>
<td>V_{in}(V) 18.36</td>
</tr>
<tr>
<td>Current</td>
<td>I_{in}(A) 7.65</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>V_{oc}(V) 21.96</td>
</tr>
<tr>
<td>Voltage</td>
<td>I_{sc}(A) 8.17</td>
</tr>
<tr>
<td>Cells of Module</td>
<td>Pcs 36(4x9)</td>
</tr>
<tr>
<td>Temperature Coefficient of I_{sc}</td>
<td>%/°C +0.05</td>
</tr>
<tr>
<td>Temperature Coefficient of V_{oc}</td>
<td>%/°C -0.35</td>
</tr>
</tbody>
</table>

In this study; the monthly mean values of solar irradiance and temperature for Tokat Region were obtained using RETScreen Software. RETScreen is most suitable and used software for renewable energy, energy efficiency, energy performance analysis and feasibility analysis. The monthly mean values of solar irradiance and temperature are shown in Table 2.

Table 2. The monthly mean values of solar irradiance and temperature

<table>
<thead>
<tr>
<th>Month</th>
<th>Solar Irradiance (kWh/M^2/g)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1.85</td>
<td>-0.4</td>
</tr>
<tr>
<td>February</td>
<td>2.60</td>
<td>0.0</td>
</tr>
<tr>
<td>March</td>
<td>3.64</td>
<td>3.9</td>
</tr>
<tr>
<td>April</td>
<td>4.52</td>
<td>9.6</td>
</tr>
<tr>
<td>May</td>
<td>5.62</td>
<td>13.3</td>
</tr>
<tr>
<td>June</td>
<td>6.53</td>
<td>16.4</td>
</tr>
<tr>
<td>July</td>
<td>6.48</td>
<td>18.7</td>
</tr>
<tr>
<td>August</td>
<td>5.77</td>
<td>18.8</td>
</tr>
<tr>
<td>September</td>
<td>4.69</td>
<td>16.0</td>
</tr>
<tr>
<td>October</td>
<td>3.19</td>
<td>11.8</td>
</tr>
<tr>
<td>November</td>
<td>2.14</td>
<td>5.9</td>
</tr>
<tr>
<td>December</td>
<td>1.54</td>
<td>1.3</td>
</tr>
<tr>
<td>Mean value of yearly</td>
<td>4.05</td>
<td>9.7</td>
</tr>
</tbody>
</table>

In the single diode model, to solve nonlinear I-V equation, electrical and thermal values of PV panel using datasheet, location variables, defining constants, finding series and parallel resistances were used and I–V characteristic curves are achieved. According to months I–V characteristic curves are shown in Fig. 2.
The maximum power of the panel was calculated for each month in Fig. 3.

The maximum power of the panel was selected as reference is 140W. The distance of power for each month from the maximum panel power was calculated by 3 methods. These are Euclidean distance, Manhattan distance and Minkowski distance. These methods are widely used in clustering methods of data mining.
Euclidean distance
It is the most commonly used distance measure in practice. Euclidean distance is an application of pythagorean theorem in two dimensional space. Euclidean space becomes a metric space.

Euclidean distance is the length of the line that is connecting A and B points (\( \overline{AB} \)). If there are two points in Euclidean as \( A = (A_1, A_2, \ldots, A_n) \) and \( B = (B_1, B_2, \ldots, B_n) \), distance \( (d) \) is calculated by Pythagorean formula.

\[
d(A, B) = \sqrt{(A_1 - B_1)^2 + (A_2 - B_2)^2 + \cdots + (A_n - B_n)^2}
\]  
(9)

This equation can be updated as equation 10.

\[
d(i, j) = \sqrt{\sum_{k=1}^{p} (X_{ik} - X_{jk})^2}
\]  
(10)

Manhattan distance
This distance is calculated as the sum of absolute distances between observations. The Manhattan distance is calculated as:

\[
d(i, j) = |X_{i1} - X_{j1}| + |X_{i2} - X_{j2}| + \cdots
\]  
(11)

Minkowski distance
The Minkowski distance is a metric in a normed vector space. It is the generalization form of Manhattan distance and Euclidean distance. Minkowski distance is calculated as:

\[
d(i, j) = \left[ |X_{i1} - X_{j1}|^m + |X_{i2} - X_{j2}|^m + \cdots |X_{im} - X_{jm}|^m \right]^{1/m}
\]  
(12)

The results that were obtained according each distance method are shown in Table 3.

**Table 3. Distance values from maximum power for each distance method**

<table>
<thead>
<tr>
<th>Months</th>
<th>Euclidean Distance</th>
<th>Manhattan Distance</th>
<th>Minkowski Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>445,895</td>
<td>651,766</td>
<td>199,311</td>
</tr>
<tr>
<td>February</td>
<td>361,105</td>
<td>533,913</td>
<td>160,663</td>
</tr>
<tr>
<td>March</td>
<td>391,222</td>
<td>573,564</td>
<td>174,029</td>
</tr>
<tr>
<td>April</td>
<td>401,174</td>
<td>582,325</td>
<td>178,576</td>
</tr>
<tr>
<td>May</td>
<td>432,161</td>
<td>622,071</td>
<td>192,617</td>
</tr>
<tr>
<td>June</td>
<td>408,133</td>
<td>585,651</td>
<td>181,766</td>
</tr>
<tr>
<td>July</td>
<td>441,138</td>
<td>639,078</td>
<td>199,892</td>
</tr>
<tr>
<td>August</td>
<td>538,385</td>
<td>759,781</td>
<td>242,965</td>
</tr>
<tr>
<td>September</td>
<td>526,058</td>
<td>741,888</td>
<td>236,821</td>
</tr>
<tr>
<td>October</td>
<td>575,231</td>
<td>809,249</td>
<td>261,269</td>
</tr>
<tr>
<td>November</td>
<td>618,088</td>
<td>866,046</td>
<td>282,895</td>
</tr>
<tr>
<td>December</td>
<td>530,120</td>
<td>759,333</td>
<td>239,895</td>
</tr>
</tbody>
</table>
Discussion and Conclusion

We studied single-diode model of solar cell to determine I-V characteristic. The performance of the PV system under change solar radiation and temperature difference are calculated in this paper. While solar radiation increases, cell’s current increases in direct proportion and open circuit voltage comparatively less increases. On the other side while temperature increases, cell’s current less increases but open circuit voltage linearly decreases. This situation affects the output power of panel. Especially in November, 60% of output power of panel is decreased was observed in numerical solutions. This situation leads to a loss of about 79 kWh of energy. Three distance methods were used. The maximum distance was calculated with Manhattan Distance while five distance methods were used. The maximum distance was calculated with Manhattan Distance method in November. To study on Physical modeling is very difficult because of the parameters of the given module. But mathematical model helps to analyse by changing values. Panels can be used more efficiently with the production of custom panels for cities or regions. Also this situation reveals the importance of hybrid systems.

References


