Measuring the Solar Cell Parameters Using Fuzzy Set Technique
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Abstract: This work studies the application of fuzzy set (FS) and fuzzy logic (FC) methods to determine the optimal operating point of solar cell. The physical parameters of the solar cell have been measured practically using silicon solar cell. The important parameters of the silicon cell are compared with each other using fuzzy set comparison method (FSCM) based on (I-V) characteristic curves of the voltage of photovoltaic cell and the maximum power resulting from the cell; which is a simple method for the measurement. The results of the simulation method show that, the fuzzy set comparison method (FSCM) is better measuring these parameters.

Keywords: Fuzzy set, solar cell, temperature, physical parameters

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1. Introduction

At present, photovoltaic cell provide the most important long time energy supply for satellites and space vehicles; have been successfully employed in small-scale terrestrial applications. Three-body problem is the major equation to solve the problem of the Kepler's orbit by means of the equations of Kepler and Barker equations[1-8]. The pioneer candidate for acquisition power from the sun is the photovoltaic cells, because it converts sunlight in direct way to electricity with high quantum efficiency with low operation cost and free of pollution. Two conditions must exist if we talk about materials that can transfer light into electricity. For first condition, it should have the ability to absorb the incident light from the lower to higher levels of energy[9-12]. For the second condition, it should contain internal electric field to accelerate the electrons into special direction to generate electrical current. Many materials have been used to improve the quantum efficiency of the PV cells[13-18]. There are many types of photovoltaic cells inorganic and organic solar cells[19-28]. For any solar cell devices the best important thing is the current-voltage characterization of the solar cell, an example for an equivalent electric circuit is shown in Figure 1. The most important part of this circuit is the current and voltage difference at the front and back contact by means of voltmeter and ammeter on can measure these important parameters (V and I) of the cell, respectively. In addition, the light intensity of the source is an important parameter for the current value measurements with the resistance as a load of the circuit.

In this research, a fuzzy set theory has been used to obtain the predicted (maximum and minimum values) of a physical parameters of a photovoltaic cell (output) in outdoor measurements, and compare all the input parameters with the output parameters using this theory. This method is used for several applications; a control command is obtained as a crisp value.

1.1 Important Parameters of Solar Cell

Based on the form of the electric circuit for solar cells;
the resistance as a load is particularly chosen to the output energy as it be maximum. \((I-V)\) curve extremely influences the performing energy output. Demonstrating current voltage plot, someone should where \(P_m\): maximum power, \(V_{oc}\): open circuit voltage, \(I_{sc}\): short circuit current. Increases a maximum power output means; higher FF. then, it is possible to demonstrate the efficiency \(\eta\) of the solar cell, which is described the ratio of output photons to the incident photons\(^{[30]}\).

\[
\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{P_m}{E \times A} \times 100\% \tag{2}
\]

where \(P_{in}\): intensity of the arriving photons (mW/cm\(^2\)), and \(A\): area of a solar cell \((\text{cm}^2)\) and the arriving photons \(P_m\) merging Eqs. 1 and 2 yields\(^{[31]}\)

\[
\eta = \frac{V_{oc} I_{sc} \times FF}{E \times A} \times 100\% \tag{3}
\]

The Eq. 3 obtains the efficiency based on the variables; fill factor, open voltage circuit, and short circuit current are required to demonstrate a solar cell. The value of the physical parameters acquired using investigating the solar cell I-V curve. Using variable voltage, calculating current, the resistance as a load is mainly changed from zero when the highest short circuit current inflow \(I_{sc}\) to infinity, gets the highest open voltage circuit \(V_{oc}\).

This paper will focus on determination the physical parameters of the photovoltaic cell and examine these parameters using fuzzy set mathematical method.

### 1.2 Fuzzy Set Method\(^{[32-38]}\)

The two basic components of fuzzy systems are utilize another factor called Fill Factor \(FF\) to gets the maximum output energy \(P_m\) based on \(V_{oc}\) and \(I_{sc}\)\(^{[29]}\).

\[
FF = \frac{P_m}{V_{oc} I_{sc}} = \frac{V_{oc} I_{sc}}{V_{oc} I_{sc}} \times 100\%
\]

fuzzy sets and operations on fuzzy sets. Fuzzy logic defines rules, based on combinations of fuzzy sets by these operations. This section is based on the basic works of Zadeh.

In general, a fuzzy rule can be represented by a fuzzy expression \(R = A \rightarrow B\), \(R\) can be viewed as a fuzzy set with a two-dimensional membership function

\[
\mu_R(x, y) = f(\mu_A(x), \mu_B(y))
\]

where: the function \(f\), called the fuzzy implication function, performs the task of transforming the membership degrees of \(x\) in \(A\) and \(y\) in \(B\) into those of \((x, y)\) in \(A \times B\), and \(f\) is a min operator and product operator.

**Crisp sets:** given a universe of discourse \(X = \{x\}\), a crisp (conventional) set \(A\) is defined by enumerating all elements \(x \in X\)

\[
A = \{x_1, x_2, x_3, x_n\}
\]

That belong to \(A\) the membership can be expressed by a function \(f_A(x)\) on a binary value

\[
f_A: x \rightarrow \{0, 1\}, f_A = \begin{cases} 1 & \text{if } x \in A \\ 0 & \text{if } x \notin A \end{cases}
\]

Thus, an arbitrary \(x\) either belongs to \(A\), or it does not, partial membership is not allowed. For two sets \(A\) and \(B\), combinations can be defined by the following operations

\[
A \cup B = \{x | x \in A \text{ or } x \in B\}, A \cap B = \{x | x \in A \text{ and } x \in B\}, \bar{A} = \{x | x \notin A \text{ and } x \in X\}
\]

Additionally, the following rules have to be satisfied

\[
A \cap \bar{A} = \emptyset, A \cup \bar{A} = X
\]

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**Figure 1.** Simple electrical circuit of a photovoltaic cell.
2. Experimental Method

In this research, the method including fuzzy set method has been utilized to determine PV physical parameters and conversion efficiency evolutionary algorithms were briefly described and compared the mathematical results with those obtained by experimental one.

3. Results and Discussion

The following data in Table 1 was performed using a commercial silicon solar cell with an active area of 44 cm² under illumination power density of 69 mW/cm², which corresponds to AM1.5 conditions. The test was achieved when the cell loaded by decade box of resistors.

The Input parameters are \( (T, J_{sc}, V_{oc}) \) and the Output parameters are \( (R_m, J_m, V_m, FF, \eta_m, \tau, R_s, R_{sh}) \) Where: \( J_{sc} \) is the open-circuit current density, \( J_m \) is maximum current density, \( R_s \) is series resistance, \( R_{sh} \) is shunt resistance, and \( \tau \) is minority carrier lifetime.

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>( J_m ) (mA/cm²)</th>
<th>( V_m ) (V)</th>
<th>( R_m ) (Ω)</th>
<th>( J_m ) (mA/cm²)</th>
<th>( V_m ) (V)</th>
<th>FF</th>
<th>( \eta_m ) (%)</th>
<th>( \tau ) (µs)</th>
<th>( R_s ) (kΩ)</th>
<th>( R_{sh} ) (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3.52</td>
<td>2.1</td>
<td>5</td>
<td>3.38</td>
<td>1.2</td>
<td>0.55</td>
<td>5.9</td>
<td>-</td>
<td>0.26</td>
<td>4.5</td>
</tr>
<tr>
<td>14</td>
<td>4.86</td>
<td>2.2</td>
<td>5</td>
<td>3.52</td>
<td>1.35</td>
<td>0.44</td>
<td>6.9</td>
<td>15.6</td>
<td>0.18</td>
<td>10</td>
</tr>
<tr>
<td>30</td>
<td>4.6</td>
<td>1.97</td>
<td>3</td>
<td>4</td>
<td>1.1</td>
<td>0.48</td>
<td>6.4</td>
<td>18.5</td>
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<td>3.9</td>
</tr>
<tr>
<td>50</td>
<td>4.8</td>
<td>1.8</td>
<td>3</td>
<td>3.4</td>
<td>1.2</td>
<td>0.47</td>
<td>5.9</td>
<td>23.1</td>
<td>0.12</td>
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</tr>
<tr>
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<td>4.4</td>
<td>1.75</td>
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<td>0.82</td>
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</tr>
<tr>
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<td>4.5</td>
<td>1.76</td>
<td>2</td>
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<td>0.85</td>
<td>0.41</td>
<td>4.8</td>
<td>29.5</td>
<td>1.0</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Table 1. The effect of temperature on the solar cell parameters\(^{[21]}\).

Figure 2 and Figure 3. Membership of T vs \( R_{sh} \), \( R_s \), \( V_m \), \( \eta_m \) at various values of T

Figure 4 and Figure 5. Membership of T vs \( R_{sh} \), \( R_s \), \( V_m \), \( \eta_m \) and \( (T vs J_m) \) at various values of T
Figure 5 and Figure 6. Membership of $J_{sc}$ vs $V_m$, $J_m$, $\tau$, $R_s$, $R_{sh}$ and (T vs. $J_n$) at various values of T

Figure 7 and Figure 8. Membership of $J_{sc}$ vs $V_m$, $J_m$, $\tau$, $R_s$, $R_{sh}$ and (T vs. $J_n$) at various values of T

Figure 9 and Figure 10. Membership of $J_{sc}$ vs $V_m$, $J_m$, $\tau$, $R_s$, $R_{sh}$ and (T vs. $R_m$) at various values of T
Figure 11 and Figure 12. Membership of $J_{sc}$ vs $V_m$, $J_m$, $\tau$, $R_s$, and $R_{sh}$ and ($J_{sc}$ vs. $R_m$) at various values of $T$.

Figure 13 and Figure 14. Membership of ($J_{sc}$ vs. $J_m$) and ($J_{ac}$ vs. $J_m$) at various values of $T$.

Figure 15 and Figure 16. Membership of ($J_{ac}$ vs. $J_m$) and ($J_{ac}$ vs. FF) at various values of $T$. 

$(J_{ac}$ vs. $R_m$)-(H)-(T=5,14,30)-L

$(J_{ac}$ vs. $R_m$)-(H)-(T=5,14)-H H

$(J_{ac}$ vs. $J_m$)-(H)-(T=5,14,30,50,60,70)-H

$(J_{ac}$ vs. $J_m$)-(H)-(T=5,14,30)-H

$(J_{ac}$ vs. $J_m$)-(H)-(T=5,14,30,50,60,70)-H H

$(J_{ac}$ vs. $J_m$)-(H)-(T=5,14,30,50,60,70)-H

$(J_{ac}$ vs. FF)-(H)-(T=5,14,30)-H
Figure 17 and Figure 18. Membership of \( (J_e \text{ vs. FF})-(H)-(T=5,30,60)-H \) and \( (J_e \text{ vs. FF})-(H)-(T=5,14,30,50,60,70)-HH \) at various values of T

Figure 19 and Figure 20. Membership of \( (V_{oc} \text{ vs. } R_m)-(H)-(T=5,14,30)-H \) and \( (V_{oc} \text{ vs. } R_m)-(H)-(T=5,14)-H \) at various values of T

Figure 21 and Figure 22. Membership of \( (V_{oc} \text{ vs. } R_n)-(H)-(T=5,14,30,60,70)-HH \) and \( (V_{oc} \text{ vs. } J_m)-(H)-(T=5,30,60)-H \) at various values of T
Figure 23 and Figure 24. Membership of \((V_{oc} \text{ vs. } J_m)\) and \((V_{oc} \text{ vs. } J_m)-(H)\) at various values of \(T\)

Figure 25 and Figure 26. Membership of \((V_{oc} \text{ vs. } FF)\) and \((V_{oc} \text{ vs. } FF)-(H)\) at various values of \(T\)

Figure 27 and Figure 28. Membership of \((V_{oc} \text{ vs. } FF)\) and \((V_{oc} \text{ vs. } V_m, \eta_m, \tau, R_s, R_{sh})-(H)\) at various values of \(T\)
4. Conclusion

Solar cells offer a potentially attractive means for direct conversion of sunlight into electricity with high reliability and low maintenance as compared with solar thermal systems. The disadvantages are high cost and difficulty of storing large amount of electricity for later use as compared with the relative ease of storing heat for later use. The cost of generating electric power with solar cells can be reduced by using concentrator to focus sunlight on to the cell.

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