Parameters Estimation of Photovoltaic Module Using Grey Wolf Optimization Method

Abstract. Parameter prediction of a photovoltaic module is fundamental to simulate the photovoltaic generator for correctly reproduce the photovoltaic curves under natural environment. In this work, a new method for solar parameter estimation applying grey wolf algorithm is presented. This technic mimics the mechanism of the chase and the chain of command of wolves in wildlife. In the grey wolf optimizer algorithm four kinds of wolves are used for simulating the control hierarchy. This technique is tested on three different photovoltaic modules. The results showed the effectiveness and validity of the method to find with great precision the parameters of the three photovoltaic modules at various values of temperatures and illuminations.


Keywords: Solar cell; modelling; parameter estimation, grey wolf optimizer.

Słowa kluczowe: ogniw fotowoltaiczne, parametry ognwa, algorytm Grey Wolf

Mathematical model of photovoltaic panel

Different models of photovoltaic cells can be found, these pattern diverge in the quantity of parameters utilized in the computation of the voltage and current of a solar cell. These models rest on the number of diode utilized; the single diode model represents a best compromise between precision and simplicity [25]. As presented in Fig. 1, a solar cell is symbolized with a current source in parallel with a diode, in practice, a parallel and series resistances are added to the model to take into account for losses and leakage current.

![Fig. 1. Electrical equivalent model of the solar cell](image)

The equation 1 and 2 describes the current–voltage relationship of solar cell:

\[
I = I_p - I_D - I_p(\exp(Q(V_{ph} + IR_{p}) - VT) - 1) - \frac{V + IR}{R_{p}}
\]

Where: \(V\) - photovoltaic cell voltage; \(I\) - photovoltaic cell current; \(A\) - ideality factor; \(I_{ph}\) - photo generated current proportional to the sunlight; \(I_D\) - diode current; \(I_{ph}\) - parallel resistance current; \(I_{D}\) - dark saturation current; \(R_{p}\) - series resistance; \(R_{p}\) - parallel resistance; \(VT\) : (\(VT = KT/q\)) the thermal voltage; \(K\) - Boltzmann’s constant; \(q\) - electron charge; \(T\) - cell temperature.

This model of a solar cell can be used to model the photovoltaic module which composed of parallel and series connected solar cells. The equation of a photovoltaic module is given by:

\[
III R R II I AV R
\]

Introduction

Application of photovoltaic panels as clean energy resources in electricity production and distribution is growing dramatically every year. To exploit these resources in efficient way and to implement them successfully, it is so important to model solar cell and analyse its behaviour and dynamics in proper method.

In the previous works, various models have been presented to define the electrical equivalent model of the solar cell to reproduce the photovoltaic curves in real environment. Two models exist to reproduce the electrical characteristics of photovoltaic cell: single and double diode model [1], [2]. The model built on one diode is the more utilized because it’s easy to implement and uses a small number of parameters. To model the solar cell using a single diode model, five parameters must be determined, such as the photo generated current, the series and parallel resistance, the saturation current of the diode and the ideality factor of the diode. These parameters depend on the climatic parameters such as temperature and sunlight [2].

In [3], an analytical technique is illustrated to calculate the parameters of the solar single diode model, from the datasheets for PV solar panels delivered by manufacturer. [4] Uses Newton Raphson method to find the solar model parameters. [5, 6] Uses differential evolution to determine the parameters of solar cells. [7]-[11] Describes other methods to predict photovoltaic parameters.

Biologically inspired algorithms have proved to be very effective for solving stochastic and non-linear problems without using complicated mathematical calculations [12,13]. Recently, numerous optimization methods such as harmony seeking method [14], the model search[15], the birds reproducing optimizer[16], the swarm optimization bee[17],genetic algorithm[18]. In [19]-[23] particle swarm optimization are implemented to compute the precise values of the parameters and finally[24] presents a new proposal using a grey wolf optimization for maximum power point.

In this work, a new method for parameter extraction of photovoltaic module is presented. The operation is based on mechanism of the chase and the chain of command of wolves in wildlife. Four kinds of wolves are used for determination of unknown parameters like reverse saturation current, series and parallel resistance at fixed temperature and irradiation.

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The grey wolf optimizer algorithm (GWO)

The grey wolf optimization algorithm presented by Mirjalili [26] imitates the chasing mechanism and the control pyramid of wolves in wildlife.

This pack is classified into four groups, alpha, beta, delta, and omega for the simulation of guidance hierarchy. Alpha is the first level and is the leader of the pack. Beta is the second level on the hierarchy of wolves and help alpha wolves to make a decision. Delta is the third level in the pack, delta wolves have to succumb alpha and beta, but they dominate omega. Omega wolves have the lowest position in the pack. They always have to succumb to all other dominant wolves. Fig 2 shows the gray wolf social hierarchy [26].

![Gray wolf social pyramid](image)

The grey wolf optimizer algorithm (GWO)

Fig.2. Gray wolf social pyramid

Hunting is also an interesting activity of wolves, as given in Fig 3, the three important phases of chasing are:

Step one: Tracking and approaching the prey.

Step two: Following, encircling, and disrupt the target until it stops moving.

Step three: Attacking the goal (prey).

![Hunting conduct of grey wolves](image)

Wolves encircle the target during the chase and the encircling is modeled by the equation 5 and 6 [27]:

\[ D = |C_x p(t) - A D| \]

\[ D = |C_x p(t + 1) - A D| \]

with \( t \) represents the current iteration, \((A, D, C)\) represent coefficient vectors, \( X_p \) is the position vector of the victim and \( X \) represents the position vector of wolf. \( A \) and \( C \) are computed with these two equations:

\[ A = 2k \cdot p - k \]

\[ C = 2r \]

\( k \) linearly reduces from 2 to 0 through the iterations and \((p, w)\) are random vectors in \([0, 1]\). The pursuit is habitually directed by the leader alpha (\( \alpha \)) followed by beta (\( \beta \)) and delta (\( \delta \)) which can sometimes contribute in chasing. \( \delta \) and \( \omega \) look after the injured wolves in the group. Alpha (\( \alpha \)) is considered the best result attributed to it the best information of the place of the target, beta (\( \beta \)) and delta (\( \delta \)) are the second and the third best solutions respectively in designing GWO. Omega is the last best. At what time the prey stops moving, the wolves terminate the chase by attacking it.

Application of GWO for parameter extraction

GWO is an optimization method able of finding optimum points by applying social communication of simple agents. Four kinds of wolves are used for determination of unknown parameters like reverse saturation current, series resistance and parallel resistance at fixed temperature and irradiation. GWO algorithm requires the definition of fitness (\( f \)) to evaluate each particle. The target is matching model parameters to a number of sampled points. Therefore, the fitness is the relative error between measurement and model prediction. The error compares the variance between the measured and the estimated photovoltaic current. The fitness function of one set of parameters is:

\[
f = \frac{1}{N} \sum (I_{real} - I_{estimated})^2 \]

\[
I_{estimated} = I_{ph} - I_a(\exp(\frac{V + IR_s}{AV_T}) - 1) - \frac{V + IR_s}{R_p} \]

\( I_{estimated} \) is predicted load current, \( I_{real} \) is measured load current, the index * means the computed value. \( N \) indicates the number of measured data points, \( I_{ph}, I_0, R_s, R_p, AV_T \) are the photovoltaic parameters to be fixed. Table 1 illustrates the parameters to be computed for photovoltaic cell.

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single diode</td>
<td>( I_{ph}, I_0, R_s, R_p, AV_T )</td>
</tr>
</tbody>
</table>

Table 1 Parameters to be computed for photovoltaic cell

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Iterations</th>
<th>Wolves number</th>
<th>( r_1, r_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>200</td>
<td>30</td>
<td>[0-1]</td>
</tr>
</tbody>
</table>

The parameters of GWO are presented in Table 2.

The flowchart of the grey wolf optimization approach is given in Fig 4.

Sahara solar breeder project (ssb)

In the context of the Sahara Solar Breeder (SSB) project a Sahara Solar Energy Research Center (SSERC) was created in the University of Saida in Algeria [28]. This research center is equipped with photovoltaic measurement system. The system measures current-voltage curve and module back-side temperature continually to appraise the effectiveness of each module under weather conditions and the natural sun light.

The photovoltaic modules installed in the university of Saida are composed of five different varieties of technologies: mono-crystalline (m-Si), CIS, poly-crystalline back contact, mono-crystalline with intrinsic thin layer (HIT) and thin film(a-Si \( \mu C \)-Si).Fig 5 shows the image of photovoltaic modules mounted in the university of Saida in Algeria.

![Photovoltaic modules](image)
Fig. 4. The GWO algorithm flowchart

Fig. 5. Photovoltaic modules mounted in the University of Saida

Table 3 Parameters of photovoltaic modules under standard testing conditions (STC)

<table>
<thead>
<tr>
<th>Type</th>
<th>P_{max} (W)</th>
<th>I_{sc} (A)</th>
<th>V_{oc} (V)</th>
<th>I_{mpp} (A)</th>
<th>V_{mpp} (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-crystalline</td>
<td>233</td>
<td>5.84</td>
<td>51.6</td>
<td>5.47</td>
<td>42.7</td>
</tr>
<tr>
<td>Thin film</td>
<td>110</td>
<td>2.5</td>
<td>71</td>
<td>2.04</td>
<td>54</td>
</tr>
<tr>
<td>CIS</td>
<td>150</td>
<td>2.2</td>
<td>108</td>
<td>1.85</td>
<td>81.5</td>
</tr>
</tbody>
</table>

where $P_{max}$ signifies power at maximum power point (MPP), $I_{sc}$ (short circuit current), $V_{oc}$ (voltage at MPP), $I_{mpp}$ (current at MPP), $V_{mpp}$ (Open circuit voltage).

The proposed technique will be applied and tested on three kinds of photovoltaic solar panels (Mono-crystalline from Panasonic model VBHNV 233Sj01A [29], thin film from Kaneka model U-VB110 [30] and CIS from Solar frontier model SF-150-S [31]) whose datasheet information is given in Table 3. The simulated and experimental results will be compared under different climatic conditions.

Results and discussion

The estimated photovoltaic cell parameters using GWO are represented in Table 4. These parameters are used to find photovoltaic electrical parameters. Table 5 shows the computed and experimental electrical parameters.

Table 4 Computed parameters of three photovoltaic modules (pV cell) at irradiance=960W/m² and temperature=67°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R_{SH}$ (Ω)</th>
<th>$R_{S}$ (Ω)</th>
<th>$I_{sc}$ (A)</th>
<th>$I_{ph}$ (A)</th>
<th>$V_{oc}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic PV module</td>
<td>3.2868</td>
<td>0.0021</td>
<td>7.063e-09</td>
<td>5.5203</td>
<td>0.0276</td>
</tr>
<tr>
<td>Solar frontier PV module</td>
<td>3.3101</td>
<td>0.0570</td>
<td>2.225e-11</td>
<td>1.9899</td>
<td>0.0347</td>
</tr>
<tr>
<td>Kaneka PV module</td>
<td>1.5290</td>
<td>0.0255</td>
<td>9.747e-10</td>
<td>2.4614</td>
<td>0.0252</td>
</tr>
</tbody>
</table>

Referring to Table 5, the parameters $I_{sc}$, $I_{mpp}$, $V_{mpp}$, $V_{oc}$ and $P_{max}$ are computed with precision.

Table 5 Computed electric parameters of three photovoltaic modules at irradiance=960W/m² and temperature=67°C

<table>
<thead>
<tr>
<th>Model of PV</th>
<th>P_{max} (W)</th>
<th>$I_{sc}$ (A)</th>
<th>$V_{oc}$ (V)</th>
<th>$I_{mpp}$ (A)</th>
<th>$V_{mpp}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic Experimental</td>
<td>200.60</td>
<td>5.487</td>
<td>48.03</td>
<td>5.12</td>
<td>39.18</td>
</tr>
<tr>
<td>Panasonic GWO</td>
<td>200.14</td>
<td>5.513</td>
<td>48.100</td>
<td>5.078</td>
<td>39.41</td>
</tr>
<tr>
<td>Error (%)</td>
<td>0.22</td>
<td>0.47</td>
<td>0.14</td>
<td>0.8</td>
<td>0.58</td>
</tr>
<tr>
<td>Kaneka Experimental</td>
<td>97.566</td>
<td>2.330</td>
<td>62.38</td>
<td>2.012</td>
<td>48.49</td>
</tr>
<tr>
<td>Kaneka GWO</td>
<td>99.228</td>
<td>2.398</td>
<td>62.40</td>
<td>2.037</td>
<td>48.67</td>
</tr>
<tr>
<td>Error (%)</td>
<td>1.71</td>
<td>2.94</td>
<td>0.03</td>
<td>1.32</td>
<td>0.37</td>
</tr>
<tr>
<td>Solar frontier Experimental</td>
<td>128.13</td>
<td>1.896</td>
<td>100.41</td>
<td>1.648</td>
<td>77.75</td>
</tr>
<tr>
<td>Solar frontier GWO</td>
<td>130.25</td>
<td>1.953</td>
<td>100.40</td>
<td>1.664</td>
<td>78.27</td>
</tr>
<tr>
<td>Error (%)</td>
<td>1.65</td>
<td>3.1</td>
<td>0.01</td>
<td>0.97</td>
<td>0.66</td>
</tr>
</tbody>
</table>

The power-voltage and current-voltage curves are shown in Fig 6a and Fig 6b respectively.

Fig. 6a. Estimated and experimental current-voltage curves of photovoltaic module at irradiance=960W/m² and temperature=67°C

Fig. 6b. Estimated and experimental power-voltage curves of photovoltaic module at irradiance=960W/m² and temperature=67°C
GWO data corresponds exactly to the measured values (open circuit, short circuit and maximum power) as presented in these figures. Furthermore, in order to evaluate the suggested extraction technique, a comparative between calculated and experimental data has been evaluated at various values of temperature and brightness of the sun. The results are shown in Table 6.

### Table 6. Computed and experimental electric parameters of photovoltaic modules at irradiance=480W/m² and temperature=25°C

<table>
<thead>
<tr>
<th>Model of PV</th>
<th>Parameter</th>
<th>Pmax (W)</th>
<th>Isc (A)</th>
<th>Voc (V)</th>
<th>Imp (A)</th>
<th>Vmpp (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic</td>
<td>Experimental</td>
<td>130.9</td>
<td>3.229</td>
<td>51.13</td>
<td>3.0279</td>
<td>43.23</td>
</tr>
<tr>
<td>GWO</td>
<td>131.28</td>
<td>3.235</td>
<td>51.20</td>
<td>3.0263</td>
<td>43.35</td>
<td></td>
</tr>
<tr>
<td>Error (%)</td>
<td>0.23</td>
<td>0.18</td>
<td>0.13</td>
<td>0.013</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Kaneka</td>
<td>Experimental</td>
<td>45.648</td>
<td>1.023</td>
<td>67.15</td>
<td>0.8760</td>
<td>52.11</td>
</tr>
<tr>
<td>GWO</td>
<td>46.786</td>
<td>1.049</td>
<td>67.18</td>
<td>0.8930</td>
<td>52.39</td>
<td></td>
</tr>
<tr>
<td>Error (%)</td>
<td>2.49</td>
<td>2.54</td>
<td>0.044</td>
<td>1.94</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Solar frontier</td>
<td>Experimental</td>
<td>66.227</td>
<td>0.894</td>
<td>105.42</td>
<td>0.7940</td>
<td>83.41</td>
</tr>
<tr>
<td>GWO</td>
<td>67.848</td>
<td>0.893</td>
<td>105.44</td>
<td>0.796</td>
<td>85.34</td>
<td></td>
</tr>
<tr>
<td>Error (%)</td>
<td>2.44</td>
<td>0.1</td>
<td>0.018</td>
<td>0.12</td>
<td>2.22</td>
<td></td>
</tr>
</tbody>
</table>

From the Fig. 7 and Fig. 8 it can be noted that the simulated results approve the experimental data accurately. Each point in the simulated power-voltage and current-voltage curves are in agreement with experimental values. This validates the precision of the identification method at various temperature and solar radiation.

**Conclusion**

A new and precise method for solar parameter estimation applying grey wolf algorithm is presented in this paper. The results demonstrate the efficiency and validity of the presented method at different climatic conditions with excellent agreement between computed and the experimental values.

The GWO algorithm has demonstrated has capability to reproduce the curves of the photovoltaic module with a low relative error and identify the solar cell parameters with a high precision.

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