Simple mathematical approach to solar cell/panel behavior based on datasheet information

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ABSTRACT

A new explicit mathematical expression is used to describe the behavior of a photovoltaic device (solar cell/panel), that is, its I-V curve, based on the characteristic points normally included in the manufacturers’ datasheets. This expression consists of two simple equations, one for voltage levels lower than the voltage at the maximum power point, \( V < V_{mp} \), and the other one for voltage levels above this point, \( V > V_{mp} \). The first equation is defined with two of the three characteristic points (short circuit and maximum power points), whereas the second one is defined with the current and voltage levels at maximum power point, the open circuit voltage, and a constant that can be adjusted based on: 1) the best fitting to the data within the bracket \([V_{mp}, V_{oc}]\), or 2) one point within this bracket, or 3) the slope of the I-V curve at the open circuit point, or 4) an estimation of that slope. Results of the solar cell/panel behavior analysis obtained with the proposed methodology, are similar to the ones obtained with the well-known 1-diode/2-resistor equivalent circuit model, in terms of accuracy.

1. Introduction

Within the last decades, the use of photovoltaic devices (solar cells/panels) has been greatly increased as a clean way to obtain energy, or due to its obvious advantages in autonomous systems such as the ones designed for space operations (i.e., satellites, spacecraft).

Today, the most common way to simulate the behavior of such photovoltaic devices is through equivalent circuits. See in Fig. 1 the 1-diode/2-resistor equivalent circuit model of a solar cell/panel whose behavior (that is, the relationship between the output current, \( I \), and the output voltage, \( V \)), is defined by the following implicit equation:

\[
I = I_{pv} - I_{D1} - \frac{V + IR_s}{R_{sh}} = I_{pv} - I_0 \left[ \exp \left( \frac{V + IR_s}{nV_T} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}},
\]

where \( R_s \) and \( R_{sh} \) are the series and shunt resistors, \( I_{D1} \) is the current through the diode, \( I_{pv} \) is the photocurrent delivered by the current source, \( I_0 \) is the saturation current of that diode, \( V_T \) is the thermal voltage (defined as a function of the temperature, the charge of the electron, and the Boltzmann constant), \( a \) is ideality factor of the diode, and \( n \) is the number of series-connected cells in the device. More information on this model can be found at [1,2]. The main problem when using the equivalent circuit consists in the parameter extraction, that is, all of the above parameters need to be correctly estimated in order to obtain a good fitting to the current-voltage I-V curve of the solar cell/panel (an example of this curve is shown in Fig. 1).

There are multiple procedures (analytical, computational) to extract the equivalent circuit parameters depending on the information available in relation to the photovoltaic device. This information can be the I-V curve measured experimentally or, in most cases, the current and voltage levels at the characteristic points which can be found in the manufacturer's datasheets (short circuit current, \( I_{sc} \), maximum power current and voltage, \( I_{mp} \) and \( V_{mp} \), and open circuit voltage, \( V_{oc} \)). In Refs. [3–8] a thorough review of the different methods for fitting the equivalent circuit to the solar cell/panel behavior can be found. The equivalent circuit parameter extraction process is not an immediate task, and even doing it by analytical methods it requires a quite large number of calculations [1,2]. Some efforts have been made in order to ease the parameter extraction procedure, the use of a reduced number of points of the
The approach to the experimental data related to a photovoltaic device is done with different equations depending on the considered bracket. If the first bracket, [0, V_{mp}], is considered, the proposed equation for the power is:

\[
\frac{I}{I_{sc}} = \left[ 1 - \left( \frac{V}{V_{oc}} \right) \right]^{\frac{k}{h \left( \frac{V}{V_{oc}} \right)}}.
\]

As said in the first section, the approach to the experimental data related to a photovoltaic device is done with different equations depending on the considered bracket. If the first bracket, [0, V_{mp}], is considered, the proposed equation for the power is:

\[
\frac{I}{I_{sc}} = \left( \frac{V}{V_{oc}} \right)^{\frac{k}{h \left( \frac{V}{V_{oc}} \right)}}.
\]
\[ P = aV(V^2 - b), \]  

(7)

where \( P \) is the power supplied by the solar cell/panel, \( V \) is the output voltage, and \( a, b \) and \( \xi \) are constants to be adjusted. Three conditions are needed in order to extract the proper values of these constants. In the first place, the value of the power divided by the voltage at the short circuit point has to be equal to the short circuit current, \( I_{sc} \), and therefore:

\[ \lim_{V \to 0} \frac{P}{V} = -ab = I_{sc}, \]  

(8)

then, from the condition at the maximum power point, \( \partial P/\partial V = 0 \), it is possible to derive the following equation:

\[ b = (1 + \xi)\frac{V_{mp}^2}{V_{mp}}, \]  

(9)

where \( V_{mp} \) is the voltage at the maximum power point. Besides, from Equations (7) and (9) and evaluating the maximum power at this point:

\[ P|_{V=V_{mp}} = V_{mp}I_{mp} = -a\xi V_{mp}^{\xi+1}, \]  

(10)

therefore:

\[ a = -\frac{I_{mp}}{\xi V_{mp}}. \]  

(11)

In addition, an expression for constant \( \xi \) can be derived from Equations (8), (9) and (11):

\[ \xi = \frac{I_{mp}}{I_{sc} - I_{mp}}. \]  

(12)

Finally, as both constants \( a \) and \( b \) can be exclusively expressed in relation to the third one, \( \xi \), Equation (7) can be expressed in terms of the characteristic points of the I-V curve:

\[ P = I_{sc}V \left[ 1 - \left(1 - \frac{I_{mp}}{I_{sc}}\right) \frac{V}{V_{mp}} \right]^{\frac{I_{mp}}{I_{sc} - I_{mp}}}. \]  

(13)

Consequently, an expression for the solar cell/panel behavior in the first bracket, which is only dependent on I-V curve characteristic points is obtained.

On the other hand, the proposed equation for the second bracket, \([V_{mp}, V_{oc}]\), is:

\[ P = V_{mp}I_{mp} \left[ 1 - \left( \frac{V}{V_{oc} - V_{mp}} \right)^{\eta} \right] ; \quad \eta > 1, \]  

(14)

where \( V_{oc} \) is the open circuit voltage and \( \eta \) is a constant to be adjusted. The value of constant \( \eta \) can be derived from the slope of the power at the open circuit point, taking into account that:

\[ \frac{\partial P}{\partial V}|_{V=V_{oc}} = \frac{\partial P}{\partial V}|_{V=V_{oc}} \bigg|_{V_{oc}} = -\eta \frac{V_{mp}I_{mp}}{V_{oc} - V_{mp}}, \]  

(15)

which leads to:

\[ \eta_{sl} = -\frac{\partial P}{\partial V}|_{V=V_{oc}} I_{mp} \left( \frac{V_{oc}}{V_{mp}} - 1 \right). \]  

(16)

In the above expression, the slope of the I-V curve can be extracted from the experimental data, or estimated:

1) using the empirical expression defined by Orioli and Gangi [31]:

\[ R_{so} = \frac{\partial P}{\partial V}|_{V=V_{oc}} = C_{S} \frac{V_{oc}}{I_{sc}}, \]  

(17)

with \( C_{S} = 0.11175 \) (based on the photovoltaic panels’ behavior studied by the aforementioned authors), that leads to:

\[ \eta_{est1} = \frac{1}{C_{S} I_{mp}} \left( \frac{V_{oc} - V_{mp}}{V_{oc}} - 1 \right), \]  

(18)

2) or using another interesting estimation of the slope of the I-V curve at the open circuit point derived from the work of Deihimi et al. [32]. Based on this work, the following expression can be assumed:

\[ \frac{\partial P}{\partial V}|_{V=V_{oc}} \approx \left( \frac{I_{sc}}{V_{oc}} \right)^2 \frac{1}{V_{oc}} \frac{\partial I}{\partial V}|_{V=0}, \]  

(19)

which, if the following approach is accepted as reasonable:

\[ \frac{\partial I}{\partial V}|_{V=0} \approx \frac{I_{mp} - I_{sc}}{V_{mp}}, \]  

(20)

leads to the following estimation of \( \eta \):

\[ \eta_{est2} = \frac{I_{sc}}{I_{mp}} \left( \frac{I_{sc}}{I_{sc} - I_{mp}} \right) \left( \frac{V_{oc} - V_{mp}}{V_{oc}} \right). \]  

(21)

Besides, the value of constant \( \eta \) can also be derived from the best fitting to the experimental data from the second bracket \([V_{mp}, V_{oc}]\), in terms of Normalized Root Mean Squared Error (NRMSE), hereinafter referred as \( \varepsilon \):

\[ \varepsilon = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \left( \frac{I_{calc} - I_{j}}{I_{j}} \right)^2}, \]  

(22)

where \( I \) stands for the current at the reference I-V curve, and \( I_{calc} \) stands for the calculated points at the same voltage levels. \( N \) is the number of points from the reference I-V curve within the bracket. Constant \( \eta \) was estimated in the present work with this procedure (i.e., minimizing error \( \varepsilon \)), in order to compare with the results obtained by the other methodologies explained above. The figures obtained by this optimization are denoted as \( \eta_{self} \) hereinafter. Finally, another estimation of \( \eta \) can be obtained with the voltage and current values \( V' \) and \( I' \), at one point within that second bracket:

\[ \eta_{p} = \frac{\ln(V_{mp}I_{mp} - V' I') - \ln(V_{mp}I_{mp})}{\ln(V' - V_{mp}) - \ln(V_{oc} - V_{mp})}. \]  

(23)

From the above equations it is possible to derive a general expression, consisting in two explicit equations, for the output current of a solar cell/panel in relation to the output voltage:
3. Model validation

3.1. Comparison to the 1-diode/2-resistor model

The model validation has been firstly carried out by comparison to the well-known 1-diode/2-resistor equivalent circuit model (i.e., Equation (1)). In order to compare both mathematical expressions, dimensionless variables are used: output current, $i = I/I_{sc}$, and output voltage, $v = V/V_{oc}$. The proposed model is then rewritten as:

$$i = \begin{cases} 
I_{sc} \left[ 1 - \left(1 - \frac{I_{mp}}{I_{sc}} \right) \left( \frac{V}{V_{mp}} \right)^{\frac{I_{mp}}{I_{sc}}} \right] & ; \ V \leq V_{mp} \\
I_{mp} \frac{V}{V} \left[ 1 - \left( \frac{V - V_{mp}}{V_{oc} - V_{mp}} \right)^{\eta} \right] & ; \ V \geq V_{mp} 
\end{cases},$$

(24)

with constant $\eta$ estimated (Equations (18), (21)), calculated if additional information is available (Equation (16) or (23)), or extracted from the best fitting to the $I-V$ curve within the bracket $[V_{mp}, V_{oc}]$.

It should also be mentioned that the above equations have the same slope at the maximum power point, that is:

$$\frac{\partial P}{\partial V} \bigg|_{V=V_{mp}} = \frac{\partial P}{\partial V} \bigg|_{V=V_{mp}} = I_{mp} + \frac{\partial I}{\partial V} \bigg|_{V=V_{mp}} = \frac{\partial I}{\partial V} \bigg|_{V=V_{mp}} = -\frac{I_{mp}}{V_{mp}},$$

(25)

which matches the mathematical equation of the slope of the $I-V$ curve at the maximum power point:

$$\frac{\partial P}{\partial V} \bigg|_{V=V_{mp}} = 0 = \frac{\partial V}{\partial V} \bigg|_{V=V_{mp}} = I_{mp} + \frac{\partial I}{\partial V} \bigg|_{V=V_{mp}} = \frac{\partial I}{\partial V} \bigg|_{V=V_{mp}} = -\frac{I_{mp}}{V_{mp}}.$$

(26)

### Table 1

<table>
<thead>
<tr>
<th>Solar cell/panel</th>
<th>Technology</th>
<th>$I_{sc}$ [A]</th>
<th>$I_{mp}$ [A]</th>
<th>$V_{mp}$ [V]</th>
<th>$V_{oc}$ [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTC France</td>
<td>Si</td>
<td>0.7605</td>
<td>0.6894</td>
<td>0.4507</td>
<td>0.5727</td>
</tr>
<tr>
<td>TNJ Spectrolab</td>
<td>GaInP2/GaAs/Ge</td>
<td>0.5239</td>
<td>0.4960</td>
<td>2.270</td>
<td>2.565</td>
</tr>
<tr>
<td>ZTJ Emcore</td>
<td>InGaP/InGaAs/Ge</td>
<td>0.4628</td>
<td>0.4389</td>
<td>2.410</td>
<td>2.778</td>
</tr>
<tr>
<td>Azur Space 3G30C</td>
<td>GaInP/GaAs/Ge</td>
<td>0.5202</td>
<td>0.5044</td>
<td>2.411</td>
<td>2.70</td>
</tr>
<tr>
<td>Photowatt PWP 201</td>
<td>Si</td>
<td>1.032</td>
<td>0.9255</td>
<td>12.493</td>
<td>16.778</td>
</tr>
<tr>
<td>Kyocera KC200GT-2</td>
<td>St polycrystalline</td>
<td>8.210</td>
<td>7.610</td>
<td>26.30</td>
<td>32.90</td>
</tr>
<tr>
<td>Selex Galileo SPVS X5</td>
<td>GaInP/GaAs/Ge</td>
<td>0.50344</td>
<td>0.48476</td>
<td>12.099</td>
<td>13.575</td>
</tr>
</tbody>
</table>

(3 points and the slope of the $I-V$ curve at one of them), one more condition is required. The slope at open circuit point:

$$r_{so} = -\frac{I_{mp}}{V_{mp}} = -\frac{1}{\frac{V}{V_{mp}}},$$

(29)

can be used, as from the work by Phang et al. [33] it is possible to derive an equation that relates parameters $r_s$ and $\lambda$ with the slope of the non-dimensional $I-V$ curve (hereinafter, the $i-v$ curve):

$$r_s = r_{so} - \lambda \exp \left( \frac{1}{\lambda} \right),$$

(30)

The above expression can be combined with the following ones (from Ref. [2]):

$$\frac{\lambda a(2\beta - 1)}{(\alpha + \beta - 1)(\alpha - \beta r_s) - \lambda(\alpha - \beta)} = \exp \left( \frac{a + \beta r_s - 1}{\lambda} \right),$$

(31)

$$r_{sh} = \frac{(\alpha - \beta r_s)(\alpha - (1 - \beta)r_s - \lambda)}{(\alpha - \beta)(1 - \beta - \lambda \beta)},$$

(32)

$$I_0 = \frac{r_{sh} + r_s - 1}{r_{sh} \exp \left( \frac{1}{\lambda} \right)}.$$  

(33)

![Fig. 2. Non-dimensional output voltage and current levels at maximum power, respectively $\alpha$ and $\beta$, for the different solar cell/panels studied in the present work (see also Table 1).](image-url)
cells/panels of different technologies (four solar cells, two solar circuit point.

i-v curve, as a function of an initial estimation of the slope at open
to obtain the five parameters of expression (28) and, therefore, the
Ipw — 1
decreased by 30% (subcases
rf
one resulting by the present model (that is, r
model calculated in three subcases: the initial slope at open circuit point equal to the
M,
Fig. 4. Difference between the non-dimensional current,
Ai, calculated with open circles. Dashed lines: corresponding
i-v curves calculated with the proposed method at
Fig. 3. Solid lines: i-v curves calculated with the proposed method at a = 0.72, 0.83
and 0.89, and β calculated with Equation (35). The maximum power points are indi
cated with open circles. Dashed lines: corresponding i-v curves calculated with the 1-
diode/2-resistor equivalent circuit model (Equation (28)).

In Table 1, the characteristic points of seven photovoltaic solar
panels, and one solar module for space applications) are included.

The coordinates [α, β] of the maximum power point related to each
one of these photovoltaic devices are shown in Fig. 2. It can be
observed in the figure that the following mathematical expression:

β = 0.8612 − 0.02173 ln(0.9 − α),
(35)
fits these points quite well. Bearing in mind this result, nineteen
different i-v curves were proposed to compare the present model to
the 1-diode/2-resistor equivalent circuit model, its non-
dimensional output voltage level at maximum power, α, ranging
from α = 0.72 to α = 0.895, and the non-dimensional output current
level at maximum power, β, defined with Equation (35).

In Fig. 3, three i-v curves calculated with the proposed model
(Equation (27)) with α = 0.72, 0.83 and 0.89, and β based on
Equation (35) are shown (solid lines). The corresponding curves
based on the 1-diode/2-resistor equivalent circuit model are also
shown (dashed lines), the value of r_{so} in each of these three cases
being based on the slope from the curves obtained with the pro-
posed method. In the graph, the differences between both models
can be appreciated. If the initial values given to r_{so} (r_{so} = 0.1414
(a = 0.72), 0.09787 (a = 0.83), and 0.04385 (a = 0.89)) are
compared to the ones calculated with the slope from the resulting
curves after the parameter extraction (r_{so} = 0.2084, 0.1218, and
0.06162, respectively), some limitations on the approximation
proposed for the calculation of r_{so} (Equation (30)) are revealed.

As a consequence, it seems that a better correlation between the
proposed model and the 1-diode/2-resistor equivalent circuit
model could be achieved if the initial values of r_{so} are modified
when calculating the parameters of Equation (28). In Fig. 4, the
differences between the non-dimensional current, Δi, calculated
with both models for the case α = 0.83, with the initial slope at
open circuit point (that is, r_{so} = 0.09787) and this slope increased
and decreased by 30% (subcases r_{so} and r_{so}), are shown. A better
correlation between models is clearly observed in the subcase r_{so},
the slope of the i-v curve calculated with Equation (28), Δi/Δv
= −9.2872, more similar to the one from the proposed model, Δi/Δv
= −10.2173, than the resulting from the curves calculated in the
other two subcases, Δi/Δv = −6.6636 (r_{so}) and Δi/Δv = −8.2131 (r_{so}).
In addition, the root mean squared difference between i-v curves
from the proposed method and the 1-diode/2-resistor equivalent
circuit model:

\[ \sigma = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \Delta i_{j}^{2}}, \]  
(36)

was calculated for the nineteen studied cases within the bracket
a = 0.72 to a = 0.895 (in the above equation N stands for the
number of points that define the aforementioned i-v curves). In
Fig. 5 the results are shown, indicating that i-v curves from the
equivalent circuit model calculated with the increased slope (r_{so})
have better correlation with the proposed method, accordingly to
the result observed for α = 0.83. Furthermore, the correlation be-
tween both models is better from α = 0.83 to α = 0.87, it becoming
worse for α → 0.9.

Some final comments can be added in relation to the series and
shunt resistor values, resulting from the 1-diode/2-resistor equiv-
calent circuit model fitted to the proposed model. First of all, the
shunt resistor does not exist (i.e., r_{sh} → ∞), as the slope of the i-v
curve at i = 0 from the proposed model is zero. This fact makes the
present method equivalent to the well-know 1-diode/1-resistor
model [34]. Secondly, taking into account Equation (30) and
the slope of the proposed method at open circuit point from Equation
(16), it is possible to obtain a simple equation that relates the series
resistor to the α parameter:

\[ i_{pv} = 1 + \frac{r_{s}}{r_{sh}}, \]  
(34)
to obtain the five parameters of expression (28) and, therefore, the
i-v curve, as a function of an initial estimation of the slope at open
circuit point.

In Table 1, the characteristic points of seven photovoltaic solar
cells/panels of different technologies (four solar cells, two solar panels, and one solar module for space applications) are included.
The above equation also relates the series resistor to the ideality factor, \( \alpha \), through the \( \lambda \) parameter; this relationship being already suggested by Araujo and Sanchez for the 1-diode/1-resistor model [35]:

\[
r_s = 2(1 - \psi - \lambda),
\]

where the new parameter \( \psi \) is defined as:

\[
\psi = \int_0^1 \eta \exp \left( -\frac{1}{\lambda} \right) dv.
\]

### 3.2. Validation of the model in relation to experimental data

Once the proposed model has been directly compared to the 1-diode/2-resistor model, revealing in which cases (non-dimensional voltage at maximum power from \( \alpha = 0.83 \) to \( \alpha = 0.87 \)) both models could have a better correlation, the model was used to modeling...
the behavior of the photovoltaic devices included in Table 1, as I-V curves of these solar cells/panels were available.

I-V curves of RTC France solar cell and Photowatt PWP 201 solar panel were obtained from Ref. [36], together with the characteristic points. I-V curves of TNJ Spectrolab and ZTJ Emcore solar cells, and Kyocera KC200GT-2 solar panel were obtained graphically from the manufacturer's datasheet (their characteristic points were also obtained from the datasheets), I-V curve of Azur Space 3G30C solar cells was kindly supplied by the manufacturer, the characteristic points being obtained from the datasheet. Finally, the I-V curve of Selex Galileo SPVS X5 solar module was measured at CIEMAT (Spain), and the characteristic points at testing temperature, $T = 20.12$ °C, were derived from the characteristic points at $T = 28$ °C obtained in the cells manufacturer's datasheet (Azur Space 3G-28%). All this curves will be referred as I-V reference curves hereinafter.

In Figs. 6–8, the reference I-V curves of each photovoltaic device are compared to:

- two I-V curves obtained with the proposed mathematical model (one calculated with the constant $\eta$ that gives the best fitting within the second bracket, $[V_{mp}, V_{oc}]$, and the other one calculated with the constant $\eta$ estimation based on Equation (21)), and
- I-V curve from the 1-diode/2-resistor equivalent circuit model, calculated analytically with the corresponding characteristic points.

Additionally, calculated values of constant $\eta$ used for the present mathematical approach within the second bracket $[V_{mp}, V_{oc}]$, are included in Table 2 for all studied photovoltaic devices. This information reveals the accuracy of the proposed Equation (21) to calculate this constant. The parameters related to the 1-diode/2-resistor equivalent circuit model (Equation (1)) are included in Table 3. The parameter extraction was performed as explained in Ref. [2]. An initial estimation of the ideality factor $a = 1.2$, was modified after a few iterations to obtain a better fitting to the I-V reference curve.

A similar correlation with the reference data of both, the curves based on the proposed methodology and the curve based on the 1-diode/2-resistor equivalent circuit model, can be observed in the graphs related to the I-V curves included in the aforementioned figures. Besides, the difference between the output current calculated with models and the one from the reference data, related to the short circuit current:
Fig. 8. On the left graphs: I-V curves modeled with the present approach and the 1-diode/2-resistor equivalent circuit model fitted to Photowatt PWP 201 (top) and Kyocera KC200GT-2 (middle) solar panels, and Selex Galileo SPVS5 solar module (bottom) reference curves. The reference curves are also included in the graphs (labeled as I-V curve). Due to the large number of points related to Kyocera KC200GT-2 solar panel and Selex Galileo SPVS5 solar module reference curves, these curves are plotted with a solid line and instead with open circles. On the right graphs: differences between the studied models and the reference curves, made non dimensional with the short circuit current (Equation (40)).
with the slope of the calculated with the best fitting, with one point within \([V_{\text{oc}} , V_{\text{mp}}]\). The comparison between the present method and the equivalent circuit method (as they imply a negligible current that leads the principal term of reference curves were calculated with Equation (21)), produce a quite reasonable fitting of the approach to the \(I-V\) curve, with a lower accuracy level when compared to the 1-diode/2-resistor model, but being of the same order of magnitude. Finally, less accurate results are obtained in the second bracket if constant \(\eta\) is calculated with the slope at open point estimated with Equation (17), proposed by Orioli and Gangi \[31\].

The authors are indebted to José Lorenzo Balenzategui, from CIEMAT (Centre de Investigaciones Energéticas, Medioambientales y Tecnológicas), for his friendly and constant support in relation to measurements involving photovoltaic devices and sensors. Authors are also grateful to Azur Space for the kind support. Finally, authors are grateful to the Reviewers for their wise comments, which helped to improve this work.

### 4. Conclusions

In the present work a new explicit mathematical expression is proposed to describe the behavior of a solar cell/panel, based on the three characteristic points of the \(I-V\) curve. The major conclusions resulting from this work are:

- The proposed explicit equations, once properly adjusted, fit the behavior of the panel as well as the 1-diode/2-resistor equivalent circuit model.
- This methodology is simpler than other mathematical methods developed previously by other researchers, as it depends on one constant estimation only.
- A new equation to estimate the slope of the \(I-V\) curve at the open circuit point has also been proposed, with reasonable results for the technologies studied (Si, triple junction).

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The authors are indebted to José Lorenzo Balenzategui, from CIEMAT (Centre de Investigaciones Energéticas, Medioambientales y Tecnológicas), for his friendly and constant support in relation to measurements involving photovoltaic devices and sensors. Authors are also grateful to Azur Space for the kind support. Finally, authors are grateful to the Reviewers for their wise comments, which helped to improve this work.
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