Characterization of degradation and evaluation of model parameters of amorphous silicon photovoltaic modules under outdoor long term exposure

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1. Introduction

The PV (photovoltaic) market continues to grow steadily worldwide. PV systems are replacing conventional energy sources becoming a major source of power generation due to their environment friendly and renewable nature [1].

PV modules are a key element of PV systems and allow conversion of solar energy directly into electrical energy. Several factors influence their performance such as solar irradiance and its spectral distribution [2], mismatches, soiling [3] and operating module temperature [4–7]. Moreover, PV modules tend to degrade after long term outdoor exposure. The degradation rate is mainly associated to the PV module technology and several studies have reported analysis of outdoor performance and degradation of PV modules of different technologies [8–11].

Crystalline silicon (c-Si) and polycrystalline PV modules supply most part of the global photovoltaic energy production with a 90% of the total annual production in 2013, while thin-film (TF) PV modules are in third position with a 10% of market share [12]. TF PV modules use materials such as amorphous silicon (a-Si), CdTe, CIGS (copper indium gallium selenide sulfide) and CIS (copper indium diselenide) among others. The main advantages of TF PV modules are their lower production costs and lower temperature coefficients relative to the c-Si and polycrystalline PV modules. However, TF PV modules present higher degradation rates than polycrystalline and c-Si [9,13]. Recently, the TF a-Si PV modules market share noted a regression probably due to this fact and to their lower module conversion efficiency [12]. Additionally, problems related to the bankability of these technologies still persist.

The a-Si PV modules present LID (light-induced degradation) due to the SWE (Staebler-Wronski effect) [14–17]. The electrical performance degradation of these modules is very important during the initial exposure to outdoor light due to changes in...
photoconductivity and dark conductivity. This effect gradually tends to stabilize at power rates ranging from 10% to 30% of the nominal power of the PV module. However, thermal annealing of the a-Si for several hours at 150 °C reverses these effects [17]. Moreover, a lower temperature annealing also allows recovering the initial performance but takes a longer amount of time [19,20].

Several works have been conducted in attempt to explain the real performance characterization of the a-Si PV modules when deployed outdoors. The degradation rate can be based on the comparison of the monitoring outdoor performance with the initial indoor measurements taken as references [21–24], or by applying LR (Linear Regression) and CSD (Classical Seasonal Decomposition) methods with temperature correction [25,26].

The studies presented in Refs. [22–24] demonstrate that TF hydrogenated single-junction amorphous silicon (a-Si:H) PV modules are degraded mainly by the SWE effect, when compared to other TF technologies. This degradation affects especially the internal parameters of the solar cell as the short circuit current, ideality factor, saturation current and series and shunt resistances [18,27].

Understanding the origin of these degradation modes and how they affect the performance of PV modules is essential to improve the reliability of PV modules, and selecting the best technology for each specific climatic condition. In this paper we analyse the behaviour of TF a_Si PV modules under outdoor long term exposure in Jaén (Spain, Latitude: 37° 47’ 14.35” N, Longitude: 3° 46’ 39.73” W, Altitude: 511 m), a relatively dry and sunny inland site with a Continental-Mediterranean climate. The period under scrutiny ranges from late July 2011 to October 2014.

On the other hand, the variation of main solar cell model parameters is also evaluated by means of parameter extraction techniques. We present a new parameter extraction procedure to obtain main model parameters of the solar cells forming the PV system. The parameter extraction has as input the daily monitored data of the PV system in real operation of work and calculates the temporal evolution of main solar cell model parameters.

The paper is organized as follows: An overview of the degradation analysis methodology and parameter extraction technique followed in the study is given in Section 2. Section 3 describes the PV array used in this study and details of the monitoring system. The results and discussion are presented in Section 4. Finally, the conclusions of the study are given in Section 5.

2. Methodology

2.1. PV array model

The PV array output is based in the well-known “five parameter” model of the solar cell in which the relationship between output current and voltage is given by the following nonlinear implicit equation [28–30]:

\[
I = I_{ph} - I_0 \left( \exp \left( \frac{V + R_s I}{nV_t} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}}
\]

where the five solar cell model parameters are: Photocurrent \(I_{ph}\); diode reverse saturation current \(I_0\); ideality factor \(n\); \(R_s\) and \(R_{sh}\) the series and shunt resistances respectively. \(I\) and \(V\) are the output current and voltage and \(V_t\) is the thermal voltage.

Eq. (1) can also be written as follows,

\[
I = I_{ph} - I_d - I_{sh}
\]

where \(I_d\) and \(I_{sh}\) are the currents across the diode and shunt resistance respectively.

Generally, PV modules are formed by parallel strings of solar cells connected in series. However, at present most PV modules include one single string of solar cells. Therefore, the model of the solar cell can be scaled up to the model of the PV array taking into account the configuration of the PV array: Number of PV modules connected in series by string and the number of parallel strings forming part of the PV array as well as the internal configuration of the PV module.

Several studies based on the simulation of PV systems applying this model were reported in the literature. The simulations were carried out in software environments as: Pspice [30–31], Matlab [34–36], or LabView [37,38] and results obtained were experimentally validated with success. In this study we have used Matlab/Simulink for the simulations and the parameter extraction.

2.2. Parameter extraction technique

One of the objectives of this work is the investigation of the variation of the solar cell model parameters for single junction a-Si PV modules in real conditions of work. Therefore, this study includes parameter extraction technique in order to find the set of solar cell model parameters able to reproduce the actual behaviour of the whole photovoltaic system with a good accuracy degree.

Monitored electrical parameters: Current, voltage and power at the DC output of the PV array together with in-plane irradiance (\(G\)) and cell temperature (\(T_c\)) profiles are needed in order to estimate the set of model parameters of the solar cells forming the PV array.

Considering the number of parallel strings of solar cells present in the PV array, \(N_p\), Eq. (2) becomes:

\[
I = N_p \left( I_{ph} - I_d - I_{sh} \right)
\]

where \(I\) is the DC output current of the PV array.

For any arbitrary value of \(G\) and \(T_c\), the photocurrent, \(I_{ph}\), is given by:

\[
I_{ph} = \frac{G}{G^*} I_{sc} + k_t \left( T_c - T^*_c \right)
\]

where \(G^*\) and \(T^*_c\) are respectively the irradiance and cell temperature at standard test conditions (STC): 1000 W/m² (AM1.5) and 25 °C, \(k_t\) is the temperature coefficient of the current and \(I_{sc}\) is the solar cell short circuit current at STC.

Each one of the strings of the PV array is formed by \(N_s\) solar cells connected in series. The shunt current, \(I_{sh}\), included in Eq. (2) can be calculated from:

\[
I_{sh} = \frac{V}{N_s} + \frac{I R_s}{R_{sh}}
\]

where \(V\) is the Therefore DC output voltage of the PV array.

The diode current, \(I_d\), included in Eq (2) is given by:

\[
I_d = I_0 \left( \frac{e^{V/\left(nV_t\right)}}{e^{V/\left(nV_t\right)} - 1} \right)
\]

where \(I_0\) is the saturation current of the diode.

The saturation current of the diode presents a strong dependence on temperature and it is usually given by:
where $I_{o ref}$ and $V_{ref}$ are the saturation current and thermal voltage at STC, respectively, $E_g$ the energy bandgap of the semiconductor and $E_{go}$ is the energy bandgap at $T = 0 \, K$.

Eq. (7) can also be written, substituting $I_{o ref}$ as a function of the short-circuit current: $I_{sc}$ and open circuit voltage: $V_{oc}$ of the solar cell, as follows:

$$I_o = I_{sc} e^{-\left(\frac{E_{go} V_{ref}}{E_g V_t}\right) \left(\frac{T_c}{T^*_{c}}\right)^3} \left(\frac{T_c}{T^*_{c}}\right)^3 e^{\left(\frac{E_{go} V_{ref}}{E_g V_t}\right) - 1}$$

The value of the energy bandgap of the semiconductor at any cell temperature $T_c$ is given by:

$$E_g = E_{go} - \frac{\alpha_{gap} T_c^2}{\beta_{gap} + T_c}$$

where $\alpha_{gap}$ and $\beta_{gap}$ are fitting parameters characteristic of the semiconductor.

The parameter extraction algorithm evaluates: $I_{ph}$, $R_s$, $R_{sh}$, $I_o$ and $n$ by using Eqs. (4)–(9). Daily profiles of monitored electrical parameters – namely, current and voltage at the DC output of the PV array, together with $G$ and $T_c$ – are used as inputs of the parameter extraction algorithm.

A nonlinear regression algorithm based on the Levenberg–Marquardt method was applied to both data sets: The daily monitored data from the PV array in real conditions of work and simulation results generated by using the described model, in order to minimize the following quadratic function [39,40]:

$$S(\theta) = \sum_{i=1}^{N} (\theta - I(V_i, \theta))^2$$

where $\theta = [I_{ph}, I_o, R_s, R_{sh}, n]$.

The toolbox has been interfaced with Simulink as illustrated in Fig. 1. The result of the parameter extraction algorithm is a set of solar cell model parameters that allow the best approach to the daily evolution of output current and voltage of the PV array.

2.3. Output power of the PV array

The effective peak power of a PV array, $P_m^*$, at STC is given by the following equation [41,42]:

$$P_m^* = \frac{G^* P_{DC}}{1 + \gamma (T_c - T_c^*)}$$

where $P_{DC}$, $G$ and $T_c$ are the DC output power of the PV array, the irradiance and cell temperature respectively, $\gamma$ is the power temperature coefficient of the PV modules and $G^*$ and $T_c^*$ are the irradiance and temperature at STC, respectively.

The power coefficient temperature, $\gamma$, is normally stated in the PV manufacturer’s datasheet. Nevertheless, it can be calculated as follows [6]:

$$\gamma = \frac{1}{P_{max}} \frac{\partial P_{max}}{\partial T}$$

where $P_{max}$ is the maximum power of PV module at STC and the reference temperature is 25 °C.

Outdoor monitoring is subject to continuously changing operating conditions as irradiation, temperature and spectrum. The evaluation of $P_m^*$ requires a previous filtering of irradiance values: $G < 800 \, W/m^2$, in order to avoid the influence of operational anomalies, such as shade on the PV array, inverter saturation, inverter-off, low irradiances, etc [41,42]. So, we eliminated the data where irradiance is too low in our monitoring profiles before the calculation of $P_m^*$ values.

As detailed in the next section, measurements of $G$ are taken by using a pyranometer. However, no spectral effects have been included in eq. (11) as the solar spectrum distribution at in-plane...
irradiance levels above 800 W/m² closely matches that of the AM 1.5G standard reference spectrum in the city of Jaén [43].

3. Experimental

3.1. Climate characterization of the site and PV system description

As commented in Section 1, Jaén is a dry and sunny inland site, with a Continental-Mediterranean climate. In this sense, Table 1 may help provide a succinct climate characterization. The PV system which has provided the necessary experimental support to this work is located in Jaén and it is shortly described below.

The 900-Wp PV field comprises 15 a-Si:H TF PV modules, with 5 parallel-connected strings of 3 series-connected PV modules each ($N_p = 5, N_s = 3$). The main electrical characteristics at STC of this PV field are gathered in Table 2. It is worth noting that the PV modules are fixed to an equator-facing open rack with a tilt angle of $35^\circ$. This tilt angle was intended to maximize the collection of annual on-plane irradiation. This criterion is widely followed when planning PV grid-connected systems, unless constraints such as those imposed by architectural integration may deter the PV project developer from following it. Bearing this in mind, the optimal tilt angle for Madrid (Spain, latitude $40^\circ$) lies precisely at $35^\circ$ [45]. This figure may be assumed for Jaén (Spain, latitude $37^\circ$) with no significant error.

The PV field is connected to a single-phase grid-tied SMA™ Sunny Boy SB1200 inverter. Two SMA™ Sunny SensorBox devices were installed on a metal plate on the same plane as the PV field to measure cell and ambient temperatures together with wind speed. Two Pt 100 resistive thermal detectors (RTD) are used as module temperature sensors being glued to the rear surface of the PV modules. The in-plane irradiance comes from a Kipp & Zonen™ CMP21 pyranometer, which is also installed on a metal plate, coplanar with the PV field. Onsite measurements of DC voltage and current are recorded at the inverter input. Data were taken at 5-min intervals.

4. Results and discussion

4.1. Evolution of the effective peak power of the PV array

The effective peak power of the PV array, $P_m^{\text{eff}}$, and the monthly irradiation, $H$, along the monitoring campaign are shown in Fig. 2. An important initial decrease of $P_m^{\text{eff}}$ can be observed due to the LID phenomenon and then the decrease occurred more slowly. On the other hand, a seasonal variation of $P_m^{\text{eff}}$ is clearly shown in Fig. 2. This seasonal variation in a-Si PV modules behaviour has been described by a number of authors [14,20,24,25]. The initial decrease in output power of the array is followed by an increase over the summer months, a decrease over winter months and once again an increase over summer months. The regeneration on summer months can be attributed to spectral effects [46], to thermal regeneration [17,20,47] and light-induced annealing [22].

The sun’s elevation angle ($\gamma_s$) in degrees at solar noon in Jaén varies from $90^\circ - \Phi - 23^\circ 27' = 28^\circ 46'$ in winter solstices to $90^\circ - \Phi + 23^\circ 45' = 75^\circ 40'$ in summer solstices, where $\Phi$ [$^\circ$] is the latitude. At solar noon, $\gamma_s$ = 52’13’ in autumnal and vernal equinoxes. Regarding the angle of incidence between the rays of the sun and the normal to the surface ($\theta_i$, in $^\circ$) it should be kept in mind that the tested PV array was deployed in the Northern Hemisphere on an equator-facing surface with an inclination ($35^\circ$) angle very close to the latitude ($37^\circ$). Hence, it may be assumed that [48]:

$$\cos \theta_i = \cos \delta \cdot \cos \omega$$  \hspace{1cm} (13)

Where $\delta$ [$^\circ$] is the solar declination and $\omega$ [$^\circ$] is the true solar time. Given that $\omega = 0^\circ$ at noon, $\theta_i$ varies very approximately from 0 (equinoxes) to $23^\circ$ (solstices) in our experimental campaign at this time of the day.

The degradation rate, $R_0$, can be analysed by a linear least square fitting method. This method is applied to the monthly effective peak power of the PV array, $P_m^{\text{eff}}$, calculated by using Eq. (14) and monitored data. Using the trend line, the degradation per year can be calculated by linear regression (LR) as follows [3,25]:

Equation of the trend line:

$$y = mx + c$$  \hspace{1cm} (14)

where $m$ is the slope of line and $c$ is the $y$ intercept, thus the degradation per year: $R_0$(%) can be calculated as follows [3]:

$$R_0 = 100 \frac{12m}{c}$$  \hspace{1cm} (15)

The degradation rate calculated from the trend line is found to be: $-2.30 \pm 0.15$/year. The analytical uncertainty reported along with the degradation rate was determined from the standard errors of the linear fit. The value obtained for $R_0$ is in the range of previous results presented in the literature for a-Si PV modules [9,25]. The highest degradation rates have been reported in Korea and the Mediterranean region [25].

The stabilized power in a-Si PV modules is achieved when the power does not decrease more than 1% in a month [13]. However, the amount of LID phenomenon depends on the distribution of light and temperature at the specific location of the PV array.

In order to analyse the stabilization period of the PV array, a second monitoring data filtering process was carried out following the procedure used in previous reported studies [14]. One point for each month of the monitored data for the tilted irradiance and working PV module temperature in the range of 900 W/m² < $G$ < 905 W/m² and 48.6 °C < $T$ < 54 °C was selected.

Table 1

<table>
<thead>
<tr>
<th>Horizontal irradiation (kWh m⁻²)</th>
<th>Ambient temperature (°C)</th>
<th>Minimum ambient temperature (°C)</th>
<th>Maximum ambient temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Rainfall (mm)</th>
<th>Barometric pressure (hPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2038</td>
<td>16.9</td>
<td>11.4</td>
<td>22.4</td>
<td>63</td>
<td>558</td>
<td>954.1</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Maximum power (W)</th>
<th>Open circuit voltage (V)</th>
<th>Short circuit current (A)</th>
<th>Voltage at maximum power point (V)</th>
<th>Current at maximum power point (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>276</td>
<td>5.95</td>
<td>201</td>
<td>4.50</td>
</tr>
</tbody>
</table>
From the data obtained in the filtering process shown by Fig. 3, the stabilization period was observed to start after 16 months of operation in Jaen. Stabilization periods around 16 months have been also reported for single junction a-Si PV modules under Malaysia’s outdoor exposure [14].

The trend line in Fig. 3 is obtained by sixth polynomial correlation with $R^2$ equal to 0.9575. In the first month, it is observed a strong initial degradation respect to the other monitored months. The DC power was degraded by about 11.2% in the first 70 days. In November 2012 the DC power exhibited a decline by the relative percentage of 18.8% and then is stabilized.

As commented in Section 3.1, the in-plane irradiance was recorded by means of a pyranometer coplanar with the PV field. Values of $G$ ranging from 900 to 905 W/m² correspond to a true solar time interval comprised between $\omega = -30^\circ$ and $\omega = 30^\circ$, when the sun elevation is then higher than that of the rest of the day. Consequently, the impact of the solar elevation on the measurements and the angle of incidence dependence may be neglected.

Fig. 4 shows the set of data after the first 16 months of operation and the trend line for the DC output power of the array obtained by fifth polynomial correlation with $R^2$ equal to 0.88. The stabilized level of DC output power of the array is around 682 W in the range of $G$ and $T_c$ considered in data filtering process. In the following months, it demonstrates a sinusoidal form attributable to the annealing effects. The effect of seasonal oscillation remains after the stabilization period for about 5% variation from the stabilized level of DC power.

4.2. Parameter extraction procedure validation

The parameter extraction algorithm calculates the five model parameters of the solar cell: $I_{ph}$, $R_s$, $R_{sh}$, $I_o$ and $n$ by using Eqs. (4)–(9) described in Section 2.2. The daily monitored data: Output DC current and voltage, irradiance and temperature of the PV array in real conditions of work are used as input data of the algorithm and it is executed until function $S(q)$, given by Eq. (10), is minimized. An average number of 10 iterations are
needed to find the set of solar cell model parameters for an input data set corresponding to one day of real operation of the PV array, the extracted parameters are given in Table 3 below.

Figs. 5 and 6 depict the electrical monitored data recorded during December 23rd, 2011: DC output current and voltage, compared with the simulation results obtained by using the set of solar cell model parameters evaluated by the parameter extraction algorithm. The DC output power of the array is obtained as a product of current and voltage in both real and simulated results and the obtained result is illustrated in Fig. 7. It should be remembered that the PV array located in Jaén (Latitude 37° 45' C) is inclined at 35° from the horizontal plane.

As it can be seen a good agreement is found between simulation results and monitored data. The coefficient of variation of the root mean square errors (CVRMSE) between both data sets are given in Table 4 for the current, voltage and power respectively.

\[
y = -8E-11x^5 + 2E-05x^4 - 1.4506x^3 + 60321x^2 - 1E+09x + 1E+13
\]

\[R^2 = 0.8804\]
4.3. Evolution of solar cell model parameters

The seasonal variation of a-Si PV modules behaviour can be also observed in the evolution of the solar cell model parameters. The monthly average value of each one of the model parameters was calculated for the whole monitoring campaign included in this study.

Fig. 8 shows the evolution of the values obtained for the ideality factor, \( n \), by using the extraction parameter technique. It can be seen that the values of \( n \) show an increase over the winter months, a decrease over the summer months and once again an increase over the winter months.

In summer, a-Si solar cells experience higher temperatures and an improvement occurs in material characteristics. There is an increase in charge carrier lifetime and a reduction in band gap [22,24]. The improvement in carrier lifetime due to a reduction of recombination effects in summer is the main responsible of the evolution of \( n \). As can be seen in Fig. 9, \( n \) is closer to 1 in summer periods. On the other hand in winter periods there is a deterioration of the p–n junction quality as can be seen from the increase in \( n \) due to an increase in recombination current [24]. The maximum seasonal variation of \( n \) observed is of 3.4%.

### Table 3
Extracted solar cell model parameters.

<table>
<thead>
<tr>
<th>Day</th>
<th>( n )</th>
<th>( R_s ) [( \Omega )]</th>
<th>( R_{sh} ) [( \Omega )]</th>
<th>( I_{ph} ) [A]</th>
<th>( I_0 ) [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/12/2011</td>
<td>1.1286</td>
<td>0.0307</td>
<td>7.482</td>
<td>0.999</td>
<td>1.09 ( \times 10^{-15} )</td>
</tr>
</tbody>
</table>

### Table 4
CVRMSE obtained for main output electrical parameters of the PV array.

<table>
<thead>
<tr>
<th>PDC [%]</th>
<th>I [%]</th>
<th>V [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.71</td>
<td>1.71</td>
<td>5.21</td>
</tr>
</tbody>
</table>

![Fig. 8. Average values of \( n \) obtained by using the parameter extraction algorithm.](image1)

![Fig. 9. Trend of the ideality factor, \( n \), over December, January, July and August from 2011 to 2014.](image2)
The variation obtained for the saturation current, $I_0$, given by Fig. 10 shows an opposite trend to the variation of $n$. Eq. (9) gives the variation of the bandgap as a function of temperature. The higher temperatures in summer period decrease the bandgap resulting in a decrease in open-circuit voltage [24]. Temperature has also a strong effect on the variation of the saturation current as shown in Eq. (8). The combination of bandgap reduction and strong increase of temperature in summer periods along with the increase in short circuit current due to LID effect lead to an increase of the saturation current despite the reduction of recombination effects in summer. As can be seen in Fig. 10, $I_0$ varies from values in the order of $10^{-12}$ A to values around $10^{-16}$ in winter periods.

The continuing decrease in short circuit current, $I_{sc}$, throughout the first 16 months of the deployment period can be observed in Fig. 11. After that it shows a more stable trend. However, the seasonal effect on $I_{sc}$ is also clearly shown in Fig. 11, being the predominant factor contributing to the large improvement in output power during summer time. There is an important decrease in AM from winter to summer and a favourable spectral distribution of the solar irradiance during summer especially in the ultraviolet region. The improvement in output current during summer time is due to the effect of solar spectral irradiance and to thermal-recovery of the LID [24,45]. The reduction of $I_{sc}$ in the worst winter months is approximately 83% from the peak value of this parameter in the months of August. The lower temperature in winter also reduces the thermal recovery rate for the a-Si solar cells.

Fig. 12 shows the evolution of the mean monthly value obtained by the parameter extraction algorithm for the shunt resistance, $R_{sh}$, along the monitoring period. There is an average constant decrease of 0.19%/year in $R_{sh}$ values that finally reduces to a 50% of its initial value. The reduction of $R_{sh}$ in TF solar cells under outdoor exposure for long periods of time has been previously reported [18,24]. On the other hand, the evolution of $R_{sh}$ shows the same seasonal trend that the evolution of the output power of the PV array and $I_{sc}$ as expected.
A continuing increase in the value of the series resistance, $R_s$, is found along the monitoring campaign. The values of $R_s$ go from an initial value of 10 mΩ to a final value of 60 mΩ. The seasonal effect is observed again in the trend of $R_s$ that present higher values in winter, with maximum values in the month of December, and reduced values in summer, with minimum values in the month of August. The behaviour of $R_s$ shown by Fig. 13 is in accordance with precious works reported in the literature for TF solar cells [18,24]. Moreover, the reduction of $I_{sc}$ observed in winter is partially due to the increase of $R_s$. Eq. (1) can be particularized in short circuit conditions, $V = 0$, and rewritten as follows:

$$I_{sc} = \frac{I_{ph}}{R_s} - \frac{I_{sc}R_s}{R_{sh}}$$

As can be seen in Eq. (16), the combination of higher values of $R_s$ and lower values of $R_{sh}$ in winter periods results in a decrease of $I_{sc}$. The effect is the opposite in summer periods, where $R_{sh}$ presents higher values while $R_s$ and $I_{sc}$ decrease.

5. Conclusion

The degradation modes of TF single junction a-Si PV modules and how they affect the performance of PV modules in a relatively dry and sunny inland site with a Continental-Mediterranean climate is addressed in this paper. The data used in this study was obtained under outdoor long term exposure of the PV system in Jaén from late July 2011 to October 2014.

A reduction of the DC power of the PV array by about 11.2% was observed in the first 70 days of outdoor deployment. The
stabilization period was observed after start 16 months of operation with a decline of the DC power by the relative percentage of 18.8% and then it is stabilized. However, the effect of seasonal oscillation remains after the stabilization period for about 5% variation from the stabilized level of DC power.

Solar cell parameters identification is also addressed in this paper by using a new parameter extraction technique. The sets of solar cell model parameters obtained by using the parameter extraction technique are able to reproduce the behaviour of the PV array in real conditions of work with a good accuracy degree. The parameter extraction technique is able to evaluate the temporal evolution of main solar cell model parameters and helps to understand the evolution of the entire system at PV module level. The seasonal variation of a-Si PV modules behaviour was also observed in the evolution of the solar cell model parameters. The evolution of each one of the model parameters along the outdoor long term exposure of the PV system has been analysed and allows achieving a better understanding of the performance changes of the PV modules and the evolution of the output power of the PV array.

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