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Intensity dependency of photovoltaic cell parameters under high illumination conditions: An analysis

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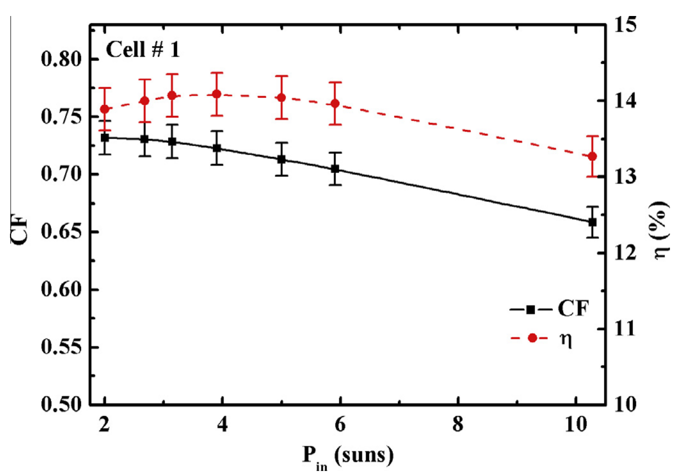
HIGHLIGHTS

- Dependency of PV cell parameters on P_{in} has been investigated under high illumination condition.
- The PV cell parameters analytically determined using single J–V curve.
- The analytically predicted values of R_{sh} and R_s decreased with increases of P_{in}.
- However, n and J_0 increased with increasing P_{in}.
- Theoretical values of parameters matched excellently with the experimental values.

GRAPHICAL ABSTRACT

The dependency on P_{in} of PV cell parameters of Si solar cells with various structures has been investigated. The analytically-predicted values of R_{sh} and R_s decreased with increases of P_{in}. The decrease of R_{sh} may be due to light induced degradation of the PV cells. The reduction in R_s values may be due to an increase of conductivity of the active region. However, n and J_0 increased with increasing P_{in}. The rate change of all the PV cell parameters was higher at lower P_{in} values than at the higher P_{in} values. The theoretically computed values of the open circuit voltage V_{oc}, curve factor CF and efficiency η using this method showed good agreement with the experimentally measured values at various P_{in}. The performance of PV systems depends on the product of the J_{sc}, V_{oc} and CF. Thus, it is important to find the optimal value of P_{in} to get the maximum output power (minimum losses due to R_{sh}, R_s, n and J_0) from a PV system. By doing so, the cost per peak watt of solar energy can be reduced to a minimal value by enhancing the performance of the PV systems.



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ABSTRACT

Previously, an analytical method was developed to extract the photovoltaic (PV) cell parameters, such as the shunt resistance, R_{sh}, series resistance, R_s, diode ideality factor, n, and reverse saturation current density, J_0, through the use of the single current density–voltage (J–V) characteristics under high illumination conditions. Accurate knowledge of the PV cell parameters under different illumination conditions is of vital importance to PV design and performance. Although several attempts have been made to examine

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the dependency of the PV cell parameters on the illumination intensity P_{in}, there are no reports on the dependence of the PV cell parameters on P_{in} under high illumination conditions. In this regards, dependency of the analytically-predicted PV cell parameters on P_{in} of Si solar cells with various structures has been investigated. The analytically-predicted values of R_{sh} and R_s decreased with increasing P_{in}. The rate of change in R_{sh}, however, was higher than that of R_s. The decrease in R_{sh} may be due to light induced degradation of PV cells. The decrease in R_s values might be due to an increase in the conductivity of the active region. On the other hand, n and J_0 increased with increasing P_{in}. This increase in n and J_0 might have a savior effect, reducing the curve factor *CF* and hence the performance of the PV cell. The rate change in all PV cell parameters was higher at lower P_{in} values than at the higher P_{in} values. The theoretically computed values of the open circuit voltage V_{oc}, curve factor *CF* and efficiency η using this method showed good agreement with the experimentally measured values at various P_{in}.

The performance of the PV systems is dependent on the product of the J_{sc}, V_{oc} and *CF*. Therefore, it is important to determine the optimal value of P_{in} to achieve the maximum output power (minimum losses due to R_{sh}, R_s, n and J_0) from a PV system. By doing so, the cost per peak watt of solar energy can be minimized by enhancing the performance of PV systems.

1. Introduction

Photovoltaic (PV) technology can affect two important issues, i.e., fulfilling human energy needs and reducing global warming. The generation of PV energy is envisaged as an efficient, natural, clean, and valuable energy source for both outdoor and indoor applications [1]. The cost of energy using this technology can be reduced using concentrated sunlight. Focusing sunlight using optical elements reduces the cost of PV materials and processing because it can increase the incident illumination intensity (P_{in}) while illuminating a smaller area of solar cells [2]. Concentrated solar cells have an important role in reducing the cost of solar energy by replacing expensive cell materials with cheaper optical devices [3]. Despite this, reliable knowledge of the performance of different PV system under actual operating conditions is essential for accurate predictions of electricity production [4]. Therefore, a study of the performance of PV under high illumination conditions is very important for evaluating the cell performance and the cost of solar energy.

Several studies have used PV/thermal hybrid solar systems, which are combination of a PV and solar thermal components/system [1,5,6], to obtain more energy. The PV/thermal hybrid system produces both electricity and heat from a single integrated component or system [5]. In this system, PV is also used as a part of the thermal absorber.

Generally, the performance of a PV cell is represented by the performance parameters, such as the short circuit current density (J_{sc}), open circuit voltage (V_{oc}), curve factor (*CF*), and efficiency (η) [7]. The value of η depends on these three performance parameters (J_{sc}, V_{oc} and *CF*) as well as P_{in}, and is defined using the following equation:

$$\eta = \frac{J_{sc} \cdot V_{oc} \cdot CF}{P_{in}} \tag{1}$$

Eq. (1) shows that J_{sc} does not affect the η value of the cell because J_{sc} and P_{in} increase linearly with increasing incident power of sunlight. On the other hand, V_{oc} increases logarithmically with increasing P_{in}, which enhances the η value of the cell.

The current–voltage (*I–V*) characteristics provide the most information on the performance of a photovoltaic cell, and are governed by the diode (PV cell) parameters of the solar cells. The PV cell parameters of solar cells are defined as the shunt resistance (R_{sh}), series resistance (R_s), diode ideality factor (n), and reverse saturation current density (J_0). The V_{oc} value basically depends on R_{sh}, n and J_0. The values of both n and J_0 provide information about charge recombination in the bulk, space charge region and at the surface of the cell. The V_{oc} and *CF* values, however, are strongly affected by n and J_0. The V_{oc} value decreases with increasing J_0. A higher n value gives a higher V_{oc} value but a lower *CF* value.

Several analytical methods have been reported to extract one or more diode parameters [2,8–22] using one [2,9,12,13,20–22], two [14] or many [8,10,15,19] *I–V* characteristics. Some researchers extracted the photovoltaic cell parameters by curve fitting or numerical methods using the single *I–V* characteristics [11,23–27]. Previously, Chan et al. [21] reported that the PV cell parameters extracted by analytical methods are more accurate than those extracted by curve fitting or numerical methods. Generally, under normal illumination conditions, analytical methods based on multiple *I–V* characteristics will determine more accurately the values of the PV cell parameters than other methods [28]. In this method [19], it was assumed the all four PV cell parameters are constant in a small span of P_{in}. The slopes of the *I–V* curve at short and open circuits, the short circuit current, and the open circuit voltage at different illumination levels have been used to extract the PV cell parameters of solar cells [19]. This method, however, provides only one set of PV cell parameters in a small span of illumination intensities [28], whereas the methods that employ a single *I–V* curve provide more sets [28]. At normal intensity, the slope at the open circuit is changed sufficiently with a small change in illumination intensity but at high illumination levels, the slope variation at the open circuit is too small to differentiate. Therefore, the methods based on multiple *I–V* curves failed to extract the PV cell parameters under high illumination conditions [2].

The analytical methods currently used are based on either single or double exponential models. At a low P_{in} value (<50 mW/cm^2), methods based on the double exponential model are more effective than methods based on the single diode model. This is because at very low P_{in} values, recombination in the space charge region is dominated by the total recombination in the bulk region and at the surface of the cell. On the other hand, under normal illumination conditions ($P_{in} \approx 1$ sun), the recombination in the space charge region becomes negligible compared to recombination in the bulk region and at the surface of the PV cells [7]. Therefore, under high illumination conditions (P_{in} value more than 1 sun), methods based on the single exponential model have similar applicability to methods based on the double exponential model.

Analytical methods that use the single *I–V* characteristics can extract the PV cell parameters accurately only under high illumination conditions [29]. Therefore, methods based on the single exponential model that use single *I–V* characteristics are applicable to the extraction of the accurate PV cell parameters under high illumination conditions [29]. In a previous study [2], an analytical method based on the single exponential model that uses single current density–voltage (*J–V*) characteristics was developed to