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An experimental analysis of illumination intensity and temperature dependency of photovoltaic cell parameters

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HIGHLIGHTS

- R_{sh} is rather sensitive to the variations in T_c.
- For higher G values, G^* is not affected from the variations in light intensity.
- Ideality factor decreases linearly with increasing T_c.
- A linear decrease of R_s and R_{sh} has been observed with increasing T_c.
- Fill factor increases exponentially with G while it decreases linearly with T_c.

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ABSTRACT

It is well known that accurate knowledge of photovoltaic cell parameters from the measured current–voltage characteristics is of vital importance for the quality control and the performance assessment of photovoltaic cells/modules. Although many attempts have been made so far for a thorough analysis of cell parameters, there are still significant discrepancies between the previously published results. In this regard, a detailed investigation of cell parameters through a comprehensive experimental and statistical work is important to elucidate the aforementioned contradictions. Therefore in the present work, effects of two main environmental factors on performance parameters of mono-crystalline and poly-crystalline silicon photovoltaic modules have been experimentally investigated. The experiments have been carried out under a calibrated solar simulator for various intensity levels and cell temperatures in the range 200–500 W/m^2 and 15–60 °C, respectively. The results indicated that light intensity has a dominant effect on current parameters. Photocurrent, short circuit current and maximum current increase linearly with increasing intensity level. A new term, solar intensity coefficient, has been defined first time to characterize the solar radiation dependency of current parameters. On the other hand, it has been observed that cell temperature has a dramatic effect on voltage parameters. Open circuit voltage and maximum voltage considerably decrease with increasing cell temperature. Temperature coefficients of voltage parameters have been calculated for each case. Shunt resistance has also been found to be rather sensitive to the variations in cell temperature. Shunt conductance of photovoltaic modules has almost remained constant as light intensity level changed. A linear decrease of series resistance has been observed with increasing cell temperature. Thermodynamic performance assessment of photovoltaic modules has also been done in the study.

1. Introduction

Solar energy is regarded as one of the most promising renewable energy technologies since it provides an unlimited, clean and environmentally friendly energy [1–6]. Renewable technologies based on solar power include solar heating, solar photovoltaics, solar thermal electricity and solar architecture which can make considerable contributions to solving some of the most urgent problems the world now faces such as climate change, energy security, and universal access to modern energy services [7]. Within a variety of solar energy applications in progress, photovoltaics (PVs) draw attention with its rapidly developing technology and remarkable potential to meet the energy demands of the world in the upcoming future. Conversion of sunlight directly into electricity by PV cells is also a key item for environmental issues. As reported by Cuce and Cuce [3], PVs

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Nomenclature

a, *b*, *c*	model constants	*c*	cell
G	illumination intensity (W/m^2)	ds	diode saturation
G^*	conductance (Ω^{-1})	en	energy
I	current (ampere, A)	ex	exergy
k	Boltzmann constant (1.381×10^{-23} J/K)	*m*	maximum
n	ideality factor	mpp	maximum power point
P	power (watt, W)	oc	open circuit
q	electronic charge (1.602×10^{-19} Coulomb)	pc	power conversion
R	resistance (ohm, Ω)	ph	photo
T	temperature (°C)	*s*	series
V	voltage (volt, V)	sc	short circuit
		sh	shunt
Greek letters		voc	open circuit voltage
β	inverse thermal voltage ($=q/kT$)	vm	maximum voltage
δ	temperature coefficient (V/°C)		
η	efficiency	*Abbreviations*	
μ	solar intensity coefficient (Am^2/W)	CF	curve factor
		FF	fill factor
Subscripts		PVs	photovoltaics
amb	ambient		

notably contribute to the CO_2 emission reduction. Moreover, PV systems are silent and free of moving parts. Therefore, operation and maintenance costs of these systems are very low. The most challenging point of PVs may be considered the high upfront investment cost and intensive efforts are made to reduce the cost per peak power obtained from PV cells. These efforts aim at narrowing the gap between PV and conventional power sources. Besides the importance of developing new manufacturing processes related to PVs, it is quite significant to provide the most appropriate operating condition for a PV system [1]. Performance parameters of a PV module strongly depend on the environmental parameters such as temperature, illumination intensity level and wind speed. An accurate knowledge of these parameters is of vital importance for the quality control and the performance evaluations of PV modules. Several methods are proposed for extracting the performance parameters that describe the nonlinear electrical model of PVs [8–12].

The steady state current–voltage (*I–V*) characteristics of a p–n junction silicon PV cell are often described based on one diode model as given in Eq. (1) [13–16]. PV cell equation consists of five parameters called light generated current (I_{ph}), reverse saturation current (I_o), diode ideality factor (n), series resistance (R_s) and shunt resistance (R_{sh}). These cell parameters have a dominant impact on the shape of *I–V* characteristics of a PV cell at any given illumination intensity and cell temperature and thus decide the values of the performance parameters such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), curve factor (CF) and efficiency (η) of the PV cell [13].

$$I = I_{ph} - I_o\left[\exp\left(\frac{\beta}{n}(V + IR_s)\right) - 1\right] - G^*(V + IR_s) \quad (1)$$

In Eq. (1), $\beta = q/kT$ is the usual inverse thermal voltage and $G^* = 1/R_{sh}$ is the shunt conductance. In recent years, several attempts have been made to investigate the dependency of PV cell parameters to main environmental factors, viz. the light intensity, ambient temperature and wind speed. It has been underlined by many researchers that the values of performance parameters change significantly as the illumination intensity level changes [17–20]. Similarly, cell temperature is of vital importance for performance of PV cells and thus temperature dependence of performance parameters and energy conversion in PV cells has been investigated by many authors [21–26,28–30,47–59]. Recently Cuce and Cuce [3] have presented a novel model for PV modules to estimate performance parameters and to perform a thermodynamic assessment. A simple one-diode model has been proposed to estimate the electrical parameters of PV modules considering the series resistance and shunt conductance. The model results have been compared with the manufacturer's data report and an excellent agreement has been observed. Despite the theoretical, numerical and limited experimental attempts for parameter extraction of PV cells, a comprehensive experimental and statistical analysis has not been conducted up to now.

In the present work, a detailed experimental and statistical analysis has been carried out to analyse light intensity and temperature dependency of silicon PV module parameters. Most silicon PV modules are designed to work under standard test conditions that correspond to $G = 1000$ W/m^2, $T_c = 25$ °C and AM = 1.5. However, as reported by previous studies, illumination intensity, cell temperature and wind speed always vary with time under real operating conditions and these environmental factors play a significant role on performance characteristics of PV modules. Therefore, an accurate knowledge of interaction between environmental factors and PV module parameters is crucial.

2. Experimental study

The experimental setup devised in the present work consists of a solar simulator, a control room (darkroom) and measurement devices.

2.1. Solar simulator

A solar simulator was manufactured in order to carry out the experiments under any constant illumination intensity. It is well-documented in literature that the xenon lamps are very efficient to simulate the solar spectrum. However, they are very expensive compared to the alternative light sources like halogen lamps. Hence in this study, a halogen lamp based solar simulator was