Electrical Power and Energy Systems 61 (2014) 101–110

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Effect of varying concentration and temperature on steady and dynamic parameters of low concentration photovoltaic energy system

Pankaj Yadav [a], Brijesh Tripathi [a,b], Kavita Pandey [a], Manoj Kumar [b,*]

[a] School of Solar Energy, Pandit Deendayal Petroleum University, Gandhinagar 382007, India
[b] School of Technology, Pandit Deendayal Petroleum University, Gandhinagar 382007, India

ARTICLE INFO

Article history:
Received 6 June 2013
Received in revised form 14 March 2014
Accepted 18 March 2014

Keywords:
Low-concentration photovoltaic (LCPV) system
Concentration photovoltaic (CPV)
Dynamic resistance
Silicon solar PV module

ABSTRACT

Low-concentration photovoltaic (LCPV) system has huge potential for further cost reduction of solar photovoltaic (PV) power as compared to flat panel PV. The dependence of steady state and dynamic parameters on concentration and temperature is crucial to extract maximum power from solar photovoltaic system. This article aims to present the effect of varying concentration and temperature on steady state and dynamic parameters of LCPV system under actual test conditions (ATC). The rate of change in I_{SC} with solar irradiation i.e., dI_{SC}/dG is found as 0.25 A/W assuming ≈±1 °C change in module temperature. The effect of temperature on inherent material properties responsible for photo-conversion efficiency is studied using impedance spectroscopy technique. A linear response of series resistance of LCPV module is observed with respect to change in module temperature, i.e. dR_S/dT from 297 to 333 K is in the range of 1.15–1.20 Ω with a rate of 1 mΩ/K. From real-time analysis of LCPV system open-circuit voltage found decreasing from 21 to 20.6 V with temperature coefficient of voltage ≈−0.061 V/K. The dynamic resistance has a positive coefficient of module temperature i.e., dr_d/dT given by 0.49 Ω/K.

Introduction

In recent years, an increased awareness to reduce global warming drives many countries around the world to encourage renewable energy applications. In this scenario solar energy has emerged as a promising resource of clean energy alternative to non-renewable energy resources. Solar energy is probably the strongest-growing electricity generating technology, demonstrating recent annual growth rates of around 23% and worldwide production of 32.34 GW in 2012 consisting of both grid connected and off grid remote power supplies [1]. The global investment in the market of photovoltaic modules has increased 20 times over the past decade [2]. Besides playing the significant role in the future energy blend, photovoltaic (PV) generation is significantly contributing to the environmental impact of electricity supply. Solar energy is effectively utilized in two ways, i.e., either by using it directly for heating or cooling of air and water without using an intermediate electric circuitry (i.e. solar thermal), or by converting it into electrical energy by using solar PV modules. Direct conversion of solar radiation into electrical energy is the most suitable way of utilizing solar energy. Among the various PV technologies, Si is one of the widely used semiconductors for the fabrication of solar cell. About 80–90% of PV cells manufactured worldwide are Si wafer based solar cells. The price of electricity generated from solar cell is quite high as compared with the conventional electricity price. Further cost reduction of the solar cell is possible by using thin c-Si wafers [3], thin film c-Si [4], Si in the form of ribbon [5,6], and concentrator Si solar cell [7,8]. In last decade price of silicon based solar module is reduced by a factor of 1/5 making it more relevant to develop low-concentration photovoltaic's using these cells.

Concentrator photovoltaic (CPV) technologies are usually classified according to its concentration ratio, i.e., low, medium and high concentration systems [9,10]. The major hindrance in medium and high concentration is as follows:

(A) The cell temperature increases with increase in concentration of light and being a semiconductor material it has negative temperature coefficient of open-circuit voltage. As a result the solar cell losses its efficiency.
(B) Concentrating system uses direct sunlight, so they require an accurate Sun tracking system. With the increase in concentration a high precision in tracking and optics is required [8].

* Corresponding author. Tel.: +91 79 2327 5428; fax: +91 79 2327 5030.
E-mail address: manoj.kumar@sse.pdpu.ac.in (M. Kumar).

http://dx.doi.org/10.1016/j.ijepes.2014.03.016
0142-0615/

Nomenclature

T_C	working temperature of solar cell (K)	I_S	cell saturation or dark current
R_{SH}	shunt resistance	q	electron charge (1.6×10^{-19} C)
R_S	series resistance	A	ideality factor
N_S	series number of cells in a PV module	V_{OC}	open-circuit voltage
N_P	parallel number of modules for a PV array	r_d	dynamic resistance
I_{SC}	cell's short-circuit current at 25 °C and 1 kW/m^2	R_d	diffusion resistance
K_I	cell's short-circuit current temperature coefficient	C_t	transition layer capacitance
T_{Ref}	cell's reference temperature	C_d	diffusion capacitance
λ	solar insolation in kW/m^2	MPP	maximum power point
r	reflection coefficient of mirror	P_{MAX}	maximum power
I_{RS}	cell's reverse saturation current at a reference temperature and solar radiation	CR	concentration ratio
E_g	band-gap energy of the semiconductor used in the cell	FF	fill factor

Low concentration photovoltaic (LCPV) systems with concentration ratio below 10 Suns present following advantages:

(A) LCPV systems can make use of conventional high performance silicon solar cells (made for 1 Sun application [11]).
(B) LCPV systems are less demanding in terms of tracking accuracy as compared to high concentration systems [12].

Recently, there has been a renewed interest in the low concentration Si solar PV systems. In this technology the commercial Si solar cell is used under the concentration of 2 Suns to 10 Suns. The improvement in performance is obtained by reducing the series resistance of the solar cell by using commercial techniques like electro-deposition of front metal contacts with Ag [4]. A lot of work has been done in designing and analysis of the low concentration photovoltaic system (LCPV) [13–20]. An industrialization potential of silicon based concentrator photovoltaic system with an estimated cost of \$0.5/W_p is reported by Castro et al. [18], where the group uses back contact solar cells under 100 Suns. A detailed review of modeling in relation to low-concentration solar concentrating photovoltaic is presented by Zahedi [13]. Li et al. have studied the performance of solar cell array based on a trough concentrating photovoltaic/thermal system [19]. Recently, Schuetz et al. [20] have reported design and construction of $\sim 7\times$ low-concentration CPV system based on compound parabolic concentrators.

The solar PV module exhibits non-linear voltage current-characteristics which vary with module temperature and solar radiation. For practical purposes it is assumed that the power delivered by solar PV module connected to maximum power point tracking (MPPT) system is always maximum [21]. Under concentration conditions it becomes difficult to track maximum power point due to extended effect offered by small variation in sunlight. The continuous variation in solar PV module output under actual test conditions (ATC) leads to improper tracking of maximum power point (MPP) [22]. In this situation it is important to analyze static and dynamic parameters of solar PV module accurately for designing better MPP tracker. Very few reports exist in literature on the estimation of dynamic parameters of a PV system [23–26] and there is no report on the real-time effect of temperature and solar radiation on dynamic resistance for a LCPV system in our knowledge. We have recently reported an experimental method to calculate static and dynamic parameters of LCPV module [17]. Present work is an extension and further generalization of the method, focusing particularly on the relative effect of solar radiation and module temperature on the dynamic parameters of LCPV system under real-time conditions.

Performance prediction model

Solar PV module is an integral part of solar power generation system. A solar PV module is made of series connected solar cells. Solar cell is basically a semiconductor p-n junction device fabricated using a thin wafer or layers of p-type and n-type semiconductor material. The solar radiation is directly converted into electricity through solar photovoltaic effect exhibited by the p-n junction. When a solar PV module is exposed to solar radiation, it shows non-linear current–voltage characteristics. The output current–voltage characteristic of solar PV module is mainly influenced by the solar insolation and cell temperature. There exist many mathematical models used for computer simulation, which describe the effect of solar insolation and cell temperature on output current–voltage characteristics of solar PV module [27–29]. A generalized model for LCPV solar system, using MATLAB/Simulink is reported model here, which is used to predict expected I–V of LCPV system under ATC.

A crystalline silicon wafer-based solar photovoltaic (PV) cell of size 156 mm $\times$ 156 mm typically produces around 3.8 W at a voltage of 560 mV. These cells are connected in series and/or parallel configuration on a module to produce required power. The equivalent circuit for solar PV module, having N_P numbers of cells arranged in parallel and N_S number of cells arranged in series, is shown in Fig. 1.

The terminal equation for current and voltage of the solar PV array is mentioned below as described by many groups [30–33]:

$$I = N_P I_{PH} - N_P I_S \left[\exp\left(\frac{q\left(\frac{V}{N_S} + \frac{IR_S}{N_P}\right)}{k_B T_C A} \right) - 1 \right] - \left(\frac{N_P V}{N_S} + IR_S \right) \Big/ R_{SH} \quad (1)$$

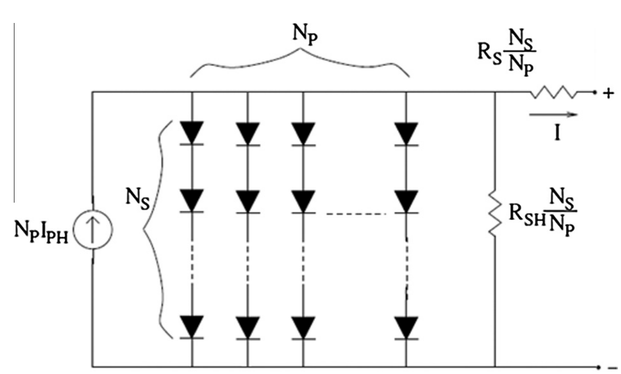

Fig. 1. The general model for LCPV module.