Energy 116 (2016) 716–734

Contents lists available at ScienceDirect

Energy

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

Detailed performance analysis of realistic solar photovoltaic systems at extensive climatic conditions

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ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
18 July 2016
Accepted 4 October 2016

Keywords:
Solar PV system
Double diode PV system
Climatic conditions
Green energy

ABSTRACT

In recent years, solar energy has been considered as one of the principle renewable energy source for electric power generation. In this paper, single diode photovoltaic (PV) system and double/bypass diode based PV system are designed in MATLAB/Simulink environment based on their mathematical modeling and are validated with a commercially available solar panel. The novelty of the paper is to include the effect of climatic conditions i.e. variable irradiation level, wind speed, temperature, humidity level and dust accumulation in the modeling of both the PV systems to represent a realistic PV system. The comprehensive investigations are made on both the modeled PV systems. The obtained results show the satisfactory performance for realistic models of the PV system. Furthermore, an in depth comparative analysis is carried out for both PV systems.

1. Introduction

The demand of electrical energy has increased all over the world due to its various advantageous features. Various alternative green energy sources such as solar energy, wind energy, biomass, small-hydro power generation are gaining popularity to bridge the energy gap and environment concerns [1,2].

A PV cell directly converts solar energy into electric power. A PV module consists of a group of interconnected PV cells connected in series and parallel combinations. An equivalent circuit model is generally used to study the PV cell behavior under different climatic conditions. In Ref. [3] the main PV model parameters such as photocurrent, saturation currents, series resistance, shunt resistance and curve fitting factor are accurately estimated.

PV array simulation models are developed based on circuit equations of a solar PV cell. In Ref. [4] a study of bypass diodes configuration on PV modules, working under partially shadowed condition in Pspice environment is presented. Simulation results are validated with a commercially available PV module Siliken SLK60P6L (209 Wp). In Ref. [5] two different simulation models of PV cell are developed in MATLAB/Simulink environment. Both the PV cell models are compared on the basis of their P–V and I–V characteristics and are also validated with a commercially available PV panel. Realistic modeling and simulation of the PV system-converter interface is presented in Ref. [6]. The authors have discussed the main problems and their existing solutions regarding PV cell modeling. The dynamic model of a PV cell is required to get a realistic picture of its operating conditions. In Ref. [7] a dynamic model of PV system based power generating unit based on experimental data is presented. The authors in Ref. [8] have proposed to develop a building cluster emulator for building operation optimization and simulation of realistic energy behaviors of a cluster of buildings and their energy generation and storage devices. In Ref. [9] critical areas related to building energy modeling and application of building energy modeling methods have been reported. Authors in Refs. [3–9] have discussed different types of PV cell i.e. single diode photovoltaic (SDPV) and double/bypass diode photovoltaic (DDPV) cells. But the detailed and combined effects of all key climatic conditions on the performance of PV cell are not reported to the best of author's knowledge.

With the motivation of above literature review, research addition of this paper is to present a mathematical relationship of the key climatic conditions such as irradiation level, wind speed, temperature, humidity and dust accumulation on the PV cell using the experimental data. The proposed relationships between the climatic conditions and PV cell output parameters are then integrated with the modeling of SDPV and DDPV cells to develop realistic models of PV cells. Furthermore, an in depth comparative analysis of the modeled PV cells is performed.

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http://dx.doi.org/10.1016/j.energy.2016.10.014
0360-5442/

2. System description

The complete system can be divide into two main parts (a) Solar photovoltaic power source (i) SDPV system (ii) DDPV system (b) Key climatic conditions (i) Standard conditions (ii) Realistic conditions. The schematic diagram of complete system is shown in Fig. 1 as,

Mathematical modeling of PV system

2.1. SDPV system

The P–V and I–V characteristics of an SDPV cell are non-linear in nature. Its most referred equivalent circuit model is shown in Fig. 2. The related expression is given in Eq. (1). As shown in Fig. 2, I_{ph} stands for generated photovoltaic current, I_D is the diode reverse saturation current, I_C is the cell current and R_s is the series resistance.

The PV cell voltage (V_C) is a function of photocurrent that is mainly determined by the load current and the solar cell operating temperature (T_C) as [7],

$$V_C = \frac{AKT_C}{e}\ln\left(\frac{I_{ph}+I_D-I_c}{I_D}\right) - (I_c \times R_s) \quad (1)$$

2.2. DDPV system

The DDPV model is also called seven parameter PV model. An equivalent circuit model of a DDPV system is shown in Fig. 3. The related expression is shown in Eq. (2). Here, I_{D1} and I_{D2} are the diode reverse saturation currents. R_s and R_p are the series and shunt resistances respectively.

The output voltage of a DDPV cell is expressed as,

$$V_c = \frac{AkT_C}{e}\ln\left(\frac{I_{ph}+I_{D1}+I_{D2}-I_C}{I_{D1}+I_{D2}}\right) - I_C\left(\frac{R_s \times R_p}{R_s + R_p}\right) \quad (2)$$

The curve fitting factor A is used to adjust the I–V characteristic of the cell. The resistance R_p and R_s represent the p-n junction layer resistance and external resistance (such as tapping wire, connections etc.) of the PV cell respectively. These parameters are important to be considered for acquiring the realistic behavior of the PV cell.

The PV cell voltage and current are affected by variation in climatic parameters which are listed below,

- Irradiation level
- Wind speed
- Temperature
- Humidity level
- Dust accumulation

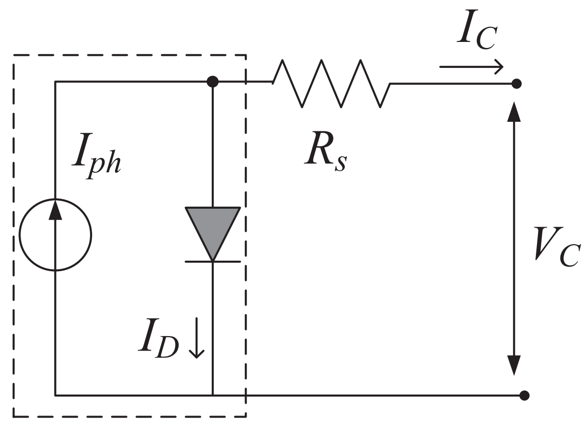

Fig. 2. An equivalent circuit model of a SDPV system.

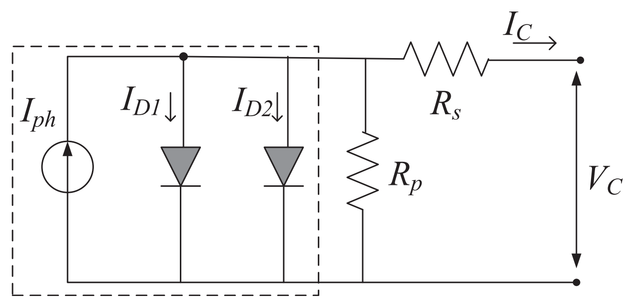

Fig. 3. An equivalent circuit diagram of a DDPV system.

These effects can be collectively incorporated in the models with the help of parameter coefficients for achieving a realistic model of PV cell.

The effect of change in irradiation level (S_x) on the voltage and photo current can be expressed with the help of constants, C_{SV} and C_{SI}, which are the correction factors for changes in cell voltage V_C and photo current I_{ph}. These are expressed in Eqs. (3) and (4) as [7],

$$C_{SV} = 1 + \beta\alpha_S(S_x - S_c) \quad (3)$$

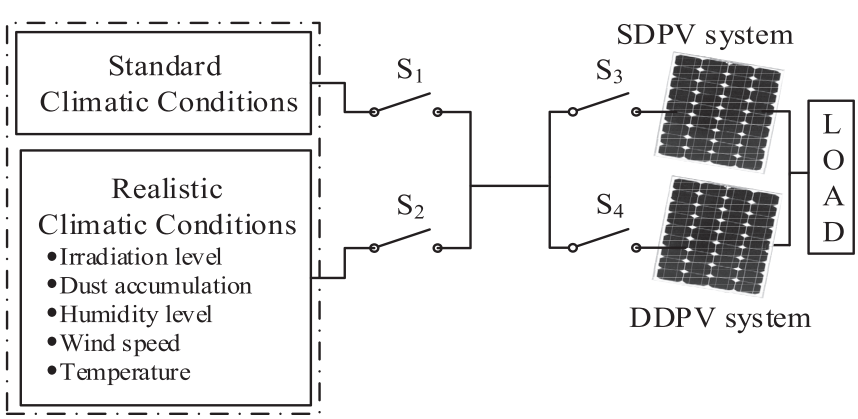

Fig. 1. Schematic representation of the proposed system.