Energy Reports 2 (2016) 171–187

Contents lists available at ScienceDirect

Energy Reports

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

A mathematical modeling framework to evaluate the performance of single diode and double diode based SPV systems

Sangram Bana *, R.P. Saini

Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee 247667, India

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
2 June 2016
Accepted 26 June 2016

Keywords:
Photovoltaic (PV)
Single diode model
Double diode model
STC (Standard test condition)
Modeling

ABSTRACT

In order to predict the performance of a PV system, a reliable and accurate simulation design of PV systems before being installed is a necessity. The present study concerns the development of single and double diode model of solar PV system and ensures the best suited model under specific environmental condition for accurate performance prediction. The information provided in the manufacturers' data sheet is not sufficient for developing a Simulink based single and double diode models of PV module. These parameters are crucial to predict accurate performance of a PV module. These parameters of the proposed solar PV models have been calculated using an efficient iterative technique. This paper compares the simulation results of both the models with manufacturer's data sheet to investigate the accuracy and validity. A MATLAB/Simulink based comparative performance analysis of these models under inconsistent atmospheric conditions and the effect of variations in model parameters has been carried out. Despite the simplicity, these models are highly sensitive and respond to a slight variation in temperature and insolation. It is observed that double diode PV model is more accurate under low intensity insolation or shading condition. The performance evaluation of the models under present study will be helpful to understand the I-V curves, which will enable us in predicting the solar PV system power production under variable input conditions.

1. Introduction

Solar PV systems are environmentally friendly and assist in minimizing GHG emissions that would have otherwise arisen due to the use of fossil fuels for power generation. Feeding electricity into the grid by solar PV plants can help in to transmit equal amounts of electricity as would have been generated from the GHG intensive grid (most power grids receive electricity from coal based power plants). However, the high cost of photovoltaic power system modules inhibits optimum and utmost utilization of available solar energy. Thus, before actually installing the system, it is necessary that reliability and accuracy of the system is ensured in simulated environments.

Solar PV systems are environmentally friendly and assist in minimizing GHG emissions that would have otherwise arisen due to the use of fossil fuels for power generation. Feeding electricity into the grid by solar PV plants can help in to transmit equal amounts of electricity as would have been generated from the GHG intensive grid (most power grids receive electricity from coal based power plants). However, the high cost of photovoltaic power system modules inhibits optimum and utmost utilization of available solar energy. Thus, before actually installing the system, it is necessary that reliability and accuracy of the system is ensured in simulated environments.

A PV system converts light into electricity. More precisely, a PV cell converts incoming solar radiation into direct current (DC). A PV cell is the heart of the solar power system, and sunlight being free of cost and available in abundance, can be used as an alternative energy source. The word "photovoltaic" originates from the word "light" pronounced as "photo" in Greek, and "voltaic" from Alessandro Volta—an electricity pioneer. The ability of photovoltaic material to convert light energy into electrical energy was discovered by Edmond Becquerel—a French physicist, in 1839. Although the use of sunlight to produce electric current in solid materials was also recognized by Becquerel, it took a century to understand this procedure of conversion. Nonetheless, scientists have identified materials that exhibit photovoltaic properties of converting light energy into electrical energy at the atomic level (Tossa et al., 2014; Alsayid, 2012). A number of solar cells are attached in series or parallel (depending upon the necessity) in a single support system known as a "PV module". Depending

* Corresponding author. Fax: +91 1332 286125.
E-mail address: sonamdah@iitr.ac.in (S. Bana).

http://dx.doi.org/10.1016/j.egyr.2016.06.004

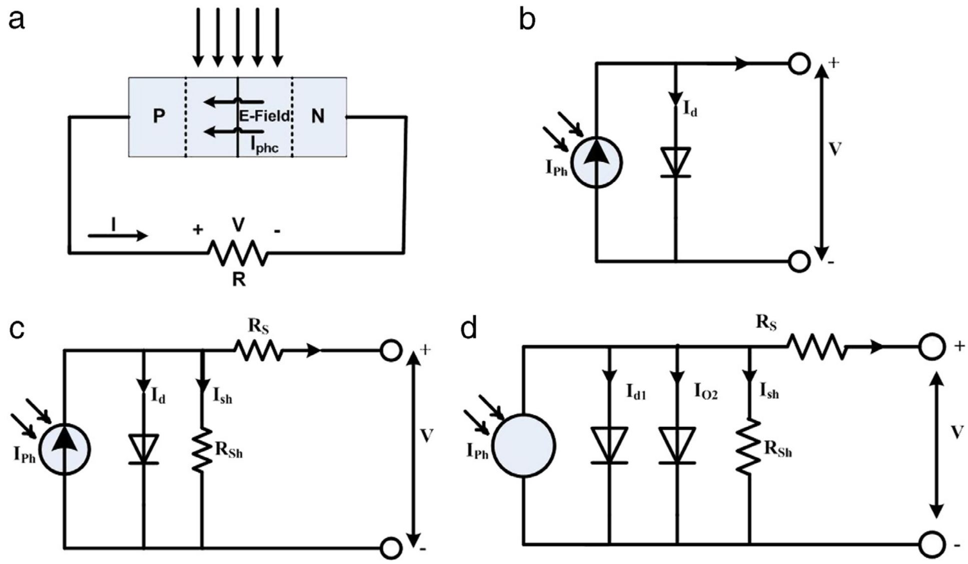

Fig. 1. Solar PV cell and its equivalent electrical circuits: (a) SPV Cell; (b) Ideal model; (c) single diode model; (d) double diode model.

upon the requirement of current and voltage combinations, these modules can further be connected in series or parallel arrangements known as "array" of PV modules (Anne and Michel, 2006; Bourdoucen and Gastli, 2007).

Performance of solar PV cell is evaluated under standard test conditions i.e. cell temperature at 25 °C; insolation of 1000 W/m^2; and solar spectrum at A.M 1.5. Thus, it is important to accurately predict the power output of PV module under real weather conditions before installing solar PV systems. Various solar PV models have been proposed by researchers and each model comes with certain advantages of its own (Phang et al., 1984; Townsend, 1989; Glass, 1996; Dongue et al., 2012; Karamirad et al., 2013). Townsend (Townsend, 1989). Further, researchers in the past have considered constant parameters (ideality factor, series and shunt resistance) for solar PV cell modeling. Results thus obtained were inaccurate as these parameters vary with change in temperature and insolation. Various studies have been carried out on the model development of the PV modules. However the modeling of these models has different level of complexity of their own. These models may be differentiated on the basis of number of employed diodes, finite or infinite shunt resistance, fixed or variable ideality factor and the techniques used to determine the unknown parameters (Saloux et al., 2011; Lun et al., 2013; Kulaksiz, 2013; Siddiqui and Abido, 2013; Ma et al., 2014). The result of comparative studies does not provide that "which model will provide better results under real environmental exposure conditions and which model should be considered to study the effect of shading and non-shading conditions?"

The present study is a comparative study of single diode and double diode solar PV models. Development of these models is done by evaluating their respective equivalent circuits. The performance characteristic of PV components is estimated on the basis of electrical parameters of the equivalent circuits. The effect of variation in environmental factors (insolation and temperature) and internal parameters (ideality factor and series resistance) on both models has been evaluated and extensively discussed in this study. This performance assessment will help in understanding I–V curves for forecasting PV system output power under inconsistent input conditions. Parameters such as ideality factor (n), series resistance (R_s) and shunt resistance (R_{sh}) are unfortunately not provided in manufacturer data sheets. (These parameters are termed as unknown parameters.) These unknown parameters have been determined by an iterative method. This study evaluates the performance of presented SPV models under variable operating conditions and analyzes their power deviation with respect to the ideal solar PV model.

The modeling process is divided into three parts: First, mathematical modeling of single and double diode models and unknown parameters are determined. Second, simulation models of these solar PV models in Matlab/Simulink environment are presented. Finally, the accuracy of the proposed models is validated by comparing simulation results against manufacturer data sheets.

The experimental data is measured at National institute of Solar Energy (NISE), Gawalpahari, Gurgaon-Faridabad road, Haryana, India. This data has been considered for comparing I–V curves of the proposed models with the measured I–V curves obtained under controlled operating conditions in this study ($latitude = 28.4700°$N $and\ longitude = 77.0300°$E). A commercial PV module MSX60 (Polycrystalline silicon), manufactured by Solarex has been considered as reference module for this study.

2. Simulation models of solar PV device

In order to determine the electrical characteristics of solar photovoltaic cell accurately, mathematical modeling of single and double diode models is presented in the following subsections.

2.1. Solar PV cells, modules and arrays

A cell is a fundamental unit of PV system. A group of cells are encapsulated to form a module. In order to increase the voltage level, modules are connected in series and to increase current levels, modules are connected in parallel depending on load requirements.

2.2. Equivalent circuits of solar PV device and their mathematical models

A solar PV cell is conventionally represented by an equivalent circuit comprising a current source and one or two forward biased diodes without the correlation of internal series resistance and shunt resistance in case of an ideal cell, and with internal series resistance (R_s) and shunt resistance (R_{sh}) in case of single diode and double diode models. The equivalent circuits of an ideal cell, a single diode and a double diode SPV cell model are represented in Fig. 1 (Tossa et al., 2014; Patel and Agarwal, 2008; Villalva et al.,