Renewable and Sustainable Energy Reviews 52 (2015) 400–417

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Modeling of photovoltaic system for uniform and non-uniform irradiance: A critical review

Debashisha Jena*, Vanjari Venkata Ramana

National Institute of Technology Karnataka, Surathkal, Mangalore 575025, India

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form
14 May 2015
Accepted 11 July 2015
Available online 14 August 2015

Keywords:
Modeling
Uniform irradiance
Non-uniform irradiance
Photovoltaic (PV) array

ABSTRACT

A critical review on various modeling approaches of photovoltaic array both under uniform and non-uniform irradiance is presented in this paper. The main approaches that have been deliberated are based on the variation of analytical methods, classical optimization techniques and soft computing techniques. The review has been taken from papers published up to 2015. In this paper a detailed description and classifications of modeling techniques for both uniform and non-uniform irradiance conditions are presented. Modeling of PV systems under uniform irradiance is classified into non-iterative methods, iterative methods, artificial intelligence based methods and dynamic models. Under non-uniform irradiance, they are classified into non-iterative methods, iterative methods and artificial intelligence based methods. It is envisaged that this paper can serve as valuable information for researchers to work on photovoltaic array modeling under partial shaded condition.

Contents

1. Introduction . . . 401
2. Review on uniform irradiance. . . . 402
 2.1. Non-iterative methods. . . . 402
 2.2. Iterative methods. . . . 404
 2.3. Artificial intelligence based methods . . . 408
  2.3.1. Genetic algorithm (GA) . . . 408
  2.3.2. Particle swarm optimization (PSO) . . . 408
  2.3.3. Differential evolution (DE). . . . 408
  2.3.4. Simulated annealing (SA) . . . 409
  2.3.5. Cuckoo search . . . 409
  2.3.6. Hybrid EA. . . . 409
  2.3.7. Other EA. . . . 409
  2.3.8. Neural networks, fuzzy and ANFIS . . . 409
 2.4. Dynamic models . . . 410
3. Review on non-uniform irradiance. . . . 410
 3.1. Non-iterative methods. . . . 410
 3.2. Iterative methods. . . . 412
 3.3. Artificial intelligence based methods . . . 413
4. Comparison of modeling techniques . . . 414
 4.1. According to perturbation of parameters . . . 414
 4.2. According to implementation complexity . . . 414

* Corresponding author.
E-mail addresses: bapu4002@gmail.com (D. Jena), venkat.vr90@gmail.com (V.V. Ramana).

http://dx.doi.org/10.1016/j.rser.2015.07.079

4.3. According to accuracy 414
4.4. According to computational speed 414
5. Conclusion 414
References 414

1. Introduction

Photovoltaic (PV) system directly converts sunlight into electricity. The fundamental device in a photovoltaic system is the photovoltaic cell. Mono-crystalline silicon, multi-crystalline silicon, amorphous silicon, cadmium telluride, copper indium and gallium sulfide, etc. are presently employed in manufacturing a photovoltaic cell. A photovoltaic cell is a semiconductor diode whose p–n junction is exposed to light. The light incident on the photovoltaic cell generates charge carriers that produce electric current. A single cell can produce around 0.7 V DC. So the PV cells are arranged in series to form modules. Modules are connected in series or parallel to form panels and group of panels constitute an array [1].

The PV model takes the temperature (T) and irradiance (G) as input and produces the electrical parameters of the equivalent circuit model as output. There are different types of equivalent circuit models viz., single diode model, two diode model, dynamic model, etc. The electrical parameters of single diode equivalent circuit are photovoltaic current or light generated current (I_{ph}), reverse saturation current of diode (I_o), diode ideality factor (a), series resistance (R_s) and shunt resistance (R_p). These parameters are to be accurately determined for modeling a photovoltaic source. A single diode model is shown in Fig. 1.

By applying KCL to Fig. 1, Eq. (1) is obtained.

$$I = I_{ph} - I_o\left[\exp\left(\frac{q(V+IR_s)}{akTN_s}\right) - 1\right] - \frac{V+IR_s}{R_p} \tag{1}$$

Fig. 2 represents a double diode model. In this model an extra diode is connected anti-parallel to current source which represents the recombination losses in the depletion region.

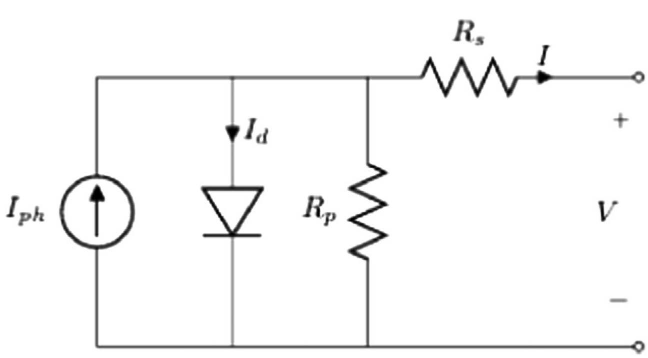

Fig. 1. Single diode model.

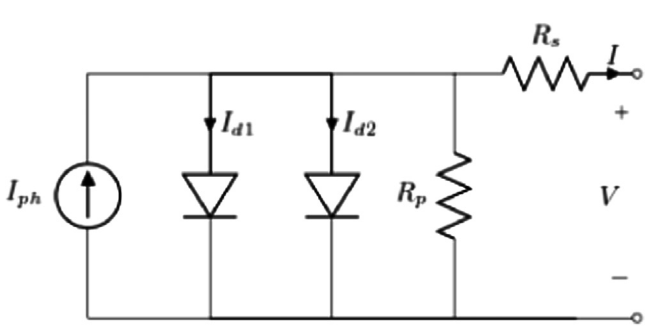

Fig. 2. Two diode model.

By applying KCL to Fig. 2, Eq. (2) is obtained.

$$I = I_{ph} - I_{o1}\left[\exp\left(\frac{q(V+IR_s)}{a_1kTN_s}\right) - 1\right] - I_{o2}\left[\exp\left(\frac{q(V+IR_s)}{a_2kTN_s}\right) - 1\right] - \frac{V+IR_s}{R_p} \tag{2}$$

In addition to the parameters in single diode model, the reverse saturation current (I_{o2}) and diode ideality factor (a_2) are the extra parameters that are to be calculated from two-diode model [1].

In some models the value of shunt resistance is neglected and it is known as R_s model. Eq. (3) represents R_s model.

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V+IR_s)}{akTN_s}\right) - 1\right] \tag{3}$$

In some cases both series and shunt resistance are neglected and the model is termed as ideal diode model. A three diode model is presented in [2]. Apart from these models there are explicit models and dynamic models. Explicit models do not require an equivalent circuit for obtaining the output voltage and output current. In order to investigate the situations like resonance on DC cables, interaction of PV array with switching frequency harmonics and under damped currents, dynamic model is developed with inductor and capacitor [125]. Apart from the forward bias characteristics, reverse bias and dynamic characteristics will be obtained from dynamic model which are significant under non-uniform irradiance conditions. The equivalent circuit of dynamic model is presented in Fig. 3 [3].

PV modules are connected in series or parallel to form panels and panels are connected in series or parallel to form arrays. When part of PV array is subjected to conditions like shadows, PV array is subjected to non-uniform irradiance. The shaded modules limit the output current passing through unshaded modules. Shaded modules will dissipate heat and hotspots will be created. In order to avoid this, all the modules are connected with bypass diodes in anti-parallel providing alternate path for the output current [4].In order to obtain maximum output power from a PV source it is very important to obtain P–V characteristics under condition of non-uniform irradiance. The authors of the review paper presented in [5] have covered the papers published in between 1960 and 2011. Even though there are papers in 2011 and beyond, most of the methods covered up to 2008 and reviews only uniform irradiance conditions. The present paper includes a critical review ranging from 1969 to 2015 and discusses modeling in both uniform and non-uniform irradiance conditions. An attempt is made to compare the methods of modeling in uniform and non-uniform irradiance conditions. The methods in dynamic modeling are also included in this review.

This paper is organized as follows: Section 2 presents review on modeling uniform irradiance conditions. Section 3 presents modeling

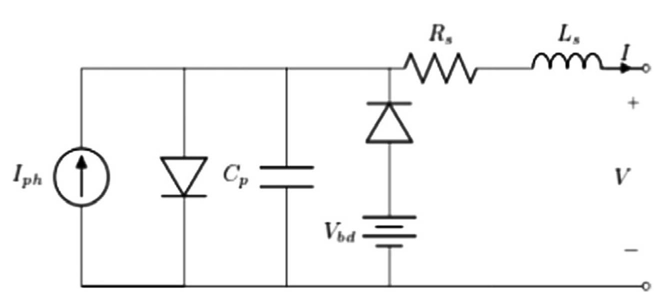

Fig. 3. Dynamic model [3].