Sustainable Energy Technologies and Assessments 16 (2016) 84–92

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

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

Original Research Article

Optimization of the characteristics of the PV cells using nonlinear electronic components

F.B. Pelap [a,*], P.D. Dongo [a,b], A.D. Kapim [a]

[a] Laboratoire de Mécanique et de Modélisation des Systèmes Physiques (L2MSP), Faculté des Sciences, Université de Dschang, BP 69 Dschang, Cameroon
[b] Laboratoire d'Electronique et de Traitement du Signal (LETS), Faculté des Sciences, Université de Dschang, BP 67 Dschang, Cameroon

ARTICLE INFO

Article history:
Received 16 May 2015
Revised 31 March 2016
Accepted 16 May 2016

Keywords:
Photovoltaic cell
Nonlinear series resistance
Power output
Optimization
Fill factor

ABSTRACT

In spite of the efforts made by researchers to improve the capacity of the solar cells to produce energy, very few studies take into account the nonlinear behavior of the photovoltaic (PV) cell and module. In several scientific domains, the nonlinear properties of the electronic components provide significant advantages in the mastering and improvement of the system's output. This paper introduces and examines the effects of a nonlinear series resistance function of the current on the characteristics of the PV cell. The choice of this component deals with its significant involvement in the decrement of the PV outputs. Based on the proposed nonlinear model of the PV cell and considering the standard test conditions, theoretical investigations are conducted. A comparative study of those characteristics for constant and nonlinear series resistances reveals that the nonlinear character of the series resistance does not worsen the shape of the characteristic curves of the cell. Furthermore, it optimizes the maximum power output of about 1.41% and modifies slightly the fill factor, independently of the mineral material constituted the cell. Then, we extend our finding to the PV module of N_S and N_p units PV cells associated in series and parallel. The established results exhibit a growth of the maximum power output and the fill factor of the PV module.

Introduction

Nowadays, the development of the renewable energy sector depends upon the assessment of resources planning and selling of their energy production technology. This technology should be in constant enhancement to ensure its proper expansion. However, the research in the PV solar domain requires great attention since it represents a doable solution for answering numerous needs of electrical energy production (lighting systems, charging of batteries, etc.) particularly for isolated sites (which are not connected to a conventional network). The production of PV solar energy essentially lies on the PV cells which are either mineral or organic and which convert solar energy into electricity. Despite the ease of setting the PV solar system, its low environmental impact, its renewable character and the little care necessary to optimize the likely output, we notice that expectations are never met because they are far greater than the output of such a system. Numerous factors such as temperature and shading have significant effects on the characteristics of the PV cells and could influence the behavior as well as the output of the PV cells and modules.

Considerable efforts were made by researchers and agencies to examine the characteristics of PV modules and the factors that affect them. Walker [1] proposed a Matlab-based model of PV modules to simulate its characteristics and studied the cumulative effects of insulation and load variation on the available power. Alonso-Gracia et al. [2] examined the impact of partial shading on the characteristics of PV modules. Based on the circuit modeling, Siyu et al. [3] studied the local inhomogeneity effects of silicon wafer solar cells and established that their impact on the output of these PV cells is bad. Besides these, some scientists focused their attention on the effects of the temperature upon the electrical performance of PV installations [4] while others carried out investigations on the electromagnetic field effects on the output of PV cells [5]. Melle [6] and Bouguema [7] worked, respectively, on the optimization of the efficiency of hetero-junctions and tandem PV cells. By a novel light trapping structures based on the prism, DongLin et al. [8] improve of 8.1–10.74% the conversion efficiency of thin film solar cell. Recently, Belarbi et al. [9] introduced the thin intrinsic hydrogenated amorphous (a-Si:H) layer in interdigitated back contact of silicon hetero-junction solar cell to improve its output. Issa et al. [10] studied the effect of external magnetic field on the

* Corresponding author.
E-mail addresses: fbpelap@yahoo.fr, francois.pelap@univ-dschang.org (F.B. Pelap).

http://dx.doi.org/10.1016/j.seta.2016.05.005
2213-1388/

PV cell and noticed that, its growth induces the decrement of the power and conversion efficiency of the PV cell. Wolf and Rauschenbach [11] looked through the effects of the internal series resistance of the PV cell on the solar cell measurements. Dongo et al. [12] optimized the maximum power output of the cell using a nonlinear series resistance of the silicon PV cell function of the temperature. Those works express researchers' great desire to deeply master the dynamics of the PV cells in order to propose approaches that assure their stability and improve their yield. Following the same objective, strongly motivated by the useful properties of the nonlinear phenomena and conscious of the limiting effect of the temperature on the behavior of electronic components exploited, we decide to explore the effects of another type of nonlinearity (which does directly depend on the temperature) to optimize the output of PV cell and module. Therefore, we choose to examine the dynamics of PV cells in which the internal linear series resistance is replaced by a nonlinear resistance whose value varies with the current across it. We are also motivated by the fact that the effects of the internal series resistance of the PV cell highlight a significant level in the flattening of the PV output characteristics such as the maximum power generated by the cell.

This paper presents the mathematical background and computer modeling of PV cell/module with nonlinear series resistance constructed with bipolar transistors [13,14]. The structure of this work is organized as follows. In section 'Study of the photovoltaic generator', we propose a circuit pattern of the PV cell with a constant series resistance and present the mathematical background that calls the Lambert W function for the research of the exact solution. Simulations of the dynamics of the obtained solutions are studied both in Matlab and Spice environments to observe the behavior of the *I–V* and *P-V* characteristics of the PV cell. In section 'Dynamics of the nonlinear PV generator', the dynamics of the new nonlinear PV cell and module are investigated. The corresponding mathematical background is built. Comparison and discussion of the obtained results are carried out for the cases of constant and nonlinear series resistances. Conclusion is devoted to discussion and concluding remarks.

Study of the photovoltaic generator

Modeling of the PV generator could be made by considering different levels of complexity. We wish to build an equivalent electrical circuit for the PV generator. First of all, we should remind that the PV cell remains the basic element of every PV generator no matter the power required. For better understanding, the electrical and mathematical models of the PV cell are presented for the analysis of its performances.

Mathematical modeling of the linear PV cell

A mathematical description of the current–voltage characteristics for PV cells is available in literature [15–17]. The electrical equivalent circuit of the PV cell is shown in Fig. 1. This circuit consists of a power source (S) which depends on both the solar insolation and the temperature, a diode (D) in parallel branch whose inverse saturation intensity is function of the temperature, and a series resistance R_S that represents the effects of the internal resistance and environmental contact with the cell. It is due to the contribution of basic resistances, the faces of the junction and, the front and back contact faces. The resistance R_{Sh} (shunt) in the parallel branch adds the complexity of the system and is related to the dissipation phenomenon at the cell's level. It accounts for the leakage current at the edges of the cell. It is reduced because of the penetration of the metal impurities in the junction. Below is pointing out the various meanings of the electrical components used in Fig. 1: I_D is the current passing through the diode, I_{Sh} designates the current which passes through the resistance of shunt (R_{Sh}), I is the output current of the PV cell, V stands for the output voltage delivered by the PV cell and V_D defines the terminal voltage of the diode. In this circuit, the resistances R_S and R_{Sh} are selected with the precaution that the resistance of shunt being larger than that of series in order to maximize the current that crosses the series resistance and to protect the diode from high current. Mathematically, to link the current delivered by the PV cell with the voltage on its terminal, we use the following equation [16]

$$I = I_{ph} - I_D - I_{sh} \tag{1}$$

In relation (1), the current through the diode is defined by the single exponential equation $I_D = I_s[\exp(V_D/V_T) - 1]$ in which I_s designates the saturation current determined by the material properties and V_T stands for the thermal voltage. Also in Eq. (1), the current crosses the shunt is given by $I_{sh} = (V + R_sI)/R_{sh}$. Hence the expression (1) becomes:

$$I = I_{ph} - I_s\left[\exp\left(\frac{V + R_sI}{V_T}\right) - 1\right] - \frac{V + R_sI}{R_{sh}} \tag{2}$$

This relation is derived from the physics of the PN junction and is generally accepted as reflecting the behavior of the PV cell. A double exponential equation may be used for the polycrystalline Silicon cells [18]. The complete behavior of the PV cells are described by five model parameters ($I_{ph}, V_T, R_S, I_s, R_{Sh}$) which is representative of a physical PV cell [18]. In fact, these five parameters of the PV cell are related to two environmental parameters (solar insolation & temperature) and owing to nonlinear nature of Eq. (2), their determination is not straightforward.

The exact solution of Equation (2)

The exact solution of Eq. (2) can be expressed in terms of the Lambert W function [19–22] which is defined as

$$W(z)e^{W(z)} = z \tag{3}$$

To make use of this function, the transcendental equation for the voltage V may be rewritten in the exponential form as

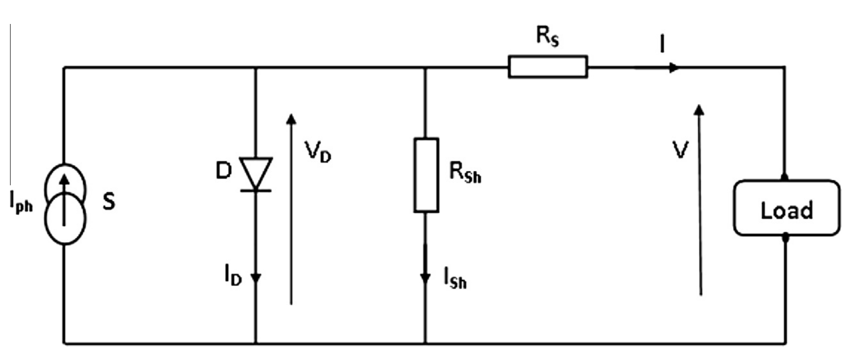

Fig. 1. Electrical equivalent circuit of the photovoltaic cell.