Energy Conversion and Management 171 (2018) 1246–1254

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Real time partial shading detection and global maximum power point tracking applied to outdoor PV panel boost converter

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A R T I C L E I N F O

Keywords:
Partial shading
Global maximum power point
PV panel
Renewable energy

A B S T R A C T

PV panels power conversion are strongly depending on chopper structure and maximum power point tracker algorithm, such as perturb and observe or increment conductance. In certain operating conditions these algorithms become inaccurate. The aim of this paper is the PV panel operation under partial shading. Until now it is solved by intelligent techniques (ANN, Fuzzy logic …) where the result cannot be explained and inaccurate under desert climate. It is proposed a new global maximum power point tracking based on detection and analyzing partial shading phenomena affecting PV panels characteristics behavior. The proposed DA-GMPPT permits a partial shading detection, once it appears and the location of the other maximum power points. Using this proposal the whole PV power system works at its optimal power point for any type of partial shading, even under aging effect.

1. Introduction

The specifications of PV Panels are their ability to convert directly the sun energy to electrical energy [1]. The question is, is it possible to connect directly PV panels to their load? The answer is yes. Is it efficient? No. To make a PV system efficient DC/DC or DC/AC converters are used [2]. These converters allow the whole PV system to convert its maximum power received from the sun.

PV panels are nonlinear sources [3], so for each given voltage and current Fig. 1a, a delivered power Fig. 1b, depending on sun irradiance level and temperature is produced. The irradiance increases the produced power, but the temperature mitigates it [4]. The nonlinear characters of PV panels are modeled by the following Eqs. (1)–(3).

$$I = N_p I_{pv} - N_p I_s * \left(e^{\left(\frac{A}{AKT}\right)} - 1\right) - N_p\left(\frac{A}{R_p}\right) \quad (1)$$

where $A = \frac{q(V+R_s I)}{N_s}$

$$I_{pv} = [I_s + k_i(T - T_r)]\frac{S}{100} \quad (2)$$

$$I_s = I_{so} * \left(\frac{T}{T_{ref}}\right)^3 * e^{\left[\left(-\frac{q.E_g}{A.K}\right)*\left(\frac{1}{T_r}-\frac{1}{T}\right)\right]} \quad (3)$$

These equations are widely used by optimization algorithms toward the maximum power point (MPP), such as Perturb and Observe (P&O) [5] or Increment conductance (Inc. Cond.) [6].

1.1. Perturb and observe technique

It is based on perturbing the voltage and observing the power [5]. The perturbation is achieved by increasing or decreasing a preset voltage step to the previous voltage Table 1. Once the maximum power is reached the corresponding voltage is fixed as a threshold, and the PV system works around its MPP according the preset voltage step. Unfortunately this technique converges slowly and presents large output voltage ripples.

1.2. Increment inductance technique

The maximum power point is characterized by its derivative relation vs. the voltage (4) Table 2 [6].

$$\frac{dP}{dV} = V\frac{dI}{dV} + I \quad (4)$$

The advantage of this technique is to speed up by large voltages steps when far from the MPP and to slow down by reducing the voltage step near the MPP. So, in addition to have a fast convergence the error around the MPP is reduced. But this technique needs voltage and current sensors with high quality, so more expensive not suitable for large use.

These two techniques are limited in searching the MPP in the case of

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https://doi.org/10.1016/j.enconman.2018.06.038
Received 31 March 2018; Received in revised form 8 June 2018; Accepted 11 June 2018
0196-8904/

Nomenclature

R_s and R_p	are the solar cell series and parallel resistances [Ω], respectively
I,I_{pv}andI_s	PV output current, cell photocurrent and cell reverse saturation current [A] respectively
$N_p$andN_s	number of cell strings connected in parallel and in series respectively
k	Boltzmann constant $1.28 \cdot 10^{-23}$
T	temperature in Kelvin
V	PV module output voltage [V]
q	electron charge $1.6 \cdot 10^{-19}$ C
k_i	short-circuit current temperature coefficient
T_r	cell reference temperature in Kelvin
S	solar irradiation mW/cm^2
I_{so}	reverse saturation at
E_g	band-gap energy of a cell semiconductor
A	dimension junction material factor
P&O	perturb and observe
Inc. Cond	increment conductance
MPP	maximum power point
MPPT	MPP tracking
GMPPT	global MPPT
DA-GMPPT	detection and analyzing GMPPT
P_{max}	maximum power
V_{op}; I_{op}	optimal voltage and current respectively
P_{Nlp}; V_{Nlp}; I_{Nlp}	power, voltage and current natural load point respectively

partial shading, when two or more MPP are possible Fig. 2. One of their MPP is the actual desired maximum power point. The above techniques stop at the first reached maximum power point, which is not necessary the best one. Many researchers choose artificial intelligence to reach the Global Maximum Power Point (GMPP) [7–9]. But these techniques (ANN, Fuzzy logic, etc…) need a large dataset and training time. The response given by these techniques is based on comparing the obtained signal to other similar signals stored before. So the decision cannot be explained analytically. The users should only trust to the obtained results, for this reason the researchers define these techniques as a black box. Another method based on scanning the entire PV panel I-V characteristic is also proposed [10–13]. This can be achieved by varying the Mosfet duty cycle of the chopper from the short circuit point I_{SC} to the open voltage V_{OC} Fig. 2. This technique is very efficient, but during the scanning time the load should be disconnected from the PV system, causing disturbances to the system. Knowing daily dynamic sunlight variation, the scanning is often launched. And this is a real drawback of this technique which requires additional equipment. Furthermore the convergence time to the GMPP is significantly important.

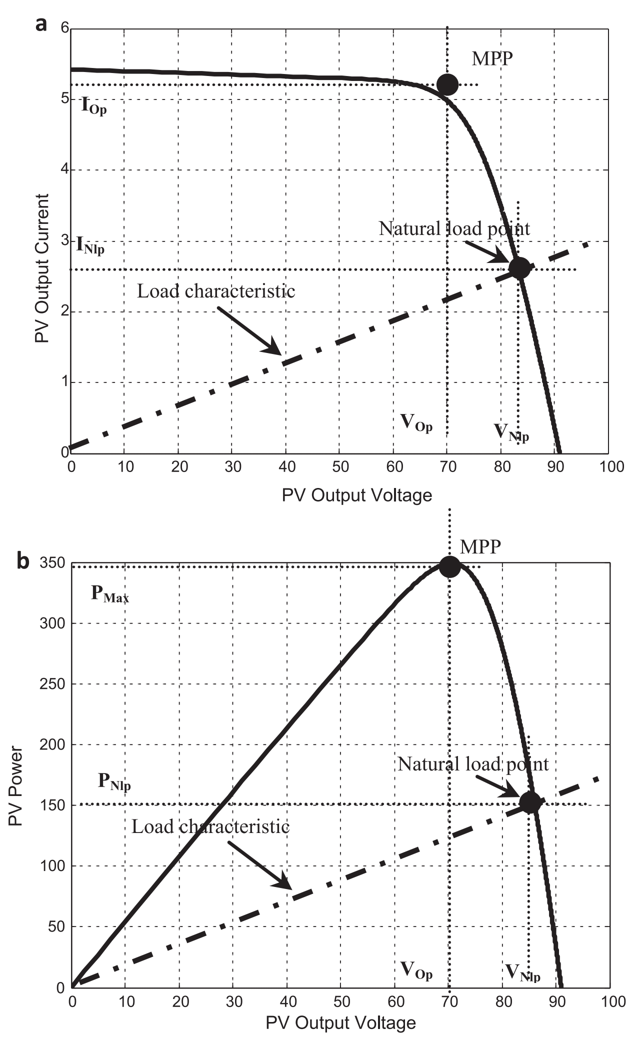

Fig. 1. PV panel characteristics.

Since the irregularity of the illumination on the surface of the panels is inevitable, the conventional techniques of the MPPT must be either improved or replaced. Although the artificial intelligence techniques are black boxes they are preferred in this case. These last are divided into two groups. For the first group such as fuzzy logic controller (FLC) and artificial neural network (ANN) [14], It is not necessary to have a mathematical model of the problem of interest, but, Their learning process itself can take very long time. The second group need to know the model, are alternative approaches use evolutionary algorithms such as particle swarm optimization (PSO) algorithm. artificial fish swarm algorithm (AFSA) [15,16], artificial bee colony (ABC) algorithm [17] or shuffled frog leaping algorithm (SFLA) [18], The main disadvantages are their stochastic character and it is easy to fall into local optimum in high-dimensional space and have a low convergence rate in the iterative process [19].

In the desert the climate is very aggressive. The parameters of the panels change considerably, where almost all the parameters defined in Eqs. (1)–(3) change, and the aging of the panels is faster than usual Fig. 3 caused by the outdoor high temperature, which makes the learning databases used by the first groups obsolete and the iterative model [19] used by the second group erroneous. So, under these climate conditions one cannot trust to the controller circuit. Because we are talking about electrical power production capability mitigation. For this purpose a novel technique suitable to Saharan and partial shading is proposed, which does not need a prior knowledge of the iterative model or a predefined database, but rather an analysis of the characteristics I-V and P-V in time.

2. PV panel under partial shading

The partial shading can happen for PV panels array. The reduction

Table 1
Perturb and observe action.

ΔV	ΔP	Duty cycle
+	+	Increase
+	−	Decrease
−	+	Decrease
−	−	Increase