Electric Power Systems Research 162 (2018) 89–98

Contents lists available at ScienceDirect

Electric Power Systems Research

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

MPPT in PV systems under partial shading conditions using artificial vision

Aranzazu D. Martin[a,*], Jesus R. Vazquez[a], J.M. Cano[b]

[a] University of Huelva, Spain
[b] University of Seville, Spain

ARTICLE INFO

Keywords:
Artificial vision
Backstepping control
DC/DC converter
MPPT algorithm
Photovoltaic system

ABSTRACT

Maximum power point tracking (MPPT) algorithms should track and extract the maximum power from photovoltaic (PV) systems under any environmental conditions. Most of conventional MPPT methods are able to reach the maximum point when there is only one peak in the P–V characteristic curve but they fail when the solar cells are affected by partial shading conditions due to the fact that multiple peaks appear in the P–V curve. Thus, a local maximum may be reached instead of the global peak. In this work, a new method to accomplish the maximum power point (MPP) under partial shading conditions using artificial vision is presented. The artificial vision uses a webcam to identify in real time the shadow irradiance and provide the reference voltage that supplies the maximum power, regardless of the number of peaks that the P–V curve presents. Then, the reference voltage is used by a robust and non-linear control, the backstepping controller, to regulate the DC/DC converter input voltage and to guarantee the PV modules maximum energy extraction. Experimental tests carried out outdoor validate the proposed method, obtaining a MPP tracking efficiency that ranges from 98.1% to 99.6%.

1. Introduction

Photovoltaic systems have become widespread everywhere as a way to extract the maximum energy from solar cells. Thus, the performance enhancement of these systems is one of the main aims of the MPPT algorithms to achieve the MPP. The power generated by PV systems depends on the temperature and the incident irradiance. Under uniform irradiance, the PV modules characteristic curves present only one maximum [1]. Conventional MPPTs are able to reach this peak [2]. However, partial shading conditions can lead to obtain several maxima in the PV systems P–V curves and the former MPPT algorithms may fail to achieve the MPP.

The mismatch concern is one of the main causes of losses in the power extraction from PV systems. They are originated from the interconnection of solar cells with different properties or under different conditions [3]. Therefore, the solar cell under the worst condition, i.e. the one that supplies the lowest energy, determines the PV array global output power. There are various types of mismatch losses, such as short-circuit current or open-circuit voltage. The most common and damaging kind is the short-circuit current, caused by the solar module partial shading [4,5].

The partial shading conditions are originated by the shadows of adjacent buildings, trees, moving clouds or even fast changes in the irradiance. Under partial shading conditions, a PV module is exposed to different values of irradiance and the shaded cells absorb the energy supplied by the unshaded cells exposed to higher irradiance, leading to highly localized power dissipation and converting this power into heat. Thus, the power generated by the partially shaded modules is much lower than the energy generated by unshaded PV cells. This may be detrimental to the PV modules and the performance of the PV system is seriously deteriorated, being this effect widely studied [6–8]. Therefore, bypass diodes are usually connected across the solar modules [9], to prevent the shaded PV modules from consuming the power generated by the unshaded modules. Then, the current flows through an alternative path when there are shaded solar cells. As a consequence of using bypass diodes, the PV array I–V and P–V curves may present multiple power peaks under non-uniform irradiance, complicating the tracking of the MPP [10,11].

Conventional MPPT algorithms are ineffective because they are not able to distinguish the global maximum from the local maxima. Lately, different MPPT methods have been modified to improve the tracking of the MPP, such as the Perturb and Observe algorithm [12], the incremental conductance method [13], the neural network method and fuzzy logic controllers [14,15], or the differential evolution of particle swarm optimization [16]. Other methods are based on the modifications of the number and/or configuration of the bypass diodes [17], others on the measurement of the PV array open-circuit voltage, the short-circuit current or the irradiance [18], amongst others [19]. Besides, there is a method that uses a thermography camera [20].

In this work, a new method using artificial vision to track the

* Corresponding author.
E-mail address: aranzazu.delgado@die.uhu.es (A.D. Martin).

https://doi.org/10.1016/j.epsr.2018.05.005
Received 8 July 2016; Received in revised form 9 April 2018; Accepted 4 May 2018

maximum power in real time is proposed to detect the shadow irradiance and provide the reference voltage that supplies the MPP. Artificial vision is commonly used in many real-time applications such as tracking systems to detect vehicles or even people, surveillance, military missions, video communication or videogames [21–23]. In this case, this technique is used to identify the partially shaded solar cells in a robust and fast way, detecting the irradiance of the shadows, the changes of shape and the shaded area in real time.

All the MPPT methods mentioned above reach the global maximum power point. The artificial vision algorithm is proposed because it is simple to implement. It also uses a low-cost camera and a low-cost microcontroller whereas other methods employs DSPACE [14], more expensive than the dsPIC. The duration of the convergence to the MPP of the artificial vision is shorter than Refs. [12] and [16], which presents fluctuations before reaching the MPP. The proposed control only requires one voltage sensor and one current sensor whereas Ref. [17] needs more sensors and it obtains a lower efficiency. Besides, Ref. [20] uses a termography camera. This camera is about 200 times more expensive than the camera used in the artificial algorithm vision.

Finally, a robust non-linear backstepping controller proposed by the authors [24–26], is used to regulate the PV modules output voltage. It controls the duty cycle of the DC/DC converter to reach the MPP taking into consideration the voltage given by the artificial vision.

The method is implemented in Matlab-Simulink environment since this software is proved to work [27–31]. This environment is appropriate to simulate the photovoltaic system conditions and environmental conditions.

2. Photovoltaic system

The used system in this paper is presented in Fig. 1. It shows series-connected PV modules and they are supervised by a webcam. The PV modules output is connected to a DC/DC power converter whereas the converter output is connected to a load.

The PV modules are series connected and the main problem of this configuration is a significant power drop when a solar cell or a group of cells are affected by the slightest shadow. Bypass diodes, which reduce the impact of mismatch losses from modules connected in series, are connected in anti-parallel with each solar module. Thus, the current flows through these diodes when the PV modules are shaded.

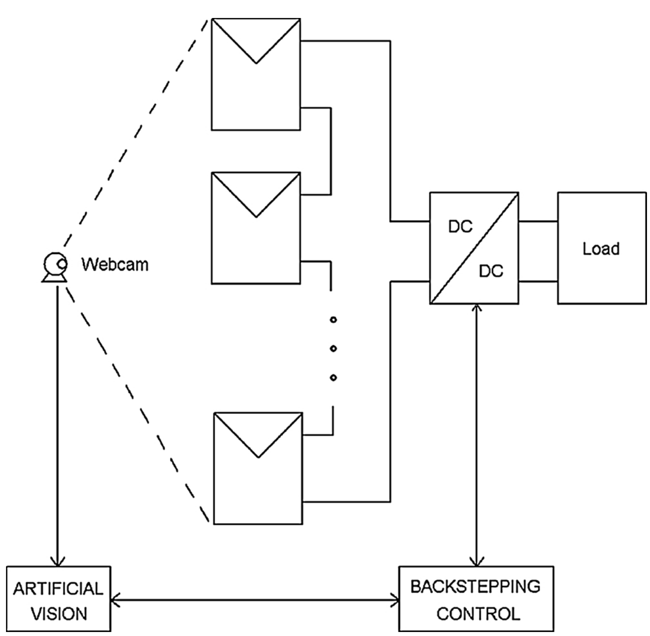

Fig. 1. Photovoltaic system with webcam to detect shadows.

Table 1
Electrical parameters of PV modules.

Parameter	Values
Maximum power (P_{max})	20 W
Maximum voltage (V_{MPP})	17.5 V
Maximum current (I_{MPP})	1.15 A
Open-circuit voltage (V_{oc})	21.6 V
Short-circuit current (I_{sc})	3.31 A

2.1. PV modules

In this work, commercial PV modules are used to validate the proposed method. The PV modules (one PV module consists of 36 solar cells connected in series) electrical features are presented under standard conditions, 25 °C and 1000 W/m^2, in Table 1. The maximum power that one PV module can supply is 20 W.

Fig. 2 presents the experimental I–V and P–V curves of a PV module under different values of uniform irradiance and temperature. The use of the bypass diodes implies P–V curves with multiple peaks when non-uniform conditions are presented, Fig. 3. In this work, three PV modules have been connected in series. Thus, the P–V curves may have a different number of peaks; it ranges from only one peak (when there are uniform conditions, Fig. 2) to three peaks (when each solar module is affected by different irradiance values). Fig. 3 shows the curves for various scenarios where the maximum power peak is located in different areas of the P–V curve, comparing the simulated model in Matlab-Simulink with real values to verify the results. Fig. 3(a) depicts a three-peak P–V curve where the MPP is located at about 15 V. Fig. 3(b) shows another three-peak P–V curve with the global maximum situated in approximately 36 V whereas Fig. 3(c) presents the global maximum in 56 V. Finally, Fig. 3(d) depicts a two-peak P–V curve because only one PV module is affected by a shadow and the MPP is located at 32 V.

2.2. DC/DC power converter

A DC/DC converter is used to control the PV modules output voltage. Thus, the maximum power must be tracked extracted. A built buck–boost converter is used [26], and it consists of power electronic components such as two capacitors, an inductor, a transistor and a diode, behaving as a non-linear load, connected as shown in Fig. 4. i_L is the inductor current, i_{PV} is the PV array output current, v_0 is the DC/DC converter output voltage, L is the inductor and it has a value of 780 μH, and C_1 and C are the capacitors, with a value of 1 mF.

The equations that model the buck–boost converter are presented in Eqs. (1) and (2). Eq. (1) presents the time derivative of the DC/DC converter input voltage and Eq. (2) is the time derivative of the inductor current.

$$\dot{v}_{PV} = \frac{i_{PV} - i_L D}{C_1} \quad (1)$$

$$\dot{i}_L = \frac{v_o}{\mathrm{L}} + \frac{v_{PV} - v_o}{\mathrm{L}} D \quad (2)$$

A non-linear backstepping control, explained in Section 3, implemented in a low-cost microcontroller regulates the buck–boost converter input voltage, v_{PV}, modifying the DC/DC converter duty cycle, D, to achieve the voltage that provides the maximum power.

3. MPPT through artificial vision

In this paper, the MPPT algorithm employs an artificial vision algorithm and a backstepping controller. The artificial vision purpose is to identify the partial shading that affects the PV modules to provide the reference voltage that supplies the maximum power to the backstepping control. Therefore, the backstepping controller regulates the