Energy 94 (2016) 466–475

Contents lists available at ScienceDirect

Energy

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

Novel fast dynamic MPPT (maximum power point tracking) technique with the capability of very high accurate power tracking

Hassan Fathabadi*

School of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Greece

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form
13 October 2015
Accepted 28 October 2015
Available online 28 November 2015

Keywords:
Maximum power point tracking (MPPT)
Maximum power point (MPP)
Photovoltaic (PV)
Convergence time
MPPT efficiency

ABSTRACT

In this paper, a novel maximum power point tracking (MPPT) technique is proposed to track the maximum power point (MPP) of photovoltaic (PV) systems. The proposed MPPT scheme concurrently uses PV voltage and current deviations to find the MPP of a PV module/array/panel under every condition. A PV system has been built to implement the proposed MPPT technique as a MPPT controller, and experimental results obtained under standard test condition (STC), uniform and non-uniform shading conditions, and partial shading conditions are presented that explicitly validate theoretical results. A comparative study together with real experimental results obtained under STC verify that the proposed MPPT technique has a dynamic response with the shortest convergence time of 12 ms and the highest MPPT efficiency more than 99.6% compared to other MPPT techniques. Static-dynamic response obtained experimentally under uniform and non-uniform shading conditions again verifies that the method has a very fast high accurate dynamic response with the MPPT efficiency more than 99.6%. It is also experimentally shown that the proposed technique high accurately tracks the global maximum power point (GMPP) under partial shading conditions, so that, the MPPT efficiency is again more than 99.6%, and the convergence time is less than 140 ms.

1. Introduction

A maximum power point tracking (MPPT) controller is an important unit that ideally adjusts the operating point of a PV module/panel to the maximum power point (MPP) [1,2]. It is widely used in PV systems to increase their efficiency, and to extract the highest possible instant power from the PV module/panel [3,4]. Different MPPT techniques have been proposed over years [5–7]. Some methods such as open-circuit voltage (OCV) and short-circuit current (SCC) are known as offline or model-based methods because the PV module/panel should be regularly disconnected to measure its physical parameters such as open-circuit voltage or short-circuit current. On the other hand, perturb and observe (P&O), incremental conductance (IC), and extremum seeking control (ESC) methods are known as online or model-free methods because they use the instant output voltage and/or current of the PV module/panel when it operates. The OCV method is an old and simple technique that measures the open-circuit voltage of the PV module, and estimates the voltage of the MPP using an approximate linear relationship [8]. A modification of the OCV method is the temperature method that considers the open-circuit voltage as a linear function of the module temperature, and so the instant open-circuit voltage is obtained at any time by measuring the module temperature [9]. The SCC method is similar to the OCV method, but it uses the short-circuit current instead of the open-circuit voltage [10,11]. In fuzzy logic technique, the PV module/panel voltage and current are converted into fuzzy parameters using a fuzzification unit, then a decision is performed using fuzzy roles, and finally, appropriate outputs are produced using defuzzification unit [12,13]. Adaptive fuzzy MPPT method was presented in Ref. [14], the approach uses a fuzzy controller with an adaptive gain as a maximum power point tracker. In fact, the MPPT technique integrates two different tasks consisting of adjusting the duty cycle of the boost converter and online adjusting the gain of the controller [14]. Artificial neural network (ANN) based MPPT methods are other techniques in which a suitable neural network is chosen and trained to determine the weights. The trained ANN is then used to determine the MPP, and to produce a set of the control signals to regulate the operating point of the PV module [15,16]. Two multilayer feed-forward neural networks including two hidden layers were proposed in Ref. [17] to detect the global maximum power point (GMPP) of the PV arrays under partial shading conditions. The P&O method is an online technique

* Tel./fax: +30 210 7722018.
E-mail address: h4477@hotmail.com.

http://dx.doi.org/10.1016/j.energy.2015.10.133
0360-5442/

that perturbs the PV module voltage/current, and then, it compares the new PV output power with the previous amount to decide how to perform the next appropriate perturbation, the perturbing value can be chosen as fixed value (P&O fixed) or variable value (P&O variable) [18]. In other version of P&O technique that is also called "three-point weighted" method, the perturbing value direction is found using three points [19]. A modified version of the P&O method that employs a dynamic perturbation step-size to reduce the oscillation, along with boundary conditions to guarantee the tracking convergence was introduced in Ref. [20]. Particle swarm optimization adaptive neuro-fuzzy inference system (PSO-ANFIS) MPPT algorithm was compared with P&O-ANFIS MPPT algorithm in Ref. [21]. The two methods are hybrid methods that track the MPP of a PV system even under partial shading conditions [21]. The IC technique uses the slope of *P–V* characteristic to find the MPP [22,23]. A modified version of the IC method that responds accurately when the solar irradiation level increases, and shows zero oscillation in the power of the solar module after tracking the MPP was proposed in Ref. [24]. The ESC method includes a nonlinear system with a feedback mechanism that adapts the system dynamic with the operating point of the PV module at any time to track the MPP [25–27]. An improve version of the ESC method called "ripple-based ESC" that uses the DC-link voltage ripple as dithering signal to track the MPP of grid-connected PV systems was proposed in Ref. [28], the technique can be only used in grid-connected PV systems. An on chip integrated power management circuit with maximum power point tracking (PM-MPPT) technique was presented in Ref. [29]. The PM-MMPT circuit decreases partial shading effects by utilizing cell-level distributed MPPT architecture; each cell has its own MPPT circuit, and produces its own maximum power without any impact on other cells or being affected by other cells [29]. A MPPT method which uses a scanning technique to determine the maximum power delivered by the PV panel at a given operating condition was proposed in Ref. [30]. A MPPT method that uses some photodiodes as irradiance sensors was reported in Ref. [31]. Using irradiance measurement, the method recognizes problematic scenarios and executes specific algorithms to prevent malfunction under these situations [31]. A combination of the direct-prediction MPP and P&O methods was proposed as a new hybrid MPPT method in Ref. [32]. A MPPT technique that uses Cuckoo Search (CS) method to track the MPP of PV systems was reported in Ref. [33]. Using the CS method exhibits several advantages such as fast convergence, higher efficiency, and utilizing fewer tuning parameters [33]. Another MPPT method that tracks the GMPP of PV arrays under any environmental conditions was proposed in Ref. [34]. The MPPT controller first senses the current and voltage values of a capacitor connected to the output of the PV array during the charging time, and then compares instantaneous power values to the theoretical maximum power to estimate the actual maximum power value and corresponding voltage value [34]. An auto-scaling variable step-size MPPT method that does not have the problems related to the conventional variable step-size method was reported in Ref. [35]. The method uses the simple judgment criterion and auto-scaling variable step size to enable the solar photovoltaic system to achieve fast dynamic response and stable steady-state output power, even under enormous weather changes [35]. A modified genetic algorithm (GA) based MPPT method was proposed in Ref. [2]. Especially, the method can successfully track the GMPP of the photovoltaic systems affected by partial shading. Another method that uses a model predictive controller to track the GMPP under partially shaded conditions was introduced in Ref. [36]. The method can be used for stand-alone photovoltaic systems, and static and dynamic loads, were used to evaluate the effectiveness of the method under different partial shading conditions.

In this study, a novel MPPT technique is proposed that concurrently uses PV voltage and current deviations to find the MPP/GMPP of a PV module/array/panel. A PV system has been constructed to implement the proposed MPPT technique as a MPPT controller, and experimental results obtained under standard test condition (STC), uniform and non-uniform shading conditions, and partial shading conditions are presented. A comparative study is also performed to evaluate the performance of the proposed MPPT technique in comparison with other techniques. The rest of this paper is organized as follows. Section 2 deals with the theoretical concepts of the proposed MPPT technique. The constructed PV system and the implemented MPPT controller are presented in detail in Section 3. Experimental results and a comparative study to evaluate the performance of the proposed MPPT technique are presented in Section 4. The paper is concluded in Section 5.

2. Analysis of the proposed MPPT technique

The *I–V* and *P–V* characteristics of a PV module are shown in Fig. 1. The output power of the PV module (P_{pv}) is expressed as:

$$P_{pv} = V_{pv} I_{pv} \tag{1}$$

As shown in Fig. 1, the conditions that should be satisfied on the different parts of the *P–V* characteristic are as follows.

At the MPP:

$$\begin{cases} \dfrac{dP_{pv}}{dV_{pv}} = 0 \\ \dfrac{dP_{pv}}{dI_{pv}} = 0 \end{cases} \tag{2}$$

At the left side of the MPP:

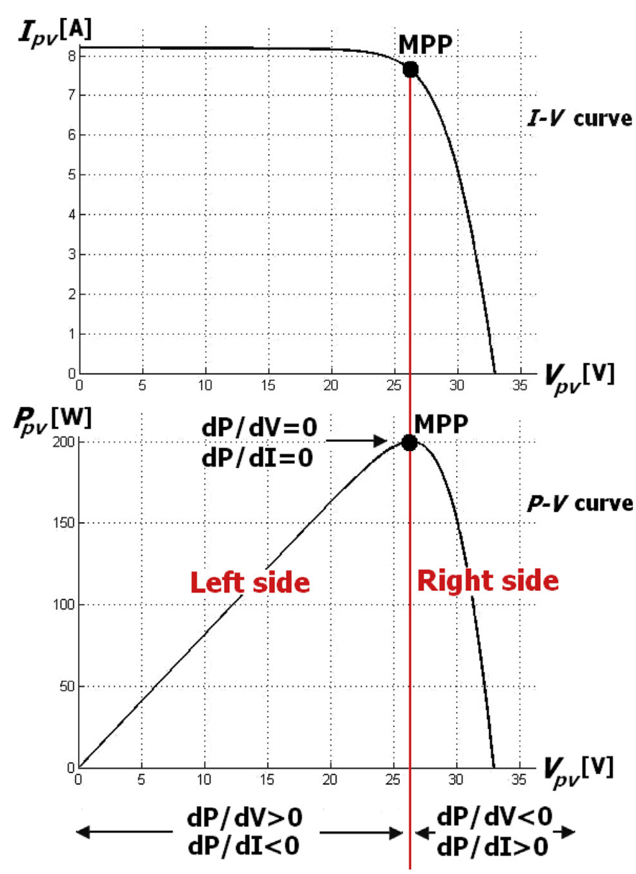

Fig. 1. *I–V* and *P–V* characteristics of a PV module.