Energy Conversion and Management 78 (2014) 843–850

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Adaptive fuzzy controller based MPPT for photovoltaic systems

Ouahib Guenounou [a,*], Boutaib Dahhou [b,c], Ferhat Chabour [d]

[a] *Laboratory of Industrial Technology and Information LT2I, University of Bejaia, Algeria*
[b] *CNRS, LAAS, 7 avenue du colonel Roche, F-31077 Toulouse Cedex 4, France*
[c] *Universite de Toulouse, UPS, INSA, INP, ISAE, UT1, UTM, LAAS, F-31077 Toulouse Cedex 4, France*
[d] *GREAH Laboratory, University of Le Havre, 25 rue Philippe Lebon, 76600 Le Havre, France*

ARTICLE INFO

Article history:
Available online 28 October 2013

Keywords:
PV panel
Adaptive fuzzy controller
Output scaling factor
Fuzzy rules

ABSTRACT

This paper presents an intelligent approach to optimize the performances of photovoltaic systems. The system consists of a PV panel, a DC–DC boost converter, a maximum power point tracker controller and a resistive load. The key idea of the proposed approach is the use of a fuzzy controller with an adaptive gain as a maximum power point tracker. The proposed controller integrates two different rule bases. The first is used to adjust the duty cycle of the boost converter as in the case of a conventional fuzzy controller while the second rule base is designed for an online adjusting of the controller's gain. The performances of the adaptive fuzzy controller are compared with those obtained using a conventional fuzzy controllers with different gains and in each case, the proposed controller outperforms its conventional counterpart.

1. Introduction

The growth of the world's population involves increased needs of sustainable energy resources. The energy consumption, always increasing, reduces the fossil fuel reserves (oil, coal...) approaching their exhaustion limit. The consequences of the massive exploitation of these natural reserves could be severe: the global industry will suffer from the shortage of fossil fuels and their burning will generate air pollution and global warming gases. The use of renewable energy sources is a solution that could reduce these problems, mainly thanks to their insignificant environmental impact and to the fact that these energies are abundant and available.

The photovoltaic renewable energy generation is attracting a growing amount of political and commercial interest. The growth of photovoltaic (PV) systems has exceeded the most optimistic estimations because of the many merits they have such as providing a green renewable power by exploiting solar energy, autonomous operation without any noise generation. In addition their easy use make them suitable to both home energy applications and small-scale power generation applications.

However, the PV systems are subject to power fluctuations caused by atmospheric conditions. It therefore becomes important to operate PV energy conversion systems around the maximum power point (MPP) in order to improve the generated power for a given set of atmospheric conditions.

Several methods have been proposed in the literature for tracking the MPP of PV systems. Among these methods, Hill climbing [1] perturb and observe (P and O) algorithms [2] were commonly used due to their straight forward and low cost implementation. However these methods suffer from oscillation of the operating point around the MPP, leading to significant energy losses especially in large scale photovoltaic systems. An alternative approach that overcomes this effect is called the increment inductance method and is proposed in [3]. However, all these listed methods did not respond correctly under rapidly changing atmospheric conditions.

Recently MPPT methods based on artificial intelligence techniques such as neural networks [4], genetic algorithms [5] and fuzzy controllers [6–8] have emerged. The use of fuzzy controllers (FC) is more suitable for MPPT compared with conventional controllers because they produce a better performance with changing atmospheric conditions [9,10]. In order to improve the efficiency of a fuzzy controller based MPPT, authors in [11] have used genetic algorithms to optimize the membership functions of the controller for which the fuzzy rules have already been created. Results in [11] show that the optimized fuzzy controller achieved good performances, fast responses with less fluctuations for rapid irradiance and or temperature variations. In the same idea, genetic algorithms (GA) have been applied to optimally choose both membership functions and fuzzy rules simultaneously for the fuzzy controller used as a maximum power point tracker [12]. It is reported [12] that the performance of the GA-FC-based MPPT is better than the classical (P and O) controller in terms of response time and fluctuations in steady state.

* Corresponding author.
E-mail addresses: wguenounou@yahoo.fr (O. Guenounou), dahhou@laas.fr (B. Dahhou), ferhat.chabour@univ-lehavre.fr (F. Chabour).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.07.093

In this work, an adaptive fuzzy controller is used to track the MPP of a photovoltaic panel. The proposed fuzzy controller is significantly different from others as it uses an adaptive output scaling factor which can provide a good performance for PV systems. The rest of the paper is organized in four sections. In Section 2, the mathematical model of the PV module is presented. The structure of the adaptive fuzzy controller is described in detail in Section 3. Section 4 presents the simulation results. Finally, a general conclusion is given in Section 5.

2. Photovoltaic panel modelization

2.1. Mathematical model

Fig. 1 shows the equivalent circuit of a solar cell [13,14]. This circuit consists of a photo current source I_{ph}, a diode D_i, an equivalent parallel resistance R_{sh} and an equivalent series resistance R_s.

The Shockley diode equation which describes the $I(V)$ characteristic is given by

$$I_d = I_0\left[\exp\left(\frac{V_d}{n \cdot V_T}\right) - 1\right] \tag{1}$$

where I_d is the forward diode current, I_0 is the reverse saturation current, V_d is the diode's direct voltage, n is the diode factor (usually between 1 and 2) and V_T is the thermal voltage which is expressed by the equation:

$$V_T = \frac{K \cdot T}{q} \tag{2}$$

where K is the Boltzmann constant, T is the cell's operating temperature expressed in Kelvin and q is the electron's charge.

The reverse saturation current I_0 varies with temperature as stated in the following:

$$I_0 = I_{rs}\left(\frac{T}{T_r}\right)^3 \exp\left[q \cdot E_g\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{3}$$

where T_r is the cell reference temperature, I_{rs} is the reverse saturation current at T_r and E_g is the bandgap energy of the semiconductor used in the solar cell.

Considering the equivalent circuit in Fig. 1 with a parallel resistance R_{sh} close to infinite, the $I(V)$ characteristic of a solar cell can be described by the following equation:

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + IR_s}{n \cdot V_T}\right) - 1\right] \tag{4}$$

where V is the cell voltage which equals to PV panel voltage divided by the number of cells in series and R_s is the equivalent series resistance.

Eq. (5) gives the cell's photocurrent I_{ph}. This last depends on the irradiation $S(\mathrm{W/m^2})$ and the temperature $T(K)$:

$$I_{ph} = I_{sc}[1 + a \cdot (T - T_r)]\frac{S}{1000} \tag{5}$$

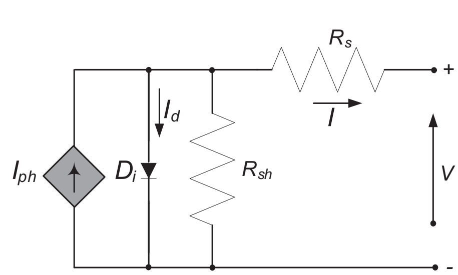

Fig. 1. One diode model of solar cell.

where I_{sc} is the cell's short circuit current at the reference temperature T_r and a is the cell's short circuit current temperature coefficient.

2.2. Power versus voltage curves

The different parameters of the PV model can be determined by examining the manufacturers datasheets. Table 1 shows the used data in our simulations for a BP SX150S panel manufactured by BP solar company.

The PV module presents a nonlinear behavior which depends on the temperature and solar radiation. Fig. 2 shows the 3D *I–V–P* characteristics of the used PV panel under variable atmospheric conditions, in terms of temperature and irradiance.

The figure shows that there are four points on the curves, called the maximum power points, at which the PV panel operates with a maximum efficiency and produces maximum output power using different irradiances and temperatures.

3. Proposed adaptive fuzzy controller

The objective of this research work is to propose a new method for tracking the maximum power point using an adaptive fuzzy controller which is described in detail in this section.

3.1. PV system structure

A typical functional diagram of a PV energy conversion system is depicted in Fig. 3. The system consists of a PV panel, a DC–DC boost converter, a maximum power point tracker controller (MPPT) and a resistive load.

The MPPT has the objective to draw as much power as possible from the PV panel under all operating conditions by adjusting continuously the duty cycle D of the boost converter.

Fig. 4 shows the main components of the DC–DC boost converter usually used in PV systems. The power switch S_w modulates the energy transfer from the input source to the load when controlled by a varying duty cycle D.

In our simulation we use the continuous current average model of a boost converter which is governed by the following basic equations [15]:

$$\begin{cases} V_O = \frac{V_i}{1-D} \\ I_i = \frac{I_O}{1-D} \end{cases} \tag{6}$$

where V_i and I_i are respectively the voltage and current at the input point, V_O and I_O are respectively the voltage and current at the output point.

3.2. Fuzzy controller as an MPP tracker

Before describing the new structure of the adaptive fuzzy controller, let us briefly recall the different components of a conventional fuzzy controller.

Fig. 5 shows the main components of conventional fuzzy controller [16].

Table 1
Parameters of BP SX150S panel.

Maximum power (P_{max})	150 W
Voltage at P_{max} (V_{max})	34.5 V
Current at P_{max} (I_{max})	4.35 A
Open circuit voltage (V_{oc})	43.5 V
Short circuit current (I_{sc})	4.75 A
Temperature coefficient of I_{sc}	0.065%/°C