

A comparative study on conventional and modern maximum power point tracking algorithms applied to photovoltaic systems

Rachid Belaidi*, Solar Equipment Development Unit, UDES / Center for Development of Renewable Energies, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria

Boualem Bendib, Solar Equipment Development Unit, UDES / Center for Development of Renewable Energies, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria

Djamila Ghribi, Solar Equipment Development Unit, UDES / Center for Development of Renewable Energies, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria

Belkacem Bouzidi, Solar Equipment Development Unit, UDES / Center for Development of Renewable Energies, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria

Mohamed Mghezzi Larafi, Solar Equipment Development Unit, UDES / Center for Development of Renewable Energies, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria

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Abstract

The main goal of maximum power point (MPP) tracking control is to extract the maximum photovoltaic (PV) power by finding the optimal operating point under varying atmospheric conditions to improve the efficiency of PV systems. In recent years, the field of tracking the MPP of PV systems has attracted the interest of many researchers from the industry and academia. This research paper presents a comparative study between the modern fuzzy logic based controller and the conventional perturb & observe (P&O) technique. The comparative study was carried out under different weather conditions in order to analyse and evaluate the performance of the PV system. The overall system simulation has been performed using Matlab/Simulink software environment. The simulation results show that the dynamic behaviour exhibited by the modern fuzzy controller outperforms that of the conventional controller (P&O) in terms of response time and damping characteristics.

Keywords: MPPT, photovoltaic system, fuzzy logic control, P&O algorithm.

* ADDRESS FOR CORRESPONDENCE: **Rachid Belaidi**, Unite de Developpement des Equipements Solaires, UDES/Centre de Developpement des Energies Renouvelables, CDER Bou-Ismaïl, 42415, W. Tipaza, Algeria. E-mail address: rachidbelaidi@yahoo.fr

1. Introduction

Recently, renewable energy has become an important source of energy due to its several features such as clean and abundant energy. Solar energy is one of the most famous sources of renewable energy.

However, the maximum output power from a PV system largely varies according to the changing atmospheric conditions (Esrām & Chapman, 2007; Khanna, Das & Bisht, 2013). For more efficiency, a maximum power point tracking (MPPT) control becomes particularly important to extract the maximum power from photovoltaic (PV) arrays, by finding the optimal operating point of voltage and current under varying meteorological conditions.

The main problem of the maximum power point (MPP) is that the position of this point is not fixed but it moves according to atmospheric conditions (irradiance and temperature) (Bendib, Belmili & Krim, 2015), thus a control method named MPPT is necessary to achieve the maximum power possible from the PV arrays, during the variations of irradiance and temperature levels (Eltawil & Zhao, 2013). In the literature, many conventional MPPT techniques have been proposed to find out the MPP of the PV arrays (Esrām & Chapman, 2007), such as hill-climbing (Rezk & Eltamaly, 2015; Shimizu, Hashimoto & Kimura, 2003), open-circuit voltage (Salam, Ahmed & Merugu, 2013), short-circuit current control (Salam et al., 2013), ripple correlation control, forced oscillation and Beta method. The most widely used conventional algorithms implemented in the commercial applications are perturb and observe (P&O) (Elbaset, Ali, Abd-El Sattar & Khaled, 2016; Invalid Citation; Mohammed, Devaraj & Ahamed, 2016; Rezk & Eltamaly, 2015) and incremental conductance (IncCond) methods (Rezk & Eltamaly, 2015; Safari & Mekhilef, 2011). The advantages of these methods are their easy implementation and low cost. However, the main disadvantages of these algorithms are low response speed and errors in tracking under rapidly changing atmospheric conditions (Hamad, Fahmy & Abdel-Geliel, 2013).

The advanced (or the intelligent) methods, such as fuzzy logic (FL) (Bendib et al., 2015; Mellit & Kalogirou, 2014), artificial neural networks (ANN) (Chekired, Mellit, Kalogirou & Larbes, 2014; Elobaid, Abdelsalam & Zakzouk, 2015; Mellit & Kalogirou, 2014) and genetic algorithm (GA) (Kasa, Ramanathan, Ramasamy & Kothari, 2016; Larbes, Cheikh, Obeidi & Zerguerras, 2009; Mellit & Kalogirou, 2014; Messai, Mellit, Guessoum & Kalogirou, 2011; Shaiek, Smida, Sakly & Mimouni, 2013) are more efficient and have fast response and are more complex with respect to the previous conventional methods that are simple, slow, low efficiency and low cost (Bendib et al., 2015; Chekired et al., 2014). Table 1 summarises a comparison between numbers of advanced and conventional methods (Bendib et al., 2015; Bouzelata, Kurt, Altin & Chenni, 2015; Chekired et al., 2014; Esrām & Chapman, 2007; Reisi, Moradi & Jamasb, 2013).

Table 1. Comparison between numbers of MPPT methods

MPPT methods	Efficiency	Complexity level	Convergence speed	Implementation complexity	Cost	Power consumption	Analog/Digital
FL	High	High	Fast	Relatively easy	Expensive	Low	Digital
ANN	High	High	Fast	Difficult	Expensive	Low	Digital
GA	High	High	Fast	Difficult	Expensive	Low	Digital
P&O	Low	Simple	Varies	Easy	Inexpensive	Low	Both
IncCond	Moderate	Simple	Varies	Easy	Inexpensive	Low	Digital
Voc	Low	Simple	Slow	Easy	Inexpensive	Low	Both
Isc	Low	Simple	Slow	Easy	Inexpensive	Low	Both

In this article, mathematical models of the PV module, DC–DC converter, are used in the comparative study on conventional and modern MPPT algorithms applied to PV systems.

The remainder of this article is organised as follows: the next section presents the modelling of the PV system and its I–V and P–V characteristics. The third section shows a comparison and analysis

between two controllers P&Q and FL. The fourth section summarises the simulations with Matlab/Simulink, and the last section of this article consists of a conclusion.

2. PV system modelling and characteristics

2.1. PV cell equivalent circuit

A PV cell is a sensor consisting of a semiconductor material (PN junction) that absorbs light energy and transforms it to electrical power. When the junction is illuminated, it has the particularity that it can function as a generator, producing a photocurrent proportional to irradiance. In the literature, various proposed models of the PV solar cell are presented, such as a single-diode model (Bendib et al., 2015; Younis, Khatib, Najeeb & Ariffin, 2012) and two-diode model (Boumaaraf, Talha & Bouhali, 2015). In this article, the used model is based on a single-diode equivalent circuit taking into account the series and parallel resistors as shown in Figure 1. This model consists of a photo-current I_{ph} , a diode in parallel with the current source, a shunt resistor R_{Sh} and a series resistor R_S .

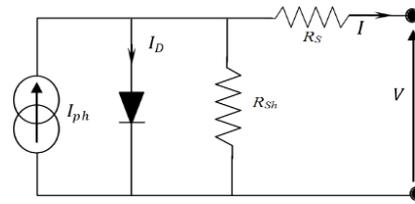


Figure 1. PV solar cell circuit model (single-diode)

The exponential equation which expresses the relationship between the PV cell current and its voltage is given by the following equation (Bendib et al., 2015; Bouzelata et al., 2015):

$$I = I_{ph} - I_S \left[\exp\left(\frac{q(V + IR_S)}{nKT} - 1\right) \right] - \frac{V + IR_S}{R_{Sh}} \quad (1)$$

where I_S is the diode reverse saturation current, n is the diode ideality factor, I is the cell output current, V is the module output voltage, K is the Boltzmann constant, T is the module temperature and q is the electron charge.

The PV cell produced only a few watts of power since this power is insufficient to supply most devices, and the voltage and current must be increased and therefore increasing the power. To increase the voltage, the cells are connected in series and in parallel to increase the current. The combination of these cells in series and in parallel is called the PV module.

2.2. MPP tracking

The main objective of the MPPT is to obtain the optimal operating point of voltage and current to increase the efficiency of the PV systems and extract the maximum power under variable atmospheric conditions (Bendib et al., 2015). For the conventional techniques, the main disadvantages of these algorithms are low response speed and tracking errors under rapidly changing atmospheric conditions (Hamad et al., 2013). In this study, the MPPT based on FL controller is used.

2.2.1. Conventional perturb and observe (P&Q) MPPT technique

Perturb and observe (P&O) is one of the most used MPPT techniques because of its simplicity and low cost with an acceptable performance (Ishaque, Salam & Lauss, 2014; Reisi et al., 2013). The implementation of this technique requires voltage and current sensors to calculate the PV output power; ($P = I \times V$) and causes a perturbation on the duty cycle D . This duty cycle is updated during each sampling period as a function of the power variation.

2.2.2. FL MPPT technique

FL control has been increasingly successful since the end of the last century, particularly in the field of power electronics and industrial control. This logic realises a relationship between the numeric and linguistic variables through memberships functions, it is applied to uncertain and unspecified data (Sivanandam, Sumathi & Deepa, 2007). MPPT control based on FL is one of the advanced methods. This technique has some advantages such as working with imprecise inputs, it doesn't need any exact mathematical model and it can handle nonlinearity of arbitrary complexity (Bendib et al., 2015; Larbes et al., 2009; Messai et al., 2011; Won, Kim, Kim, Kim & Kim, 1994). The FL controller generally consists of three main components, such as fuzzification module, inference engine and defuzzification module. The performance of the FL is based on both the shape of the membership function and the inference engine rules.

2.2.2.1. Fuzzification

The fuzzification process converts numeric variables into a linguistic variable. The input variables of the proposed FL MPPT are the error (E) and the variation of this error (ΔE), which are defined as

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad (2)$$

$$\Delta E(n) = E(n) - E(n-1) \quad (3)$$

where n is the sampling time and $P(n)$ and $V(n)$ are the power and voltage of the PV array, respectively. These inputs are chosen in such a way that the instantaneous value of $E(n)$ indicates whether the operating point of the load power is situated to the right or to the left relative to the actual position of P_{max} , whereas $\Delta E(n)$ expresses the displacement direction of this point. The output variable is the duty cycle (ΔD) and transmitted to the DC–DC buck converter (Larbes et al., 2009). In this work, triangular membership functions are used for the three variables, the error (E), the variation of error (ΔE) and output (ΔD). Each one of these variables (E , ΔE and ΔD) is expressed by linguistic variables such as positive big (PB), positive small (PS), zero (ZO), negative small (NS) and negative big (NB) as shown in Figure 2.

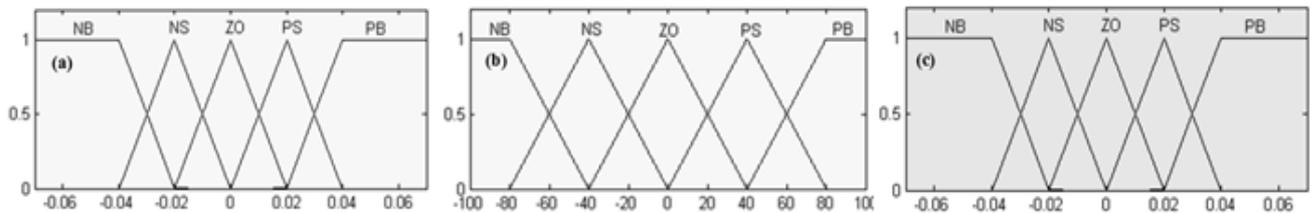


Figure 2. Membership functions for (a) input E , (b) input ΔE , (c) output ΔD

2.2.2.2. Inference engine

Table 2 shows the rule table of the FL controller, where all the entries of the matrix are fuzzy sets of error (E), change of error (ΔE) and change of duty cycle (ΔD) to the converter. These rules are used for controlling the buck converter to extract the maximum power from the PV module (Bendib et al., 2015; Bendib, Krim, Belmili, Almi & Boulouma, 2014).

The linguistic sets and FL inference mechanism such as:

1. If (E is NB) and (ΔE is NB) then (D is ZO)
2. If (E is NB) and (ΔE is NS) then (D is ZO)

and so forth.

Table 2. Fuzzy control rule table

$E \setminus \Delta E$	NB	NS	ZO	PS	PB
NB	ZO	ZO	NB	NB	PB
NS	ZO	ZO	NS	NS	NS
ZO	PS	ZO	ZO	ZO	PS
PS	NS	NS	PS	ZO	ZO
PB	NB	NB	PB	ZO	ZO

2.2.2.3. Defuzzification

It is necessary to transform this fuzzy information into crisp output (real number), this transformation is called defuzzification. The output of the FL controller is the change of duty cycle ΔD . Figure 3 shows the Simulink diagram of the FL algorithm.

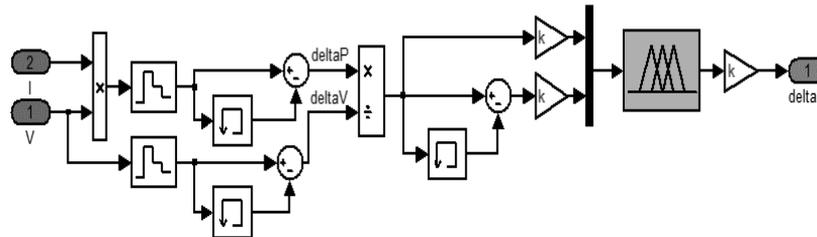


Figure 3. Simulink diagram of FL algorithm

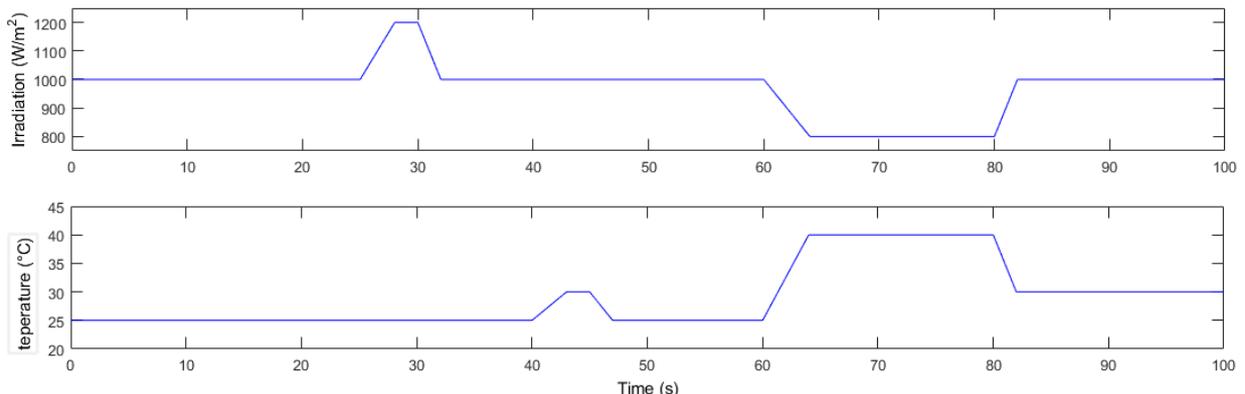
3. Comparison of the two MPPT methods (FL and P&O)

In order to verify the performance of the proposed FL technique, a comparison has been made with the conventional P&Q method.

The simulation started under STC from 0 to 25 seconds. The duty cycle is initialised in the value of $D = 0.7$. The FL controller follows rapidly the expected MPP within 2 second, and it manages to adjust the duty D very quickly. However, with the P&O technique, the MPP is achieved slowly within about 8 second, as shown in Figure 3. The results demonstrate how the FL MPPT algorithm reduced the response time (until eight times) of the PV system compared with the P&O technique. In addition, the FL controller has a high dynamic performance with few oscillations and is more robust under fast variation in atmospheric conditions.

For the conventional P&O method, the results show the continuous oscillation around the MPP, low tracking speed and tracking in the wrong direction under a fast change of atmospheric conditions.

Also, observation showed clearly that the system without MPPT control has an important loss of power (about 35%).



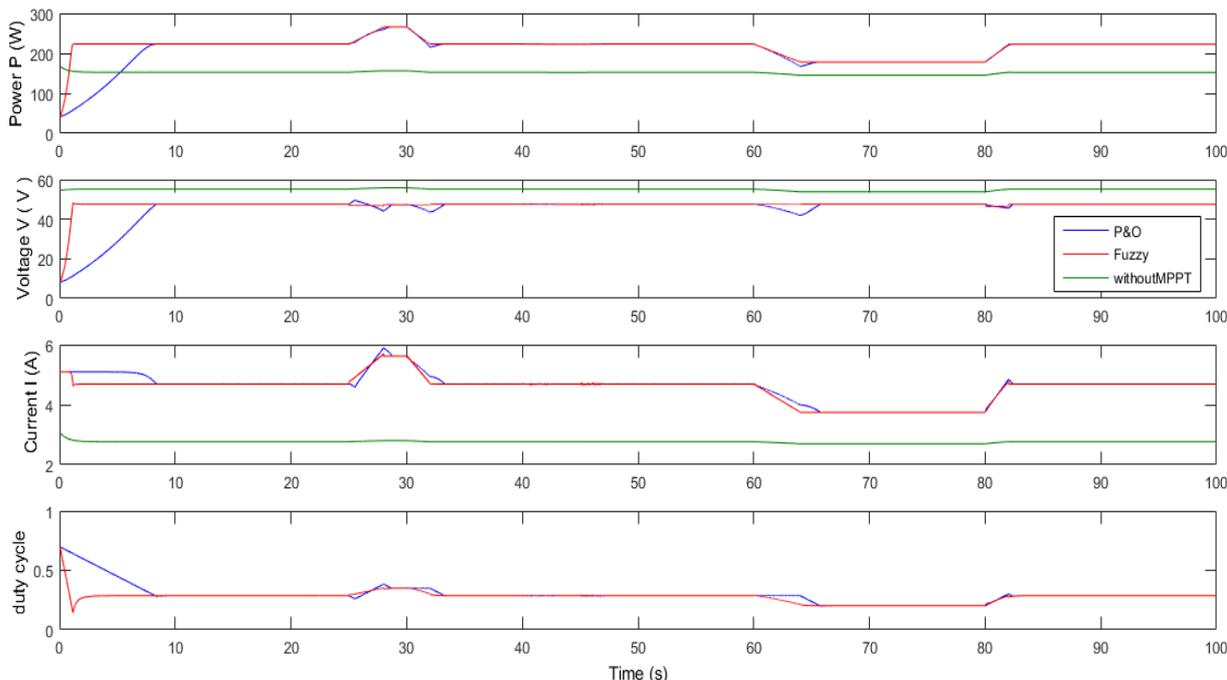


Figure 4. Comparison of two MPPT (FL and P&O), and without MPPT

4. Conclusions

In this article, a comparative study on conventional P&O and modern FL MPPT controllers is presented and discussed. The proposed system has been carried out using Matlab/Simulink software. The modern FL controller provides a better response compared to the conventional P&O controller in terms of the maximum power tracking performance.

The simulation results show better functioning of the modern FL controller with higher dynamic performances than the conventional controller (P&O) in terms of response time and damping characteristics. The results proved that the modern (FL) controller tracks the best point of maximum power providing faster convergence and lower steady-state error. Moreover, it is more robust to changes in atmospheric conditions.

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