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Optimal Design of Fuzzy Controller for Photovoltaic Maximum Power Tracking Using Particles Swarm Optimization Algorithm

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Abstract—Solar panels have non-linear current-voltage characteristics and a specified maximum power point, which depends on environmental factors like the solar radiation and ambient temperature. The voltage-power curve of the photovoltaic system has multiple peaks under different atmospheric conditions that reduce the efficiency of the maximum power tracking techniques. This paper proposes an optimal design of a fuzzy controller using particle swarm optimization algorithm to track the maximum power point of a photovoltaic system operating under different conditions to improve its performance. The proposed system optimizes the particle swarm to produce an optimal working coefficient, which varies with photovoltaic parameters to extract maximum power. Results of simulations – performed using the MATLAB software - show the advantages of the proposed method, namely the ability to track the maximum power point in a short time and maintain the output waveform despite the relatively high variations in environmental conditions.

Keywords— Particles swarm optimization algorithm; Maximum power point tracking; Photovoltaic system; Fuzzy logic controller.

1. INTRODUCTION

The growth of energy demand, energy shortages, the limited ability of residual resources, the intensification of greenhouse gases have always been a major challenge in the industrial sector. This necessitates need for the clean and environmentally friendly renewable energy sources such as wind and the sun on a large scale [1-3]. A photovoltaic phenomenon is referred to a phenomenon that generates electricity through light irradiation without the use of stimulus mechanisms [4-6]. The combination of a number of solar cells results in a photovoltaic modulus or solar panel, the attachment of a number of which creates a solar array [7, 8]. To better harness the incident solar radiation, maximum power point tracking systems are utilized with solar arrays [9-13]. Such systems have differences in terms of price, efficiency, complexity and required sensors [14, 15]. Their main goal is to track the maximum power with the highest accuracy and the least disturbance around the work point [8, 16, 17]. Algorithms utilized for power tracking are classified according to the type of used control variable, i.e., voltage, current and pulse width [8]. Some types of these algorithms are: perturb and observe algorithm (P&O), incremental conductivity (INC), hill climbing (HC), short circuit current (ISC), open circuit voltage (VOC), variable stage (VSS),

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fuzzy logic and particle swarm optimization (PSO) [5, 6, 18]. All these methods have disadvantages, the common types of which are: low efficiency [19, 20] and stable state oscillations around the point of operation, as well as the inability to track power peaks under shady conditions [21-23].

2. RELATED WORKS AND PARTICLE SWARM OPTIMIZATION ALGORITHM

The particle swarm optimization algorithm is a social search algorithm that is modeled on the social behavior of bird categories [24]. In fact, the swarm of particles that search for the minimum value of a function behave like bird species that are looking for food. The basis of the particle swarm optimization algorithm is based on the principle that, at any given moment, each particle adjusts its location in the search space according to the best location so far and the best place in its entire neighborhood. The particle movement is performed in accordance with the best position of the particle and the best target position. To summarize, the particle movement is in accordance with the current position (PP), the best position (PB), and the best target position (GB). In other words, PB is the best experimental location that particle ever had, while GB is the best experimental state that has had the sum of all the particles in the previous replications [24]. This method is capable of performing quick calculations and is easy to use for its simple style. In fact, the particle swarm optimization algorithm is a powerful tool for applying nonlinear practical functions; it has fairly good convergence and has solved many problems of maximum power point tracking. However, in many reported research works, other algorithms in the field of engineering and optimization have been used simultaneously to accelerate and increase accuracy. In [25], fuzzy PWM based on genetic algorithm is investigated. In [26], De Oliveria et. al. studied a grid-tied photovoltaic system based on PSO-MPPT technique. Chao et al. improved PSO in photovoltaic module arrays system [27]. In [28], Seyedmahmoudian et al. studied a partial shaded photovoltaic array system model. Femia et al. showed optimal control of photovoltaic arrays in their simulation [29]. In [30], Rahmani et al. implemented a fuzzy logic system in the photovoltaic plan. In [31, 32], a study on photovoltaic system under partial shading conditions has been done. In [33-37], the photovoltaic plan has been considered based on FPGA in the designation. In [38], Ishaque et al. studied a photovoltaic system under partial shading condition using PSO. Sizing and analysis of an off-grid photovoltaic system for a house are studied by Ozogbuda et al. in [39]. Almomani et al. proposed the application of artificial intelligence techniques for modeling and simulation of photovoltaic arrays [40]. Shwan et al. performed a a comparison between PID, fuzzy logic and ANFIS controllers in one power system model [41]. In [42], Abu-Ghazal et al. simulated the fuzzy controller in electric vehicle system. All of these researches show the importance and beneficial usage of these algorithms in the mentioned plan.

In Table 1, the parameters of particle swarm optimization used in this paper are given.

2.1. Photovoltaic Cell Model

Several models for solar cells are used. The single diode model is the simplest and most widely used model, as it provides both simplicity and precision [7, 8, 10]. The model is shown in Fig. 1.

The output current is defined as follow:

$$I = I_{\text{ph}} - I_o\left[\exp\left\{\frac{q}{nkT}(V + R_s I)\right\} - 1\right] - \frac{V + R_s I}{R_{\text{sh}}} \tag{1}$$

where R_s is series resistance, R_p is parallel resistance in ohms, n is factor of diode and q is the electron charge, K is the Boltzmann's coefficient, T is the temperature, I_{ph} is photocurrent and I_o is the reverse saturation current of diode.

Table 1. Parameters of particle swarm optimization algorithm.

Parameter	Size of parameter
Maximum Number of Iteration	50
Population Size	30
Inertia Weight	0.9
Personal Learning Coefficient	0.012
Global Learning Coefficient	0.012

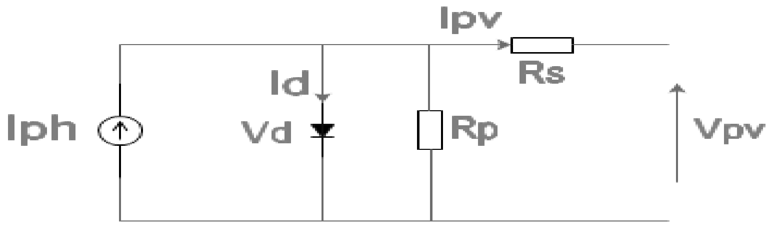

Fig. 1. Single diode model of the solar cell.

3. THE PROPOSED MAXIMUM POWER POINT TRACKING METHOD

In this paper, an improved fuzzy controller is proposed with a particle swarm optimization algorithm for obtaining a maximum power point in solar cells, since one of the problems of the fuzzy method is that the parameters of the membership function are set to be tangible and error-free. The paradigm of the membership function in fuzzy logic used is particle swarm optimization algorithm. Block diagram of the proposed system is exhibited on Fig. 2.

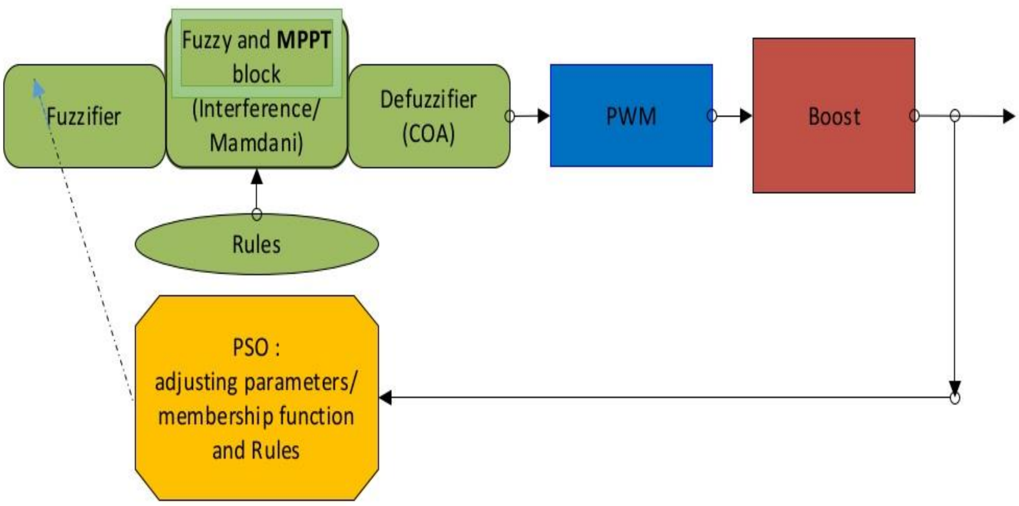

Fig. 2. Block diagram of the proposed maximum power point tracking system.

4. RESULTS AND DISCUSSION

For comparison purposes, we have simulated the proposed system using several algorithms; this is described in the following subsections

4.1. Simulation with P&O Algorithm

Fig. 3 shows the MATLAB block diagram of proposed system that is simulated with P&O algorithm.

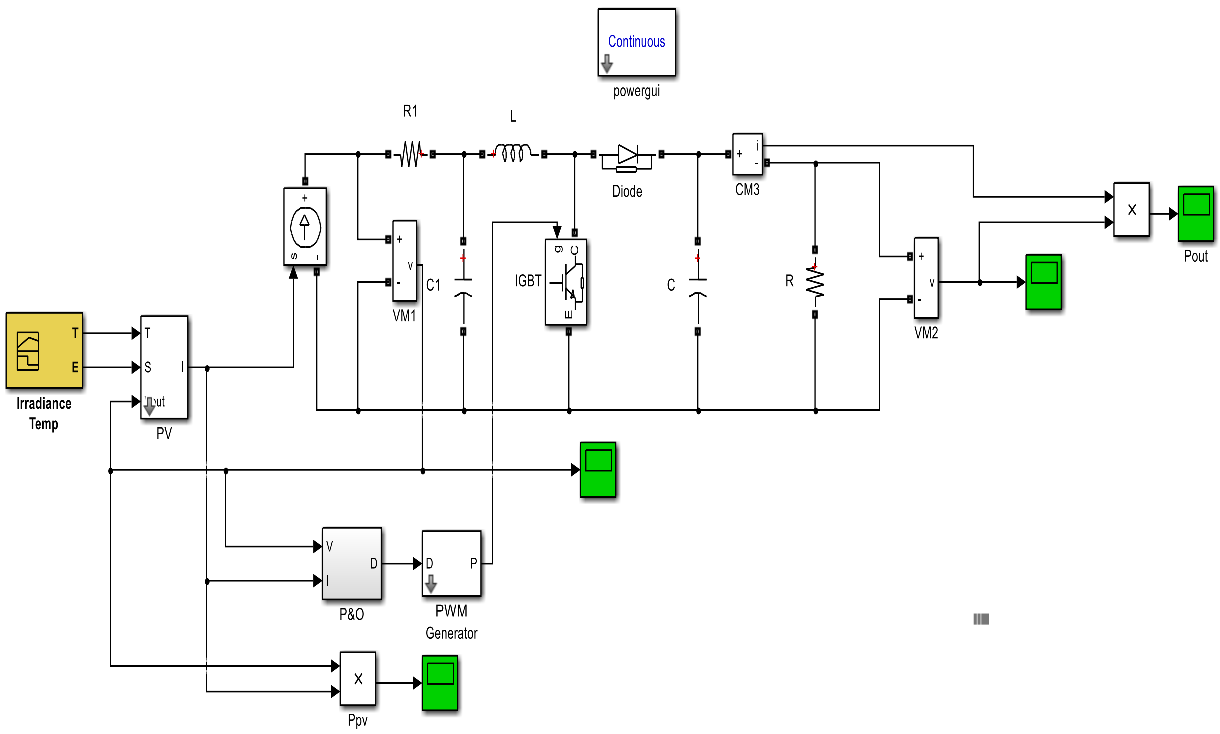

Fig. 3. MATLAB block diagram of proposed system, simulated with P&O algorithm.

The input signals for averaged ten hours (four sunny days) data of temperature and radiation - utilized in simulation - are depicted in Fig. 4.

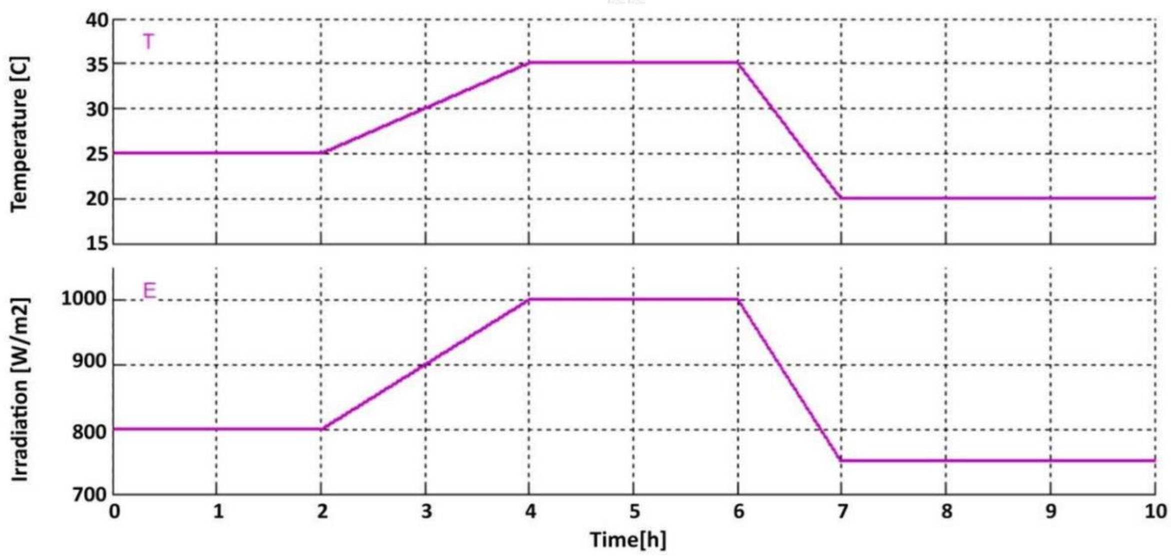

Fig. 4.Input signals of temperature and radiation used in the simulation.

In this work, we first simulated a photovoltaic system that follows the following relationships [1, 4, 6, 7]:

$$I_{PV} = I_{sc}\left[1 - C_1(e^{\frac{V_{pv}-DV}{V_{oc}*C_2}} - 1)\right] + delta(I) \quad (2)$$

$$delta(I) = I_{ph} - I_{sc} \quad (3)$$

$$T - T_n = delta(T) \quad (4)$$

$$I_{ph} = \frac{E}{E_n}[I_{sc} + K_1 * delta(T)] \quad (5)$$

$$-Kv * \left(delta(T)\right) + Rs * \left(delta(I)\right) = delta(V) \quad (6)$$

$$\frac{\left[\left(\frac{Vm}{Voc}\right)-1\right]}{Ln\left(1-\frac{Im}{Isc}\right)} = C2 \quad (7)$$

$$e^{\frac{-V_m}{V_{oc}*C_2}} * \left(1 - \frac{Im}{Isc}\right) = C1 \quad (8)$$

where Ipv is the photovoltaic generated current, C_1 and C_2 are the simplified factors, K_1 and Kv are short circuit current temperature factors, V_m and I_m are the maximum voltage and current points, E is the irradiation and T is the temperature. These values are taken at a temperature of 25° and radiation of 1000 W/m^2. The output signal from the PV block is used to track the maximum power. In Fig. 3, the internal structure of P&O block used in this work is shown to act as a loop with a dp / dv metric and allows for maximum power tracking. As seen, in each cycle, Vpv (k) and Ipv (k) are measured to estimate Ppv (k) . Ppv (k − 1) is calculated in the previous cycle with Vpv (k-1) and Ipv (k − 1), and finally, the coefficient D is calculated to control the boost converter. So P&O is working to change the output power signal PWM block into the gate of the power transistor that is activated to enable the DC-to-DC best work cycle, which means the controller changes the duty cycle of PWM to decrease and increase the voltage until the maximum point is reached. The output signal from the P&O blocks comes in the PWM block. When a PWM is applied to the power transistor gate, the transistor turns on or off from one specified time to another. The output signal from the PWM block into the gate of the power transistor is activated. This signal enables the DC-to-DC converter. When the cycle is turned on, in the sense of being in the high position or when the cycle is turned off, or the pulse width modulation cycle is set to low power, the alternation between the capacitor and the voltage power supply is established.

The fuzzy rules table shows the relation between change error, CE, and error E. The particle swarm algorithm sorted the fuzzy logic rules. Also, in the design of membership functions and the selection of triangular membership functions in fuzzy logic, the PSO algorithm accompanies us for selecting their ranges. The indexed membership functions are named as shown in Table 2 and for example one of rule can describes as the follow: If input 1 as CE is S and input 2 as C is M then the output is GP, as membership function in Fig. 5.

Table 2. Fuzzy controller rules.

E CE	V S	S	M	L	VL
VS	PG	PM	PP	GM	PG
S	PG	PP	GP	M	PM
M	PM	M	GM	GP	PP
L	PP	GP	GG	GM	M
VL	M	M	GG	GG	GP

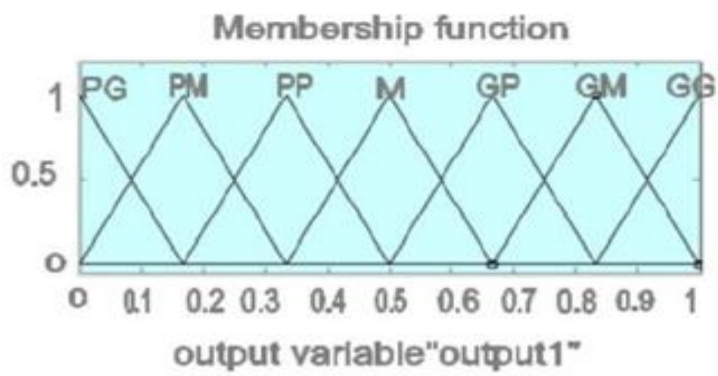

Fig. 5. Signal output function.

4.2. Simulation with Optimized Fuzzy Controller Using PSO Algorithm

Here, we simulate the system with a fuzzy logic controller optimized by the evolution of the particle swarm optimization. The fuzzy system used in this work is of the Mamdani type and the fuzzy controller acts as the maximum power point detector. The fuzzy controller consists of three main sections: the fuzzy section, the fuzzy rules section, and the defuzzy part, which are shown in Figs. 6 to 8. As shown in Fig. 6, two error inputs and error modifications are applied as fuzzy variables to the Mamdani fuzzy system. The proposed converter control system is presented based on the fuzzy logic method which intelligently tracks the maximum power point accurately and quickly, by adjusting the duty cycle of the converter, providing the most power in the output. In order to improve the performance of fuzzy logic, we used the particle swarm optimization algorithm. By this algorithm, fuzzy logic rules were selected and determined. Also, in the design of membership functions and the selection of triangular membership functions in fuzzy logic, the particle swarm algorithm was used to determine error triangular membership functions and error derivative membership functions. This evolutionary algorithm selected the three vertices of the triangle in the membership functions and delivered the appropriate function to the fuzzy system.

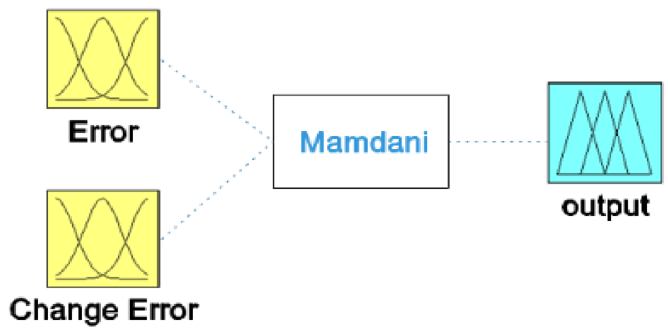

Fig. 6. The utilized fuzzy system.

In fact, the Mamdani section is responsible for receiving and processing the fuzzy rules. The fuzzy logic controller tests the photovoltaic output power for each sample and considers the power changes in voltage ($\frac{dp}{dv}$). If this value is greater than zero, the pulse width controller modifies the pulse width to increase the voltage to maximize, or makes $\frac{dp}{dv} = 0$. If

($\frac{dp}{dv}$) is less than zero, the pulse width controller modulates the pulse width to decrease the voltage to maximize power or makes ($\frac{dp}{dv} = 0$). There are two inputs for the fuzzy controller, which include the voltage-voltage curve slope, the value of which changes, so that the output varies in power and duty cycle from DC to DC convertor.

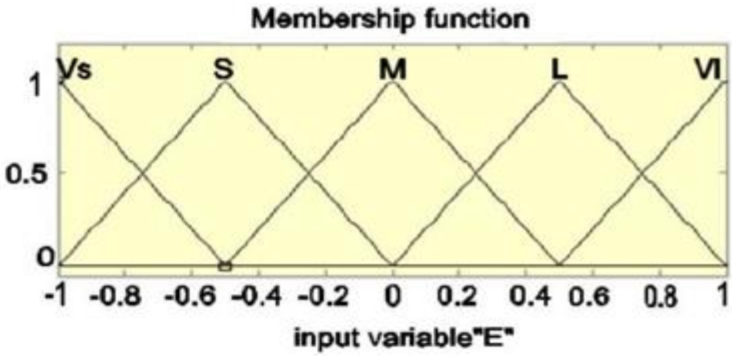

Fig. 7. Error signaling membership functions.

The membership functions and fuzzy rules have been determined in an optimal way, using the PSO algorithm. Also, as result, the proposed controller changes the duty cycle of PWM to reach the maximum voltage and approach the higher power. The main idea is that dp / dv is zero until it reaches the maximum power level.

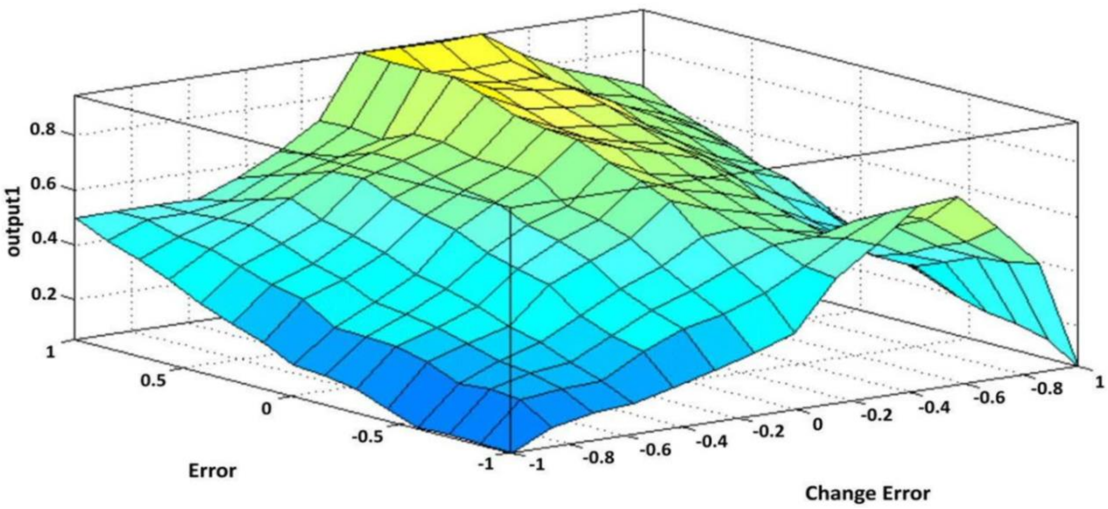

Fig. 8. Fuzzy rule changes.

In Fig. 8, the system output for fuzzy rules is show for the error signals and the system error changes. The output of the fuzzy controller is named D and it is as an input to the pulse width modulations block. The procedure for applying inputs and outputs and command rules in the fuzzy controller is given in Table 2. The fuzzy logic controller is based on the following two equations. The most commonly used defuzzification method is known as the Center of Area method (COA) and commonly is called the centroid method is used.

$$Error_{(n)} = \frac{dp}{dv} = \frac{P_{(n)}-P_{(n-1)}}{V_{(n)}-V_{(n-1)}} \tag{9}$$

$$Change\ Error_{(n)} = E_{(n)} - E_{(n-1)} \tag{10}$$

The output power and voltage signals from the photovoltaic array with the optimized fuzzy controller with PSO algorithm are depicted in Figs. 9 to 11.

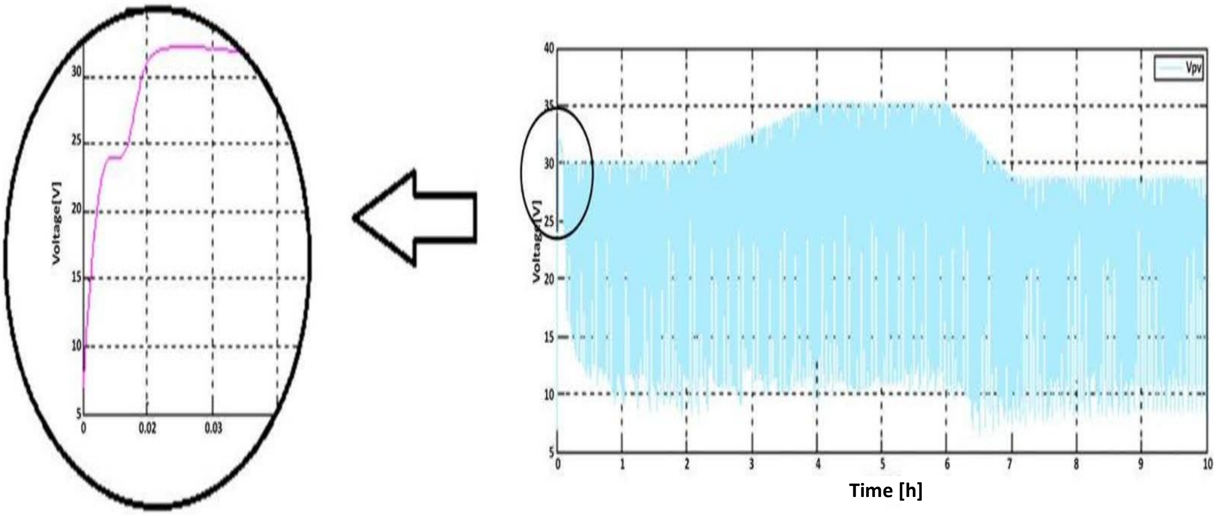

Fig. 9. Output voltage of the photovoltaic system.

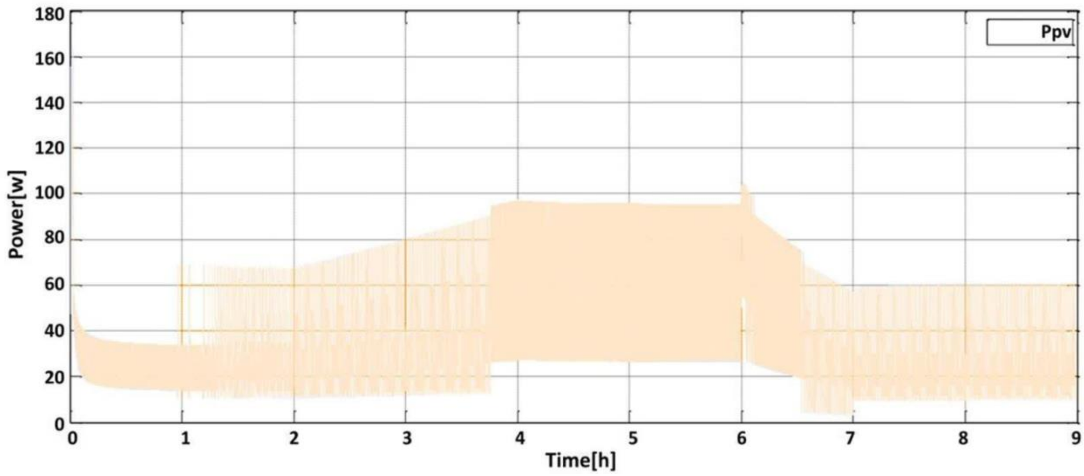

Fig. 10. Output power of the photovoltaic system.

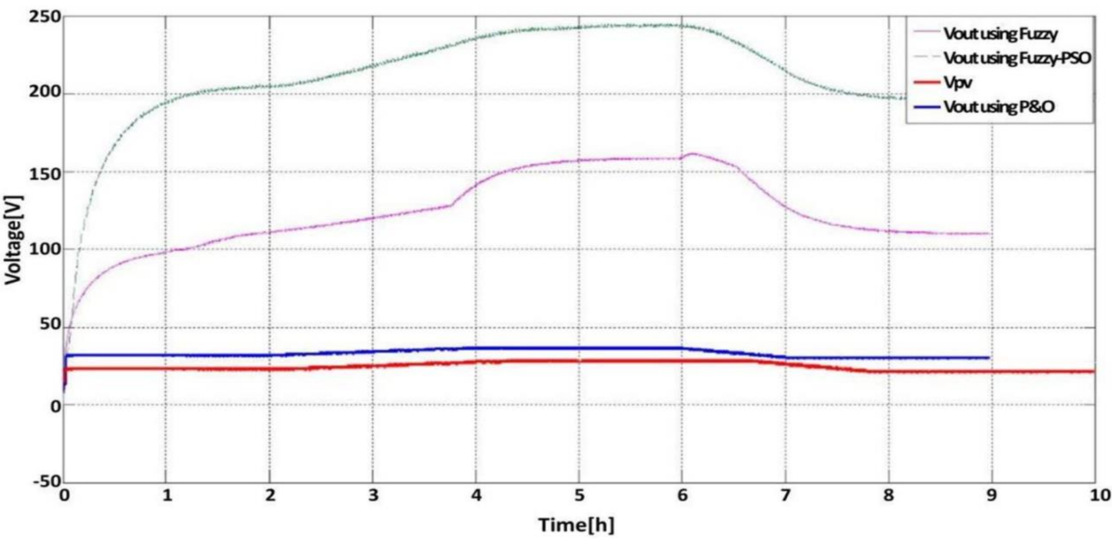

Fig. 11. Output voltage of the photovoltaic system with various algorithms

The output voltage of the photovoltaic system is exhibited in Fig. 9. It shows that because of the changes in temperature and irradiation, a small change in its output voltage is noticed.

In our simulation there is fast and rapid switching, so the switch may cause small fluctuations in non-controlled voltage simulation. Interference of the observation algorithm and fuzzy logic controller under variable environmental conditions, temperature, and radiation are nominal. The voltage is controlled by the buck-boost converter, while the fuzzy controller makes the input of the converter. The interface has a low convergence rate. The efficiency of the PSO algorithm depends on the number of particles and repetitions. The convergence rate of the algorithm depends on factors such as the acceleration of the motion. Optimization algorithms for particle swarm track the optimal value in different environmental conditions and levels of radiation. The output power is also used when using the algorithm and the particle swarm has a smaller wavelength than the P&O state.

5. CONCLUSIONS

In this paper, an optimal design of fuzzy controller for photovoltaic maximum power point tracking using PSO has been proposed for a solar panel. This scheme has the ability to track the maximum power in variable environmental conditions, including extreme changes in radiation and temperature. The main feature of this method is to reduce the static state oscillations, which is the maximum power point. This method works on the basis of optimal search, which is the main problem in most commonly used power tracking techniques. The results show that the optimized fuzzy controller with particle swarm algorithm has several advantages, in addition, to its high output efficiency. However, our proposed scheme includes a very high track rate compared to its rivals. The combination and cooperation of the fuzzy and evolutionary algorithm coherently, show the advantages of our simulations. In the future work, we will try to study the fast shadowing and nonstationary condition.

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