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Genetic algorithm to improve power output of photovoltaic system under partial shaded condition

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Article Info

ABSTRACT

The Partial Shaded Condition (PSC) is a process of non-optimal power capture in photovoltaic (PV) system; it will happen when one or all the PV solar cells get shaded by external factors. This phenomenon makes a sudden change in cell irradiance and lead to non-optimal power capture and reduces the generated power in PV systems. Cell under PSC generates one global peak (GP) and many local peaks (LPs), but the tracking of GP under (PSCs) effectively are still a big challenge to the researchers. In this paper, Fuzzy Logic Control (FLC) and optimized FLC algorithms were developed to track the PV power during the PSCs. The configuration of both algorithms are designed, simulated and evaluated using MATLAB/Simulink and their performance was compared with other literature techniques to study their capability to track the MPPT under PSCs. Proposed GA-FLC achieved 0.7 S as tracking time to find and track the Global Peak of Maximum power Point (GMPP) under PSCs and the usage of buck/boost converter in this technique achieved 98.5% of tracking accuracy. GA-FLC shows good dynamic performance in terms of tracking accuracy and complexity under PSCs compared to other techniques.

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1. INTRODUCTION

Solar photovoltaic (PV) system is one of the most famous and modern technologies ln the world, because it is clean, abundant, noise free, and friendly to the environment compared to other sources [1, 2]. The output power (P) with respect to the panel voltage (V) is equal to zero at Maximum Power Point (MPP) in PV systems. The Partial Shaded Condition (PSC) is a process of non-optimal power capture in photovoltaic (PV) system; it will happen when one or all the PV solar cells get shaded by external factors. This phenomenon makes a sudden change in cell irradiance and lead to non-optimal power capture and reduces the generated power in PV systems [3]. Cell under PSC generates one global peak (GP) and many local peaks (LPs), but the tracking of GP under (PSCs) effectively are still a big challenge to the researchers [4-8]. Numerous of MPPT techniques have been classified in tracking the MPPT under PSCs, into traditional algorithms [9-11], intelligent algorithms [12-15] and hybrid algorithms [16-22]. The LPs under PSC can be tracked efficiently and accurately using conventional, soft computing or hyper MPPT algorithms. Whereas, GP under (PSCs) can only be tracked by soft or hyper techniques and tracking speed and efficiency are still a big challenge to the researchers. Therefore, an effective MPPT technique should be carried out to track these peaks effectively and accurately in PV systems.

Based on Figure 1, the equivalent circuit of a PV model consists of a photocurrent, diode, parallel resistor which represents a leakage current, and series resistor which represents an internal resistance to the current flow.
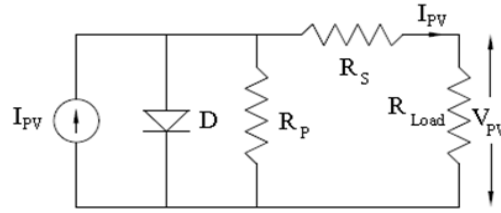

Figure 1. Equivalent circuit of PV cell

The output current equation is given by [23].

$$I = N_P I_{ph} - N_P I_o \left[\exp \left(\frac{q(V_{pv} + IR_S)}{AK\,T_c\,N_S} \right) - 1 \right] - \left(\frac{V_{pv} + IR_S}{R_p} \right) \tag{1}$$

where Ns is the number of series resistance cells, N_P is the number of parallel resistance cells and R_p is the parallel resistance, which is very high, so, its current can be neglected. The term (1) can be simplified as

$$I = I_{ph} - I_o \left[\exp \left(\frac{q(V_{pv} + IR_S)}{AK\,T_c\,N_S} \right) - 1 \right] \tag{2}$$

where q is the electronic charge ($q = 1.6 \times 10^{-19}$), k is Boltzmann's constant ($k = 1.38 \times 10^{-23}$ J/K), A is the ideal factor of the diode (A=1.6), I_o varies with the change in temperature and is given by

$$I_o = I_{ro} \left(\frac{T_c}{T_r} \right)^3 \exp \left[\left(\frac{q\,E_g\,(1/T_r - 1/T_c)}{AK} \right) \right] \tag{3}$$

where Eg is the band gap energy of the semiconductor and I_{ro} is the saturation current of the diode at 25ºC, which is calculated by

$$I_{ro} = \frac{I_{sc}}{\exp[q\,U_{oc}/AK\,T_r\,N_S] - 1} \tag{4}$$

where U_{oc} and Isc are the open-circuit voltage and short-circuit current of the PV module at STC ($T = 25º$ C, $S = 1000\,W/m^2$).

$$I_{ph} = I_{sc} + KI\,(T_c - T_r)G \tag{5}$$

where KI is the short-circuit current temperature coefficient of the cell. Tc and Tr are the cell temperature and the reference temperature, respectively. G is the relative irradiance coefficient under STC [23].

## 2. RESEARCH METHODOLOGY
2.1. FLC based MPPT structure

FLC has wide range of PV systems applications, it can play as MPP trcker under PSCs since it has the advantages such as robust, relatively simple to design and it only require the knowledge of the model [16]. In this technique, based on the characteristic of PV panel, a FLC optimized by GA, is proposed to track the MPP of the module under PSC. The process of FLC can be classified into three stages, fuzzification, rule evaluation and defuzzification and it has two inputs and one output. The input and output variables are converted into linguistic variables based on the membership functions of (6), (7), and (8) respectively [16].

$$\Delta V = V_{(K)} - V_{(K-1)} \tag{6}$$
$$\Delta P = P_{(K)} - P_{(K-1)} \tag{7}$$

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \tag{8}$$

The inputs are the change in the voltage of the PV panel (ΔV), change in the power (ΔP) and the output variable is duty cycle. Five fuzzy levels are used for inputs and outputs variables: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big) as shown in Figure 2. The MFs of the input variables; both ΔP and ΔV MFs are in triangular form and the MF of the output (duty cycle step size ΔD), which is also in triangular form.
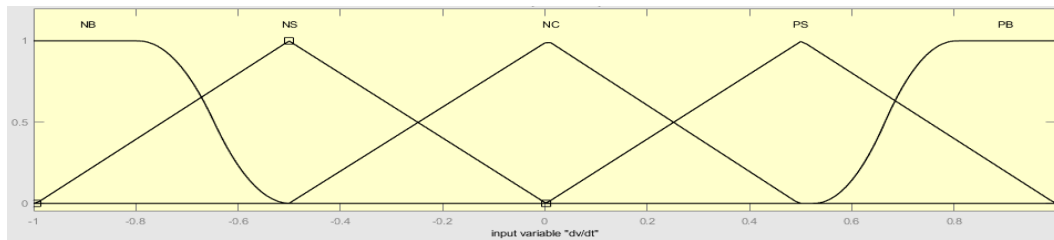
(a)
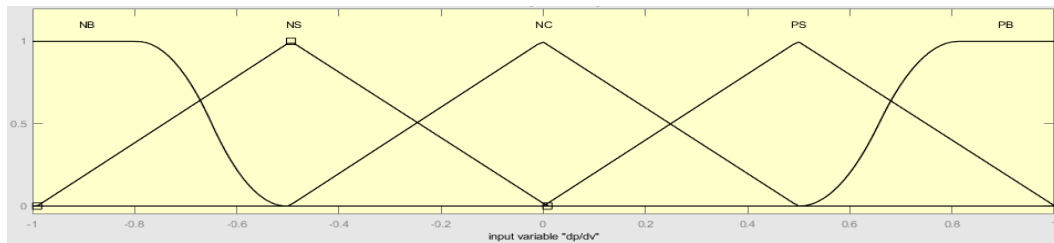
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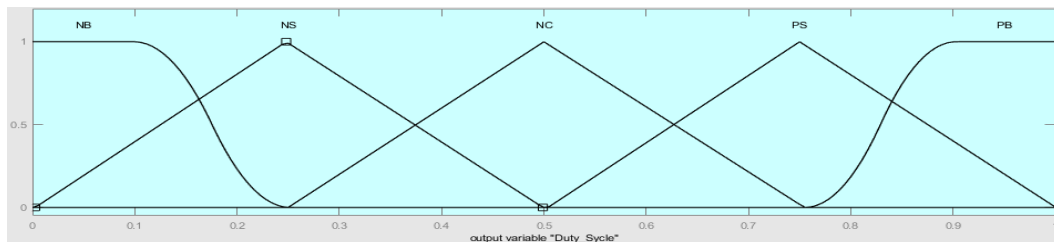
(c)

Figure 2. The Membership function of the input variable (a) (ΔV), (b) (ΔP) and output variable (ΔD)

The maximum power in the P-V curve of PV cell can be obtained when $|\Delta P/\Delta V|$ equal to zero. As shown in Figure 3, the operating point can be moved from right to left along the *P-V* curve, therefore, the algorithm has to add a large ΔD to reach the MPP if the point in A or B, or adding a smaller ΔD to reach the MPP if the operating point in C or D. The signal of ΔD depends on the operating point in the PV curve, for example if the operating point in the right side of MPP (point D or B), the ΔD will be positive value and if the operating point in the left side of MPP (point A or C), the ΔD will be negative value. Based on this concept, a complete set of fuzzy rules for the proposed FLC are summarized in Table 1.
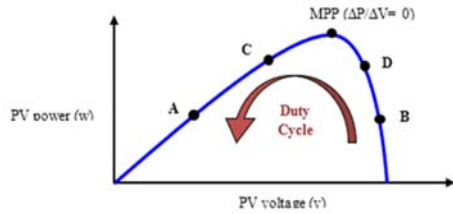
Figure 3. Proposed MPPT technique in *P-V* curve

Table 1. Memberships rules used in the FLC

		ΔP				
		ZE	NS	PS	PS	PS
		ZE	ZE	ZE	ZE	ZE
ΔV		PS	ZE	NS	ZE	NS
		PS	PS	ZE	NS	NS
		PB	NS	PB	NB	NS

2.2. Genetic optimization steps of FLC

To improve FLC's tracking speed; GA was implemented to obtain the optimal FLC membership functions. This is achieved according to the following stages:

2.2.1 The optimization criterion

The quadratic criterion to be minimized is [16].

$$J = \int_0^\infty e^2(t)\, dt \tag{9}$$

Where

$$e(t) = V_{(Max)expected}(t) - V_{(Max)PV}(t) \tag{10}$$

$V_{(Max)PV}$ is the instant tracked voltage which was given by PV module under STC.
The relations and the values between *Ci, Ci' Ci'',* and *xi, yi, zi* are respectively given by

$$\begin{cases} x_1 = C_4 + C_3, x_2 = C_3 \\ x_3 = C_1, \ x_4 = C_1 + C_2 \end{cases} \quad \begin{cases} y_1 = C_4' + C_3', \ y_2' = C_3' \\ y_3 = C_1', \ y_4 = C_1' + C_2' \end{cases}$$

2.2.2. Creation of the initial population

In the design of the proposed GA-FLC, two inputs, *V(k), P(k)*, and one output, *D*, are used. Each variable is described with five membership functions, as illustrated in Figure 4 (a). The population has a set of individuals, each individual has three chromosomes: *ΔV(k), ΔP(k)* and *D* as shown in Figure 4 (b) and described by:

- For the chromosome *ΔV* (k) the genes: C1,C2,C3,C4 in variation [-0.99 to +0.99].
- For the chromosome *ΔP (k)* the genes: C1', C2', C3', C4' in variation [-0.99 to +0.99].
- For the chromosome *D* the genes are: C1", C2", C3", C4" in variation [-0.99 to +0.99].

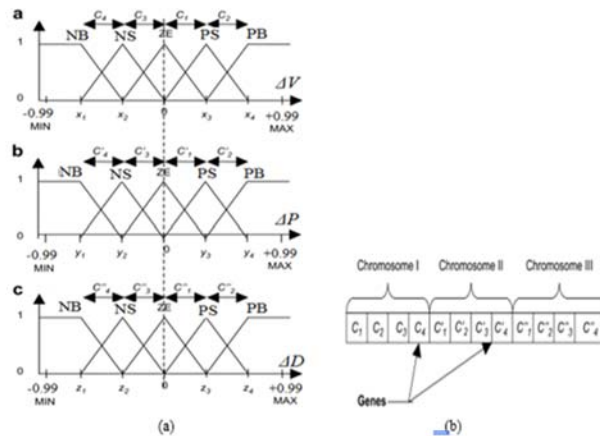Figure 4. (a) Memberships function coding *ΔV*, *ΔP* and *ΔD*, (b) Description of an individual

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3. RESULTS AND ANALYSIS

3.1. Effect of the irradiance and temperature on PV system

Depending on Figure 5, the PV module was designed using modeling terms (1), (2), (3), (4) and (5) which are discussed in section 1. The module has three inputs: radiation intensity, voltage and operation temperature, and two outputs: voltage and current (power can be obtained by multiply voltage in current). The MPPT was designed using GA-FLC. The input voltage was adjusted to 24 V, the radiation adjusted to 1000 W/m^2 and the operation temperature was adjusted to three values (25°C - 50°C - 75°C).
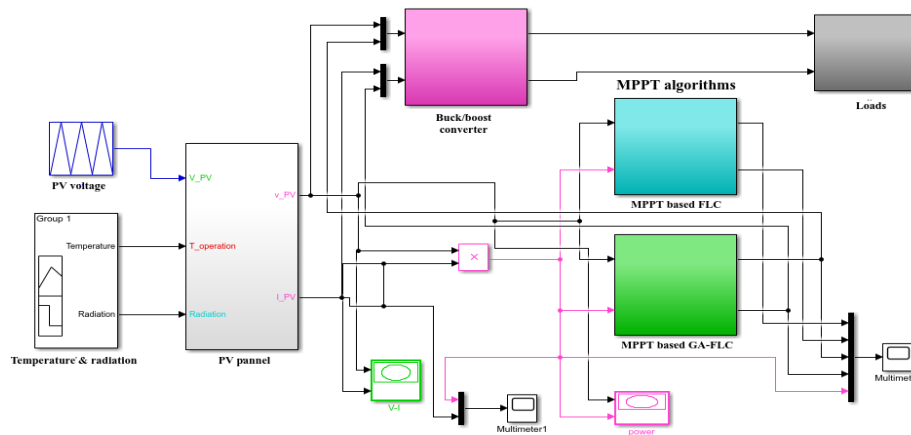

Figure 5. PV module under PSCs with MPPT algorithms in Simulink MATLAB

To discover the effect of temperature on the solar PV performance, solar irradiation level was assumed constant at 1000 W/m^2 while allowing temperature to vary between 0 °C and 75 °C and the result is shown in Figure 6 (a), for the I-V and P-V characteristics as temperature was set to 25, 50 and 75 °C respectively. The cell voltage decreases as operating temperature increases and output power decreases. This indicates that operating temperature can affect on both voltage and power output of the solar panel significantly. Figure 6 (b) shows the changes in open-circuit voltage and current of PV panel when a panel temperature increases. When operating temperature is increased, the current decreases and the voltage increases. This indicates that, temperature of the PV panels can affect in both efficiency and power output of the solar panel.
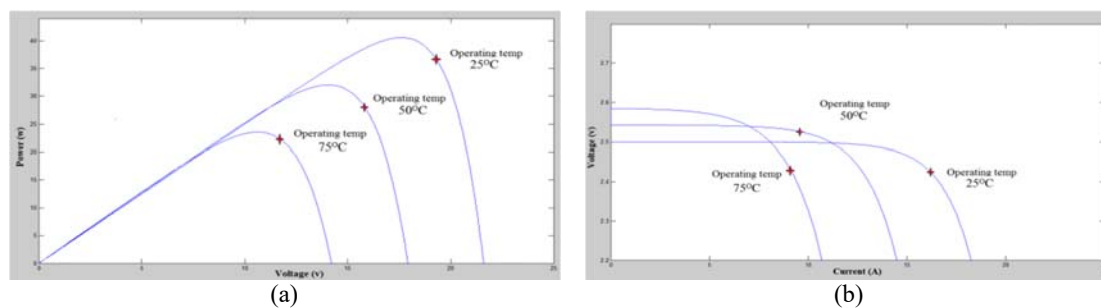

Figure 6. (a) P–V curve under temperature changes, (b) I–V curve under temperature changes

3.2 Performance of the proposed MPPT based GA-FLC

Figure 7 (a) shows the performance of proposed MPPT based FLC and GA-FLC to the fast change during PSCs. The results proved that, when radiation changes happened during PSCs, the MPPT algorithm based GA-FLC responded faster than FLC to overcome power decreasing in the solar panel. The response time of GA-FLC is about 0.7 S and for FLC is about 1.75 S. Based on Figure 7 (b), when power of PV panel dropped down by PSCs both FLC and GA-FLC algorithms overcome this dropping, but the overcome of optimized FLC is bigger than FLC. Also, in Figure 7 (c), when generated power by PV cell was dropped,

both FLC and optimized FLC algorithms discharged power from the battery to overcome this dropping and this case, the performance of optimized FLC is better than FLC, but the tracking speed needs more analysis and discussions in real time experiment under different atmospheric conditions.
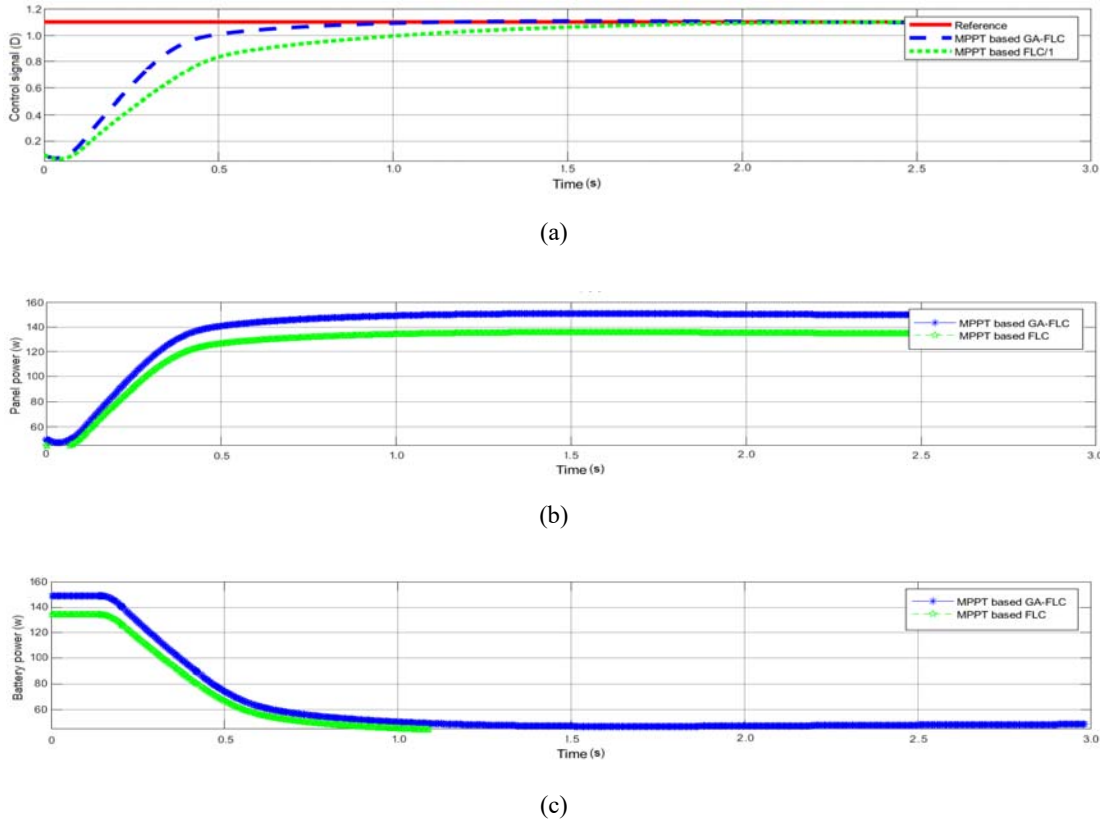

(a)

(b)

(c)

Figure 8. (a) Response of the MPPT based FLC and GA-FLC to the PSCs change, (b) response of proposed algorithms to the discharge in PV panel during PSCs change; (c) response of proposed algorithms to the overcharge in the battery of PV panel during PSCs change

Table 2 shows the results obtained from proposed GA-FLC algorithm under PSCs compared to other MPPT techniques under PSCs in literature review. The results proved that, the proposed GA-FLC is the most efficient algorithm to find and track GMPP in terms of accuracy, tracking speed and complexity under PSCs comparing to other techniques such as FLC, GA-P&O and ANN-FLC.

Table 2: Results of proposed GA-FLC compared to other MPPT techniques under PSCs

Refference	Year	MPPT technique	Converter	Accuracy %	Tracking speed (s)	Level of technique Complexity
[24]	2014	GA-P&O	Buck	95.5	0.9	High
[22] [25]	2009 2018	ANN-FLC	Boost	92.1	0.85	High
[16]	2012	GA-FLC	Boost	95	-	High
Prposed MPPT	2019	FLC	Buck/boost	86	1.75	Low
Prposed MPPT	2019	GA-FLC	Buck/boost	98.5	0.7	Medium

4.   CONCLUSION

In this paper, FLC and optimized FLC algorithms were developed to track the PV power during the PSCs. The configuration of both algorithms is designed, simulated and evaluated using MATLAB/Simulink and their performance was compared with other literature techniques to study their capability to track the MPPT under PSCs. Proposed GA-FLC achieved 0.7 S as tracking time to find and track the GMPP under

PSCs and the usage of buck/boost converter in this technique achieved 98.5% of tracking accuracy. The tracked power of PV systems under PSC is affected directly by the tracking speed and any delay in tracking time affects in efficiency of a whole system. The obtained results proved that, proposed GA-FLC showed good dynamic performance in terms of tracking time, accuracy and complexity under PSCs compared to other techniques such as FLC, GA-P&O and ANN-FLC. For the future work, the performance of proposed optimized FLC needs to be validated by experimental test. Furthermore, the tracking speed needs more analysis and discussions under different atmospheric conditions.

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