Apply Modified PSO Algorithm Technology Based on MPPT of a Photovoltaic System Under Condition Difference

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Abstract

Solar systems are considered one of the easiest and least expensive ways to implement, but their low efficiency and short life cycle are the major obstacles to their use, as they are completely linked to external climatic factors such as temperature and solar radiation.

To increase its efficiency, the researchers relied on tracking the maximum power point of the photovoltaic system using classic and modern control techniques it differs among themselves in terms of simplicity and complexity in implementation, so choosing an appropriate control technique is important to obtain the best results.

In this work, modified control Particle Swarm Optimization algorithm PSO for maximum power point tracking and comparative study with fuzzy logic.

Both technologies are classified under the category of intelligent control. To achieve the system, the MATLAB/SIMULINK simulation environment is used for both techniques and compared the results, according to these results and under similar standard test conditions, it is concluded that both methods are highly effective, but the PSO method provides a better response rate and tracking accuracy than fuzzy logic.

Keywords: photovoltaic (PV), fuzzy logic controller (FLC), boost converter, particle swarm optimization algorithm (PSO), tracking the maximum power point (MPPT).

1. Introduction

With some countries, including the United States of America, relying on the manufacture of electric cars and other consumption models such as smart homes to reduce greenhouse gas emissions, they expect energy demand to increase by 30% by 2040, but power generation using traditional sources such as fossil fuels constitute a threat to the environment to increase emissions. This makes the trend towards generating energy from renewable and environmentally friendly sources, such as solar energy, an appropriate economic and environmental solution. In addition, it is used as an economical option in many applications such as lighting, water pumping, etc...[1] Under weather changes (radiation and temperature) Characteristics of P-V and I-V are non-linear, so controllers based on algorithms of different complexity are used for maximum power point tracking (MPPT) to increase the efficiency of PV systems [2].artificial intelligence techniques and their applications for MPPT such as intelligent algorithm [3-4] and neural networks [5-6] and fuzzy logic controllers (FLCs) [7-8]have significantly improved the tracking performance under different conditions compared with conventional methods. FLCs are intelligent systems with features that make them attractive to system designers. Among these features are insensitive to variation of the structure, parameters, and operating conditions of non-linear controllers [4]. Particle swarm optimization (PSO) technology is considered one of the best control techniques, the most effective, the simplest to implement, and its results are more accurate [9]. It uses a swarm of potential solutions to find and improve the optimal solution [10]. In this paper, a comparative study of two techniques for MPPT algorithms fuzzy logic and PSO is presented. These two methods are applied to control the switch of the boost converter device by adjusting the duty cycle to track the maximum power point to increase the efficiency of the solar PV array.

2. PV array system

A solar photovoltaic cell is essentially a p-n semiconductor. When photons fall on the cell, a phenomenon called the photoelectric effect [11-12] generates a dc that changes linearly with the photovoltaic irradiance to design a photoelectric application [13].

The photovoltaic cell is modeled with an equivalent circuit as shown in Figure1, while Figure 2 shows the characteristics of the PV array.

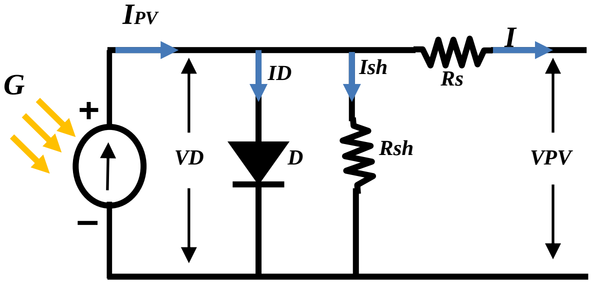


Figure.1. Equivalent circuit for a PV cell.

Through the equivalent circuit, the current is expressed by the following Eq. (1):

$$I = I_{PV} - I_D - I_{sh} \qquad (1)$$

Equation (2) is the (I_{PV}) current is given by the form:

$$I_{PV} = [I_{sc} + K_I(T_c - T_{ref})]\, G/G_{ref} \qquad (2)$$

and (I_D) is the Shockley diode equation which can be represented as follows Eq. (3) [13]:

$$I_D = I_s\left(e^{\left(\frac{q.(V+R_sI)}{N.K.T}-1\right)}\right) \qquad (3)$$

Equation (4) for current (I_{sh}) in resistance (R_{sh}) is as follows:

$$I_{sh} = \frac{(V+R_sI)}{R_{sh}} \qquad (4)$$

Substituting Eq (2), (3), and Eq. (4) in Eq (1), the expression for current is as follows Eq. (5):

$$I = [I_{sc} + K_i(T_c - T_{ref})]\, G/G_{ref} - I_s\left(e^{\left(\frac{q.(V+R_sI)}{N.K.T}-1\right)}\right) - \frac{(V+R_sI)}{R_{sh}} \qquad (5)$$

Where

I_{PV}: current generated by the incident light.
I_{sc}: the short-circuit current[A].
K_i: the temperature coefficient of the short-circuit current [%/K].
I_D: The Shockley diode equation.
V_D: voltage across the diode (V).
V_{PV}: solar cell output voltage (V).
I_s: reverse saturation current of the diode (A).
q: electron charge (1.60217646*10^-19c).
K: Boltzmann constant (1.3806503*10^-23) and T is cell Temperature in Kelvin (k) and N is Ideality factor of the diode, R_s is solar cell series resistance (Ω), R_{sh} is shunt resistance of cell (Ω).

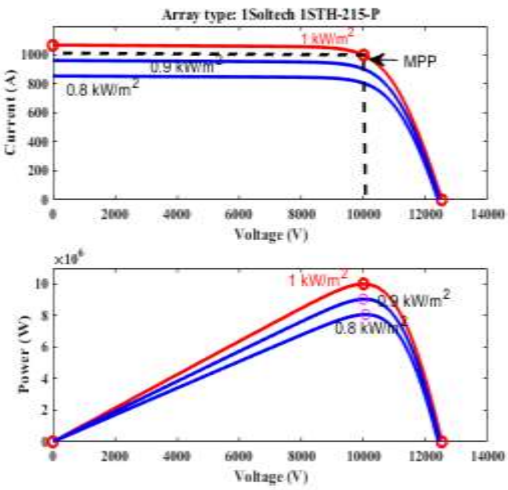


Figure 2. I-V and P-V characteristics of PV array.

3. DC-DC boost converter

The boost converter is a DC-DC step-up converter. It raises the low input voltage and lowers the high input current. Its principle of operation is simple; the switch in the boost converter is opened and closed by transmitting a PWM pulse. The current flowing through the inductor (L) forms a magnetic field stored as induced voltage when the switch is on. when the switch is off the output capacitor (C_{out}) is charged to a voltage higher than the input voltage by the induced voltage. The following Figure 3 shows the design of the boost converter [14] [15].

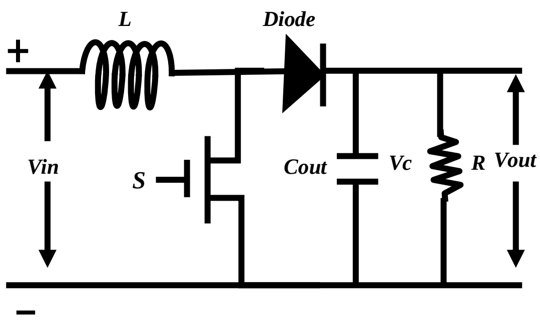


Figure 3. DC-DC Boost Converter.

The relationship between the input voltage V_{in} and the output voltage V_{out} of a boost converter is expressed by the following Eq. (6).[13]:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \tag{6}$$

Where D is the duty cycle, it is between 0 and 1.

3.1 Choice of inductor

At the maximum input voltage of the ripple current of an inductor, the value of the inductor is determined by the following Eq. (7):

$$L = \frac{V_{out}(V_{out}-V_{in})}{\Delta_{IL} \cdot f_{sw} \cdot V_{out}} \tag{7}$$

Where, Δ_{IL} is the estimated inductor ripple current.

For high efficiency up to 95%, the boost converter is operated in continuous conduction mode [16] and the following Eq. (8) determines the boundary value of the inductance:

$$\mathrm{L_b} = \frac{\mathrm{DR_0(1-D)^2}}{\mathrm{2f_{sw}}} \tag{8}$$

3.2 Choice of capacitor

The value of the capacitor is calculated by estimating the change in voltage ripple ΔV_r by the following Eq. (9):

$$C = \frac{D}{R.f_{sw}.\Delta V_r} \tag{9}$$

For a voltage ripple of 1%, the minimum capacitor value is calculated by the following Eq. (10)[13]:

$$C_{min} = \frac{D}{R.f_{sw}.0.01} \tag{10}$$

4. MPPT techniques

In the topologies or the literature, there are many algorithms and MPPT designs to track the maximum power point of a PV system, some simple and others more complex, which depends on the change in voltage or current These algorithms generate a duty cycle (D) changes in the form of PWM pulses that control the switching in the usually used boost converter., these techniques are also used in different sources such as wind power, fuel cells, etc. [14], Here two methods of different complexity are discussed.

4.1 MPPT based on PSO algorithm

Metaheuristic techniques and their ability to capture GP and avoid falls in one of the LPs contributed to its selection as the MPPT for the PV system. The PSO algorithm is considered one of the best metaheuristic techniques, and it is a high-quality research tool in engineering applications. The founder of this algorithm was James Kennedy and Russell Eberhart in 1995 [16-17]. He was inspired by the idea of the social and cooperative behaviour of different animals, such as flocks of birds. This method depends on a swarm of particles.

The output power is calculated by measuring the current and voltage of the photovoltaic array, and the PSO algorithm and its duty-cycle fitness that controls the switching is applied to the boost transformer to reach the [19] [19-20]. The search process is carried out through some steps as follows:

Step 1: Initialization of PSO parameters, Initialization of particle position and velocity.

Step 2: The output power is calculated by measuring the current and voltage of the photovoltaic array

Step3: Each particle searches for the best solution within a random molecular value; each particle compares the best value between the previous and next values (P_{bi}) and (X_i^k), respectively, to determine and choose the best. Particle positions are defined as the duty cycle of the DC-DC converter.

Where the current value of power P (d_i^k) is compared with the value of the previous vector P($d_{best,i}^{k-1}$). If the current power is greater, P($d_{best,i}^{k}$) is refreshed, and the duty cycle value is stored in a vector $d_{best,i}^{k}$. If the condition is not met, the current power is compared to the best global power value $G_{best,i}^{k}$, if the current power value exceeds $G_{best,i}^{k}$, the transmission is updated $G_{best,i}^{k}$, and the duty cycle value is stored in the variable $dG_{best,i}^{k}$. This process is repeated until all particles have been evaluated.

Step 4: The velocity and position of each particle in the swarm are updated by Eq (11) and Eq (12).

$$V_i^{k+1} = \omega(k).V_i^k + r_1.c_1\left(P_{bi} - X_i^k\right) + r_2.c_2\left(G_{bi} - X_i^k\right) \quad (11)$$

$$X_i^{k+1} = X_i^k + V_i^k \quad (12)$$

Therefore, the velocity of each duty cycle and the swarm particle can be calculated by Eq. (13). Eq. (14)

$$V_i^{k+1} = \omega(k).V_i^k + r_1.c_1\left(d_{best,i}^k - d_i^k\right) + r_2.c_2\left(G_{best,i}^k - d_i^k\right) \quad (13)$$

$$d_i^{k+1} = d_i^k + V_i^k \quad (14)$$

Finally, the convergence criterion of the algorithm is verified, if the criterion is not met, the iteration number is incremented and returns to the objective evaluation function, but the maximum power tracking is terminated if the criterion is met. Figure 4 show a Flowchart of modified the MPPT PSO algorithm.

Where
X_i^{k+1},X_i^k is the position of each particle in the current and previous iteration,
V_i^{k+1},V_i^k is the particle's velocity in the current iteration and the previous iteration.

k: The number of repetitions,

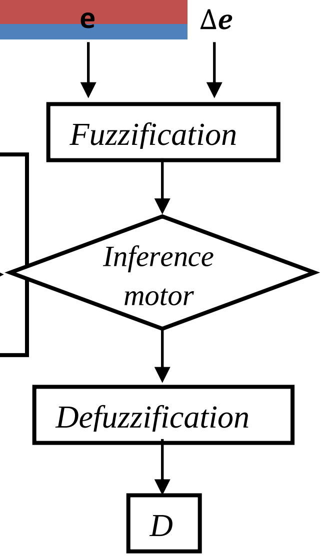
ω =0.45 Factor of the inertia weight of velocity
$c_1 = 0.9, c_2 = 1.25$ is Cognitive and social parameters, respectively,
$r_1 = r_2 = 0.3$ is random variables between 0 and 1.

4.2 MPPT based on FLC

Researchers have largely abandoned the classical control theories and methods because it depends depend mainly on the mathematical model of the controlled system.

Considering the change of parametric because of the work of the system, these control techniques can lose their accuracy and efficiency [19-20].

This necessitated the use of modern techniques such as fuzzy logic, as they do not require an accurate mathematical model, as they can work with fuzzy input values and deal with non-linear systems. The MPPT-FLC fuzzy controller synthesis collection goes through three basic stages: fuzzification, inference motor, and defuzzification as shown in Figure 5[24-25].



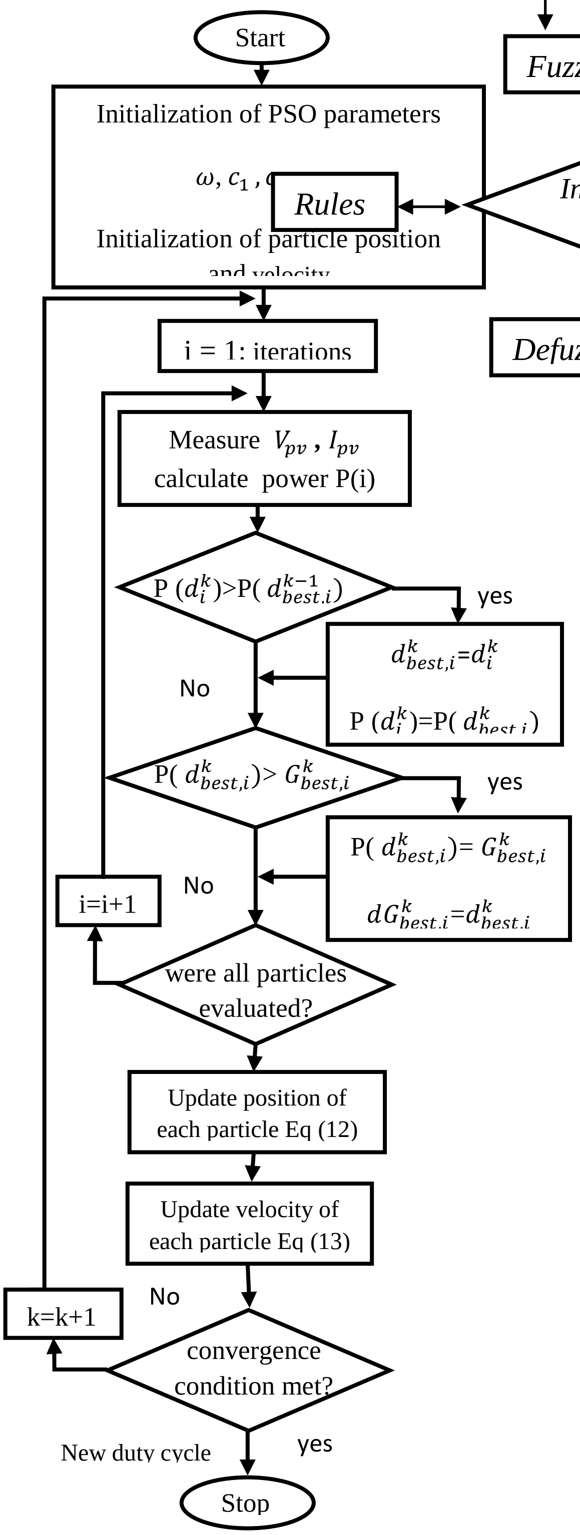


Figure 4. Flowchart of modified the MPPT PSO algorithm.

Figure.5. The stages structure of the fuzzy controller.

- **The fuzzification**: in this stage, the numeric input variables are transformed into Linguistic variables according to the membership function. There are two inputs, the voltage e, and the change in the voltage Δe shown in Eq. (15) and Eq. (16).

$$e(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \qquad (15)$$

$$\Delta e = e(k) - e(k-1) \qquad (16)$$

The alphabet expresses linguistic variants where P and N represent positive and negative, respectively. In contrast, Zero Equivalent, Big, Middle, and Small are expressed as ZE, B, M, and S, respectively. Figures 6,7,8. show the structure of the membership functions of (e), (Δe), and D.

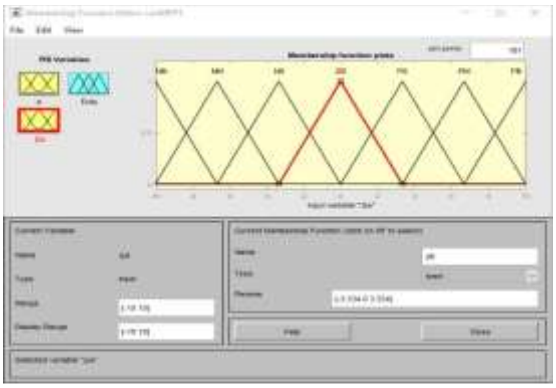


Figure 6. Software interface with membership functions of (e) input.

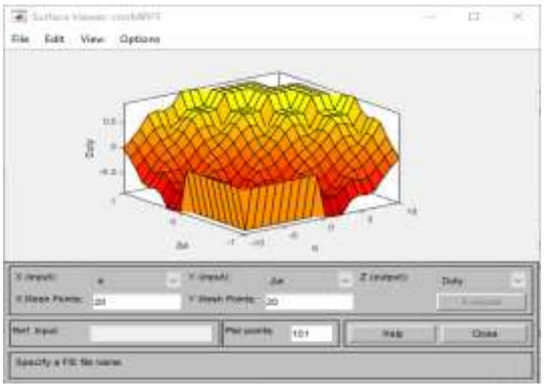


Figure 7. Software interface with membership functions of (**Δe**) input.

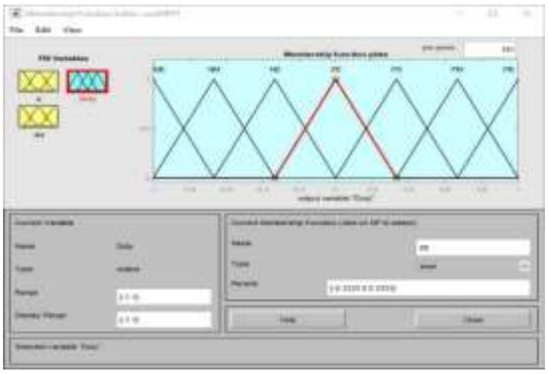


Figure 8. Software interface with membership functions of duty cycle output.

Inference engine: in this stage, the change in the duty cycle D is calculated based on Mamdani using Eq. (17)

$$(\text{Rule}_i): \text{if}\{e(k) \text{ is NB and } \Delta e(k) \text{ is PS}\} \text{ then } \{\Delta D \text{ is NM}\} \qquad (17)$$

Where D represents the fuzzy logic output, Table 1. 49 summarizes the fuzzy control rule, which is used to control the DC-DC boost converter connected to the PV array, while Figure 9. shows the surface viewer MPPT-FLC.

Table 1 FLC RULES

		variation of the error (Δe)						
		NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
Error (e)	**NB**	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NM	NB	NM	NS	ZE	PS
	NS	NB	NS	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PS	PM	PB
	PM	NS	ZE	PS	PS	PM	PM	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

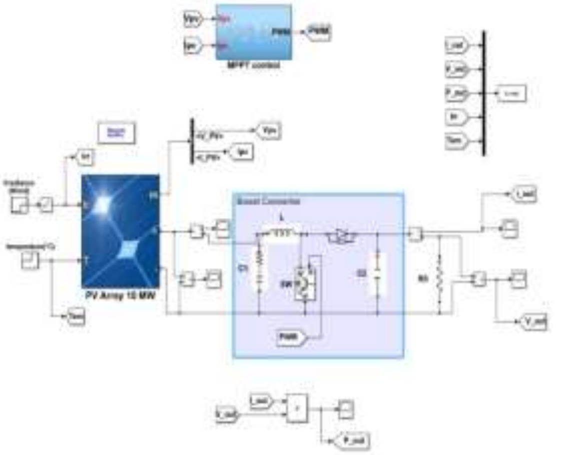


Figure 9. Software interface with surface viewer MPPT-FLC.

- **The defuzzification:** in this stage, the deduced variables are converted from linguistic variables to numerical variables to be connected to the reinforcement converter to control it.

The defuzzification is based on the weighted average method in designing FLCs because it is simple and gives good results. This method is given by the following Eq. (18) [6]:

$$D = \frac{\sum_i^n \mu(D_i) D_i}{\sum_i^n \mu\,(D_i)} \quad (18)$$

The output value D is converted to PWM by a DC-DC generator to control the gate MOSFET of the boost converter.

5. Simulation and Results

A simulation of the photovoltaic system is carried out on the basis of FLC and on basis of PSO the results are compared in a MATLAB / Simulink environment.

The system consists of a PV array of 1Soltech 1STH-215-P (136 parallel strings and 345 series panels for each string) connected to a Boost converter.

Figure 10. shows the proposed system, while Table 2 and 3 shows the specifications of the photovoltaic system and DC-DC Boost converter used. The system has been tested under different irradiation and temperature conditions shown in Figures 11,16.

Figure 10. PV system model in MATLAB/Simulink.

Table 2 Specifications of the PV array

Parameter		PV array
Maximum power	P_{mpp}	10 MW
Maximum power point voltage	V_{mpp}	10 KV
Maximum power point current	I_{mpp}	999.6 A
Open circuit voltage	V_{OC}	12.520 KV
Short circuit current	I_{SC}	1066 A

Table 3. Specifications of Boost Converter.

Parameter		Boost Converter
Voltage ripple	ΔV_r	≤ 1 %
Current ripple	Δ_{IL}	≤ 20 %
The minimum capacitor	C_{min}	150 uF
The boundary value of the inductance	L_b	12.520 KV
Switching frequency	f_{sw}	10 KHz

5.1 Case Solar irradiance difference

In this case, defaults values of different radiation conditions (1000W/m2 900W/m2 800W/m2), and constant temperature (25°C) and resistive load = 40.9 are applied as shown in Figure 11.

Figures 12,13,14 show the results of the output current, output voltage and output power of the boost converter using the FLC and PSO algorithm.

In these Figrues, we have noticed that the two methods have the same oscillation, but the PSO algorithm method is more stable than the FLC method, and the output current, output voltage and output power are greater than the FLC method.

Figure 14 also shows theoretical power that is obtained from the PV arrays given in Figure 15. Moreover, the two methods tested try to keep the output power close to or equal to its maximum value.

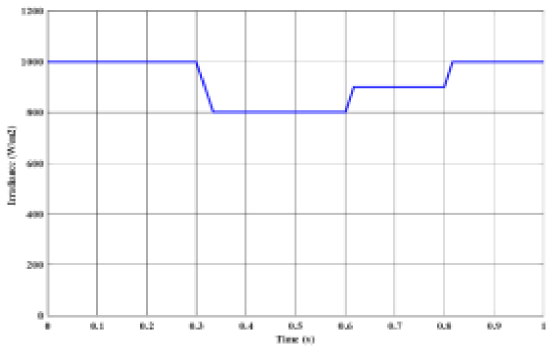


Figure 11. Solar irradiance profile variation.

Figure 12,13 and 14 show the results of the output current, output voltage, and output power of the boost converter using the FLC and PSO algorithm.

In these figures, we have noticed that the two methods have the same oscillation, but the PSO algorithm method is more stable than the FLC method, and the output current, voltage, and power are greater than the FLC method. Figure 14 also shows the theoretical power obtained from the PV array given in Figure 15.

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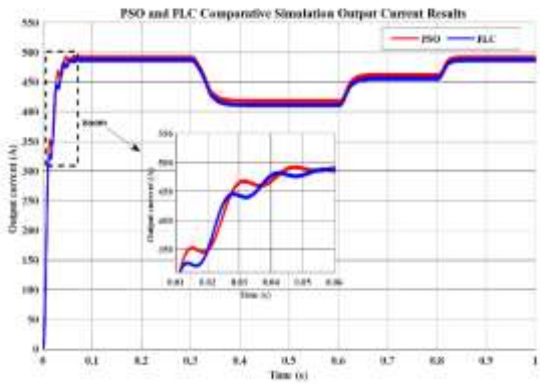

Figure 12. The Boost output Current Results of PSO algorithm and FLC.

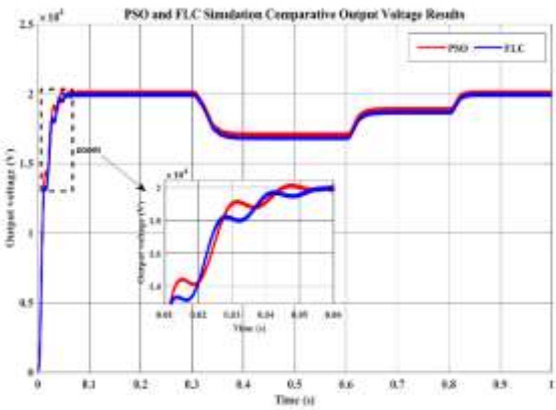

Figure 13. The Boost output Voltage Results of PSO algorithm and FLC.

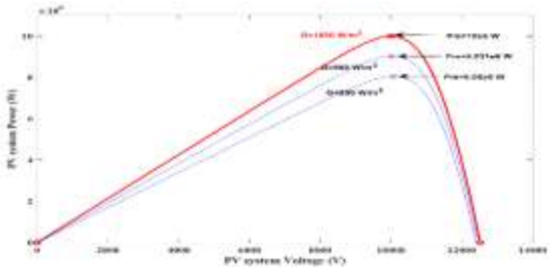

Figure 14. P-V curves of PV system at different insolation conditions.

Table 4 summarizes the MPPT efficiencies values for two techniques applied under different insolation conditions. The results show that the efficiencies of the two technologies are good even at rapid changes in insolation.

However, the algorithm PSO gave efficiency and performance index is slightly better than the FLC technique.

Table 5. MPPT efficiency under different temperature conditions.

Irradiance (W/m2)		1000	900	800
Theoretical power from PV array (MW)		10	9.031	8.06
PSO MPPT	Power (MW)	9.955	8.806	7.202
	Efficiency (%)	99.55	97.51	89.35
FLC MPPT	Power (MW)	9.783	8.570	6.963
	Efficiency (%)	97.83	94.89	86.39

where the MPPT efficiency is calculated by the following relation Eq. (16):

$$Eff = \frac{Power\ from\ MPPT\ technique}{Theoretical\ power\ from\ PV\ array} \times 100 \qquad (16)$$

5.2 Case Temperature difference

In this case, default values of different temperature conditions (25°C, 35°C, 45°C) and constant irradiance 1000 (W/m2) are applied, as shown in Figure 16.

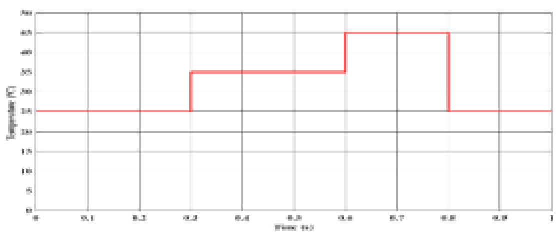

Figure.16. Temperature profile variation.

Fig 17 and 18,19. Represent the results of the output current, output voltage, and output power of the boost converter using FLC technology and PSO algorithm, while Fig.20 shows the theoretical power of the photovoltaic array at different temperatures. Table 5 shows the efficiency results of the PV array obtained under different temperature conditions.

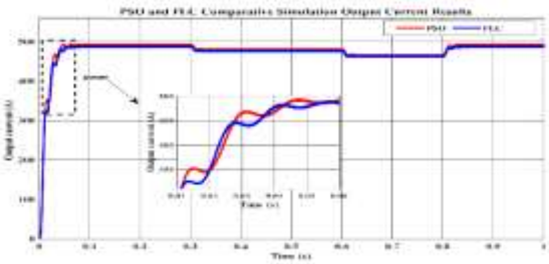

Figure 17. The Boost output Current Results of PSO algorithm and FLC.

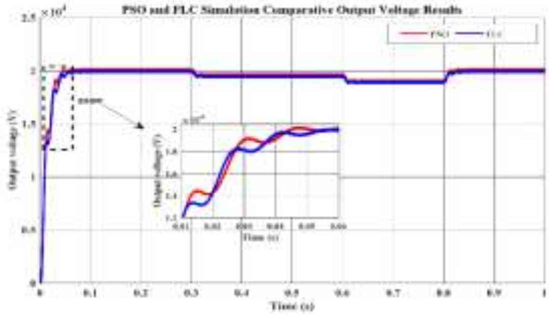

Figure 18. The Boost output Voltage Results of PSO algorithm and FLC.

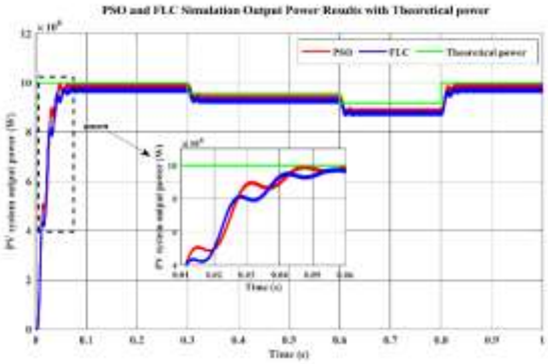

Figure 19. The Boost output Power Results of PSO algorithm and FLC.

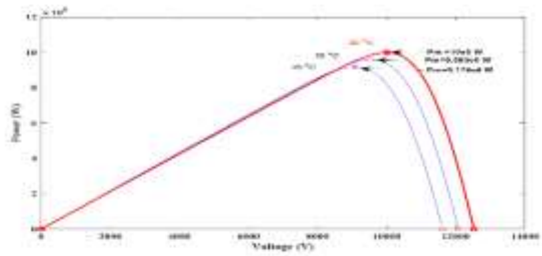

Figure 20. P-V curves of PV system at different temperature.

Table 5. MPPT efficiency under different temperature conditions.

Temperature (°C)		25	35	45
Theoretical power from PV array (MW)		10	9.583	9.176
PSO MPPT	Power (MW)	9.955	9.457	8.930
	Efficiency (%)	99.55	98.69	97.32
FLC MPPT	Power (MW)	9.783	9.342	8.824
	Efficiency (%)	97.83	97.49	96.16

Through Figure 19 and Table 5, when the temperature changes, the two methods try to make the output power of the PV arrays very close to the maximum power.

Hence, it can be said that both technologies have an excellent efficiency of more than 96%.

Through some previous studies and the results obtained, the results can be compared with [1][7][25-26-27] . It can be said that the presented study gave good and close results in terms of efficiency, but it offers a more stable power output.

6. CONCLUSION

In this study, we apply the Modified PSO algorithm for maximum power point tracking and comparative with FLC technology, the two proposed technologies are simulated in MATLAB/Simulink.

The obtained results show that both techniques extract the maximum power of the photovoltaic arrays under different weather conditions and provide high efficiency and very close performance under all the applied conditions.

The two techniques show a ripple caused by fluctuation around the MPP that affects the average maximum power output.

It is also concluded that MPPT based on the PSO algorithm extracts higher average power than FLC technology.

7. FUTURE WORK

In future works, can possibly mix the FLC method with the PSO method to get better results, especially in terms of efficiency and performance.

Besides, can use optimization techniques from one of the meta-heuristic techniques for better results.

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