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Improving the Efficiency of Solar Systems by Tracking the MPP under Different Test Conditions

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Abstract—The great technological development, the increase in the number of factories, and the large population growth led to an increase in the demand for the consumption of electric energy that we get from traditional methods (fossil fuels). Moreover, the global shortage in fossil fuel sources and their high costs, the global financial and economic crisis, and the harmful emissions it causes for the environment have made researchers look for electrical energy from alternative and environmentally friendly sources. As a renewable energy, solar energy is considered one of the most important sources of electrical energy today because it is easy to obtain at a low cost. However, this type of energy suffers from low efficiency and is greatly affected by changing weather conditions. To address this problem, several techniques have been proposed by research groups, and MPPT is one of those techniques that has been frequently used in recent years to extract maximum power from solar panels despite the instability in weather conditions. This technique can also generate pulses to control the DC-DC boost converter to provide a certain level of voltage. In this paper, three algorithms, namely Perturbation and Observation (P&O), Fuzzy Logic Controller (FLC), and Particle Swarm Optimization (PSO) are modified and applied in the MPPT technology to control the duty cycle of a DC-DC converter. The photovoltaic system consisting of MPPT technology, solar panels, and a DC-DC boost converter was simulated using MATLAB/Simulink. The performances of the three algorithms were compared to determine the best one that guarantees the highest efficiency under multiple test conditions. The simulation results show that PSO was a better performer than others with (99.32%, 97.02%, and 98.33%, respectively).

1. INTRODUCTION

The reason for the increase in demand for electric energy that we get by traditional methods from fossil fuels (gas and oil derivatives) is large population growth and the increase in the number of factories and companies [1]. In addition, traditional electric power generation causes environmental pollution and great noise, as well as a significant rise in fossil fuel prices [2, 3]. All these factors and others have increased the interest of researchers to look for alternative ways to generate electricity from cost-effective, less noisy, and eco-friendly sources. Renewable energy is the best option that has attracted considerable attention from those interested in this field in recent years [4, 5]. To counteract the shortcomings of these traditional methods, renewable energy sources have been developed into a dependable and clean alternative. These kinds of sources rose to the top of the list of electricity sources needed by electric networks worldwide. The majority of contemporary nations have recognized the value of photovoltaic systems (PV) and are investing large sums of money each year using this kind of energy [6].

Renewable energies (such as solar energy, wind energy, hydro energy, tidal energy, geothermal energy, and biomass energy) are important sources of electricity generation. Because of its availability and ability to provide ecologically friendly, silent, and endless energy, solar energy is regarded as one

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of the most significant sources of renewable energy for the production of electricity [7, 8]. Therefore, researchers and major investment companies in the field of solar energy, especially in Europe, China, and the United States, care about solar energy and work to develop it to find advanced ways to harvest it. However, solar energy suffers from decrease in its efficiency due to the great impact of changes in weather conditions such as temperature and intensity of solar radiation which make its (I-V) curve have clear nonlinear characteristics [9–11]. This is due to being totally dependable on solar panels as the only medium for converting this kind of energy into electric one. These panels are connected in different ways (series or/and parallel) in the photovoltaic system based on the required current and voltage for the loads. Each panel consists of a group of cells that are mainly made of semi-conductive materials that produce electrical energy when sunlight falls on them. The value of the voltage and current generated by such panels depend mainly on two factors: the intensity of irradiation and ambient temperature. The standard values adopted globally by manufacturing companies for these factors are $1000\,\mathrm{W/m^2}$ and 25°C, respectively [12].

The issue of increasing the efficiency of photovoltaic systems has become the focus of many manufacturers, developers, and researchers in the field of solar energy to find ways to increase their efficiency [13]. Today, charge controllers are considered one of the most important methods that adjust the voltage and current values coming from the solar panels and going to batteries [14]. These controllers play a vital role in reducing wasted energy, increasing the speed of charging batteries, and improving the efficiency of the overall system functionality. Therefore, charge controllers have become an important part of solar energy systems. These controllers are classified into two main types: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking) [11, 15]. Because of its high efficiency in extracting the maximum power from solar panels and providing a faster charging rate for batteries, MPPT technology has become a preferable alternative compared to PWM one [15]. Due to this researchers have proposed several algorithms to be applied in MPPT to achieve the aforesaid advantages [16, 17]. Among the traditional and commonly used algorithms with MPPT were Perturb & Observe (P&O) algorithm and the Incremental conductance (IC) algorithm [8, 18]. Nevertheless, these techniques have shown their deficiency when weather conditions change as they oscillate around the Maximum Power Point (MPP) causing significant energy loss. The second group of methods used in MPPT are Artificial Intelligence (AI) algorithms [19, 20]. Examples for such algorithms are Fuzzy Logic Controller (FLC) and Artificial Neural Networks (ANNs) [21]. These methods have demonstrated less oscillation than the first group around MPP. The third group is based on optimization such as Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) algorithms [22]. This group is characterized by high response speed and high accuracy for MPP tracking [21].

The main goal of this paper is to increase the efficiency of the photovoltaic system to provide a constant voltage level from solar panels. To achieve this goal, three algorithms, namely P&O, FLC, and PSO are modified and applied in the MPPT technology of the photovoltaic system to control the duty cycle of a DC-DC boost converter, extract the maximum power generated from the solar panels, and track the MPP. Each algorithm is utilized and experimented separately in the MPPT technology using the MATLAB/Simulink environment. The configured system is tested under three different test condition states. The first state is conducted under standard testing conditions, which implies constant irradiation intensity of $1000\,\mathrm{W/m^2}$ and temperature of 25°C. The second state changes the irradiation intensity while keeping the temperature value constant at 25°C. The last state tests the system with constant irradiation intensity at $1000\,\mathrm{W/m^2}$ and varies the temperature [11]. Prior to conducting our experiments, the DC-DC boost converter is designed to supply a constant voltage of (40 V).

The rest of this paper is organized as follows. In Section 2, the materials and methods used are explained. Section 3 is concerned with presenting the algorithms applied in MPPT technology. In Section 4, an explanation of a DC-DC boost converter is provided. In Section 5, the simulation methods under different test conditions are listed. In Section 6, the simulation results are demonstrated and discussed. Finally, in Section 7, the conclusion and future work are outlined.

2. MATERIALS AND METHODS

In this section, the materials and methods used in this paper are discussed. First, the equivalent circuit of the photovoltaic cell and the mathematical equations that work on it are presented. Secondly, the PV module characteristics curve are studied under different test conditions. Thirdly, the MPPT technology and the three algorithms applied to this technology are explained. Finally, the DC-DC boost transformer will be used in this paper

2.1. Equivalent Circuit for a PV Cell and Mathematical Model

Photovoltaic cell is made of p-n junction semiconductors that release an electric current when being exposed to solar light without making any noise and free from pollution. Photocells are connected in series and/or in parallel to form photovoltaic arrays [20]. The equivalent circuit of a photovoltaic cell can be simulated using single-diode or two-diode models. In this research, the single-diode model will be used for its simplicity of composition, and it gives better linear results than the two-diode one. The equivalent circuit in Figure 1 represents the photocell [23, 24].

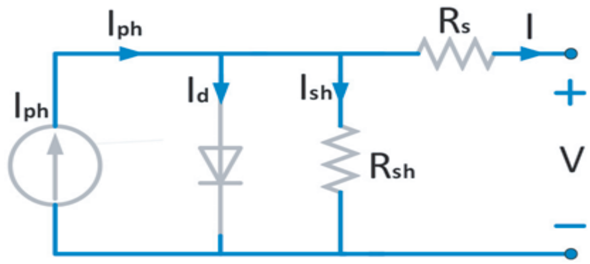


Figure 1. The equivalent circuit of a PV cell.

The total current given by the PV model can be calculated from the following equations:

$$I = (I_{ph} * N_p) - (I_d + I_{sh}) \tag{1}$$

$$I_{ph} = G_k * [I_{sc} + K_I * (T - T_{ref})] \tag{2}$$

The following is the equation for the shunt current:

$$I_{sh} = \frac{V_{pv} + (I_{pv} * R_s)}{R_{sh}} \tag{3}$$

The equation used to determine the dark current I_d is:

$$I_d = I_s * \left[\exp\left(q * \frac{V_{pv} + (R_s * I_{pv})}{(N_s * V_t)}\right) - 1\right] \tag{4}$$

The equation below shows how temperature affects the reserved saturation current:

$$I_s = I_{rs} * \left(\frac{T}{T_{ref}}\right)^3 * e^{\left[\frac{q*Eg}{nk} * \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]} \tag{5}$$

Finally, the following formula can be used to determine the total current:

$$I=(N_p*I_{ph}) - (N_p*I_s) * \left[\exp\left(\frac{(q*V_{pv})+(R_s*I_{pv})}{(N_s*V_t)}\right) - 1\right] - N_p * \frac{V_{pv}+(I_{pv}*R_s)}{R_{sh}} \tag{6}$$

After the resistor values:

$$R_s = 0 \quad and \quad R_{sh} = \infty$$

Following is the new form of the preceding equation:

$$I=(N_p*I_{ph})-(N_p*I_s) * \left[\exp\left(\frac{A*V_{pv}}{N_s*n}\right) - 1\right] \tag{7}$$

Nomenclature			
V	The output voltage of a PV cell [V].	R_s	A PV cell's series resistance [Ω].
I	The output current of a PV cell [A].	A	Ideality factor.
N_s	A series' total number of connected modules.	T	Cell temperature [Kelvin].
N_p	The quantity of parallel-connected modules.	q	The constant of electron charge (1.602×10^{-19}°C)
$I_{\mathbf{ph}}$	In a PV cell, a current is produced by light [A].	T_{ref}	Reference temperature [Kelvin].
I_s	In PV cells, the saturation current [A].	I_{sc}	Current shorts out in a PV cell at 25°C and 1000 [W/m^2].
Eg	A silicon's band gap [eV].	R_{sh}	Photovoltaic cell shunt resistance [Ω].

2.2. Characteristics of PV System Curves

To operate the photovoltaic system at maximum power and obtain the best efficiency, we need to study the characteristics of the photovoltaic cell represented by voltage-current (V-I) and power-voltage (P-V) curves, which are affected by weather factors (changes in temperature and intensity of radiation). Most companies manufacturing solar panels use standard test conditions (Te = 25°C and ir = 1000 W/m^2) due to the difficulty of relying on weather conditions because they are volatile [11]. In this research paper, a solar panel of the type 1 Soltech 1STH-215-P is used [25], which shows the electrical characteristics in Table 1.

Table 1. Solar module electrical characteristics data sheet1 Soltech 1STH-215-P.

Module Parameters	
Maximum Power (W)	213.15
Voltage in the open circuit (VOC)	36.3
The voltage at Maximum Power (V_{MPP})	29
Temperature coefficient of VOC (%/deg · C)	−0.36099
Cells per module (Ncell)	60
Current in a short circuit I_{SC} (A)	7.84
Maximum power current (I_{MP})	7.35
ISC temperature coefficient (%/deg · C)	0.102
Light-generated current IL (A)	7.8649
Current Saturation of a Diode Io (A)	2.9259e-10
Diode ideality factor	0.98117
Shunt resistance R_{sh} (ohm)	313.3991
Series resistance R_s (ohm)	0.39383

Through the equivalent circuit model of the photovoltaic module, it is possible to obtain a characteristic curve of the solar panel between voltage-current (V-I) and power-voltage (P-V) under different test conditions. Figures 2, 3, and 4 show the electrical characteristics of the solar panel drawn using MATLAB.

3. MPPT ALGORITHM

To determine the maximum power point (MPP), researchers and scientists have been creating, discovering, and publishing several MPPT technology algorithms during the past few years [5]. These

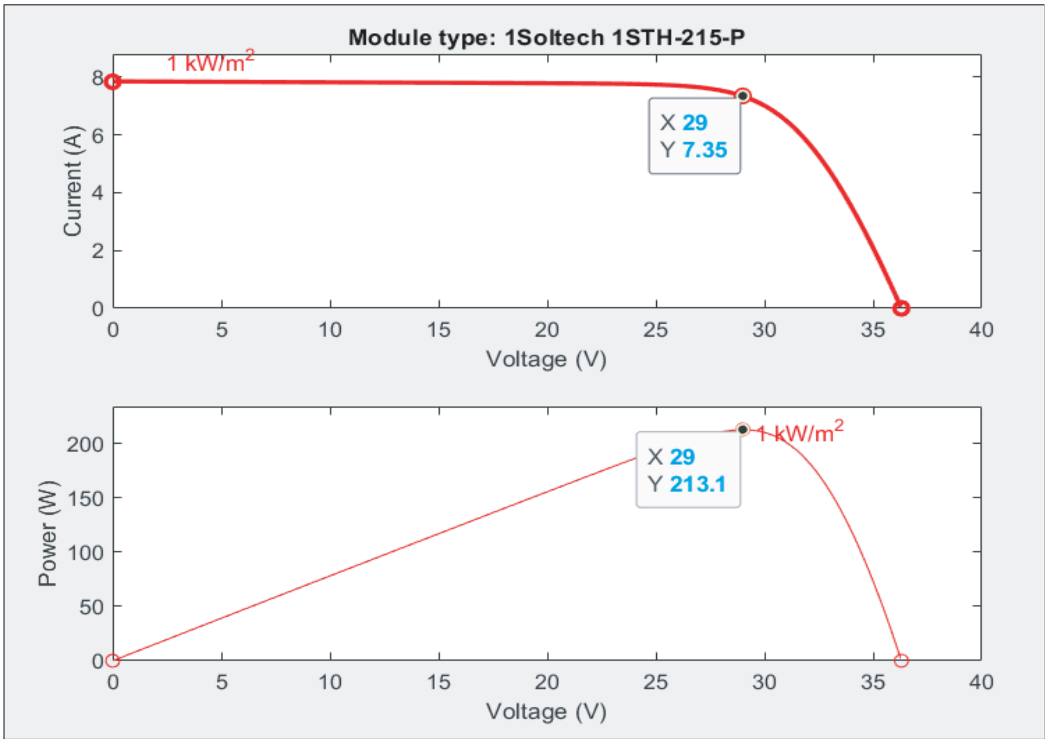


Figure 2. Characteristic curves of PV (I-V & P-V) under standard testing conditions.

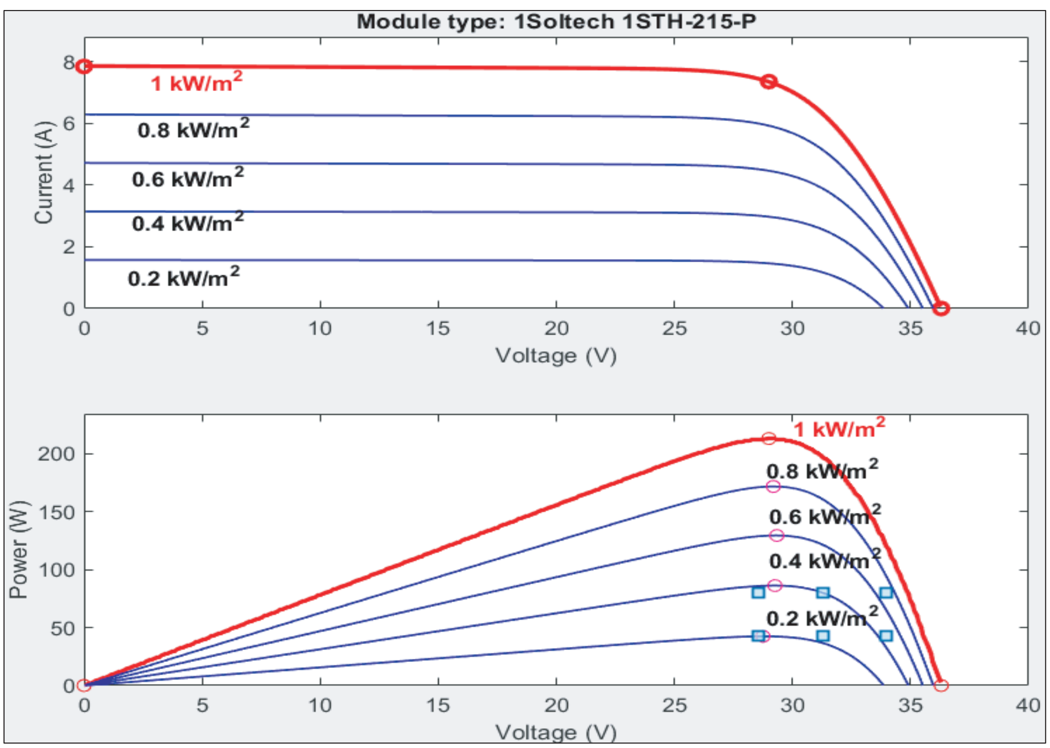


Figure 3. Characteristic curves of PV (I-V & P-V) when radiation intensity changes.

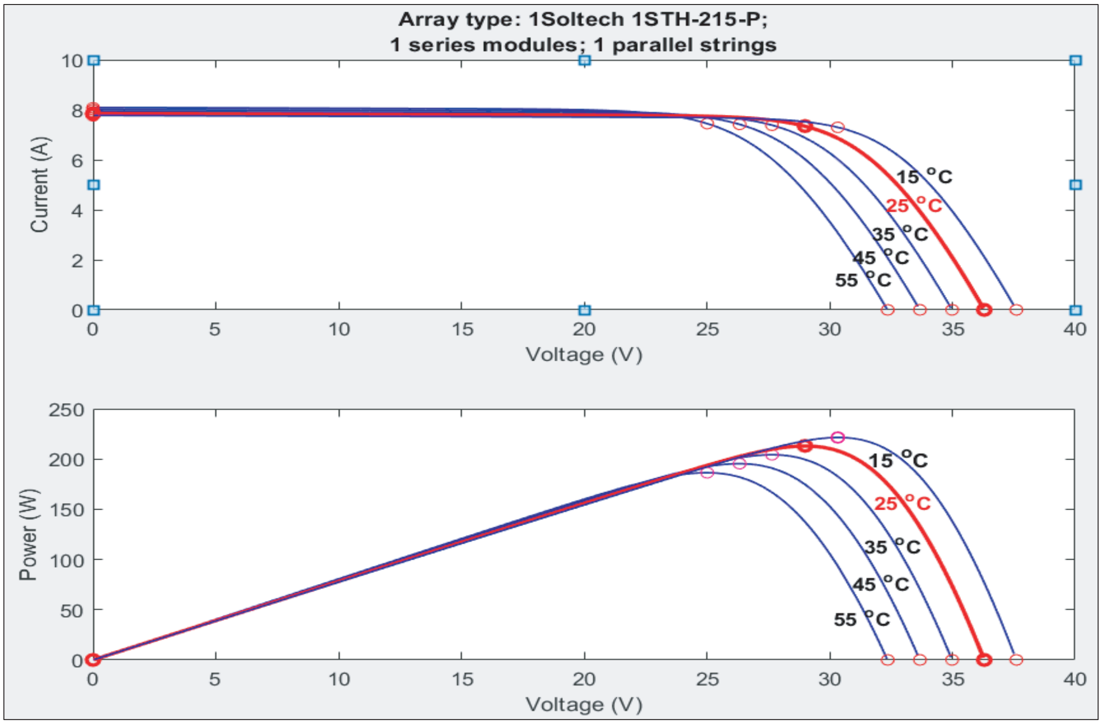


Figure 4. Characteristic curves of PV (I-V & P-V) when temperature changes.

algorithms differ from one another in various aspects including, but no limited to, the required current and voltage sensors, the complexity of the structure, the speed of convergence, and the correct tracking when the radiation intensity and/or the temperature [16, 26] are varying. Accordingly, MPPT algorithms, shown in Figure 5, are classified into three different groups: traditional, Artificial Intelligence (AI), and optimization algorithms [27].

In this paper, three different algorithms (P&O, FLC, and PSO) are studied and modified, and the simulation results are compared to determine the best algorithm for increasing system efficiency and tracking the maximum power point.

3.1. Perturb and Observe (P&O)

The P&O algorithm is one of the traditional method algorithms and one of the most common and used in photovoltaic applications. Due to the simplicity of its results, ease of use, and low costs, it is widely used under standard test conditions (STC). The principle of the P&O algorithm depends on increasing the disturbance voltage of the plate and calculating the output voltage and comparing it continuously over time. If the energy difference is positive, (i.e., it is located to the left of the MPP), the disturbance is increased in the same direction, and process continues until the energy difference becomes negative. Conversely, when energy is located to the right of the MPP, the operating voltage is gradually reduced, and the direction of the disturbance is reversed until the energy difference becomes equal to zero [28]. At this point, we have obtained the maximum power point (MPP). Figure 6 shows the characteristics curve of the P&O algorithm, and the stages of disturbance change to reach the MPP [27].

The perturbation motion in the P&O algorithm can be illustrated by the mathematical equations below [11, 16]

$$\frac{dP}{dV} = 0 \ldots\ldots\ldots (\text{at the MPP}) \tag{8}$$

$$\frac{dP}{dV} > 0 \ldots\ldots\ldots (\text{at the left side of MPP}) \tag{9}$$

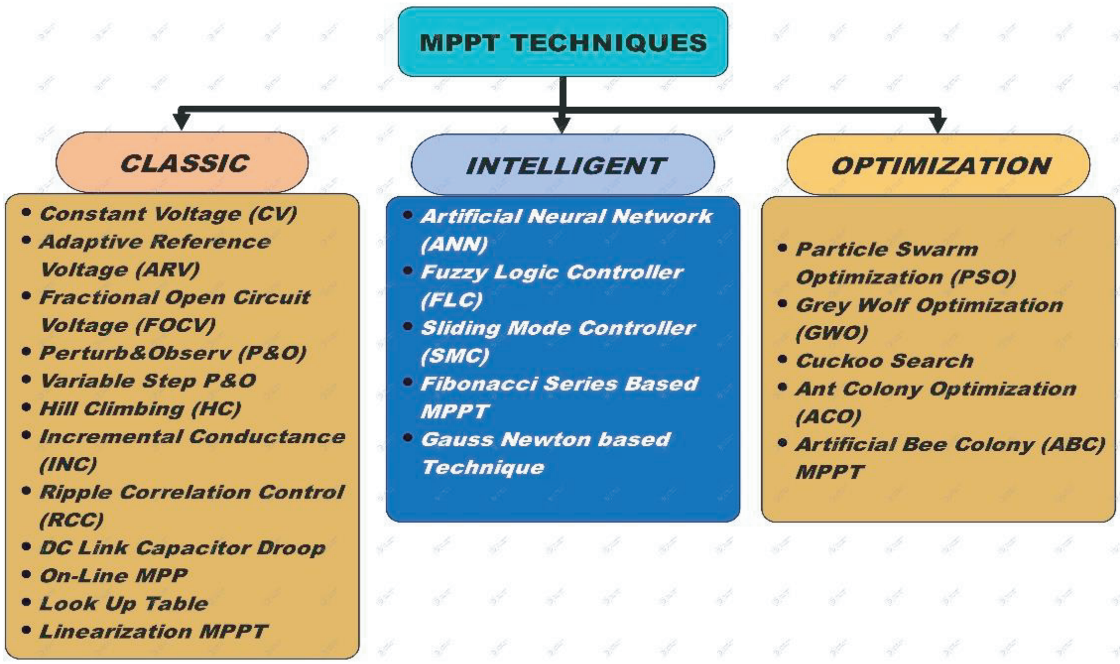


Figure 5. Classification of MPPT algorithms.

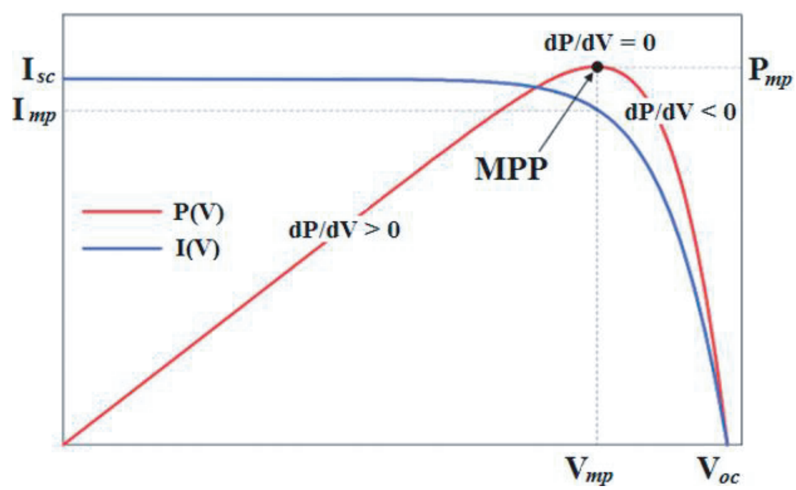


Figure 6. The P&O method's P-V curve.

$$\frac{dP}{dV} < 0 \ldots\ldots\ldots \text{(at the left side of MPP)} \tag{10}$$

A flowchart that outlines the P&O algorithm's specifics is shown in Figure 7. We can see that when the operating voltage decreases, the output power is decreased accordingly. Therefore, the algorithm increases the perturbation in the positive direction (i.e., increases the voltage) to maintain the output power at a certain level [29].

3.2. Fuzzy Logic Control (FLC)

Artificial intelligence algorithms are among the most important algorithms used in recent years. In this paper, we use a fuzzy logic controller (FLC) algorithm for its application in MPPT technology to control

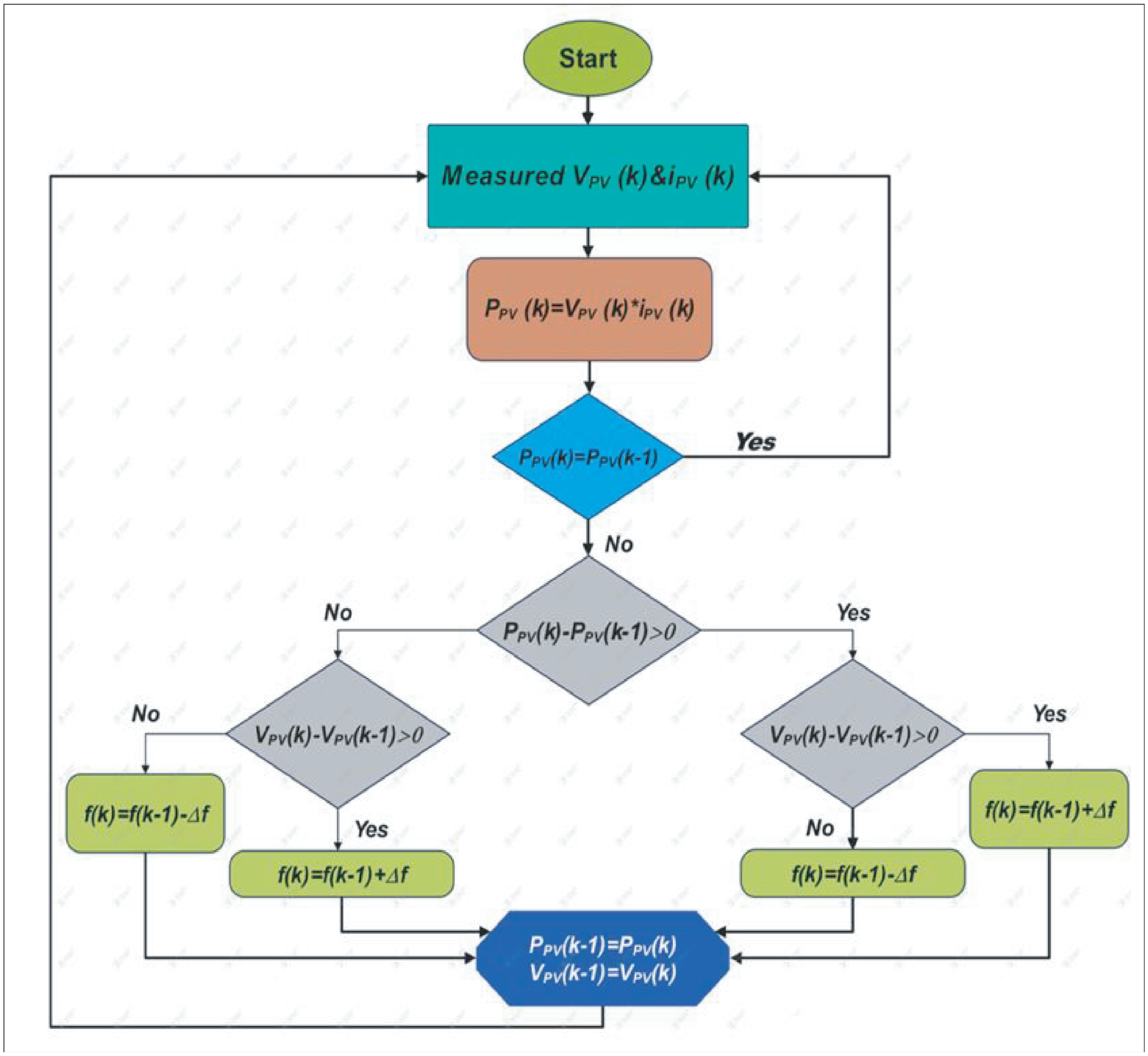


Figure 7. Flowchart for the P&O algorithm.

the converter duty cycle and increase the efficiency of the photovoltaic system. Fuzzy logic is predicated on the notion that human decision-making involves more than just "ones and zeros" or "yes or no". IF-THEN rules are the foundation of fuzzy control rules [30]. The FLC algorithm is particularly effective because it does not require the use of sophisticated mathematical models or system settings [28]. Due to the soft calculation characteristics of fuzzy logic, systems that use it achieve their maximum power point more quickly during load or when the weather is changing [31]. In general, FLC involves three major parts: fuzzification, interference with the rule base, and defuzzification. Figure 8 illustrates the basic structure of the FLC algorithm [32].

The output variable is the duty cycle's variations (ΔD). Various FLC-based MPPT approaches alter the input variables. The error E and the change in error ΔE often serve as the input variables [32]. The slope of the P-V curve can be used to determine the error E, as shown in the equations below [33]:

$$E\left(k\right) = \frac{P\left(k\right) - P(k-1)}{V\left(k\right) - V(k-1)} \tag{11}$$

$$\Delta E\left(k\right) = E\left(k\right) - E(k-1) \tag{12}$$

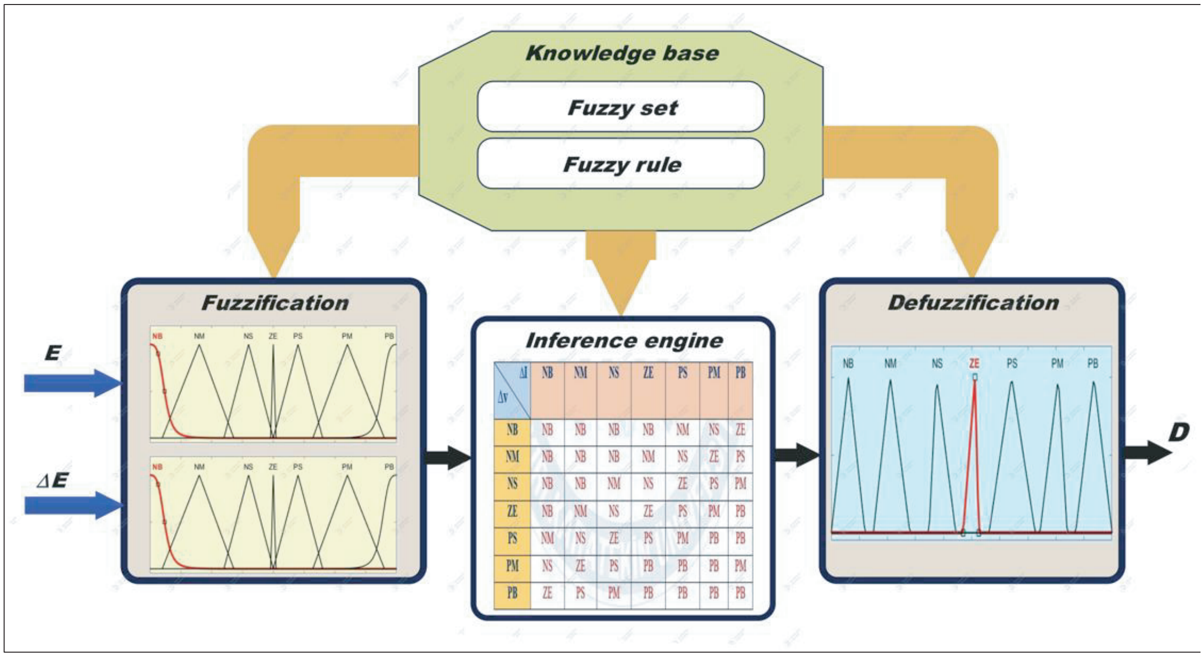


Figure 8. Basic parts of the FLC algorithm.

For MPPT applications, FLCs frequently employ the Mamdani model for interference, the Max-Min model for fuzzy combination, and the center of gravity (COG) model for defuzzification [31, 32].

- Fuzzification: The main objective of the fuzzification process is to create input fuzzy sets from the linguistic equivalents of the numerical input variables.
- The If-Then rules that make up the rule-base control the controller in various ways. According to how many input membership functions are used, there are a certain number of rules. Seven membership functions are present in each input in this research, producing 49 rules [31], as seen in Table 2.

Table 2. Fuzzy logicrules.

Δv \ ΔI	NB	NM	NS	ZE	PS	PM	PB
NB	**NB**	**NB**	**NB**	**NM**	**NM**	**NS**	**ZE**
NM	**NB**	**NB**	**NM**	**NM**	**NS**	**ZE**	**PS**
NS	**NB**	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**
ZE	**NB**	**NS**	**NS**	**ZE**	**PS**	**PM**	**PB**
PS	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**	**NM**
PM	**NS**	**ZE**	**PS**	**PB**	**PB**	**PB**	**NB**
PB	**ZE**	**PS**	**PM**	**PB**	**PB**	**NM**	**NS**

- Defuzzification: It is the conversion of fuzzily-defined data into deterministic data.

3.3. Particle Swarm Optimization (PSO)

The social behavior of flocking birds and schooling influenced this population-based stochastic technique. The PSO technique has been researched by various researchers for MPPT applications because of its quick convergence, straightforward structure, and simplicity in implementation. The initialization of

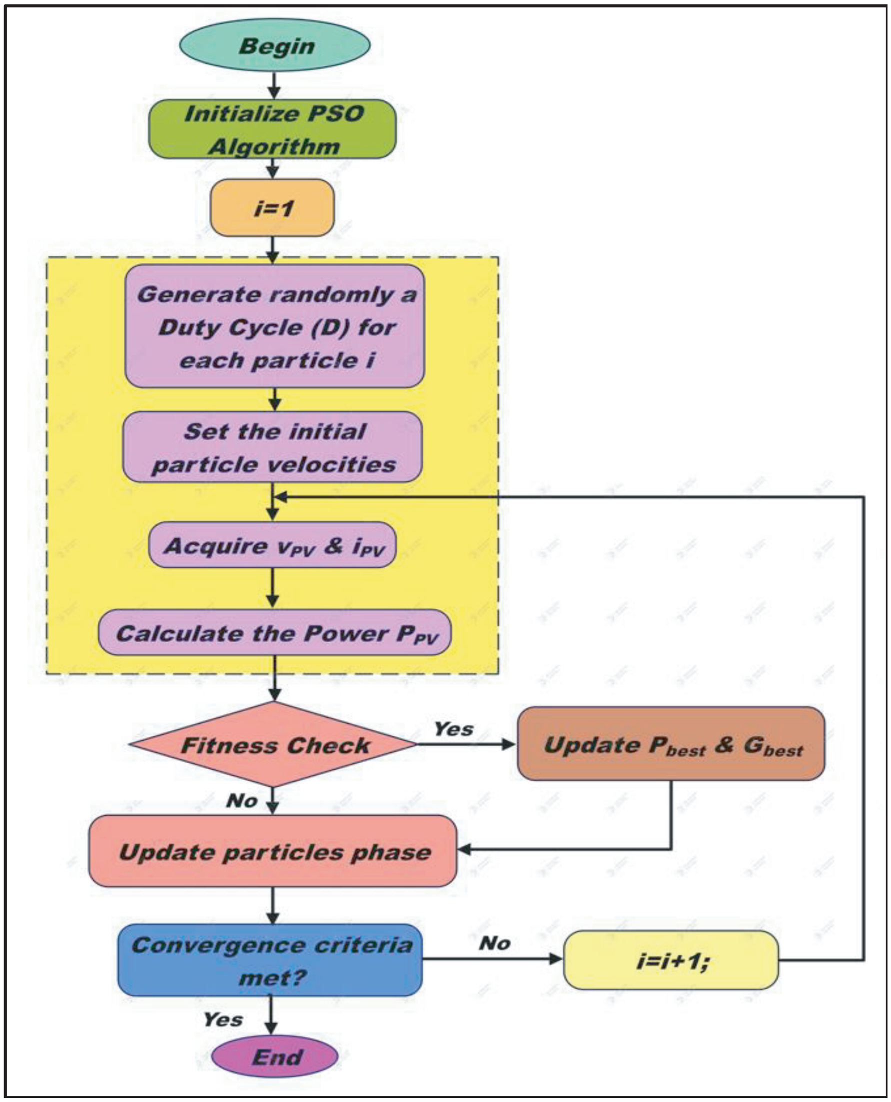


Figure 9. PSO algorithm flowchart.

a set of random particles (solutions) is the first step in this technique, which then employs update generation to look for optimum solutions. Particles are updated after each repetition by using the top two values. The first one is the Pbest, which stands for each particle's personal best position; it is updated after each iteration. The second one is the Gbest, which stands for the group's overall best position [34, 35]. When the two ideal values are discovered, the particle changes its position and speed using Eqs. (13) and (14) [36]. The flowchart for the PSO algorithm design method is shown in Figure 9.

$$v_i^{k+1} = wv_i^k + c_1r_1 * \left(pbest - S_i^k\right) + c_2r_2 * \left(gbest - S_i^k\right) \tag{13}$$

$$S_i^{k+1} = S_i^k + v_i^{k+1} \tag{14}$$

v_i^{k+1}: the particle velocity at iteration k
w: the inertia weight factor
c_1 & c_2: acceleration constants
r_1 & r_2: random numbers
S_i^k: the particle position in the search space at iteration k.

4. DC-DC CONVERTERS

Because of its extreme vulnerability to changes in weather conditions (temperature change and solar radiation intensity change), solar energy systems are not ideal for generating constant voltage. Even when the maximum power point (MPP) is reached, it is difficult to transfer the maximum power from it directly to the load in a constant manner, so the response curve must be controlled according to weather changes [37]. To address the problem of instability of the voltage coming out of the solar panels, an electronic circuit is added whose location is between the solar panels and the load. The circuit works to supply the loads with a constant voltage, despite the changing weather conditions. The duty cycle of the converter is controlled by MPPT technology. In this paper, a DC-DC boost converter will be used, as this converter is characterized by raising the level of the input voltage, and according to the need, its electronic components are designed based on the required voltage [37, 38]. Figure 10 shows the electronic circuit of the boost converter.

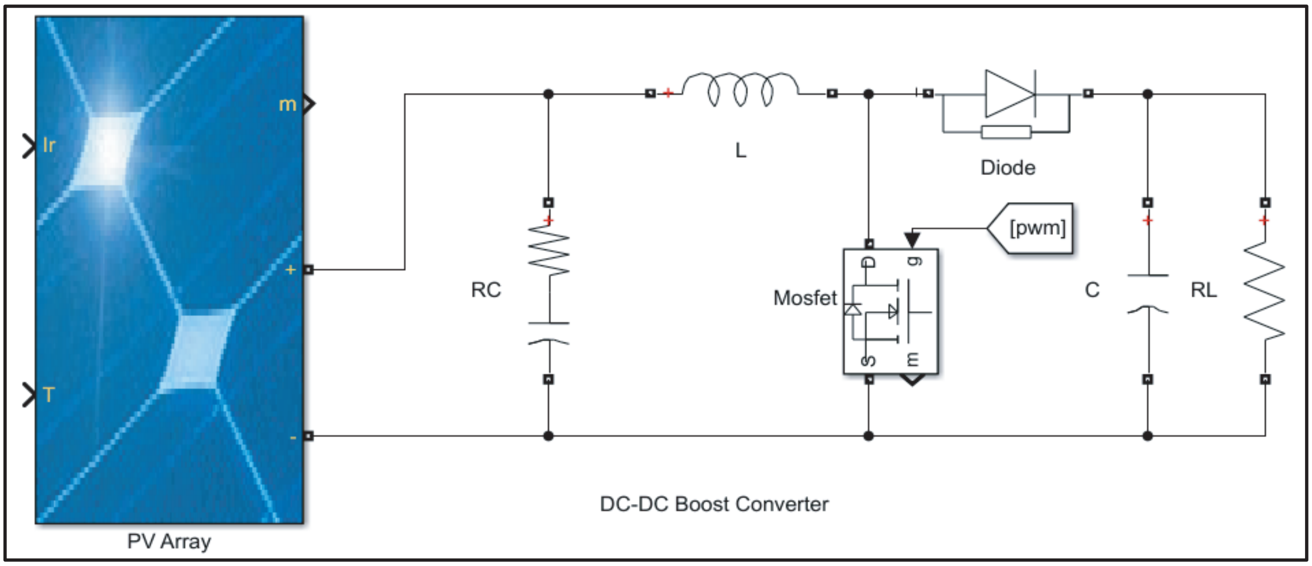


Figure 10. DC-DC boost converter circuit simulation model.

5. DESIGN OF A PV SYSTEM WITH MPPT BASED ON THREE DIFFERENT ALGORITHMS USING MATLAB/SIMULINK

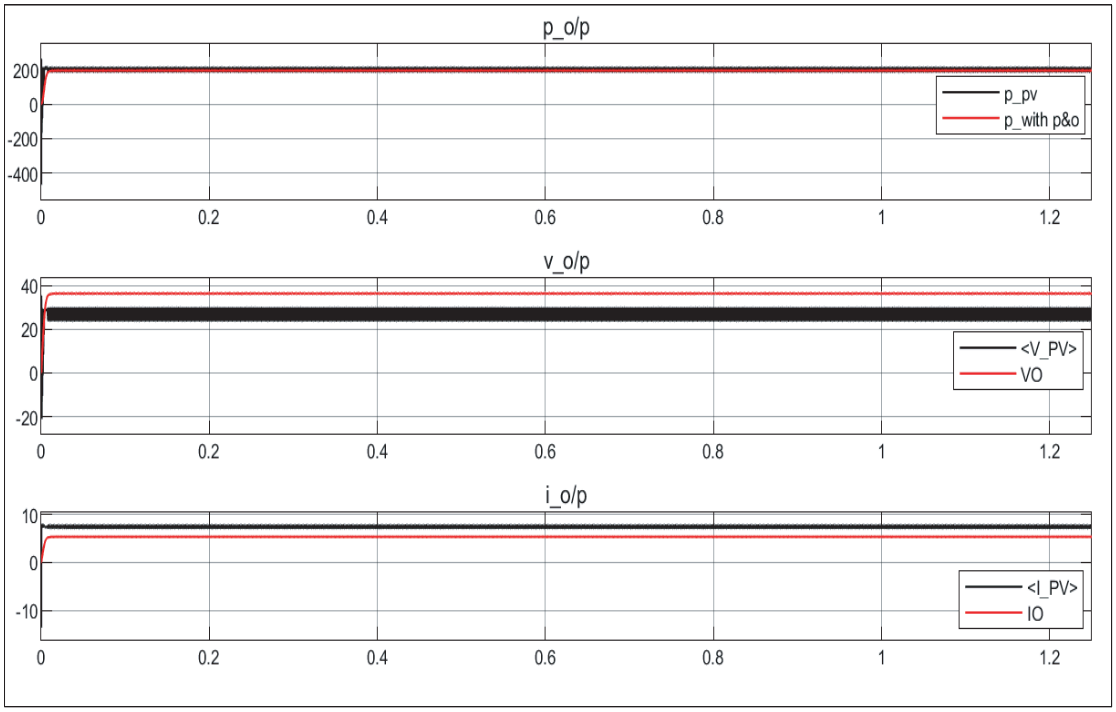
In this section, a PV system consisting of three main parts (solar panels, MPPT technology, and boost converter) is simulated. It shows the application of three different algorithms in MPPT technology to control the converter duty cycle and MPP tracking to increase the efficiency of the system. They are tested under standard test conditions, then under variable test conditions (change in solar irradiation intensity, temperature change). Using MATLAB/Simulink, simulation results can be observed through the input and output signals (voltage, current, power) for each algorithm.

5.1. PV System Testing under Standard Test Conditions (STC)

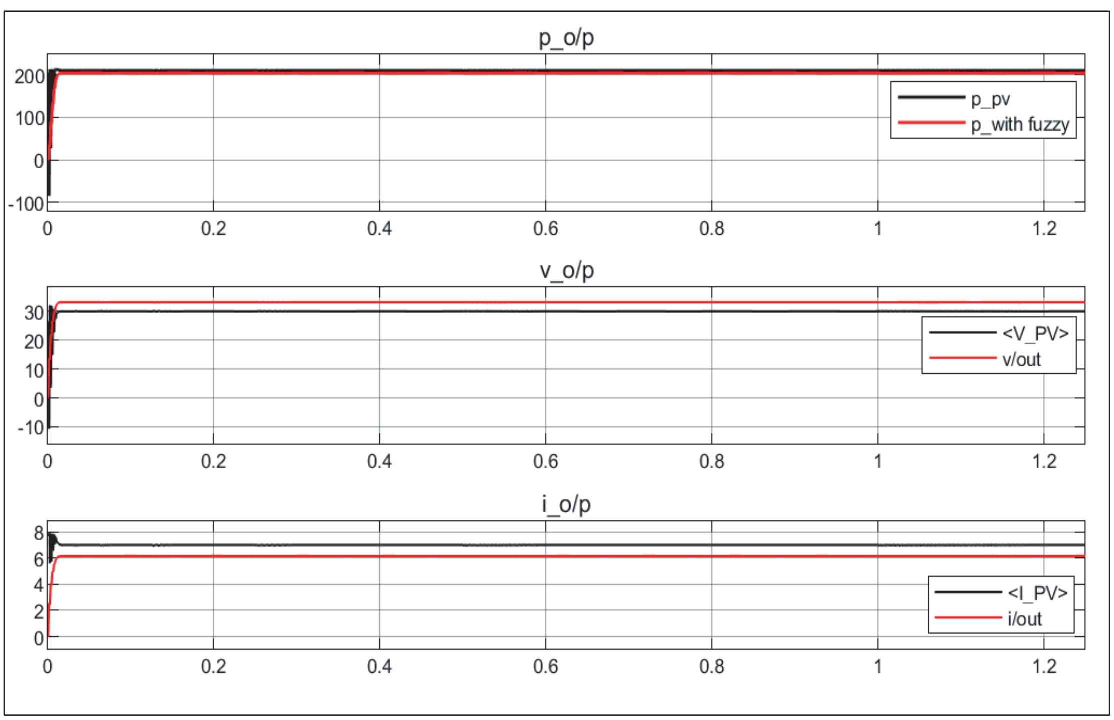
In this part, the photovoltaic system was tested under standard test conditions (ir = $1000\,\mathrm{W/m^2}$, Te = 25°C) using MPPT technology based on three different modified algorithms (P&O, FLC, PSO). Figures 11(a), (b), and (c) show the simulation results for each algorithm through the signals (voltage, current, power) extracted from the solar panels and the output of the boost converter.

5.2. Testing the PV System under Variable Test Conditions (Variable Irradiation Intensity and Constant Temperature)

In this part, the photovoltaic system was tested under variable test conditions (variable irradiation intensity and constant temperature Te = 25°C) using MPPT technology based on three different



(a)



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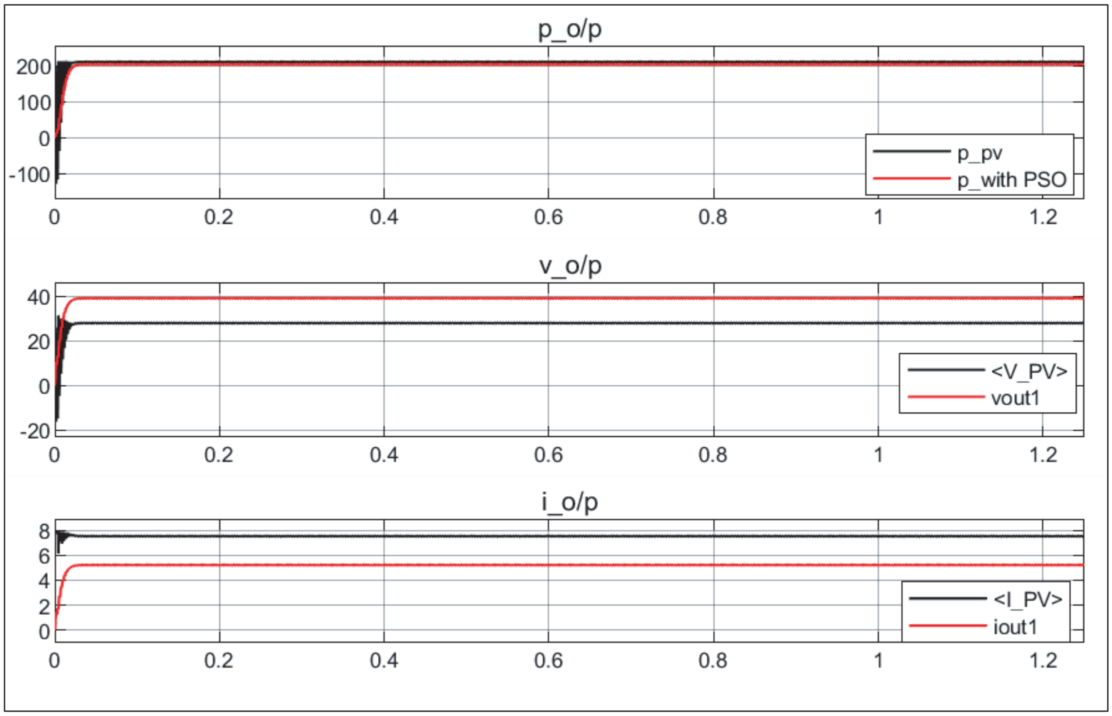
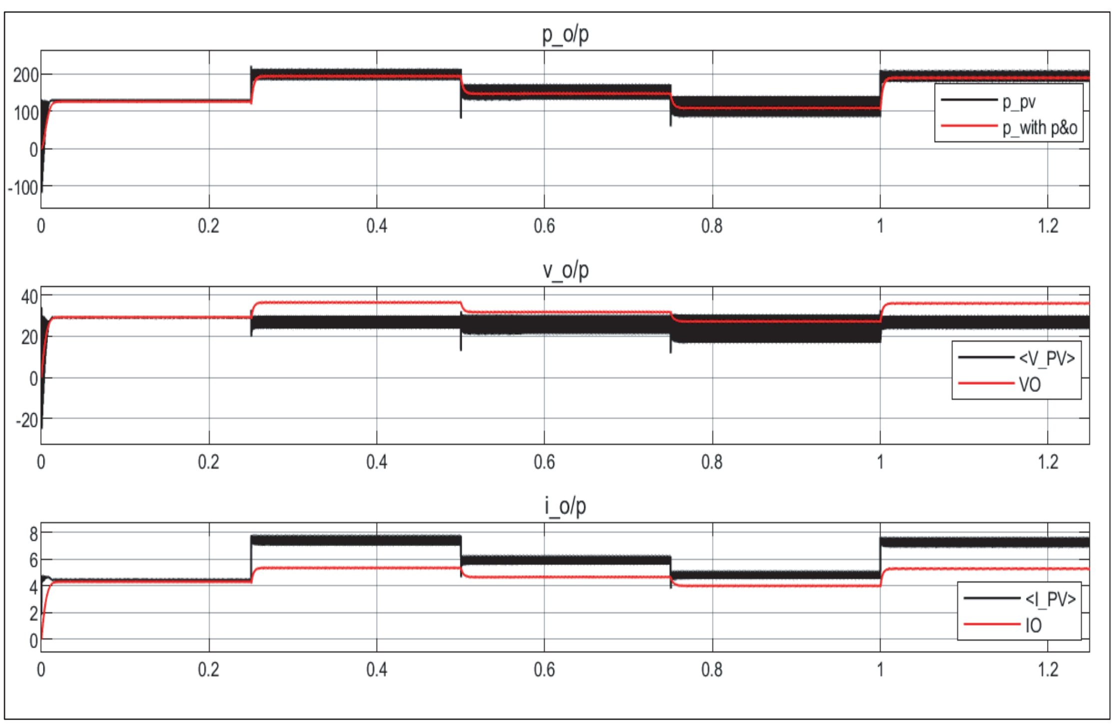
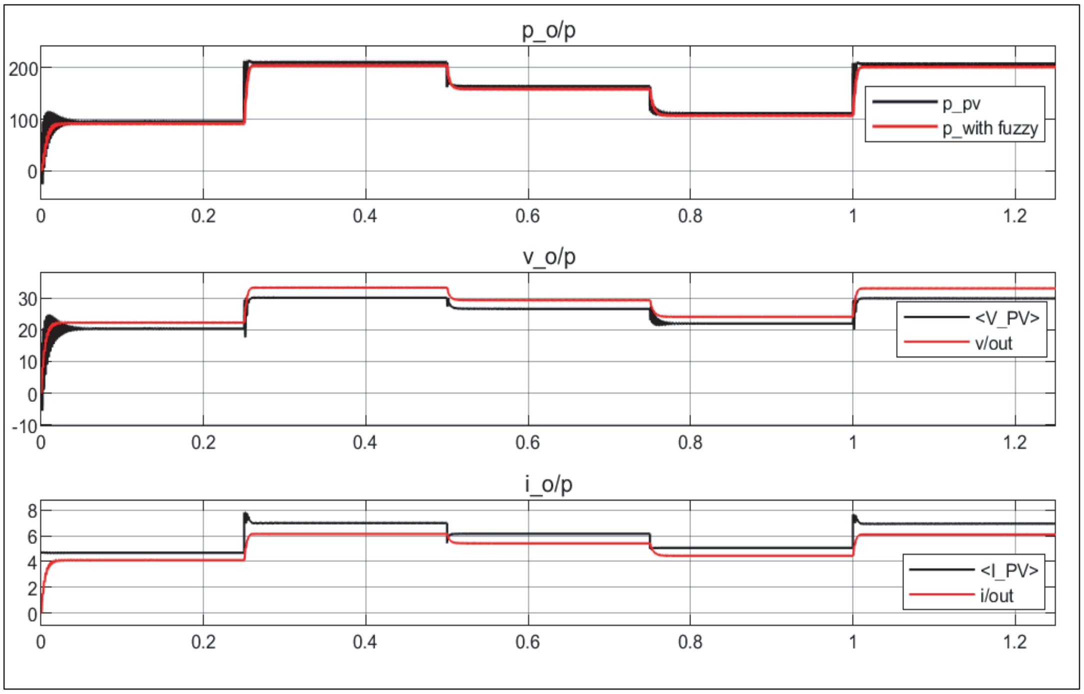


(c)

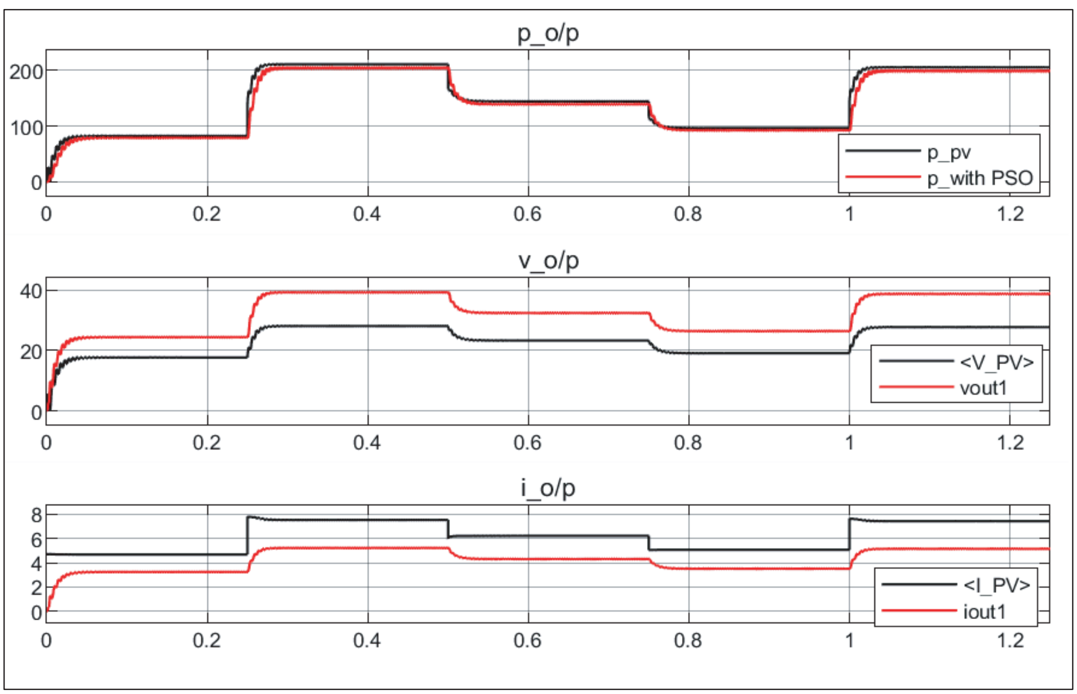
Figure 11. (a) When applying the P&O algorithm. (b) when applying the FLC algorithm. (c) When applying the PSO algorithm.



(a)



(b)



(c)

Figure 12. (a) When applying the P&O algorithm. (b) when applying the FLC algorithm. (c) When applying the PSO algorithm.

modified algorithms (P&O, FLC, PSO). Figures 12(a), (b), and (c) show the simulation results for each algorithm with the signals (voltage, current, power) extracted from the solar panels and the output of the boost converter.

Table 3. Simulation results of (P&O, FLC, and PSO) algorithms.

Test conditions	algorithms	$P_{I/P}$ (W)	$V_{I/P}$ (V)	$I_{I/P}$ (A)	The efficiency of extracting power	$P_{O/P}$ (W)	$V_{O/P}$ (V)	$I_{O/P}$ (A)	MPPT Technology Efficiency
(STC) $ir = 1000\,W/m^2$, tem = 25°C	P&O	205.6	26.10	7.87	96.45%	197.5	36.98	5.34	96.06%
	FLC	208.3	30.64	6.79	97.72%	203.8	32.79	6.21	97.83%
	PSO	211.7	28.14	7.52	**99.32%**	208.5	39.38	5.29	**98.48%**
variable irradiation intensity	P&O	200.1	25.9	7.72	93.87%	187.9	35.75	5.25	93.90%
	FLC	204.6	29.97	6.82	95.98%	198.2	33.46	5.92	96.87%
	PSO	206.8	28.15	7.34	**97.02%**	201.3	38.86	5.18	**97.34%**
variable temperature	P&O	198.9	25.77	7.71	94.31%	191.3	36.02	5.31	96.17%
	FLC	207.2	29.76	6.96	97.20%	201.6	32.85	6.13	97.29%
	PSO	209.6	28.12	7.45	**98.33%**	205.6	39.24	5.24	**98.09%**

5.3. Testing the Photovoltaic System under Variable Test Conditions (Change in Temperature, Constant Irradiation Intensity)

In this part, the photovoltaic system was tested under variable test conditions (variable temperature and constant irradiation intensity $ir = 1000\,W/m^2$) using MPPT technology based on three different modified algorithms (P&O, FLC, PSO). Figures 13(a), (b), and (c) show the simulation results for each algorithm with the signals (voltage, current, power) extracted from the solar panels and the output of the boost converter.

The solar system simulation results showed that all the algorithms that were modified and applied in the MPPT technique perform very well under standard test conditions. They were accurate in tracking the MPP, minimizing fluctuations around it, extracting maximum power from the solar panel, and controlling the duty cycle of the converter perfectly as shown in Figures 11(a), (b), (c). However, when testing conditions in volatile weather, we noticed a low level of performance of the P&O algorithm, and it fluctuates greatly around MPP, which causes wastage of energy. While the performance of the other two algorithms (PSO and FLC) continued at a good level with less fluctuation, the (PSO) algorithm was superior in terms of its ability to adapt the fluctuations in intensity of radiation and temperature very smoothly, as shown in Figures 12(c), 13(c).

6. RESULTS AND DISCUSSION

In Table 3, we show all the results obtained from the simulation of the photovoltaic system with the application of MPPT technology based on three different algorithms (P&O, FLC and PSO) that have been modified to increase system efficiency. First, the voltage, current, and power ($V_{I/P}$, $I_{I/P}$, $P_{I/P}$) extracted from the solar panel are calculated when applying each algorithm separately and calculating the efficiency of power extraction. Then the voltage, current, and power ($V_{O/P}$, $I_{O/P}$, $P_{O/P}$) given by the photovoltaic system through the boost converter are calculated for each algorithm as well as calculating the efficiency of the MPPT technology.

The efficiency of the extracted power of the solar panel is calculated by dividing the extracted power from it, $P_{I/P}$, by the power of the solar panel (213.15 W) mentioned in the data sheet of the panel and shown in Table 1 and Eq. (15)

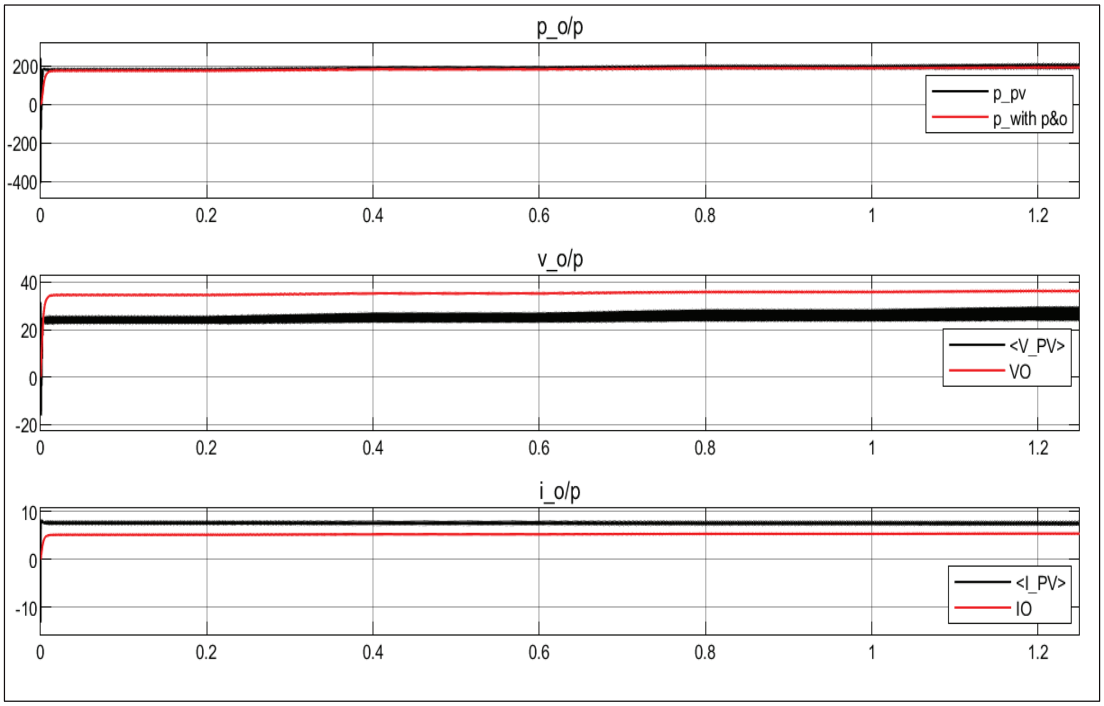
$$\eta = \frac{P_{I/P}}{P_{PV}} * 100\% \tag{15}$$

As for calculating the efficiency of MPPT technology, it is done by dividing the output power $P_{O/P}$

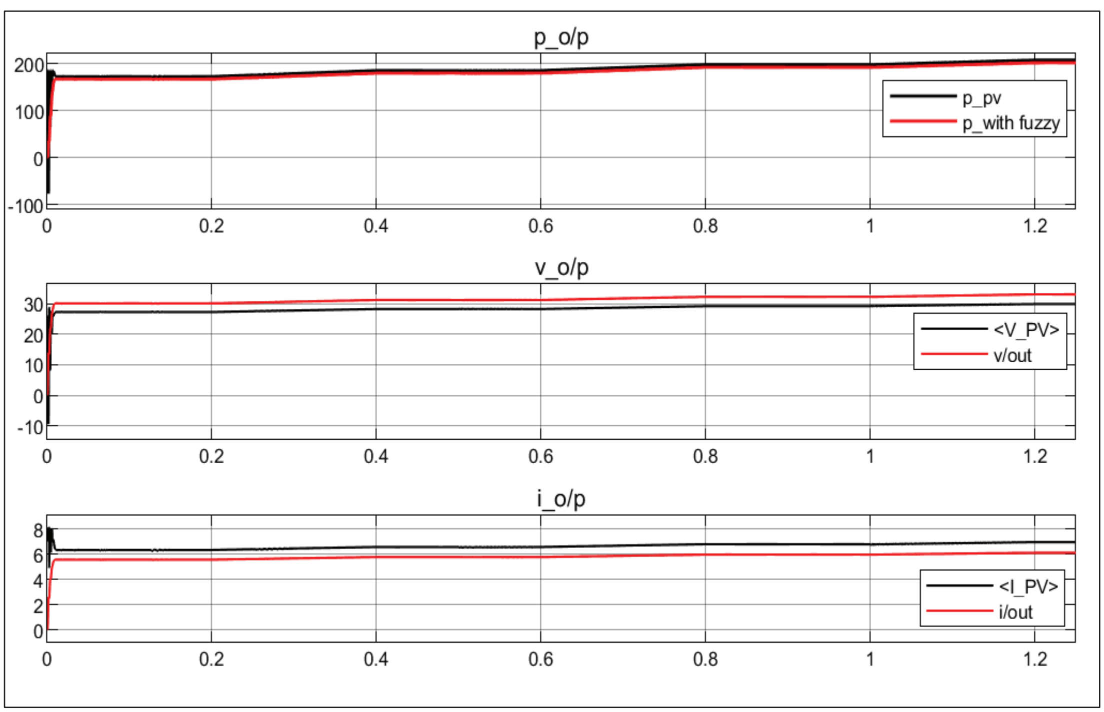
from the boost converter by the input power $P_{I/P}$ extracted from the solar panels. Eq. (16) explains this.

$$\eta = \frac{P_{O/P}}{P_{I/P}} * 100\% \tag{16}$$

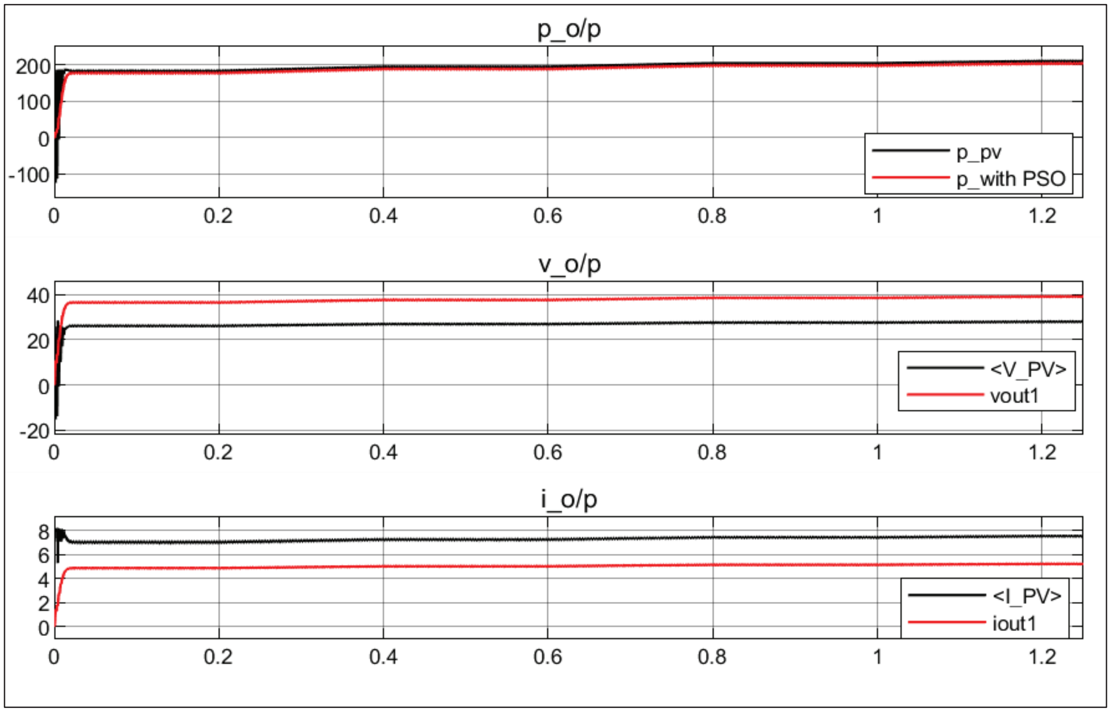
The simulation results prove that all algorithms that have been modified and implemented in MPPT



(a)



(b)



(c)

Figure 13. (a) When applying the P&O algorithm. (b) When applying the FLC algorithm. (c) When applying the PSO algorithm.

technology perform very well under standard test conditions. It is clear from the results mentioned above (Table 3) that the best result was obtained when the PSO algorithm was applied under the same conditions in the process of extracting the maximum power from solar panels and controlling the performance of the DC-DC boost converter to produce the required voltage. PSO achieved higher efficiency than the algorithms FLC and P&O. However, under the changing selection conditions, the performance of the P&O algorithm decreased due to its lack of quick response to weather changes and its continued oscillation around the MPP, which caused energy waste and lower system efficiency. As for the two algorithms (FLC and PSO), their performance was better under the same changing conditions, but the PSO algorithm achieved the best performance and the highest efficiency in both test cases. The results also shows that when the temperature factor is changed the performance of PSO was higher than its performance when the radiation intensity factor is changed.

7. CONCLUSION

Renewable energy is considered one of the most promising sources for generating modern electric power because of its advantages such as availability, sustainability, environmentally friendly, and working without noise. All these factors and more made it the focus of attention of researchers and scientists to seek for finding inexpensive ways to increase its efficiency. Among the valuable renewable energy sources, solar energy comes to the fore. In this paper, the problem of low efficiency of PV systems has been addressed by applying three algorithms (PSO, FLC, and P&O) in the MPPT technology that forces the system to operate at a maximum power. MATLAB/Simulink environment is used to simulate the photovoltaic system. The simulation results have shown that the three adopted algorithms gave satisfactory performance values when being applied in standard test conditions. Under volatile weather conditions, however, PSO achieved higher performance and efficiency than the other two methods. One disadvantage related to the PSO algorithm is that it takes a longer response time to reach a stable state, while the time required for the FLC method is much shorter. To address this problem, one possible solution is by investigating other less time-consuming optimization methods to be applied in the MPPT technology without compromising the performance. Furthermore, as FLC showed the lowest response time and achieved the second-best performance under varying test conditions, a combination of two or more AI algorithms may also be considered in the future to improve the overall performance with reduced computation time.

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