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PV Sistemler için MPPT Kontrol Cihazı Tasarımı ve Karşılaştırılması

Design And Comparison of MPPT Controller for PV Systems

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Öz

Elektrik enerjisi insan hayatında çok önemli ve vazgeçilmez bir unsurdur, bu yüzden elektrik üretimi yollarını bulmak ve kesintiye uğramamak için çalışmalar yapılmalıdır. Elektrik enerjisi üretiminin ana kaynağı fosil yakıtlardır, ancak maliyetlerinin artması ve genel kıtlık ve büyük nüfus artışı ile birlikte teknolojik ilerleme nedeniyle elektrik enerjisi talebindeki artış araştırmacıların yenilenebilir ve sürdürülebilir enerji üretimine yöneltmektedir. Güneş enerjisi, yenilenebilir çevre dostu enerjinin en önemli kaynaklarındandır. Ancak güneş enerjisi düşük verimliliğe sahiptir, bu nedenle araştırmacıların verimliliği artırmanın yollarını bulmaları için bir ilgi kaynağı haline gelmiştir. Maksimum Güç Noktası İzleme tekniği, günümüzde fotovoltaik sistemlerin verimliliğini artırmak için kullanılan tekniklerden biri olarak kabul edilmektedir. Araştırmacılar, maksimum güç noktası takibi için MPPT teknolojisinde uygulanacak bir dizi algoritma geliştirmeye ve uygulamaya, farklı ölçüm koşullarında güneş panellerinden maksimum gücü çıkarmaya ve belirli bir seviye sağlamak için bir DC-DC dönüştürücünün görev döngüsünü kontrol etmeye odaklanmaktadır. Bu çalışmada, üç farklı algoritmayı maksimum güç noktası izleme tekniğinde uygulayacağız, bunlar Pertürbasyon ve Gözlem (P&O) algoritması, bulanık mantık denetleyicisi (FLC) algoritması ve parçacık sürüsü optimizasyonu (PSO) algoritmalarıdır. Fotovoltaik sistem tasarımları MATLAB/Simulink kullanılarak simüle edilmiş ve simülasyon sonuçları standart ve değişken test koşulları altında karşılaştırılmıştır. Sonuçta en verimli algoritma parçacık sürüsü optimizasyonu algoritması olmuştur.

Anahtar Kelimeler

"Maksimum güç noktası takibi, Fotovoltaik (PV) sistem, Perturb ve Observe kontrolörü, Bulanık mantık kontrolörü, Parçacık sürüsü optimizasyonu"

Abstract

Electric energy is a very important and indispensable element in human life, so work must be done to develop it and find ways to provide it and not be interrupted or depleted. The main source of electric power generation is fossil fuels, but due to the increase in its costs and general shortage and the increase in demand for electric energy due to large population growth and technological progress, researchers are turning to renewable and sustainable energy. Solar energy is the most important source of renewable and environmentally friendly energy. But solar energy suffers from a problem of low efficiency, so it has become a source of interest for researchers to find ways to increase efficiency. The Maximum Power Point Tracking (MPPT) technique is considered one of the most important techniques used at the present time to increase the efficiency of photovoltaic systems. The researchers focused on developing and implementing a set of algorithms to be applied in MPPT technology for MPP point tracking, extracting the maximum power from solar panels in different measurement conditions, and controlling the duty cycle of a DC-DC converter to provide a certain level of voltage. In this paper, we will develop three different algorithms and apply them in the MPPT technique, they are the Perturbation and Observation (P&O) algorithm, and fuzzy logic controller (FLC) algorithm and particle swarm optimization (PSO) algorithm, The photovoltaic system was simulated using MATLAB/Simulink and the simulation results were compared under standard and variable test conditions. As a result, the most efficient algorithm has been the particle swarm optimization algorithm.

Key Words

"Maximum power point tracking, Photovoltaic (PV) system, Perturb and Observe controller, Fuzzy logic controller, Particle swarm optimization"

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1. Introduction

Due to the shortage of fossil fuels, their high prices, and the increasing demand for electrical energy due to population growth and technological progress, researchers and scientists were forced to find new ways to provide electrical energy at the lowest costs, so they focused on renewable energy (such as wind energy, solar energy, etc.) due to its abundance and that it is environmentally friendly and sustainable energy. All of these features, as well as others, drew researchers and scientists to develop them. And figuring out how to get it and keep it stable amid shifting weather circumstances (Abdelaziz and Almoataz, 2020; Abdellatif et al., 2021). Renewable energy sources, such as (Solar energy, Wind energy, Hydro energy, Tidal energy, geothermal energy, Biomass energy), are also environmentally friendly and limitless (Abdelwahab et al., 2020).

Solar energy is the most important source of renewable energy and the most widely used today to generate electrical energy. Electrical energy is obtained by shining sunlight on photovoltaic panels made of semiconductors, which in turn produces electrical energy whose value depends on two main factors, namely, the intensity of solar irradiation and temperature (Abo-Sennah et al., 2021).

Photovoltaic power generation systems suffer from two main problems: The first is the high costs of purchasing and installing panels, batteries, and chargers. The second problem is the low efficiency of photovoltaic energy systems due to their being affected by weather conditions such as (change in the intensity of solar irradiation and temperature change), so the electrical characteristics (I-V and P-V) of photovoltaic (PV) systems are always nonlinear and depend on the intensity of solar irradiation and temperature (Arpacı et al., 2019; Senthilkumar et al., 2022). The sudden unexpected change in atmospheric conditions leads to a change in the efficiency of the photovoltaic system because the solar panels are made of semiconductors that are affected when sunlight falls on them and cause the movement of photons that cause the flow of electric current and are also affected when the temperature changes. This leads to the locations of the maximum power point (MPP) constantly changing with changing weather conditions, causing energy loss and a decrease in the efficiency of the photovoltaic system (Abdelaziz and Almoataz, 2020).

To address the problem of declining solar energy system efficiency, researchers have tended to find ways to increase efficiency by tracking the maximum power point (MPP) that solar panels produce when exposed to solar irradiation. These methods are called Maximum Power Point Tracking (MPPT) (Arpacı et al. 2019; Talbi et al. 2020), several MPPT techniques have been identified in the literature developed by researchers that It is used to increase the output power to the maximum and stabilize the voltage at a certain level. And control the duty cycle of the boost converter (Mao et al.,2020). Including traditional methods such as the Perturb and Observe (P&O) algorithm and the Incremental conductance (IC) algorithm (Abo-Sennah et al. 2021; Ronilaya et al. 2018; Mohamed and Sattar, 2019). These algorithms are simple to implement and do not require knowledge of the photovoltaic generator's characteristics, so they work independently, and their efficiency is good under test conditions stable. However, when the weather conditions (solar irradiation intensity and temperature) change, the algorithm begins to oscillate around the MPP point and is unable to track the MPPT, reducing the overall system's efficiency (Talbi et al., 2021). Artificial intelligence algorithms, such as the fuzzy logic controller (FLC) and artificial neural network (ANN) algorithms, are the second class of algorithms (Abdelaziz and Almoataz, 2020). The maximum power point is accurately monitored in stable and variable atmospheric conditions, but it is more sophisticated than earlier traditional methods, where these algorithms are characterized by their high efficiency and high response speed (Sennah et al., 2021; Ali et al.,2021). The optimization algorithms (Cuckoo search (CS), Ant colony optimization (ACO), and Particle swarm optimization (PSO) algorithms) are the third type of algorithm used in MPPT technology. This type of modern algorithm is characterized by rapid convergence and high accuracy, especially under volatile weather conditions, which improves the efficiency of the photovoltaic system (Zafar et al., 2020; Chao et al., 2021).

In this study, the MPPT technology will be developed by developing three algorithms that will be used: the Perturb and Observe (P&O) algorithm, the fuzzy logic controller (FLC) algorithm, and the particle swarm optimization (PSO) algorithm to increase the efficiency of the photovoltaic system by extracting the maximum power From solar panels, MPP point tracking and control of the output voltage in various test conditions (standard and variable), as well as control of the duty cycle of the DC-DC boost converter. The photovoltaic system was simulated using the MATLAB / Simulink environment, and through the simulation results, the results of the three algorithms will be compared under standard and variable test conditions (intensity of solar irradiation change and temperature change), To determine the best algorithm in response speed, extract the maximum power, and control the duty cycle of the converter to produce a specific voltage level. A 1Soltech 1STH-215-P solar panel, consisting of one cell connected in parallel and one in series, is used in this study as the model used in the simulation. The electrical elements that go into building a DC-DC boost converter are designed based on the voltage required to be prepared for the load (40 volts) and using the theoretical values for voltage, current, and power given by the solar panel mentioned (Nkambule et al.,2019; Hekss et al.,2019). Algorithms will be simulated under standard test conditions (irr=1000w/m2 and tem=250c) and measure the voltage, current, and power extracted from the solar panel and compared with the characteristics of the electrical panel to calculate the efficiency, then measure the current, voltage, and power out of the photovoltaic system and compare it with the values extracted from the solar panel to calculate. The efficiency of each algorithm and finally calculate the voltage provided by the boosting converter and compare it with the required voltage (40 volts) to calculate the efficiency of the transform to determine the best algorithm in performance and increase the efficiency of the photovoltaic system. The same calculations will be repeated, but with different test conditions (change of solar irradiation intensity and temperature change).

2. Materials and Method

2.1. Mathematical Model and Equivalent Circuit for a PV Cell

Sunlight is converted into power by a photovoltaic module. To put it another way, when a PV module is exposed to sunlight, it generates a direct current that is free of noise and pollution. Photovoltaic cells are connected in series and/or parallel in solar modules. These cells are essentially photosensitive P-N junction semiconductor diodes (Senthilkumar et al., 2022). PV modules can be joined together in series or parallel to form PV arrays (Abdelaziz and Almoataz, 2020). Single-diode and two-diode models are two types of equivalent circuits often used to simulate a PV cell. Single diode, double diode, vulture, and other models are available.

A large number of comparable circuits are being developed. The two-diode equivalent circuit has a more intricate construction and exhibits more nonlinear properties than the single-diode equivalent circuit. As a result, two-diode units are rarely employed. The single-cell circuit model is the most common since it delivers real results. In this study, the single-diode equivalent circuit model was used (Mars et al., 2017). The photovoltaic cell is represented in the equivalent circuit shown in figure 1.

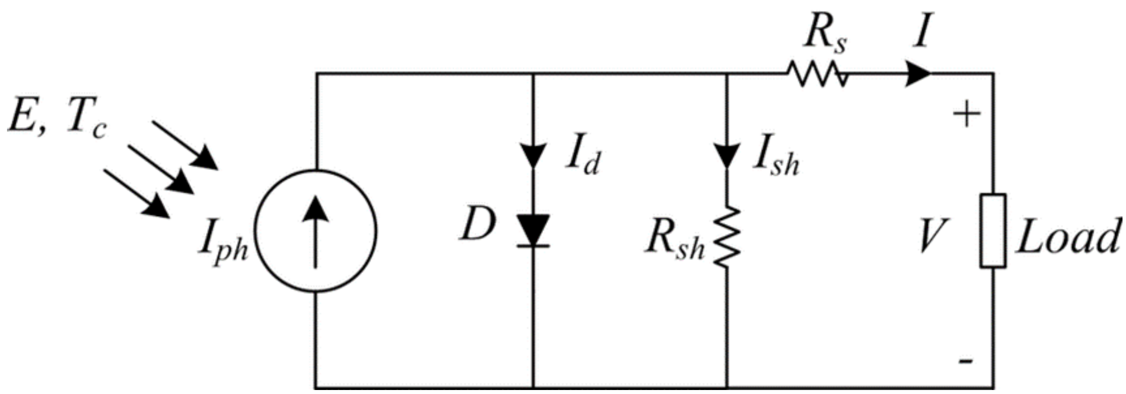

Figure 1. Equivalent circuit of a photovoltaic (Said and Latief, 2018).

The equations that define the PV module model are as follows (Mars et al., 2017; Said and Latief, 2018):

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

Module photo-current was rated as follows:

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

The equation for the shunt current is as follows:

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

The equation for calculating the dark current I_d is as follows:

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

The following equation describes how the reserved saturation current varies with temperature:

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

Finally, the total current can be calculated using the following formula:

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

When the values of the resistors

R_s=0 and R_{sh}=∞

The previous equation will become as follows:-

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

Table 1 shows the equation terminology.

Table 1. Equation Terminology

V	*PV cell output voltage [V].*	A	*Ideality factor.*
I	*PV cell output current [A].*	T	*Cell temperature [Kelvin].*
N_s	*The number of modules are connected in a series.*	q	*The electron charge constant (1.602x10-19 C)*
N_p	*The number of modules are connected in parallel.*	*T_ref*	*Reference temperature [Kelvin].*
I_{ph}	*Current generated by light in a PV cell [A].*	*I_sc*	*PV cell short-circuits current at 25°c and 1000[w/m2].*
I_s	*Saturation current in PV cells [A].*	*R_sh*	*Shunt resistance of a PV cell [Ω].*
R_s	*The series resistance of a PV cell [Ω].*	*Eg*	*The band gap for silicon [eV].*

2.2. Curves of Characteristics for PV Systems

To get the best photovoltaic cell efficiency, you need to study and understand its properties, which are mostly affected by solar radiation intensity and temperature. The voltage-current (V-I) and power-voltage (P-V) characteristics must be stated as a result. Because it is difficult to predict changing weather conditions and study their properties, all photovoltaic cell manufacturers use standard conditions when manufacturing them for solar irradiation intensity and temperature (temp= 250°C and irr=1000 W/m^2) (Al-Majidi et al., 2018). In this study, 1Soltech 1STH-215-P solar cell was used, whose electrical characteristics are shown in Table 2.

Table 2. Trina Solar 1Soltech 1STH-215-P Module Parameters

Maximum Power (W)	213.15
Open Circuit Voltage (V_{OC})	36.3
The voltage at maximum power point (V_{MPP})	29
Temperature coefficient of V_{OC}(%/deg.C)	-0.36099
Cells per module (N_{cell})	60
Short-circuit current I_{SC} (A)	7.84
Current at maximum power point (I_{MP})	7.35
Temperature coefficient of I_{SC} (%/deg.C)	0.102
Light-generated current IL(A)	7.8649
Diode Saturation Current Io (A)	2.9259e-10
Diode ideality factor	0.98117
Shunt resistance R_{sh} (ohm)	313.3991
Series resistance R_s (ohm)	0.39383

Using the equivalent circuit model of a photovoltaic cell whose type and mathematical equations were mentioned earlier, and whose electrical specifications are given in Table 1, we can plot the characteristic curves of current-voltage (I-V) and power-voltage (P-V) according to standard test conditions (STC). Where the MATLAB/Simulink environment is adopted to simulate the equivalent circuit of a photovoltaic cell and plot its electrical characteristics under standard test conditions and variable test conditions (solar irradiation intensity and temperatures) (Said and Latief, 2018). As shown in Figures 2, 3, and 4 respectively (Al-Ghezi et al., 2022).

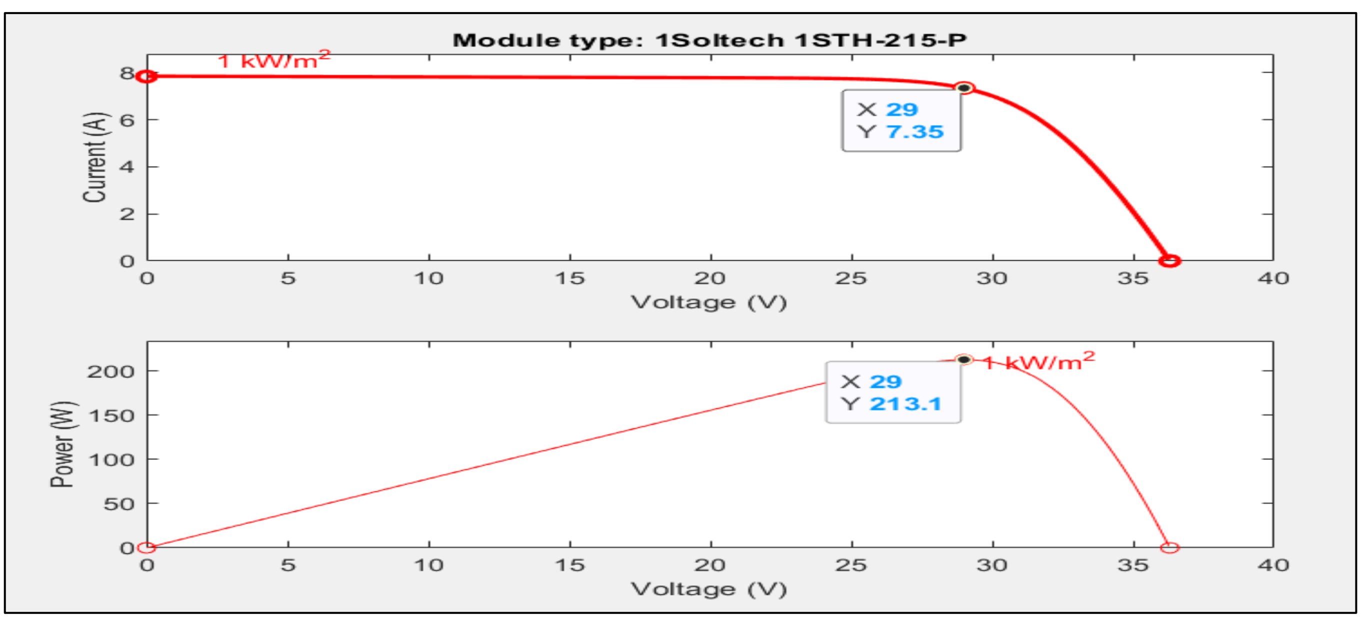

Figure 2. Under STC conditions, a PV module's I–V and P–V characteristics.

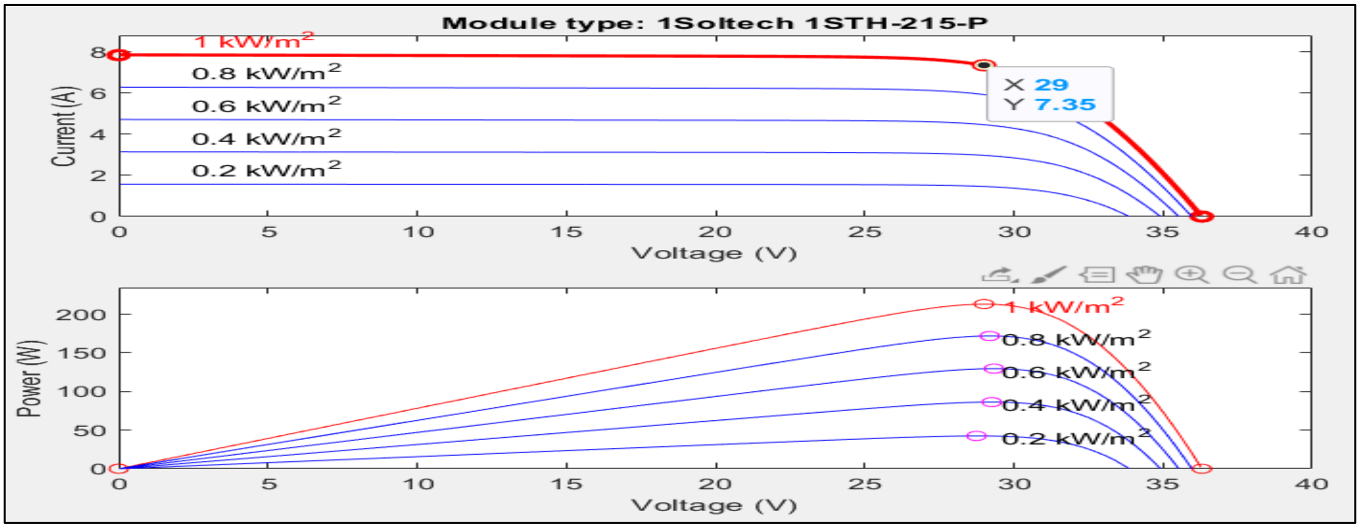

Figure 3. Characteristics curves (I-V & P-V) of the photovoltaic panel when the irradiation intensity changes.

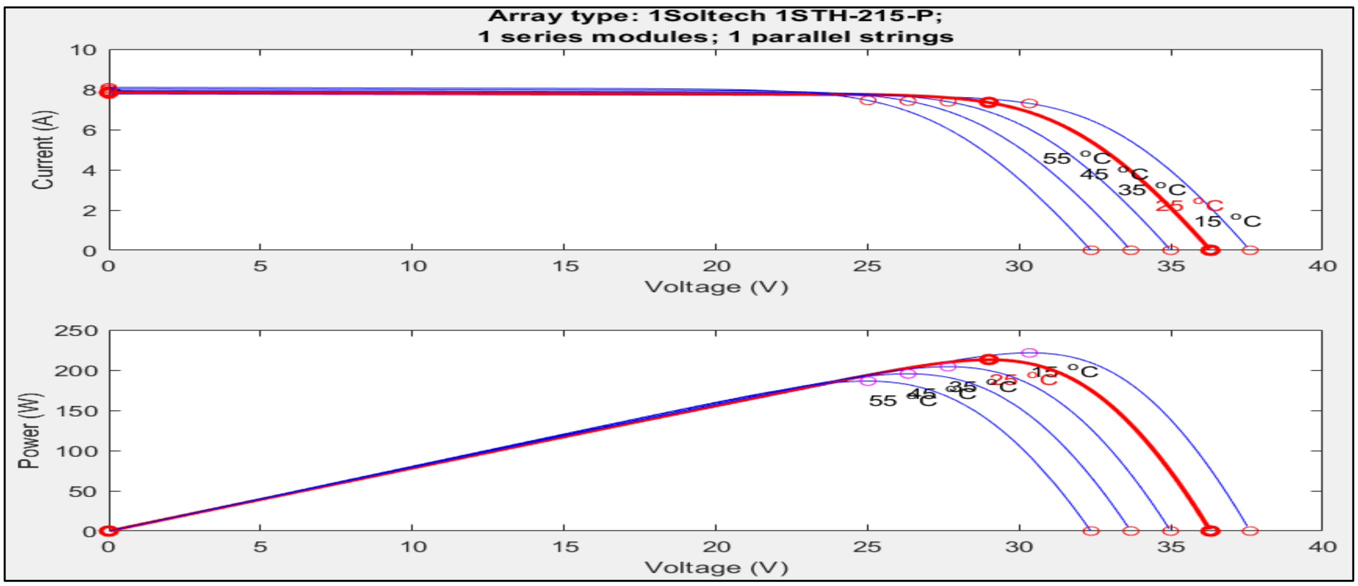

Figure 4. Characteristics curves (I-V & P-V) of the photovoltaic panel when temperature change.

3. Maximum Power Point Tracking

Since the output characteristics of the photovoltaic system are not linear and vary with different weather conditions (intensity of solar radiation and temperature), which makes the efficiency of photovoltaic systems low, so the researchers took care of this problem and developed several techniques in order to extract the maximum power from the solar panel and to obtain the maximum power point MPP to increase system efficiency. Figure 5 shows the I-V characteristics of MPPT (Szczepaniak et al., 2021).

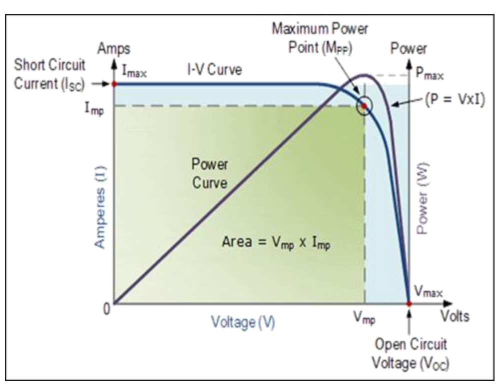

Figure 5. The I-V characteristics of MPPT (Anowar and Roy, 2019).

The Maximum Power Point Tracking (MPPT) technology is one of the most widely used and advanced technologies in PV applications (Acharya and Aithal, 2020). The application of MPPT technology increases the efficiency of the photovoltaic system by 20% to 40% under Standard Test Conditions (STC) and low temperatures, In the literature, many algorithms have been developed in order to improve the efficiency of photovoltaic systems. In this study, we will develop and simulate three algorithms for their application in MPPT technology.

4. Maximum Power Point Tracking Algorithms

Researchers and scientists have been developing, discovering, and publishing several MPPT technology algorithms over the past years, to find the maximum power point (MPP). The differences between the technologies used are identified at many points such as the required current and voltage sensors, their effectiveness, their efficiency, the complexity of their form, their cost, the speed of convergence, the correct tracking when the radiation intensity is variable, and/or the temperature, and the devices needed to install and implement them, Among many other things. Pilakkat et al. (2020) and TIRTH et al. (2020) provide comprehensive reviews of a wide range of MPPT algorithms. Bollipo et al. (2020) figure 6 shows the most frequent algorithm strategies. The three main types of algorithms are traditional algorithms, artificial intelligence algorithms, and optimization algorithms (Bollipo et al., 2020).

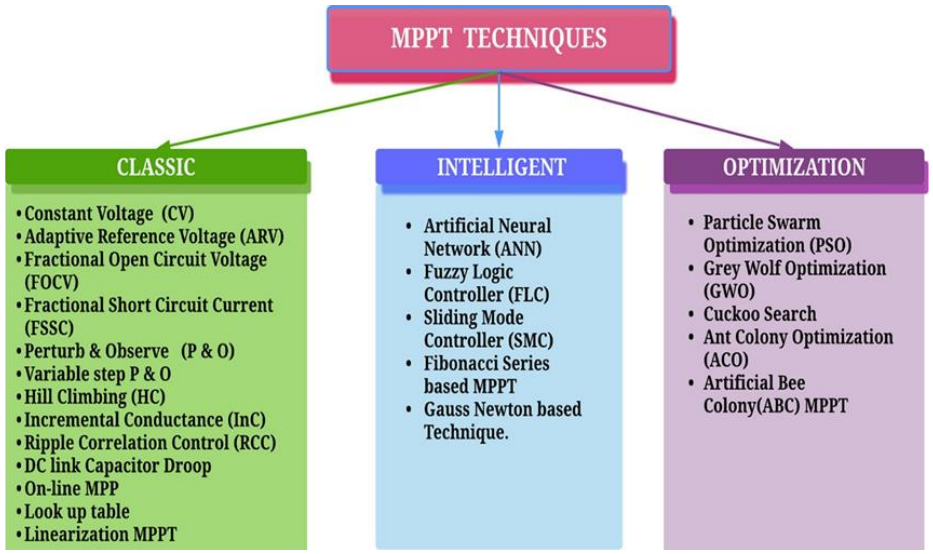

Figure 6. Classification of MPPT technique (Bollipo et al., 2020).

In this study, three algorithms will be developed and implemented: the Perturb and Observe (P&O) algorithm, the fuzzy logic controller (FLC) algorithm, and finally the particle swarm optimization (PSO) algorithm.

4.1. Perturb and observe (P&O)

The P&O algorithm is one of the most popular and widely used MPPT techniques due to its simplicity, ease of use, low costs, and simple results, especially under stable conditions (Abdelwahab et al., 2020). P&O works by gradually raising the perturbation of the panel's operational voltage, allowing the power output to be recorded and compared over time. When the operational point is located to the left of the MPP, the P&O method works by increasing the voltage, which causes the power output to rise, as shown in Figure 7.

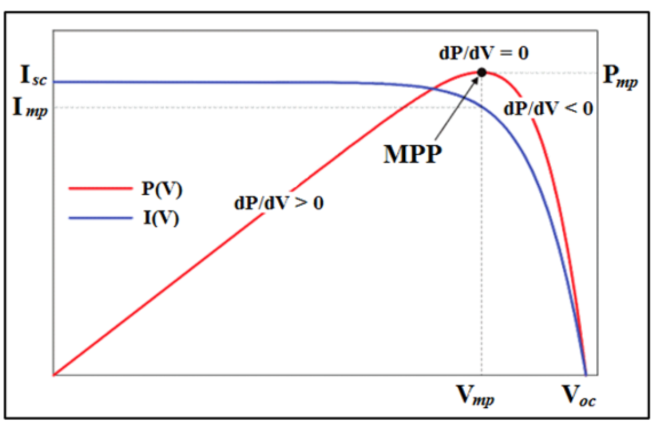

Figure 7.The Perturb and observe method's P-V curve.

If the power differential is positive, more disturbance in the same direction is applied to the working voltage, and the output power is measured again. The process of perturbation continues until the energy difference is negative. As a result, the operating voltage's disturbance direction must be reversed. When the operating point of the P&O is to the right of the MPP, the voltage is reduced, the power output is increased, and the P&O operates in the opposite direction (Kamran et al., 2020).

The equations below show the mathematical relationships of a technique for the P&O algorithm.

- $\frac{dP}{dV} = 0$ at the MPP (8)
- $\frac{dP}{dV} > 0$ *at the* left side of MPP (9)
- $\frac{dP}{dV} < 0$ at the left side of MPP (10)

4.2. Fuzzy Logic Control(FLC)

One of the types of artificial intelligence techniques and the most used in recent years is the fuzzy logic (FLC) algorithm. Fuzzy logic is based on the idea that human decision-making is more than just "ones and zeros" or "yes-no." The fuzzy control rules are basically IF-THEN rules. In solar systems with non-linear features, MPPT technology based on the fuzzy logic control (FLC) algorithm is used. Because the FLC algorithm does not require the usage of complex mathematical models or system parameters, it is very efficient. As a result of this characteristic, FLC-based MPP point tracking and charge control technologies have become one of the most widely used MPPT technologies. Fuzzification, inference system, and defuzzification are the primary components of Fuzzy Logic Controller (FLC) for MPPT Technologies (Alshareef, 2021; Abdellatif et al., 2021). Figure 8 shows the most important parts of the fuzzy logic control (FLC) algorithm.

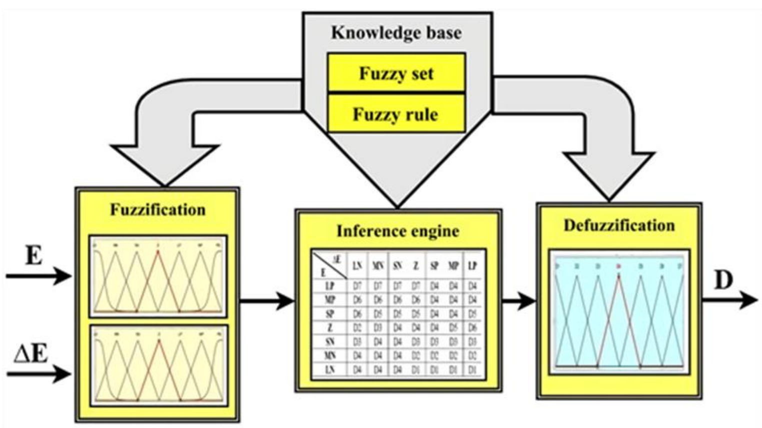

Figure 8. Illustrates the structure of an FLC (Baramadeh et al., 2021).

Fuzzy logic systems reach their maximum power point faster during load or under changing atmospheric conditions due to the soft calculation features of fuzzy logic. Fuzzy Logic based on MPPT systems works without oscillation or at a low level after achieving their maximum power.

- Fuzzification: It is the process of converting crisp values into fuzzy sets, and it is called membership functions.
- The rule-base is made up of a series of If-Then rules that regulate the controller. The number of rules is proportional to the number of input membership functions that are employed. Each input contains seven membership functions in this study, resulting in 49 rules as indicated in Table 3.
- Defuzzification: It is the process of fuzzy data into deterministic data.

Table 3. Fuzzy logic rules.

ΔI / Δv	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PB	PB	PB	PM
PB	ZE	PS	PM	PB	PB	PB	PB

The fuzzy inputs are designed for "voltage change" and "change in current", the output from the fuzzy logic controller is the change in duty cycle (D), as shown in Figure 9 (Baramadeh et al., 2021).

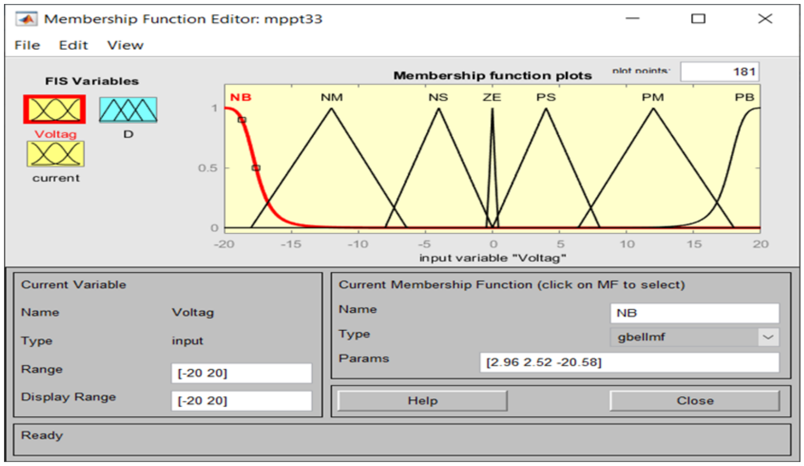

Figure 9. The membership functions editor's interface

4.3. Particle swarm optimization (PSO)

PSO is an optimization method based on the social behavior of birds or fish swarms. The PSO algorithm is based on the individual and herds social behavior of the organism (swarm). Due to its simple algorithm structures and fast convergence rates controlled by only a few parameters, this population-based optimization (PSO) method is frequently used by academic and industry researchers (Putri et al., 2019; Hu et al.,2019). Figure 10 shows the flowchart of the PSO algorithm design technique.

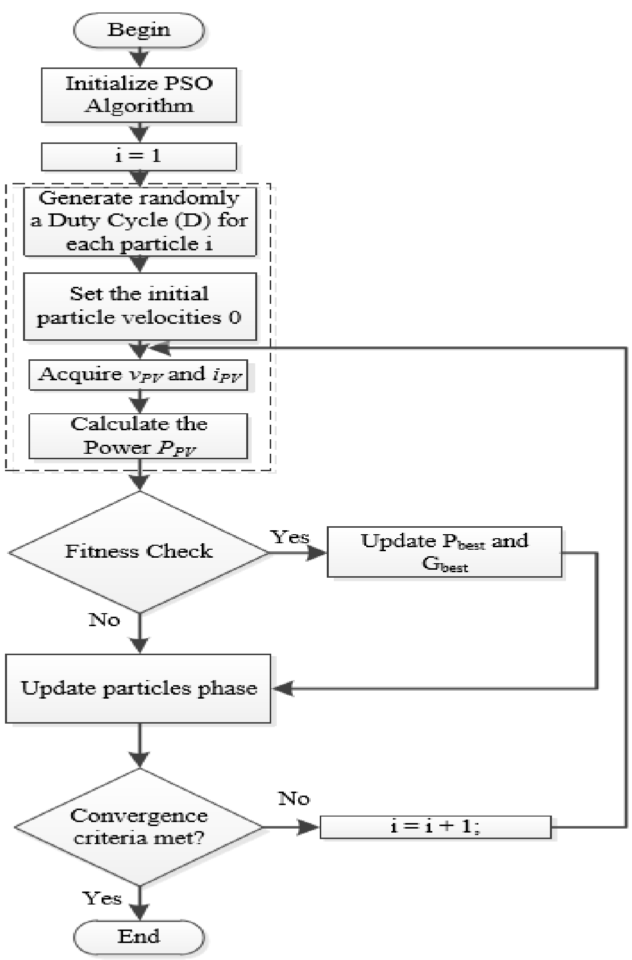

Figure 10. PSO algorithm flowchart(Rocha et al., 2019).

5. DC-DC Converters

Solar energy systems are not ideal for generating consistent power because they are strongly influenced by weather conditions. As a result, even if the maximum power point (MPP) is attained from photovoltaic panels, it is extremely difficult to transfer the maximum power generated by them straight to the loads on a continuous basis. Because the PV system is impacted by the intensity of sunlight and the temperature, the load curve must be adjusted in response to weather variations (Irwanto et al., 2020; Palanisamy et al., 2019). We can achieve this by adding an electronic system whose location is between the solar panels and the load. The duty cycle of the converter is controlled through MPPT technology to control the level of voltage to be output (Prabhu and Babu, 2021). In this study, a DC-DC boost converter will be used, as this converter has the advantage of raising the input voltage and outputting a higher voltage as needed. Figure 11 shows the electrical elements that make up the converter, whose values will be designed based on the data of the solar cell and the voltage required to be supplied to the load.

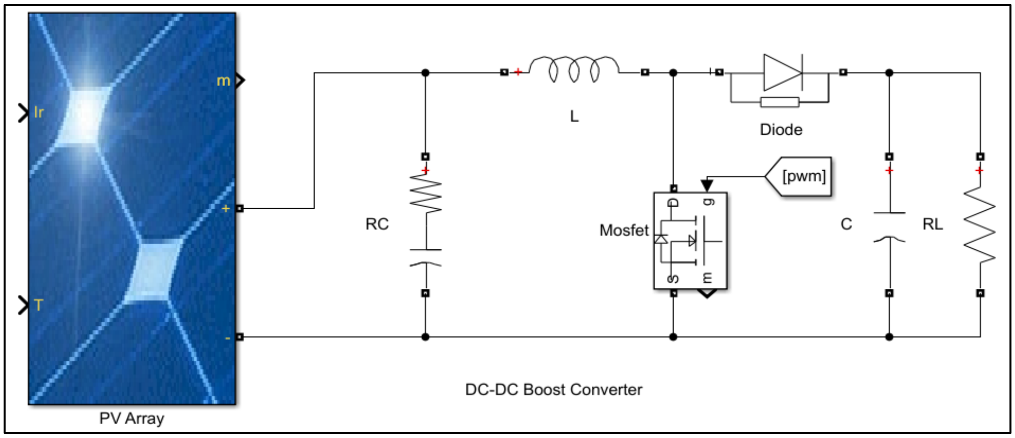

Figure 11. Simulink model of the DC-DC boost converter.

6. Design of MPPT Based on Several Algorithms Using MATLAB / Simulink

In this section, the photovoltaic system consisting of three main parts is simulated (solar panel, MPPT technology, DC-DC boost converter) with the application of three different algorithms (P&O, FLC, PSO) and tested under standard conditions (STC) and variable (change of irradiation intensity and temperature) using MATLAB/Simulink. Figures 12, 13, and 14 represent the simulation results for the signals (voltage, current, power) entering and leaving the photovoltaic system after processing and extracting the maximum power using MPPT technology based on three advanced algorithms (P&O, FLC, PSO), where it can be observed the difference between the signal In and out in terms of oscillation processing around MPP for comparison of algorithms.

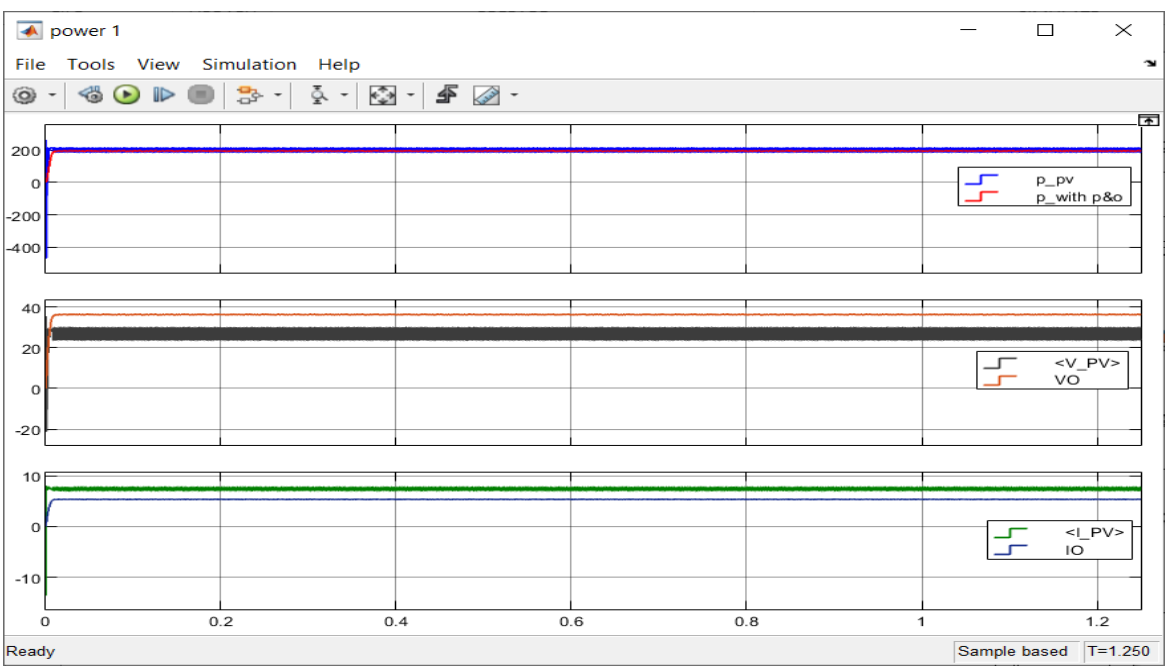

Figure 12a. Simulation of the (P&O) algorithm under standard test conditions.

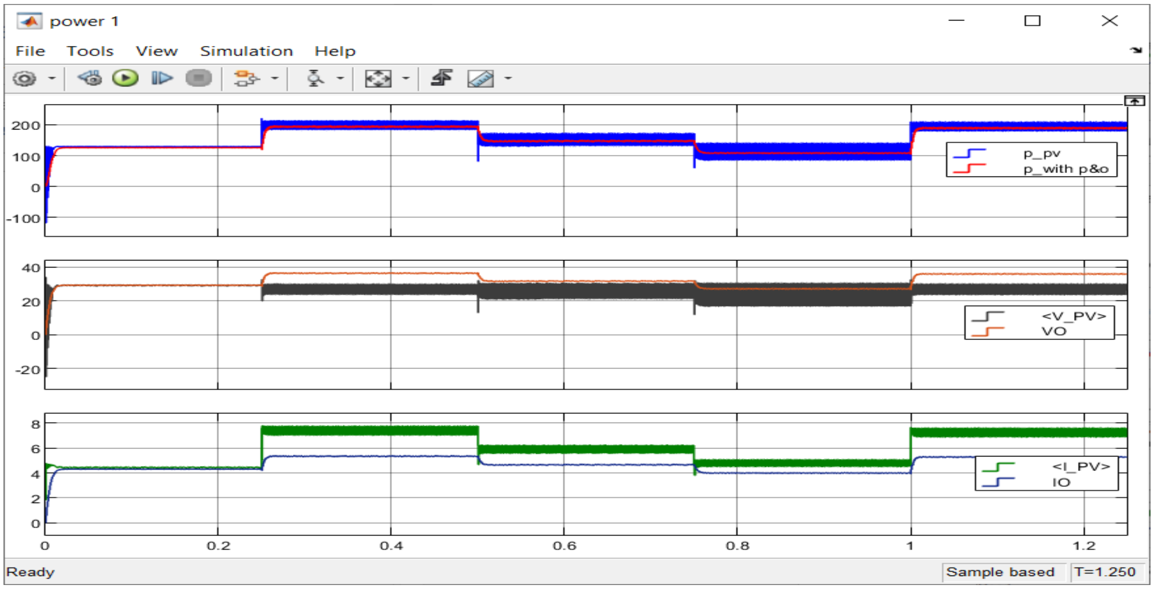

Figure 12b. Simulation of (P&O) algorithm when irradiation intensity changes.

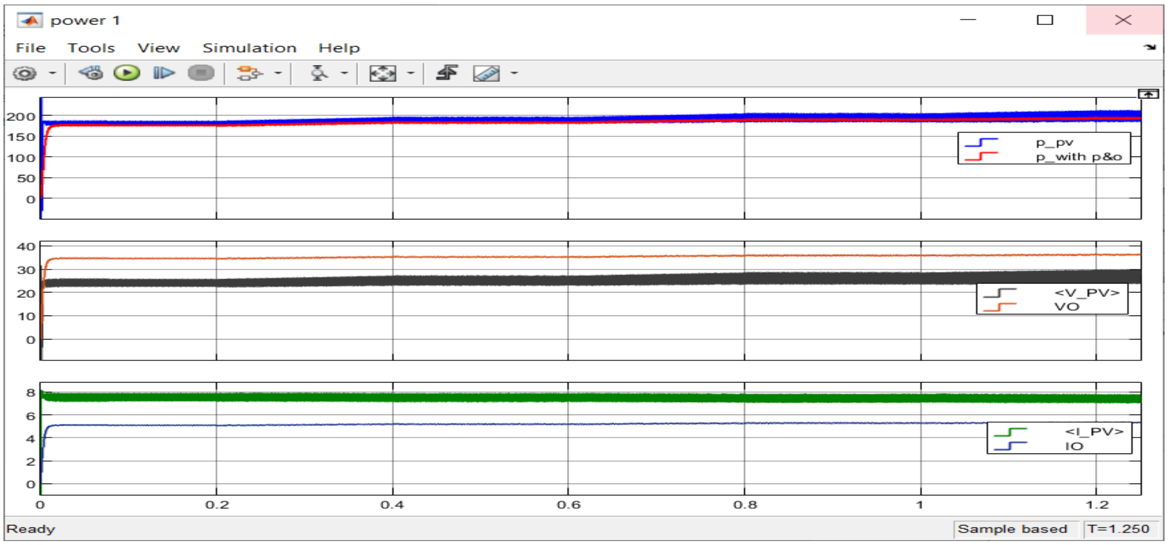

Figure 12c. Simulation of the (P&O) algorithm when the temperature changes

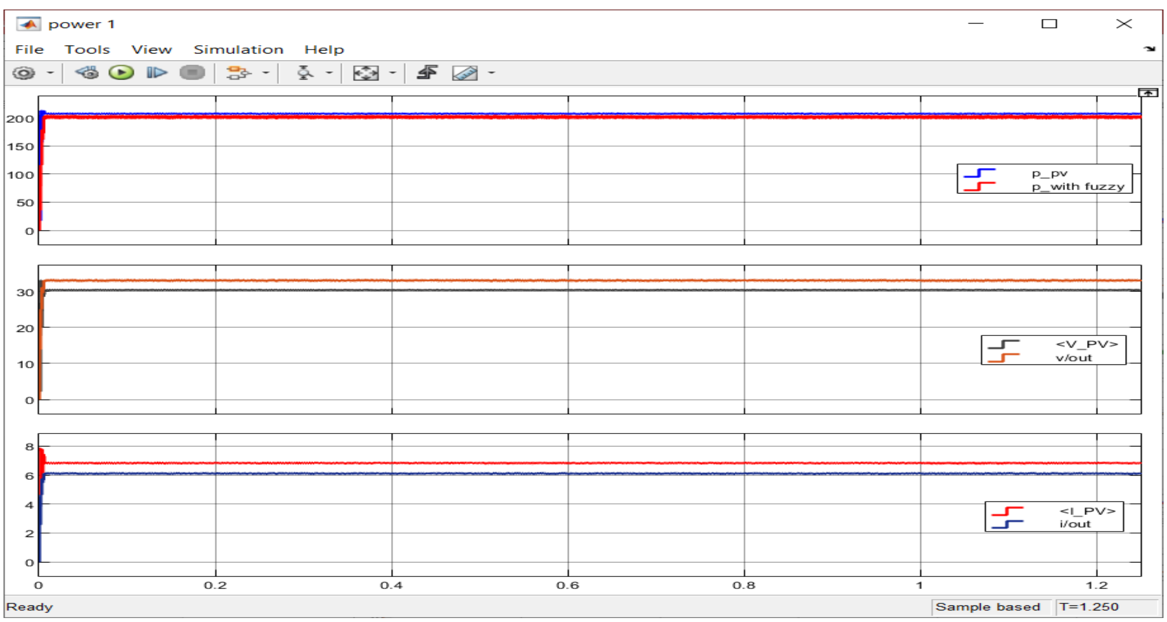

Figure 13a. Simulation of the (FLC) algorithm under standard test conditions.

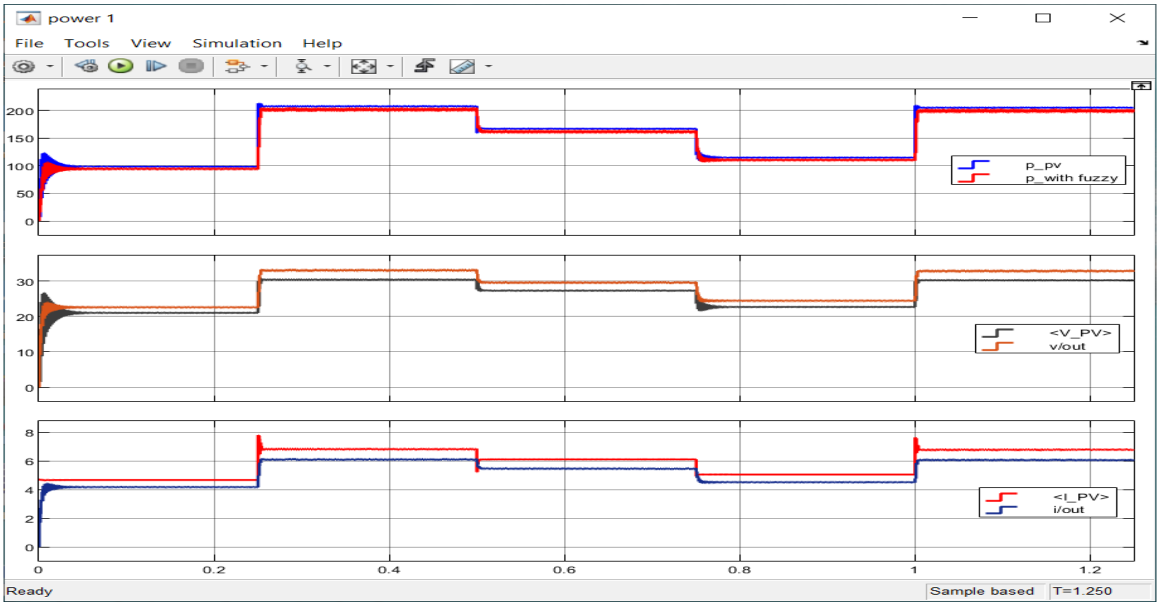

Figure 13b. Simulation of (FLC) algorithm when irradiation intensity changes.

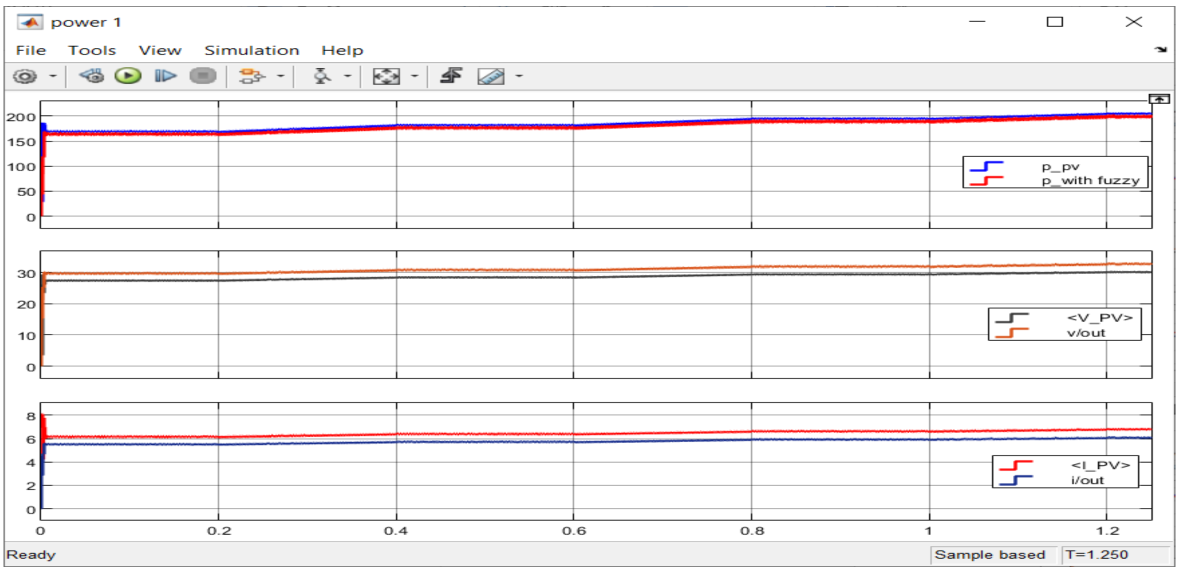

Figure 13c. Simulation of the (FLC) algorithm when the temperature changes.

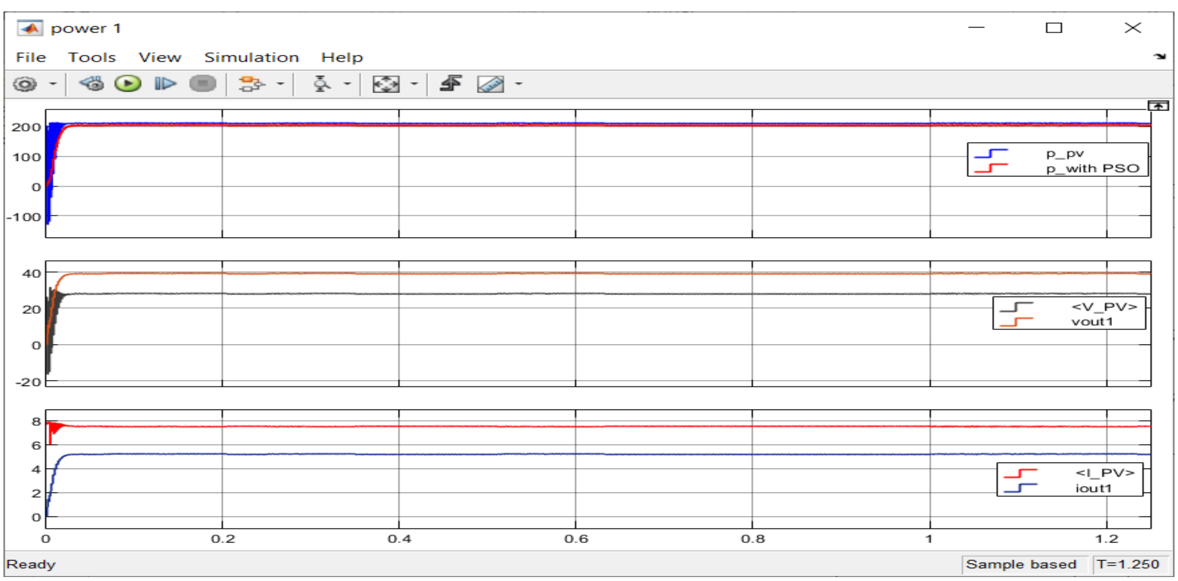

Figure 14a. Simulation of the (PSO) algorithm under standard test conditions.

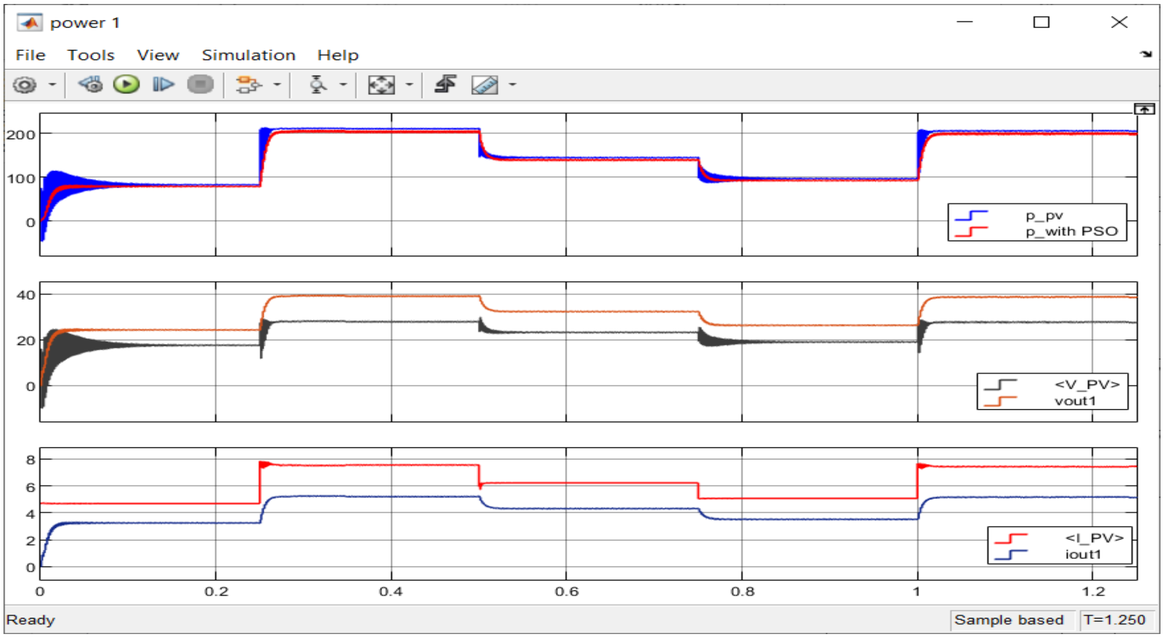

Figure 14b. Simulation of (PSO) algorithm when irradiation intensity changes

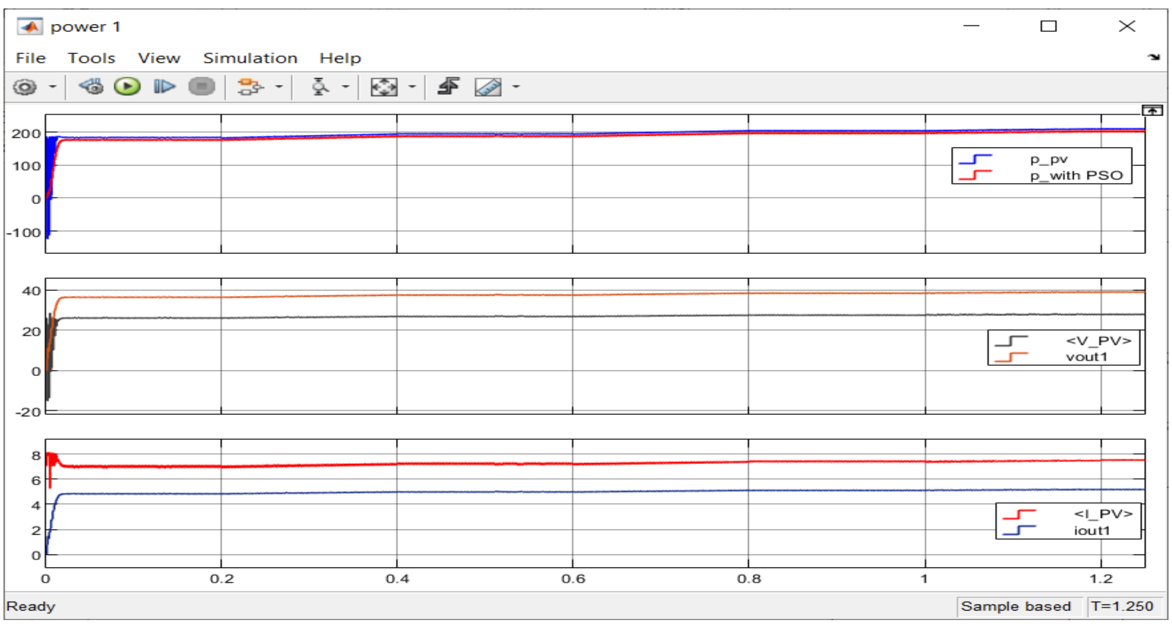

Figure 14c. Simulation of the (PSO) algorithm when the temperature changes.

7. Results and Discussion

Table 4 shows the results of simulation of the photovoltaic system based on three algorithms (P&O, FLC, PSO) under standard test conditions and others in which (irradiation intensity, temperature) change at a time when the efficiency was calculated in two locations, the first is the efficiency of extracting the maximum power from the solar panel and the second is the output efficiency of The maximum power when applying MPPT technology. The efficiency was calculated in order to compare the three algorithms and determine the best algorithm in extracting the maximum power, tracking the MPP point, reducing oscillation around it, and controlling the duty cycle of the boost converter. Through the simulation results, we note that the algorithms (P&O, FLC, PSO) that were developed and implemented in MPPT technology work very well and with very high performance, but there are simple differences that distinguish one from the other. We note the performance and efficiency of the (PSO) algorithm that is the best and the most efficient in extracting the maximum power and tracking the MPP point perfectly with the least swing around it, and controlling the duty cycle of the DC-DC boost converter perfectly to supply voltage to the load. Where the (PSO) algorithm achieved an efficiency of (99.22%), while the (FLC) algorithm achieved an efficiency of (98.56%), and finally the (P&O) algorithm achieved an efficiency of (96.64%) in the standard test conditions. Also, the (PSO) algorithm achieved the highest efficiency (98.65%) when changing weather conditions compared to the two algorithms (P&O, FLC). It also achieved the highest voltage (39.38 volts) at the output of the photovoltaic system by controlling the duty cycle of the boost converter.

Table 4. Photovoltaic system simulation results

Test Conditions	Algorithms	$P_{I/P}$ (W)	$V_{I/P}$ (V)	$I_{I/P}$ (A)	Efficiency Extracting Power	$P_{O/P}$ (W)	$V_{O/P}$ (V)	$I_{O/P}$ (A)	MPPT Technology Efficiency
Irradiation 1000W/m^2, Temp=25^{0}C	P&O	206	26.89	6.934	96.64%	196	36.49	5.37	95.14%
	FLC	210.1	30.05	6.914	98.56%	204.6	33.26	6.152	97.38%
	PSO	211.5	28.14	6.763	99.22%	206.6	39.38	5.246	97.68%
Irradiation Intensity Change	P&O	201.2	26.8	8.394	96.31%	186.7	35.62	5.242	92.79%
	FLC	205.7	29.95	6.869	98.46%	200.3	33.01	6.067	97.37%
	PSO	206.1	27.77	6.673	98.65%	201.2	38.86	5.177	97.62%
Temperature Change	P&O	199.2	25.82	8.423	94.31%	190.6	35.99	5.296	95.68%
	FLC	207.8	29.88	6.875	98.39%	202.3	33.07	6.117	97.35%
	PSO	210.4	28.06	6.745	99.62%	205.5	39.28	5.232	97.67%

8. Conclusion

In this paper, three algorithms (P&O, FLC, and PSO) were developed and implemented in order to track the maximum power point and extract the maximum power from the photovoltaic system in various measurement conditions, and the simulation results were very satisfactory. Through the simulation results, it was found that the (PSO) algorithm has achieved the best performance and the highest efficiency (99.22%) by extracting the maximum energy from the solar panel and controlling the duty cycle of the booster transformer to produce an electrical voltage (39.38 volts), which is very close to the required voltage.

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