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A Study on An MPPT Control Approach Using Artificial Intelligence and the Perturb and Observe Method

Saif Talal Bahar[1*], Yasir G. Rashid[2]

[1]Department of Electrical Techniques, Baquba Technical Institute, Middle Technical University, Baghdad, Iraq
[2]Department of Electrical Power and Machines, Collage of Engineering, University of Diyala, Diyala, Iraq

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ABSTRACT

A maximum power point tracking (MPPT) control procedure constructed based on the Artificial intelligence optimization algorithm is proposed. A mathematical model of photovoltaic cells was established under varying light intensity and ambient temperature. Maximal power tracking control for iterative search using an artificial intelligence (AI) optimization technique Excellent, the artificial intelligence-based MPPT algorithm's principle is presented. Simulation results it shows that the artificial intelligence algorithm can faster and exactly track the maximum power point and remains stable, and compared to Perturb and Observe algorithm under dynamic shadow conditions and artificial intelligence MPPT control method, which has higher tracking accuracy and faster convergence speed. Faster and smaller oscillation amplitude, which is the best response to sunlight conditions for photovoltaic maximum power point tracking technology Flexibility. Using Matlab/Simulink software to build a simulation model of an independent photovoltaic system. It controls variables by keeping the temperature continuous and changes the light intensity to simulate different lighting environments. The identical comparison was conducted between all based MPPT methods such as the fuzzy control approach, demonstrating that the fuzzy control based technique exhibits higher results in terms of efficiency.

1. Introduction

Energy is extremely important in our lives and economies. The industrial revolution has caused a significant increase in energy consumption. Fossil fuels are progressively being exhausted. Our civilization's long-term viability is under tremendous jeopardy. However, greenhouse gas productions continue to rise as a result of traditional energy generation. Reducing carbon dioxide productions, maintaining secure, clean, and inexpensive energy, and achieving environmentally friendly energy systems are all significant worldwide challenges [1]. Renewable energy sources provide clean and environmentally friendly power. Renewable energy comes from a diversity of sources, containing solar and wind energy. The photovoltaic (PV) system has received a lot of interest from academics since it looks to be one of the most likely future renewable energy sources. Solar energy is environmentally friendly, maintenance-free, pollution-free, and produces little noise outstanding to the lack of touching components [1, 3]. Nevertheless, two major problems restrict the use of solar systems. These are great expenses for construction and little efficiency of converting energy [2]. One efficient way for lessening photovoltaic power

* Corresponding author.
E-mail address: saif.talal@mtu.edu.iq
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system expenses and improving solar energy usage efficiency is to use a maximum power point tracking system for photovoltaic panels [4]. Maximum power point tracking, or MPPT, is a knowledge that extracts the maximum power since a PV module and delivers it to the load, increasing efficiency [4].

The initial stage in researching the proper control mechanism for solar systems is to understand how to model and create a PV system connected to a power converter and grid. In overall, PV systems have nonlinear power-voltage (P-V) and current-voltage (I-V) properties that are heavily influenced by the amounts of radiation absorbed and the ambient circumstances. The computational representation of the photoelectric device is required for investigating methods for tracking the maximum power point, evaluating the dynamic properties of converters, and modeling photoelectric components utilizing circuit simulators [5]. Notwithstanding recent breakthroughs in PV cell devices, the impacts of some harmful environmental conditions, which significantly diminish the efficiency of photovoltaic cells, constitute an unavoidable obstacle. A typical environmental occurrence is partial shading, which results in several peaks on the power output curve and has a significant influence on the efficiency of most standard MPPT methods [5, 6]. As a result, a thorough investigation into photovoltaic system modeling and simulation is required in order to simplify the development of potential MPPT strategies and suitable PV unit setup.

The MPPT mechanism unit adjusts the duty cycle of the DC-DC boost converter in actual period, controlling the switch of the inverter. Consequently, the system generates largest power regardless of weather conditions. Researchers have developed many techniques using MPPT for optimizing PV power, including partial open-circuit voltage [6, 7], and short-circuit current [6, 8]. These approaches use a relation that is linear to calculate short-circuit current and open-circuit voltage by using the maximum power point (MPP) current or voltage. The perturb and observe (P&O) approach [9] is widely used to determine the greatest power due to its simplicity of execution.

To address these issues, MPPT control mechanisms were created. They mostly use AI techniques such as fuzzy logic (FL), artificial neural networks (ANN). They are better suited than traditional techniques for improving reaction period, tracking efficiency, and minimizing overshoot in the period of transition, as well as oscillation associated with the MPP due to irradiation and/or temperature fluctuations [10]. (FL) is currently utilized for monitoring the MPP of solar power plants since it is resilient, relatively straightforward to develop, and requires no expertise in a specific model[11]. In this article, theoretical representations of solar energy systems and DC-DC conversion devices are utilized to analyze the FL-based MPPT approach.

This paper uses Matlab/Simulink software to build a simulation model of an independent photovoltaic system. It controls variables by keeping the temperature continuous and changes the light intensity to simulate different lighting environments. Artificial intelligence and the Perturb and Observe method. Through comparison, it is found that compared with the other two control algorithms, the improved artificial intelligence algorithm can track MPP faster, with higher tracking accuracy, and with smaller fluctuations in the tracking process, regardless of static or dynamic conditions.

2. Literature review

In [12-13], the researchers demonstrated the nonlinearity of the I-V and P-V characteristics when the PV system is illuminated uniformly by sunshine. In overall, each PV system has a specific operating point known as the maximum power point, which produces the most power at the optimal voltage and current. The researchers in [14] shown that the MPP varies with solar irradiation because PV attributes vary with meteorological conditions. Cell temperature is one among the parameters stated in [13] that will affect MPP's position. Nevertheless, [14] and [15] did not address the impact of completely shadowed conditions on the PV systems. A study, the Perturb and Observe (P&O) approach is generally employed since to its ease and inexpensive employment costs. P&O can increase the power production of the PV system by continually tracking the MPP despite fluctuating climatic conditions. The investigations in [14] demonstrate that when the PV array is partly shaded, the array characteristics become complicated with several MPPs. PSC is described as a situation in which one or more PV modules in the array get less solar irradiation. The existence of several MPPs may lead the PV array to become stranded at the local MPP. At this working situation, the PV array will provide less output power. On the other side, if the PV array is running at perfect MPP, it may provide more output power[15]. As a result, a PV array operating at actual MPP can outperform a trapped local MPP in terms of power efficiency.In recent years, artificial intelligence algorithms have relied on their excellent data processing speed and accuracy, and their data training and learning capabilities. Can be gradually applied in various fields. Researchers introduced it into the field of MPPT control. Hu [16] introduced (ANN) is combined with the traditional conductance increment method to use the trained ANN output as the initial the duty cycle is shifted to the DC-DC Boost Converter section, bringing the output of the PV system closer to the desired one[17].

3. Photovoltaic cell characteristics

An ideal photovoltaic cell can be equivalently constructed by an ideal diode and a constant current source [18-20]. Figure 1 is a photovoltaic cell circuit model, which is constructed based on the principle of photovoltaic effect of photovoltaic cells. Based on the basic principles of the circuit and the equivalent circuit model of the PV cell, the load current formula can be obtained as understands: Equation (1).

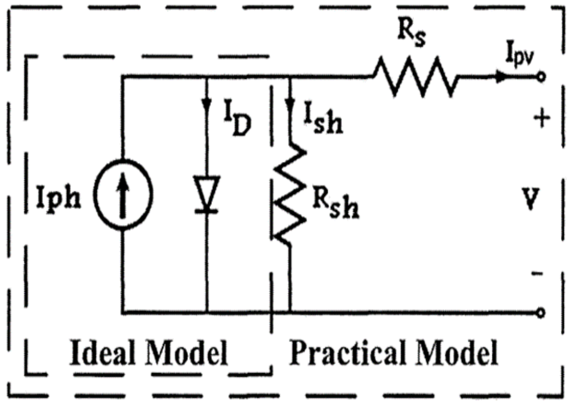


Figure 1. Model representation

$$I_{pv} = (I_{ph} - I_D - I_{sh}) \quad (1)$$

In the above formula, I_D represents the current flowing through the diode, which can be expressed by the following formula (2). I_{sh} is the current generated by the bypass resistor R_{sh}, which is called the bypass current. Its formula can be obtained according to Kirchhoff's second law, as presented in formula (3).

$$I_D = I_o(e^{(\frac{q(V+I_{pv}*R_S)}{nkT}-1}) \quad (2)$$

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

Substituting the above two, equations into formula (1), the characteristic equation of the photovoltaic cell I-V curve can be obtained, as shown in formula (4).

$$I_{pv} = I_{ph} - I_o(e^{(\frac{q(V+I_{pv}*R_S)}{nkT}-1}) - \frac{(V+I_{pv}*R_S)}{R_{sh}} \quad (4)$$

Where I_{ph} the current created by the PV cell, I_D is the diode current, I_{sh} is the current done shunt resistance and I_{pv} is the ending current created by the PV cell. WhileR_{sh}, R_s are parallel and series resistance. K is Boltzmann's constant, the value is approximately 1.38x10^{-23} J/K , n represents the diode factor and q represents the electron load, and the value is approximately 1.6x10^{-19} C. I_o is the saturation current under standard conditions. Figure.2 displays the I-V and P-V curves under unchanging irradiance situation with an exclusive (MPP).

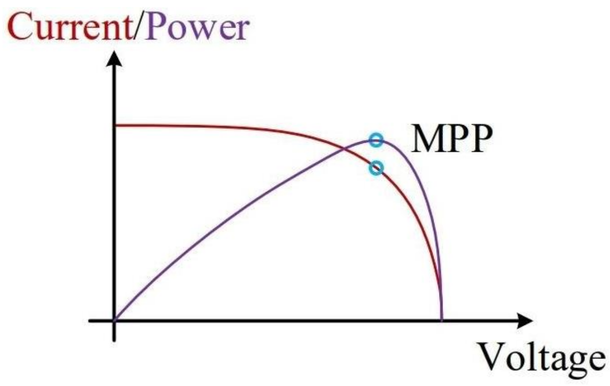


Figure 2. The I-V and P-V curves

4. MPPT methods describing

Controllers can use a variety of approaches for improving an array's power output. Maximum power point trackers are able to employ numerous algorithms and switch between them depending on the array's circumstances of operation. Some MPPT techniques:

(1) Perturb and Observe Methods
(2) Incremental Conductance Method
(3) Fuzzy Logic-Based MPPT Method
(4) Artificial Neural Networks Based MPPT Method.

4.1 Implementing of MPPT methods

When a load is connected directly to a solar panel, the panel's operating point is rarely at maximum power. The impedance seen by the panel determines the solar panel's operating point. Thus, by adjusting the impedance observed by the panel, the point at which it operates may be adjusted closer to peak power point. Because panels are DC devices, DC-DC converters are devices that must be used to transfer the impedance of one circuit (source) to another circuit (load) [19]. Varying the duty ratio of the DC-DC converter causes an impedance change, as visible on the panel. At a given impedance (or duty ratio), the operational point will correspond to the highest power transfer point. The I-V curve of the panel can change significantly depending on meteorological variables such as radiance and temperature. As a result, with such constantly changing operating circumstances, a fixed duty ratio is not practical. MPPT systems use algorithms that frequently sample panel current and voltage measurements and alter the duty ratio as required. Microcontrollers are used to implement computations. Modern versions frequently use bigger processors for analytics and load predictions.

4.2 DC- DC Converter

DC-DC converters are used in various applications, including power supply. There are four types of structures: boost converter, buck converter, buck-boost converter, and Cuk converter. The last of these is the most costly. The Cuk converter outperforms all other isolated DC-DC converters in terms of switching losses and efficiency. This is a two-inductor, non-isolated switch mode DC-DC converter that transmits power through a perfect switch [21]. The duty cycle and voltage gain of the converter do not have an exponential relationship. As the duty cycle of the conversion changes, the voltage changes accordingly. Adjust the duty cycle of the converter by moving the operating point to the opposite side or left of the IV characteristics. The Cuk converter inverts the output signal from positive to negative, or the other way around. The main control system to regulate the voltage V_1 of the PV array is the duty cycle D of the boost converter. The essential typical of a boost converter is displayed in Figure 3, which involves of an input side inductor L, a diode, a switch, and an output adjacent capacitor C. The calculated relation for duty cycle is given as: (5) represent the voltage obtain, current obtain and their calculated association with duty cycle.

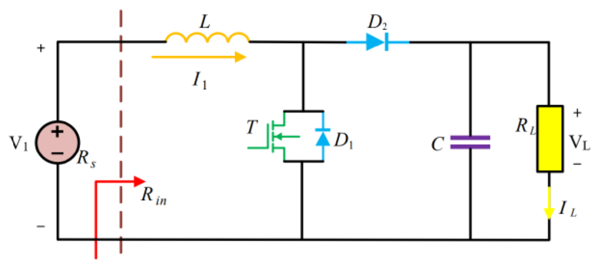


Figure 3. Boost circuit topology

$$\frac{V_L}{V_1} = \frac{I_L}{I_1} = \frac{1}{1-D} \quad (5)$$

Where V_L and I_L is the output voltage and outputs current respectively of the power boost converter. V_1 and I_1 are PV module voltage and PV module current respectively.

5. Perturb and Observe algorithm (P&O)

This method applies perturbation to the PV module or array voltage. The PV module voltage is boosted or lowered, and the power is also boosted or lowered [21]. When voltage increases, power increases, which specifies that the PV module's working point is to the left of the MPP [22]. As a result, additionally commotion towards the right is required to achieve MPP [23]. If an increase in voltage results in a reduction in power, this specifies that our PV module's working point is to the right of the MPP, necessitating further perturbation to approach MPP. Figures 4 and 5 show the P&O method's PV graph and flow chart. The magnitude and frequency of perturbations have a significant impact on steady-state fluctuations. Maintain a small perturbation frequency to allow the PV system to stabilize until the next disturbance.

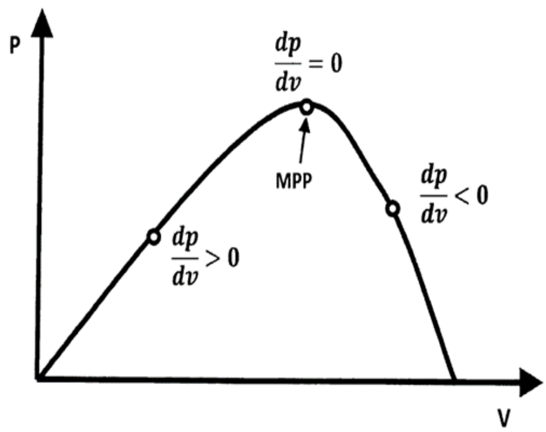


Figure 4. The P&O algorithm PV curve

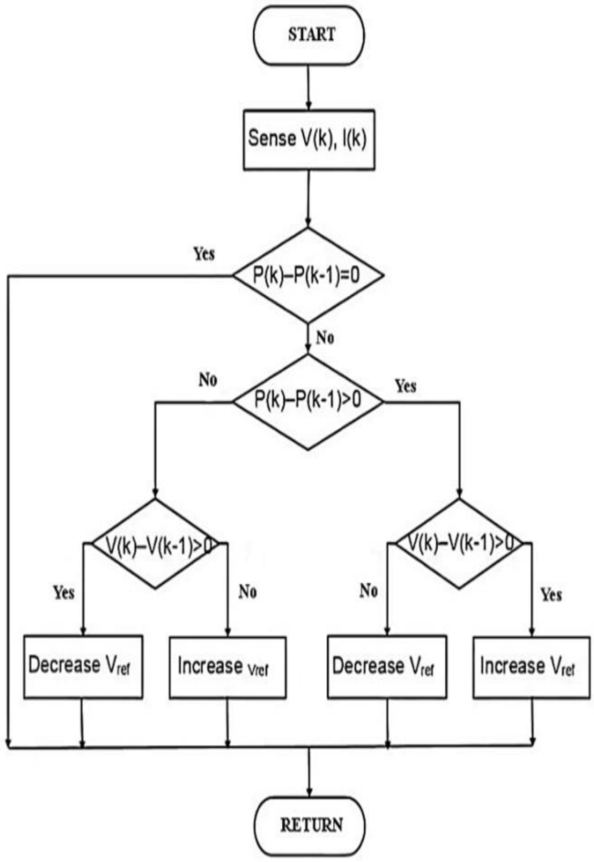


Figure 5. The block diagram of the algorithm (P&O)

6. Fuzzy Logic-Based MPPT Method

The fuzzy system is a system that utilizes the notions of imprecise inference. The idea is now being used in several domains of technology, such as architecture regulators for process control, problem modeling, and system and regulation performance improvement [24,25]. FL control is often distributed into 3 steps: fuzzification, rule basis list lookup, and defuzzification, as shown in Figure 6. Fuzzy controllers typically receive two inputs: an error (E) and a modification in the error (ΔE). The designer can select the error, however it is often ΔP/ΔV because to its zero value at the MPP.

The key benefits of the FL-based MPPT approach are the lack of a necessity for a precise numerical model of the system, the capacity to operate with indeterminate inputs, the ability to handle nonlinearity, quick and accurate integration, and others [26]. The key drawback is that the preparation of the input and output membership functions is dependent on involvement and extensive system info, which is complex and onerous. Figure 7 shows a block scheme for the FL-based MPPT approach. Figure 8, 9 and 10 show the membership functions (μ (E), μ (CE) and μ (ΔD).

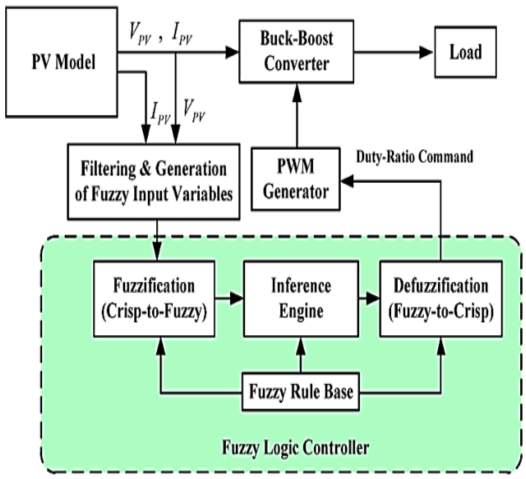


Figure 6. Scheme of PV system with Fuzzy Logic-based MPPT method

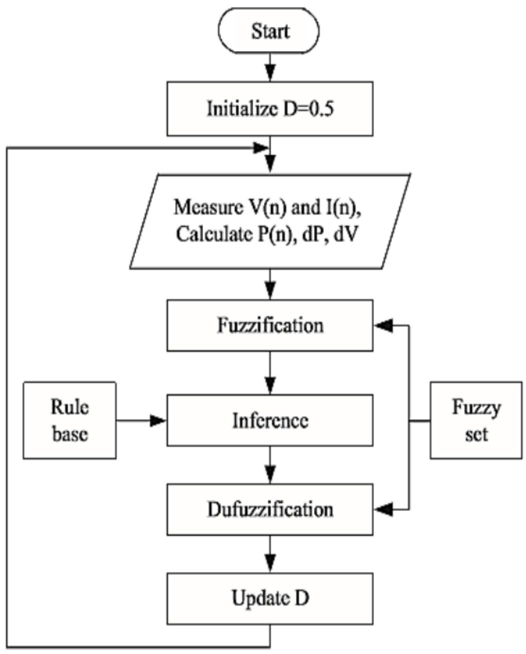


Figure 7. Block scheme of FL based MPPT method

Table 1 presents the fuzzy procedures utilized to regulate DC-DC. The matrix elements include the fuzzy error set (E), converter error (CE), and duration modification (ΔD).

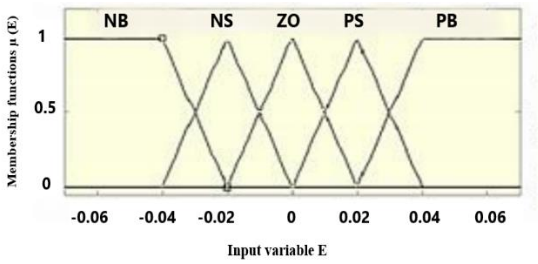


Figure 8. The membership functions μ (E)

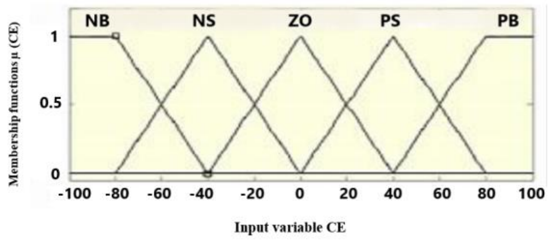


Figure 9. The membership functions μ (CE)

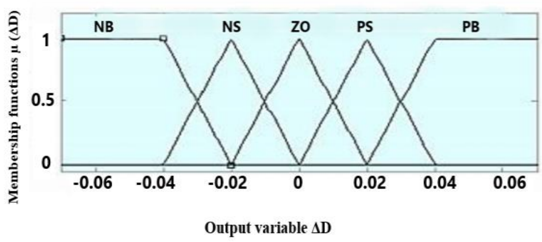


Figure 10. The membership functions μ (ΔD)

Table 1: Rule base lookup of the fuzzy control

E	**EC**				
	NB	**NS**	**ZO**	**PS**	**PB**
NB	ZO	ZO	NB	NB	NB
NS	ZO	ZO	NS	NS	NS
ZO	NS	ZO	ZO	ZO	PS
PS	PS	PS	PS	ZO	ZO
PB	PB	PB	PB	ZO	ZO

7. Neural networks based MPPT method

A neural network consists of 3 layers: the input, hidden, and output layers. Inputs to a network can include the array terminal voltage, solar irradiation level, and any additional metrics required by the method of MPPT [27]. The output is often one or more reference signal(s), such as a duty cycle indication, which drives the power converter to track at or adjacent the MPP[28]. The link among nodes j and i is identified with a weight of w_{ij}. The hidden layer is primarily responsible for the efficiency of this MPPT approach and the amount of training the network got. The weights among the neurons are tweaked to provide the desired output, this may be instructed to modify the duty cycle of a DC converter. Many advances are achieved in the field of ANN regulators [29]. Conservational data such as irradiation and temperature are sent into ANN as input. At the output step, a duty cycle is formed for a DC/DC boost converter, which pushes the PV voltage to its ideal level [30]. Figure 11 shows a block scheme for ANN approach .Equations (6) and (7) represent the input and output respectively:

$$y_j^h = f(\sum_{i=1}^{n} w_{ij} * x_i + \Theta_j^h) \quad (6)$$

$$y_j^o = f(\sum_{j=1}^{n} w_{kj} * y_j^h + \Theta_k^o) \quad (7)$$

Where, w_{ij} and $w_{kj}$are weights. And are the bias values. x_i and y_j^h are the indication values for inputs and outputs lines.

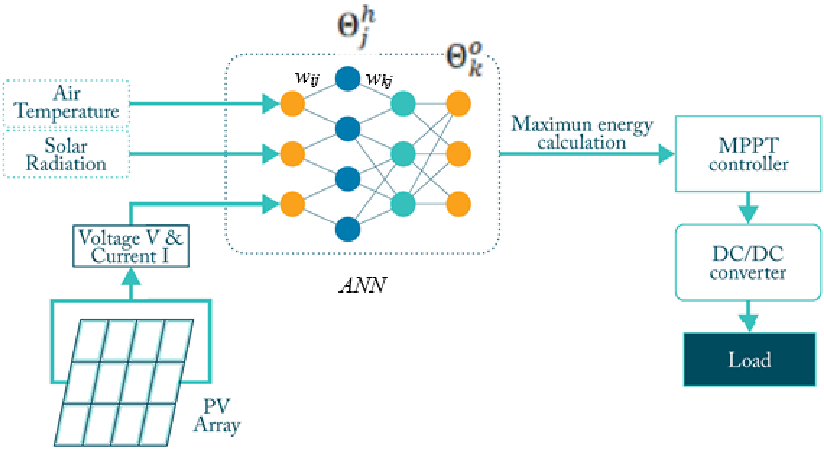


Figure 11. Description structure for a suggested ANN-based MPPT system

An additional benefit of the ANN-based MPPT technique is that it may give adequate MPP tracking accuracy despite the need for specific model consideration information [31]. Nevertheless, Artificial Neural Networks have a drawback: they must be properly trained for the PV system on which they are to be deployed [32]. Furthermore, the PV system's P-V and I-V properties fluctuate over time, necessitating constant neural network training to enable precise as well as effective [33].

The steps in the training procedure are as follows:

- Step 1: Set the network synaptic weights to tiny random values.
- Step 2: Use an input vector (solar insolation) for determining the network's output values.
- Step 3: Evaluate the mistake by comparing the actual outputs to the reference voltage.
- Step 4: Adjust the weights and update all connections.
- Step 5: Repeat steps 2–4 for all training vectors until the error is decreased to an acceptable level. MPP tracking.

8. Results and discussion

The simulation model of the PV power generation system is mainly collected of PV array, DC-DC converter, MPPT control procedure, Boost circuit and PWM pulse width modulation.

The specific parameters in the photovoltaic system model are capacitance C= C2=200e-6 F, inductance L=3e-3 H, and resistance R=300Ω. The photovoltaic system diagram is shown in Figure 12 .Simulation diagram is shown in Figure 13 .

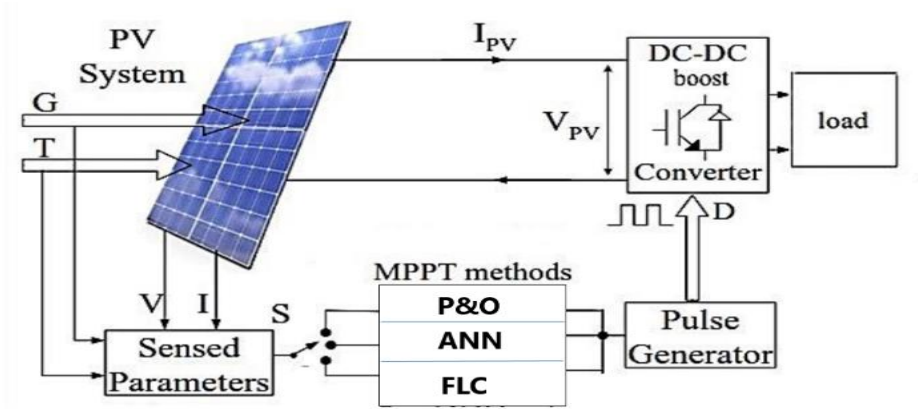


Figure 12. The PV system diagram of 3-methods

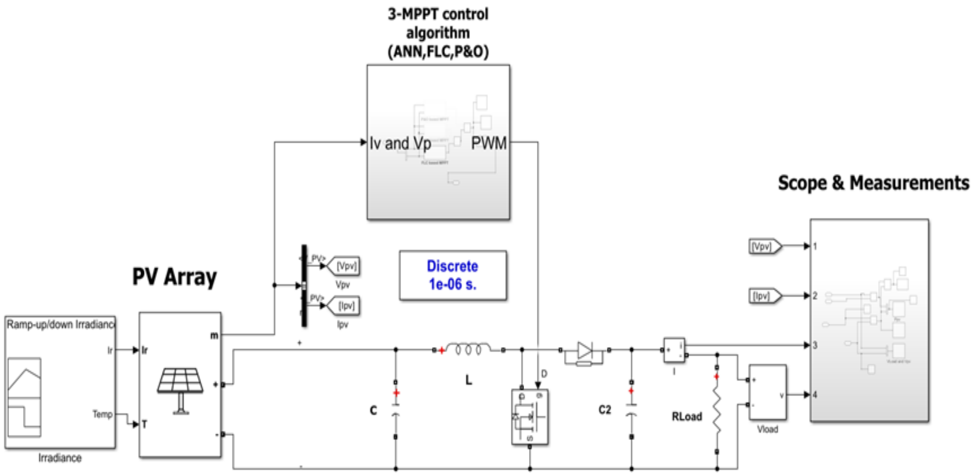


Figure 13. Simulation circuit diagram of photovoltaic system

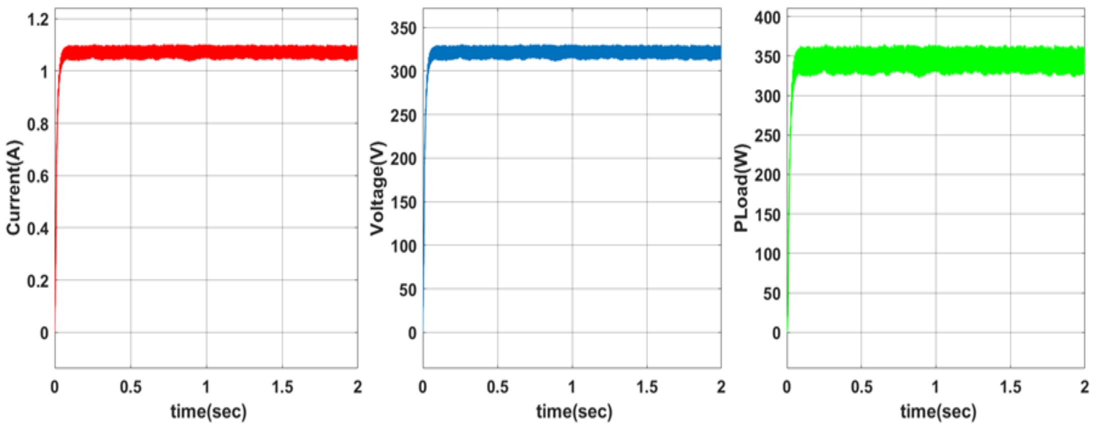
Traditional the ambient temperature to 25°C and the light intensity to 1000 W/M^2. Through simulation, the characteristic curve of the output power of all three methods in the steady state can be obtained, as shown in figure 14. After reviewing the results, note that the fuzzy control method has fast tracking speed. The advantages FLC fast initial optimization speed, higher efficiency, and precise control. Accurate, small overshoot.

When the set light intensity suddenly changes, the power of the entire system will increase significantly. At this time, the differences method can be used to detect whether the algorithm used should be re-enabled. When the difference between the new maximum power point and the original maximum power point is too large, the algorithm used is re-enabled. This is used to quickly reach a new maximum power point. The light of this research setting the light intensity suddenly changes from 800W/M^2 to 1000W/M^2. Temperature T=25°C remains unchanged. The comparison results are shown in figure 15. They are the maximum power points of the three control methods: P&O method, ANN method and FLC method.

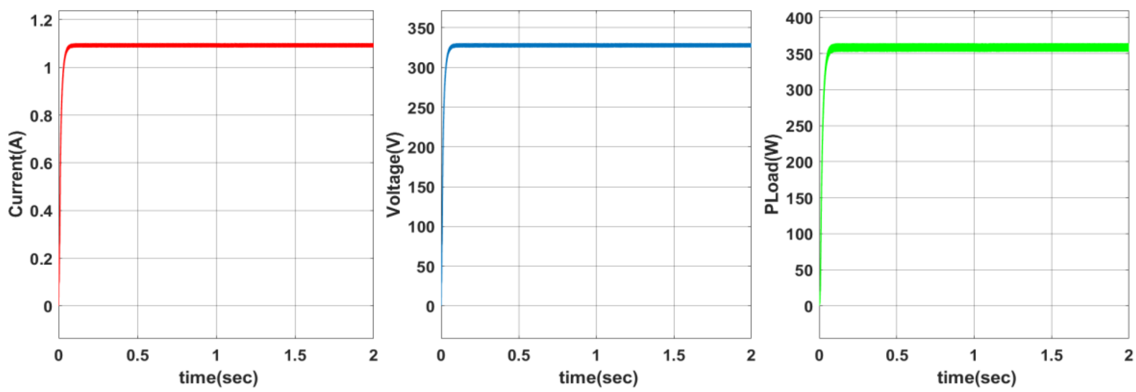
After reviewing the results, note that output power and optimization speed of the three algorithms are different. The dynamics state power accuracy of the fuzzy control is better, the maximum power value of tracking is larger, and the tracking speed is faster. , the speed of re-tracking is faster when faced with a sudden increase in illumination amplitude. The period occupied by the fuzzy control scheme to reach the maximum power point is shorter than that of ANN and P&O methods. From the Table 2, it is inferred that the FLC MPPT algorithm ripple power comparatively lessen than that of all algorithms.

Table 2: The comparison between the three methods

Methods	Time to reach MPPT for the first time	Overshoot	Ripples of Power
P&O	0.12s	High	9.63%
ANN	0.098s	Less	4.62%
FLC	0.094s	Small	3.11%



a)



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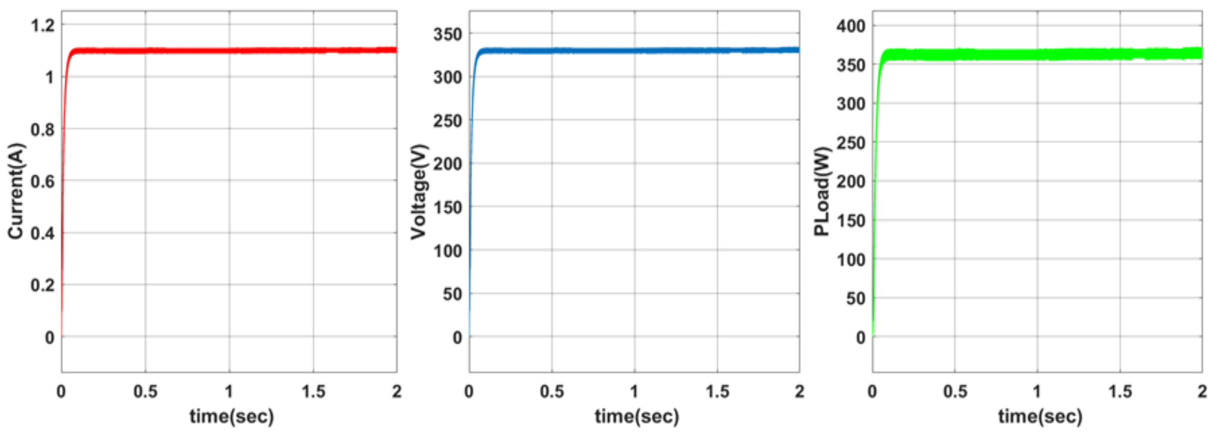

c)

Figure 14. Current, Voltage and Power Load Curve at 1000 W/m^2 and 25°C a) P&O, b) ANN method, c) FLC method

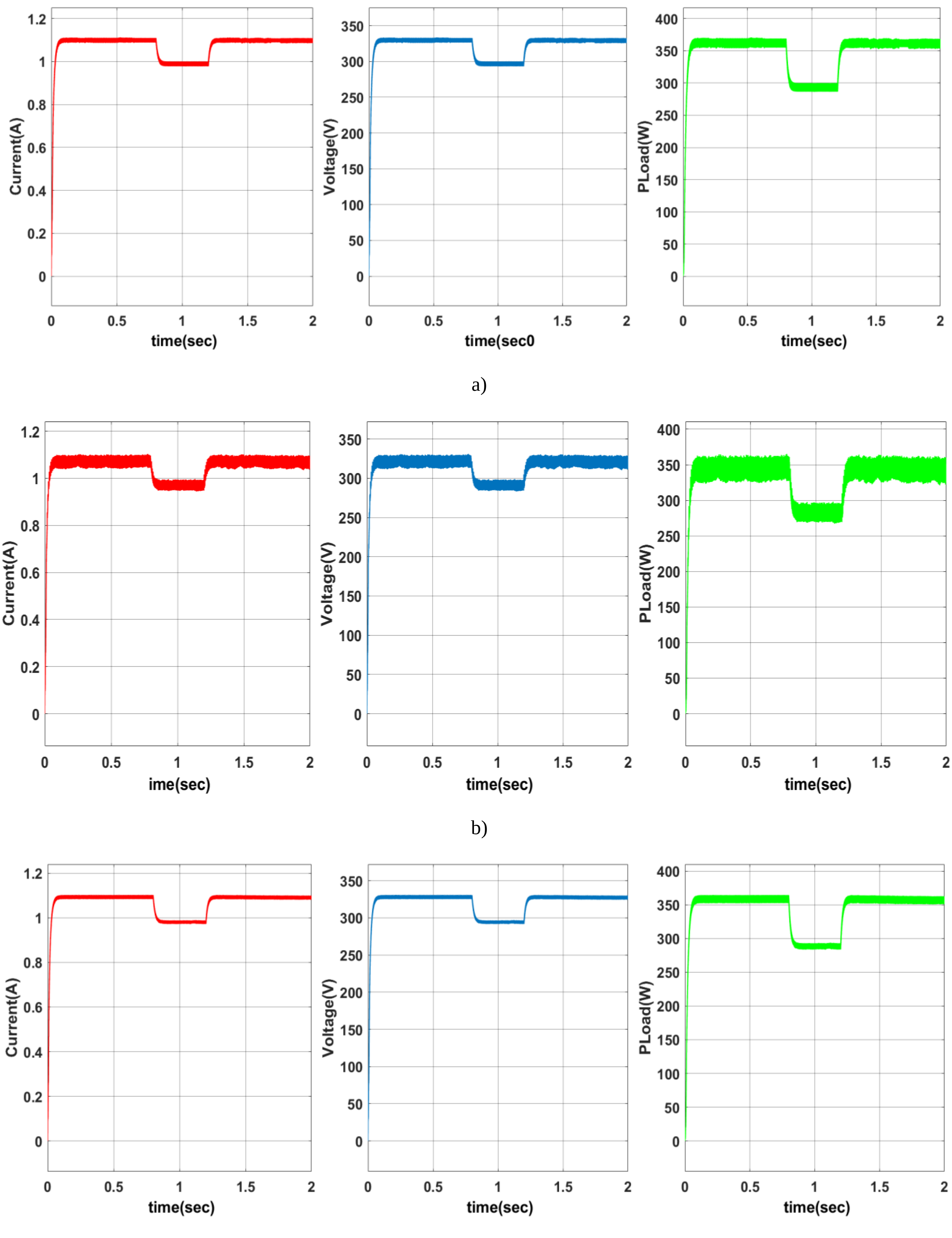

Figure 15. Current, Voltage and Power Load Curve at (1000-800) W/m^2 and 25°C a) P&O, b) ANN method, c) FLC method

9. Conclusions

This paper suggested an MPPT control method that utilized the artificial intelligence evaluation technique. A computational representation of photovoltaic cells was developed for various light intensities and environmental temperatures. Unresolved, the basic idea of a MPPT technique that utilizes artificial intelligence is presented. The key advantages of the AI-based MPPT approach are the lack of a necessity for a precise mathematical model of the system, the capacity to operate with indeterminate inputs, the ability to handle nonlinearity, quick and accurate integration, and others. Its key drawback consists of the generation of the input and output membership functions is reliant on knowledge and extensive knowledge regarding the system, which is complex and taking period. Artificial intelligence (AI) method, are more efficient.

List of Acronyms

Acronym	Description
MPPT	maximum power point tracking
AI	Artificial intelligence
FLC	fuzzy logic control
PV	photovoltaic
ANN	Artificial neural networks (ANN).
MPP	maximum power point
P&O	The perturb and observe (P&O)

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