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A painstaking analysis of various conventional and AI based MPPT approaches to the PV framework

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ABSTRACT

Electricity is the best technological advancement ever. Power is now used for everything in our culture because of how far it has come. Quiddity of life would not be possible without it. We know that the sole free hotspot for the PV module in our environmental factors is the sun. The PV cell changes sun-powered energy into electrical energy when the sun radiates on it. At the point when you produce power with the sunlight-based chargers, no ozone-harming substance emanations are placed into the climate. Since, the sun creates more energy than any manmade process at any point requires so as a result, in this article we will look at a variety of ways as well as a successful MPP strategy with high efficacy. It encompasses incremental conductance, perturbs & observe, and fuzzy logic approaches. A boost (DC-DC) converter ameliorates the likeness between a solar array and storage or power grid. In many solar-producing systems, DC/DC converters assist in surveilling the utmost power point by acting as a bridge betwixt load and solar panel. The intent of achieving the highest possible electricity can be done by calibrating the load to compare the current and voltage of a photovoltaic cell.

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1. INTRODUCTION

Due to a rise in residential and industrial demand, there is currently a global electricity crisis. Photovoltaic (PV) frameworks are one of the quickly developing sustainable power assets due to expanding levels of petroleum derivative value that cause climate issues like air contamination, and unnatural weather change. Charge controllers use an algorithm known as MPP tracking which is used in specific circumstances to have the maximum possible power from the photovoltaic system [1], [2]. A DC-DC converter helps in converting solar panels' greater DC-produced voltage to their lower-produced voltage, which is necessary for charging batteries. The goal of maximum power point tracker MPPT is to use the PV module's highest available power by operating it at the optimum potential [3], [4]. Firstly, MPPT will evaluate the produced result of the PV module and then weigh up with battery voltage, after that it determines the optimal possible power the PV module is capable of producing, and then converts that into the finest maximum voltage [5], [6]. The best conditions for MPPT are under cold temperatures, overcast or foggy days, and when a battery is deeply discharged. Due to the PV solar system's reliance on the weather, its effectiveness is reduced, and solar PV panels' produced voltage and current are most impacted [7]. Numerous techniques focused on MPP have been developed to address this issue. MPPT algorithm can be applied to both of these converters relying upon their framework plan [8]. The step-down converter is helpful for battery framework where voltage is compeer to or below 48V whereas in the step-up converter the battery framework voltage is more prominent than 48 V [9], [10]. MPPTs typically function in the 20–80 kHz range at very elevated audio frequencies. High-frequency circuits in MPPTs have the benefit of being able to be constructed with very high-efficiency transformers. Theoretically, the effectiveness of the sunlight-based power framework with the regulator of MPPT will increment by half, while as indicated by genuine tests, a definitive MPPT effectiveness can be expanded by (20-30)% since there is energy lost to the general climate [11]. There is various benefit of MPPT such as it is more efficient compared to MPPT solar charge controller, it can improve voltage differences, it offers DC load optimization, it provides more output and hence high capacity, it would simplify the system. Because of its reasonable cost, simplicity of use, and comparably strong tracing operation to other techniques, the perturb, and observation approach is nearly employed in all practices [12], [13]. Fuzzy logic has proven to be a successful approach for such irregular PV systems among AI-based MPPT techniques without the need for precise system data. Despite all the benefits listed above, MPPT techniques are required to maximize the extracted energy, which results in low conversion efficiency and a significant upfront cost. It is important to emphasize that there is just a single MPP for each curve at an irradiance level and specific temperature [14], [15]. So, in this article, we did a painstaking analysis of the above-mentioned approaches and compared them in terms of competence, and cost-effectiveness.

2. METHODOLOGIES

2.1. Fuzzy logic approach

There is a need to inspect the latest method for energy which are modest and climate amicable. The slow exhaustion of these non-inexhaustible sources such as petroleum archetypal, oils, and so on drives the agricultural nations towards the un-maintainability of human advancement. Energy is created using sustainable power sources; however, it is flawless and controllable. The photovoltaic framework is the most effective inexhaustible wellspring of energy which has acquired incredible consideration from specialists. The above method cannot be fully implemented because of the high installation costs and inefficient energy conversion. Here MPPT is used to maximize the output of the photovoltaic panel and deliver into the load to boost competency [16], [17]. Constant voltage tracking is one of the approaches to boost the produced power of PV modules. In order to continually increase the duty cycle of the DC-DC converter and run the PV module at the predetermined point extremely close to the MPPT, this method compares the recorded voltage of the Photovoltaic module with a reference voltage. Another reasonably easy approach is the constant voltage tracking (CVT) method [18], [19]. Even in cloudy conditions, it can maintain track of the MPP. Following that, the voltage is adjusted to point in the direction of a higher voltage. In this paper, a newly designed method for the MPP tracking controller is presented to accomplish MPP tracking. The solar cell can resist in two different ways. Parallel resistance and series resistance each make up one of them. Series resistance is because of the losses in the path of the current brought on by the metal frame and current connecting the bus. The parallel resistance is used to represent a slight current leakage across the p-n junction most probably created by the resistive passageway [20], [21]. The analogous circuit is shown in Figure 1.

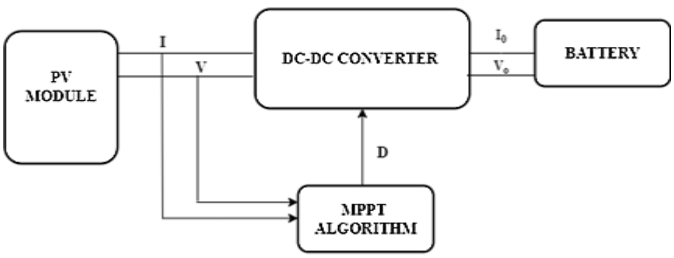

Figure 1. Schematic diagram of the PV system

This MPP tracking set of rules which is based on fuzzy logic in this algorithm as shown in Figure 2 takes voltage and current in the form of inputs using which it advances the duty cycle of our machine to get the maximum possible output power from the array. Before calculating the power, the fuzzy logic MPPT technique, first of all, calculates the value of voltage and current at each instant K. To calculate the power change and the current change respectively, this value of power and the previous instant current are compared. The inaccuracy is detected by dividing the power change by the current change [22], [23]. The solar cell should be operated at its maximum point on the power curve to produce the most power possible.

Here, “Y” stands for the highest power point. The relationship between a PV module's open circuit voltage (OCV) and cell temperature is well-established mathematically, so regardless of the cell temperature, the OC voltage of a PV module varies. Due to environmental changes, the OCV decreases as the temperature rises. Therefore, the power output is reduced [24]. When designing a solar PV system, it is important to consider the PV module temperature coefficient, which compares the projected average cell temperature in the working environment to the STC data used to determine the module output.

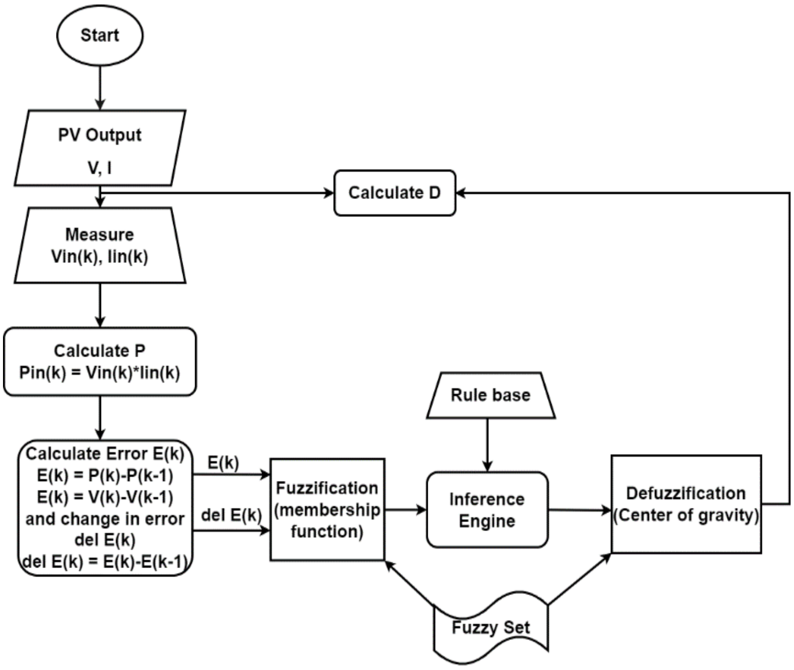

Figure 2. Flowchart of fuzzy logic-based MPPT algorithm

2.2. Perturb & observe (P&O) approach

One of the most popular and conventional methodologies concerned with finding the peak power point is perturb and observe technique. This technique involves applying disturbances (perturbations) to the PV system's reference voltage or current signal. Easy to build on any microcontroller thanks to its algorithm's simplicity. A literature survey reveals that this method depends on finding and adhering to the MPP by trial and error [25], [26]. P&O computation contrasts the positions of the voltage and the power at two places on the P-V curve. The voltage is then adjusted properly to follow the MPP. The flowchart for this P&O approach is displayed in Figure 3. Fundamentally, this method first looks for a variation in cell power (dP), then it enquires for a cell voltage sign (dV). D is adjusted based on the values obtained. To examine the actual movement of the operational point, P-V curve data is used. If the (dP / dV) is greater than zero, the actual point seemingly will be in the MPP's left side, otherwise in the negative half, depending on the curve. Additionally, this assessment action proceeds until (dP / dV) mean zero. There are two main issues with this approach.

First of all, it is challenging to ascertain the optimal perturbation step size. The likelihood that the algorithm would oscillate around the MPP increases with the size of the perturbations, and the speed at which the algorithm converges decreases dramatically with the size of the perturbations [27], [28]. To address this concern, as the algorithm comes closer to the MPP, we employ a differential or varying perturbation size. Second, in dynamically changing environmental conditions, this algorithm is subject to tracking mistakes. To solve these issues modified variations of this MPPT method are employed. The standard P&O algorithm is unable to simultaneously meet the performance objectives of quick dynamic reaction time and high exactness in a steady state. This is due to the fact that the oscillation will rise near the peak power operating point during the steady state and result in a loss in energy production if the step size is adjusted to be large sufficient for a quick dynamic reaction time [29]. Performance characteristics of both dynamics and stable states can be improved using a novel approach. The PV module here used for modeling is SunPower SPR-305-WHT.

2.3. Incremental conductance approach

This MPPT framework focuses on the feature that highlights the PV system's I-V slope to track the peak power point of the system. This approach makes use of the special relationship between the I-V curve. This calculation recognizes the PV cell's estimated current and voltage values and measures the derivative of the PV cell current (dI) and voltage (dV). The working point's trajectory is determined using the PV current-voltage curve. It encompasses every characteristic to be the most noteworthy one in the literature for uniform circumstances [30]. The InC method relies on the fact that at the MPP, the derivative of output power P with respect to panel voltage V is equal to zero. This MPPT method's main benefit is that it can be used as a practical remedy for environmental situations that change quickly. The tracking efficiency increases as the system's increments get bigger [31]. With bigger increments, the system will, however, oscillate about the MPP, which also leads to sub-optimal MPP yielding.

The PV module here used for modeling is SunPower SPR-305-WHT. Figure 4 depicts the InC's workflow-based execution strategy. Using the slope of the system's P-V curve as a starting point, this approach tracks the MPP using all of the data. Only the tracking procedure is completed if the P-V curve's slope or the PV array power's derivative (dP/dV) is zero [32]. Tracking MPP will be more difficult whenever the atmospheric circumstances are rapidly changing, and the pace of tracking will also drop exponentially due to the P-V curve's continual change.

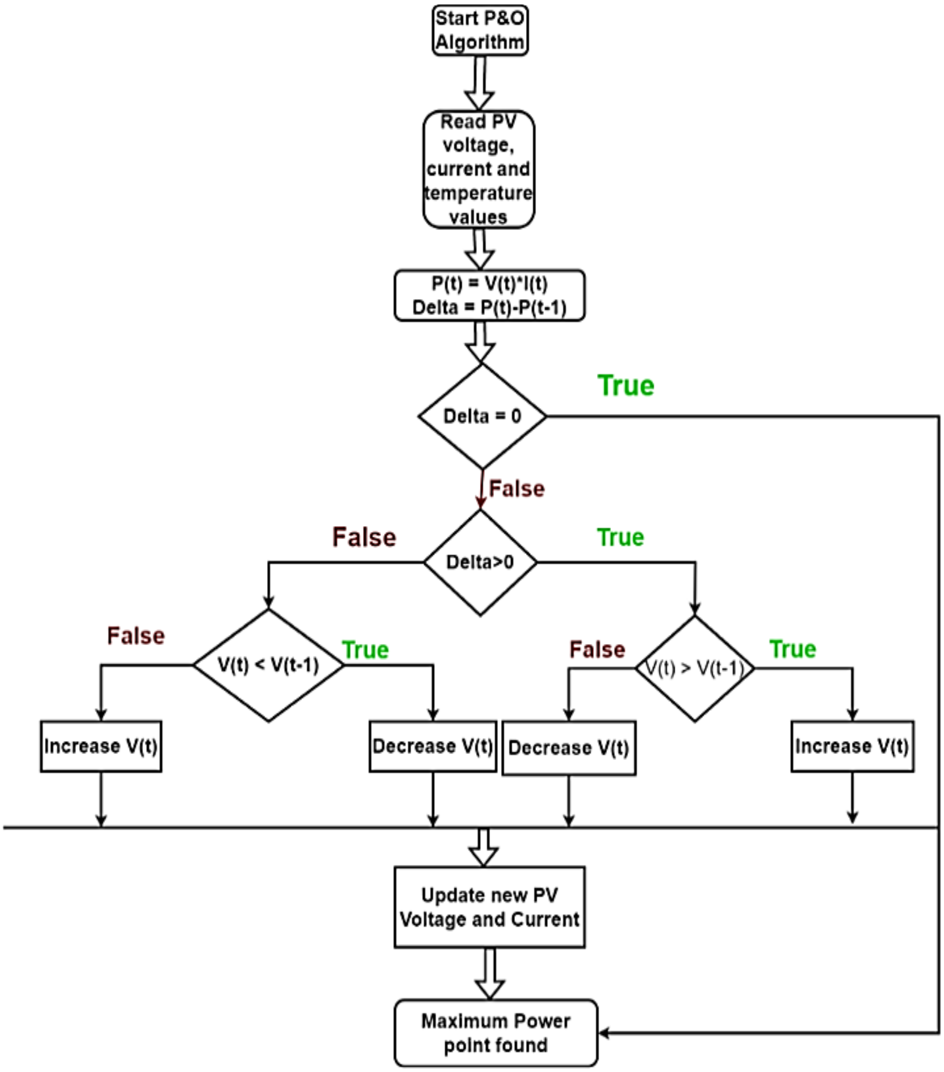

Figure 3. Flowchart of perturb and observe approach

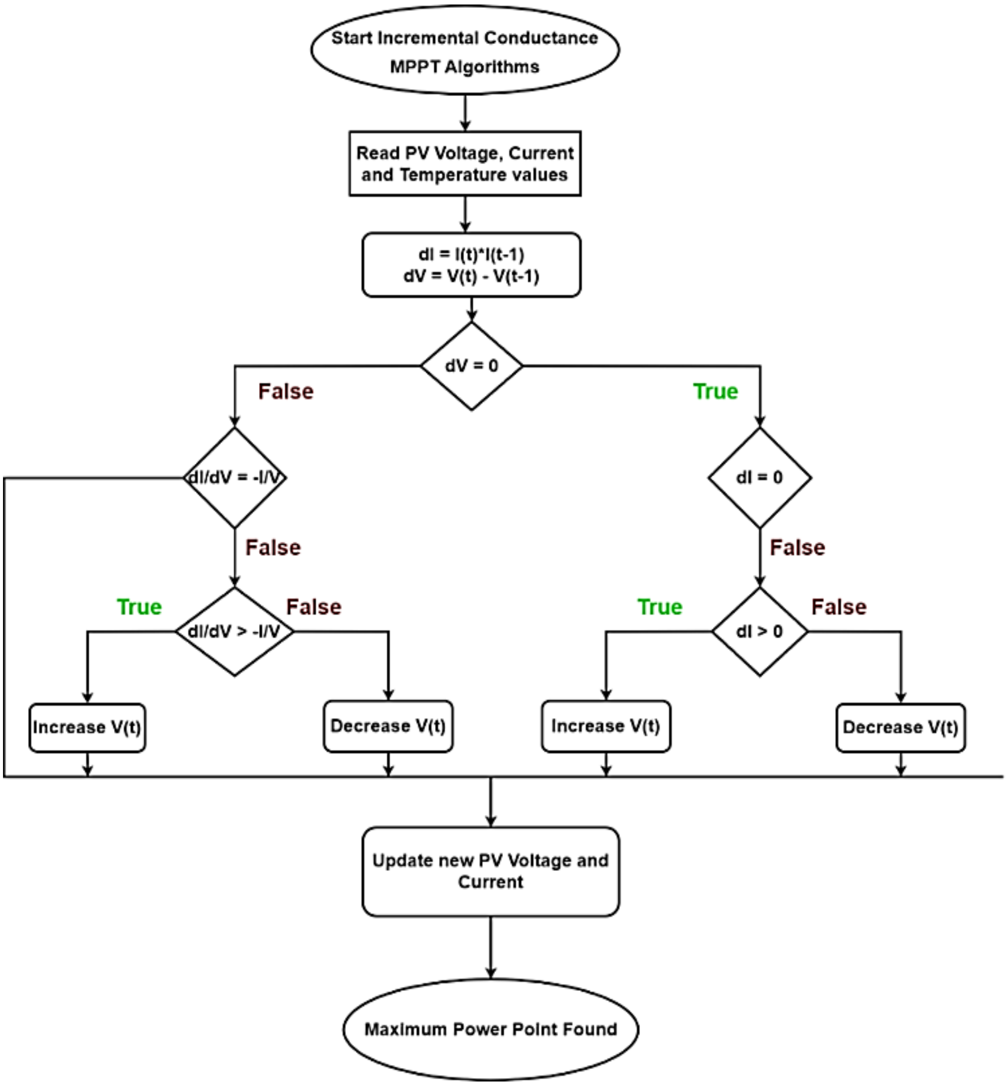

Figure 4. Flowchart of incremental conductance-based MPPT algorithm

3. RESULT AND DISCUSSION

3.1. Fuzzy logic (FL)

In the first test of this circuit the parameters of the photovoltaic (PV) cell are assumed at fixed values. Also, standard value of irradiance and temperature is considered initially and then at variable conditions. Figure 5 shows the voltage across the load versus time plot. As we can see here it initially oscillates around and then achieves a steady state form around 0.252 secs. The mean and RMS values of this signal are 18.59 V and 19 V. This signal has peak-to-peak value of 29.9 V. Initially it tends to overshoots and reaches the max value of 29.9 V and then gradually stabilizes. The power and voltage waveform looks same (shape and behavior wise) because power is the product of voltage and current therefore their waveform does not have much difference.

3.2. Perturb & observe (P&O)

Standard values of irradiance and temperature is considered initially and then at variable conditions. Initially there are some oscillations and the voltage tends to overshoot (positive) by 18.962% to a maximum value of 36.51 V, but after some time it becomes bit stabilized as it goes into its steady state condition around 0.118 sec. So, in Figure 6, the PV voltage fluctuates between 28 V to 29 V. The average voltage comes out to be 29.14 V. The mean and RMS values obtained in this case turns out to be 29.14 V and 29.15 V.

Figure 7 shows the power generated by the PV module using the perturb and observe algorithm. The boost converter is intended to convert a variable solar panel voltage to a greater constant DC voltage. It employs voltage feedback to maintain a steady output voltage. The output voltage of buck-boost converters can be configured to be greater or lower than the input voltage. A microcontroller software controls the amount of output voltage produced by regulating the pulse widths created by PWM signals. The output voltage and power of PV module responses are nonlinear by nature, with a fluctuating output voltage with a significant ripple that is controlled by a boost converter. The simulations yielded an average PV module output power and the voltage value of 1063 W and 29.14 V, respectively. The P&O MPPT algorithm can track the peak power point, allowing power generated by the PV module to be transferred to load resistance. It is clear that the suggested converter provides effective control over fast voltage fluctuations with minimal ripple which was primarily expected from it. P&O MPPT and boost converter work together to improve control over PV output power. Even if the output power of the PV module fluctuates substantially at first, the converter can efficiently moderate this shift which was the ultimate motivation behind using this DC-DC converter in this circuit.

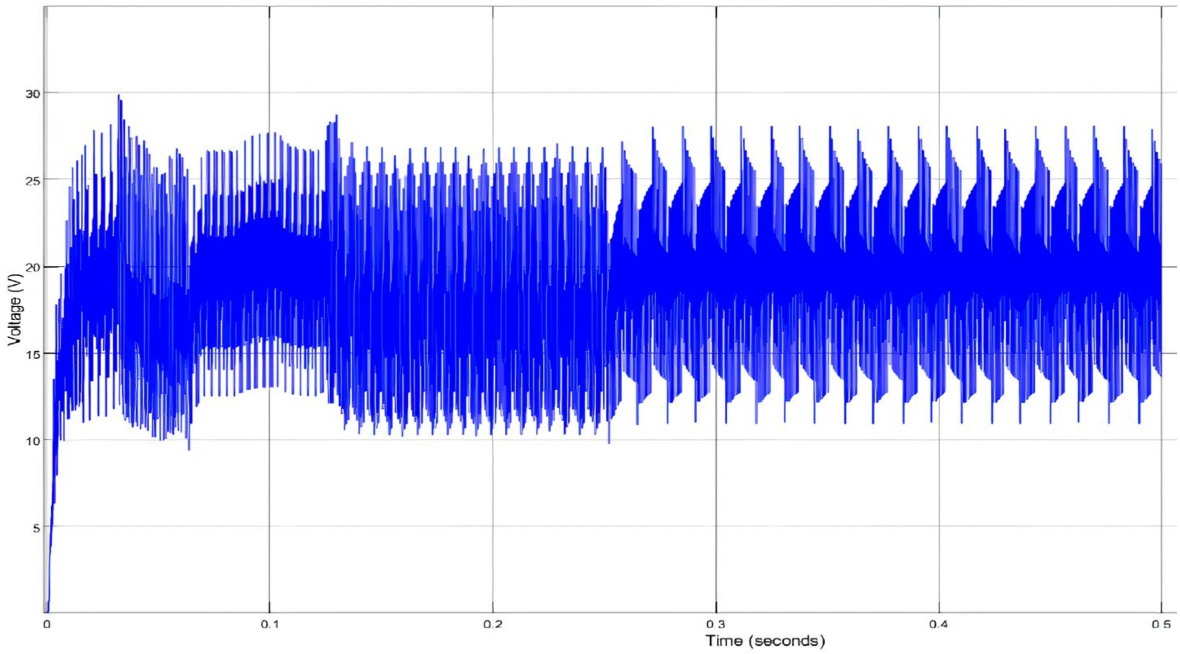

Figure 5. Voltage across the load versus time

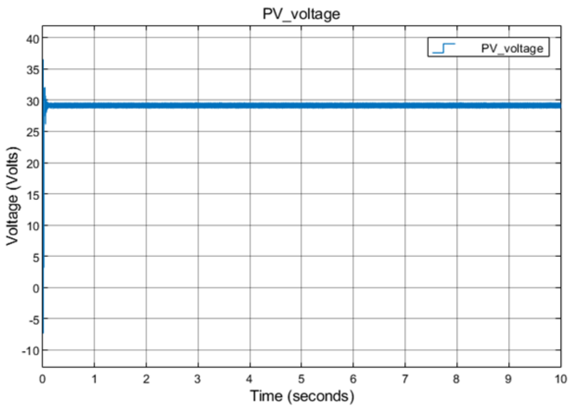

Figure 6. PV voltage versus time

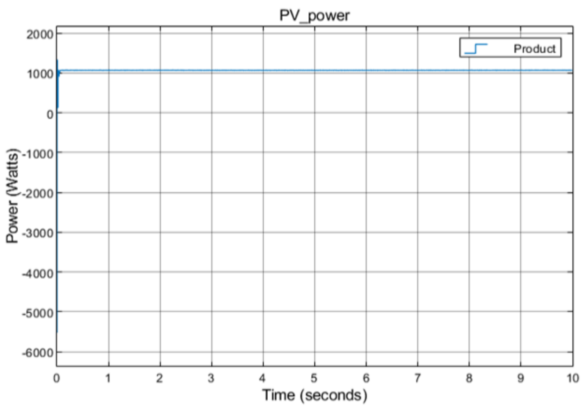

Figure 7. PV power versus time

3.3. Incremental conductance

Figure 8 shows the power demanded by the load (in Watts) vs time and the second one shows the output power of the PV array (in watts) Vs time using the incremental conductance algorithm. The PV reaches its maximum value of 1.007e+05 Watts at 0.144 seconds. Here we are getting an overshoot of 28.324%. It is much more stable as compared to the PO method as the oscillations in this one is comparatively low.

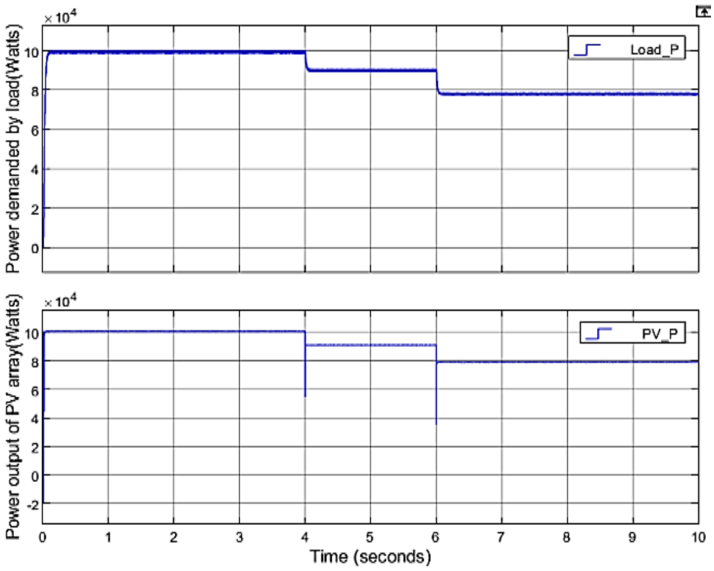

Figure 8. Power demanded by load (W) versus time, and power output of PV array (W) versus time

3.4. Performance comparison table under variable conditions

Table 1 presents the comparison of efficiency under different conditions. The efficiency can be calculated by (1). From this comparative study, it can be concluded that FL and IC are the two best MPPT approaches. The efficiency of different conventional based and AI based approach by using (1).

$$Efficiency(\%) = \left(1 - \frac{Power\ at\ mpp - output\ power\ of\ mppt\ method}{Power\ at\ mpp}\right) * 100 \quad (1)$$

Table 1. Performance comparison under different conditions

Parameters	P and O	IC	FLC
Efficiency (%)	93.43	94.99	97.99
Rise time: 4th sec			
Voltage	0.38	0.31	0.15
Current	0.29	0.25	0.12
Power	0.37	0.30	0.15
Fall time: 6th sec			
Voltage	0.33	0.27	0.19
Current	0.31	0.26	0.16
Power	0.33	0.26	0.19

4. CONCLUSION

This work examines in depth the scientific modeling and analysis of a solar PV system that has been used to generate electricity. The suggested system incorporates multiple MPPT techniques along with a PV model. The performance of IC MPPT is superior to other approaches in the area of conventional MPPT methods. Despite using two sensors, P&O offers the benefit of functioning close to the peak power point without being affected by changes in temperature or irradiance. The derivative of the current w.r.t the voltage is calculated by IC at fast speed and with low steady-state inaccuracy. The FLC controller is a reliable system that is quicker to handle and doesn't require precise inputs. The MPPT is a major component of the solar-based system. As they can handle a variety of input sources, fuzzy logic techniques are more accurate and produce findings considerably faster in this study. It takes about 0.03s to track the highest power. Virtually all consumer goods use fuzzy control logic. Some of its illustrations are regulating the temperature of our rooms with the use of air conditioners and washing machines. According to the specific analyses of each technique efficiency of CV and P&O is low. From this comparative study, we conclude that FL and IC are the two best MPPT approaches.

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