Design of an Optimum MPPT controller for Solar Energy System

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Abstract

In this paper, we propose a new hybrid algorithm for optimum maximum power point tracking algorithm with the combination of Perturbation and Observation (P&O) and incremental conductance (INC). The maximum efficiency is achieved when the PV works at its Maximum Power Point (MPP) entirely depends on the irradiation and temperature. However, many traditional methods have defects for these applications. The proposed method is prompt in the transient of maximum power point tracking and has good steady-state response. Theoretical analysis and the design principle of the proposed method are described in detail. Simulations are performed to demonstrate the effectiveness of the proposed hybrid MPPT method against the traditional methods.

Keywords: MPP, MPPT, P&O, INC and Hybridalgorithm

1. Introduction

Photovoltaic power generation throughout the world is becoming increasingly popular due to combination factors: low maintenance, minimal wear and tear of components due to absence of moving parts, absence of fuel cost [1].

PV has developed to an essential source of power for wide range of applications. This is generally due to the focus on greener source of power. Cost reductions of PV modules and improved qualities of panels, that are used to convert light energy into electrical energy have helped in the growth of PV systems.Small scale PV-Installations has become popular as lightining and water pumping solutions in most of the developing countries that has considerable amount of solar irradiation. Major aim is to maximise the output power from the PV system under various lighting conditions together with higher efficiency and reduced cost. [2]

Major issues faced is when the PV system tends to exhibit non-linear behavior which eventually varies the MPP with the solar insolation as this is a concern related to increasing the efficiency of the PV system and compensating the initial installment cost of the system. Different strategies have been applied and test in the prospect of fabricating newer methods to achieve the optimum out of the solar cell modules. However; the other option is to boost output power of the PV system by improving its maximum power point tracking (MPPT) capability. This is because MPPT is the most economical way to improve the overall PV system efficiency [3].

In comparison to the above mentioned factors, improving the MPPT is much easier and is less expensive; having redefined and tuned methods of converter technologies would allow the efficiency of the overall PV system to increase and would therefore decerease the cost of installing such systems, hence it can easily be retrofitted in the existing PV system plants. The essential aim of the MPPT is to ensure that, at any environmental condition, the maximum power is extracted from the PV modules by matching its I-V operating point with the corresponding power converter. Typically, a photovoltaic array operates in conjunction with the DC to DC power converter, where the duty cycle is adjusted to track the maximum power point (MPP) of the array [4]. Additional power harvested from the MPPT is then made available as increased battery charge current.

This journal provides a comprehensive commonly used MPPT techniques which are Perturb and Observe (P&O), Incremental Conductance (INC), and Hill Climb.These techniques are different from each other by their cost, complexity, benefits and drawbacks. Use of such techniques results to non-linear I-V characteristics of the PV source under varying

environmental conditions and complexity in the design, thus tracking of MPP becomes inaccurate at times. Hence, this paper elaborates more on a new hybrid MPPT controller is technique that combines the benefits of existing MPPT controllers to get the maximum output power from the PV system under various lighting conditions.

2. MPPT Techniques

MPPT is an electronic system that operates PV modules in a way, so that modules are capable of producing maximum power for which they are designed for. Maximum Power Point Tracking is an adaptive structurethat is used to control the converter between load and the solar panel. Over the years, most of the MPPT techniques are being studied, analyzed and are further defined to bring quality output. Different techniques have different algorithm and convergence speed which is further discussed below.

2.1. Perturb and Observe (P&O) Alogrithm

This technique is the most commonly used out of all MPPT methods due to its simplicity of execution and implementation. P&O technique can be easily programmed and it provides satisfactory results within the convergence. P&O algorithms work by periodically perturbing (i.e. increasing or decreasing) the array terminal voltage and compares the PV output power with that of the previous perturbation cycle. The alogrithm keeps incrementing or decrementing the reference voltage based on the previous value of power until it reaches the maximum power point (MPP) [5-8]. The perturbation moves the operating point towards the MPP if dP/dV is greater than zeroas illustrated in Figure 1. It continues to perturb the PV voltage in the same direction until it reaches required MPP. If dP/dV is less than zero, it is assumed that the perturbation moves the operating point away from MPP; hence, P&O technique reverses the direction of perturbation.
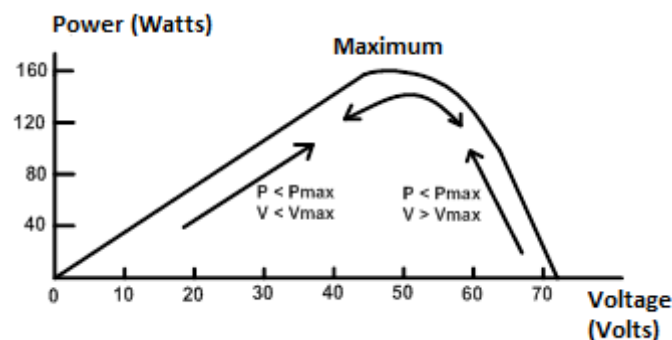

Figure 1. P&O Power Voltage Characteritic [9]

In steady state operation the output power oscillates around the MPP and results in voltage oscillations. Hence, when multiplied to the current, these voltage oscillations cause power fluctuations which results in power losses. P&O technique can also fail under rapidly changing atmospheric conditions [10].

2.2. Incremental Conductance (IC) Alogrithm

Incremental Conductance method was designed to overcome some of the drawbacks of P&O technique in the year 1993 [11] the main purpose of designing this method was to offer good performance under rapidly changing atmospheric conditions [12]. Array terminal voltage is always adjusted according to the MPP voltage when used with Incremental Conductance method. Eq.1-3 shows incremental conductance equations.

$$\frac{dI}{dV} = \frac{-I}{V}, \quad \text{at MPP} \tag{1}$$

$$\frac{dI}{dV} > \frac{-I}{V}, \qquad \text{left of MPP} \tag{2}$$

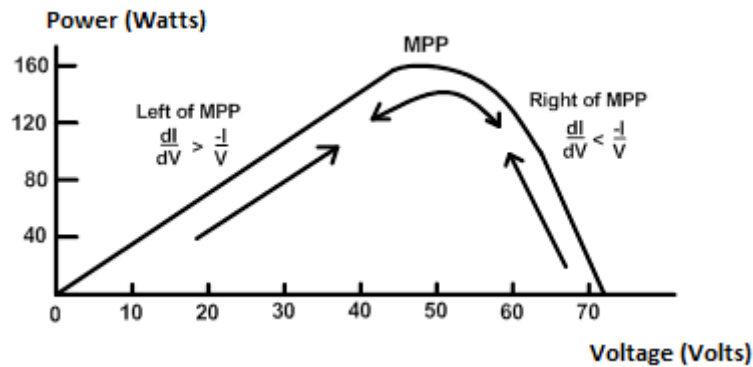$$\frac{dI}{dV} < \frac{-I}{V}, \qquad \text{right of MPP} \tag{3}$$

Figure 2. Incremental conductance PV curve [9]

As illustrated in Figure 2, incremental conductance method compares two parameters from PV source; current and voltage. Firstly, difference in current and voltage is found. Once difference in voltage and current is found comparison is made between the ratio of current to votgae and ratio of difference in current to difference in voltage as indicated in Eq. 1-3.

Drawbacks of the incremental conductance technique are that it has a complex design which is hard to implement and has high implementation cost [13].

3. Proposed Hybrid MPPT Controller

As discussed above, there are many types of MPPT controllers. With all of these techniques there is certain level of difficulties which yields an undesired output. Most commonly used MPPT controllers are Perturb and Observe MPPT and the Incremental Conductance MPPTcontroller.These controllers also have few drawbacks which at times could be an issue while tracking power from PV modules. Hence, a new hybrid MPPT controller is proposed in this paper that eliminates the down falls of both P&O and INC MPPT controller. The proposed MPPT controller also aims to combine the benefits of both existing MPPT controllers. The proposed method vigorously compares all the three parameters voltage, current and power to extract the maximum output power efficiently and under rapidly changing atmospheric conditions. PV curve for proposed hybrid method is shown in Figure 3.
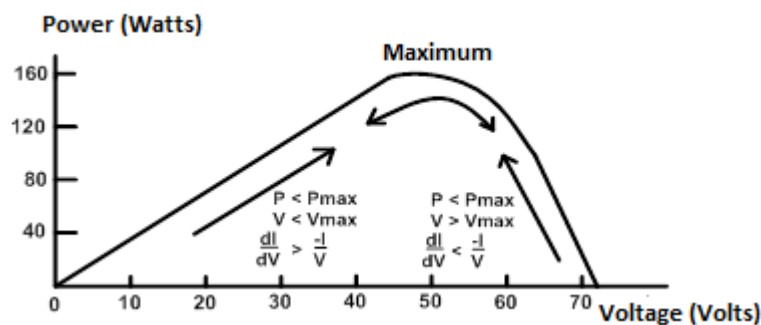

Figure 3. Proposed MPPT PV Curve

This Proposed MPPT method extracts the maximum power using the two parameters directly from the PV source. It measures voltage and current from the solar panel and calculates output power using Eq.1. After calculating the output power, proposed algorithm stores power, measured voltage and measured current in a temporary memory for comparison [12]. Now, it compares the power with previous value of power by finding the change in power. After making certain comparisons it moves to the next parameter which is voltage. It then finds the difference in voltages and makes respective comparison before it moves to the final parameter current. The proposed algorithm calculates the change in current and checks whether $\Delta I/\Delta V$ is greater than, less than or equal to $-I/V$. After comparing all the three parameters respectively, the proposed hybrid algorithm makes its decision, whether to increase or decrease the terminal voltage.The algorithm of proposed hybrid controller is shown in Figure 4.
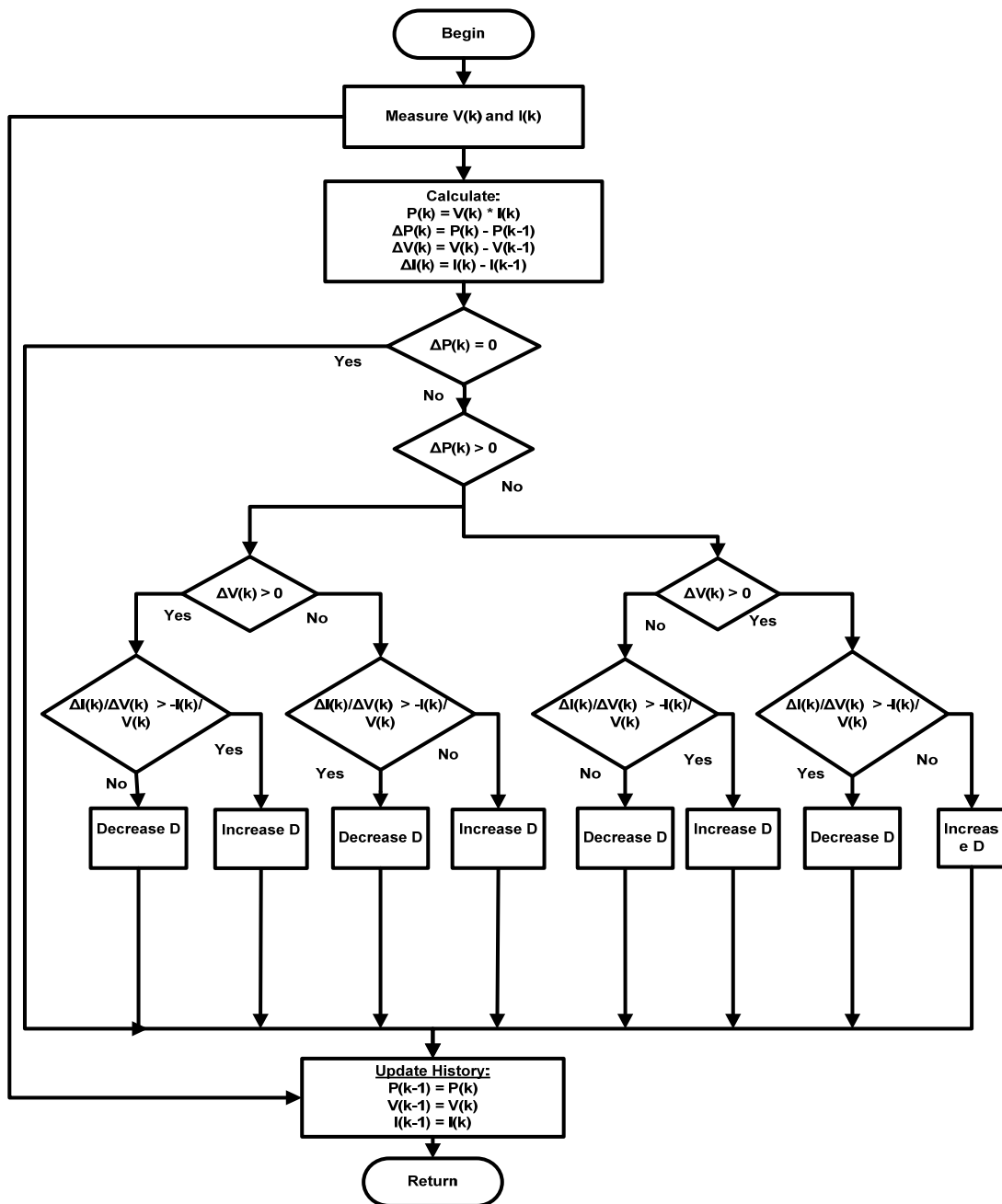

Figure 4. Proposed Hybrid MPPT Flowchart

Table 1. Decision made by the hybrid MPPT Controller

$\Delta P > 0$	$\Delta V > 0$	$\dfrac{\Delta I}{\Delta V} > -\dfrac{I}{V}$	Decision
No	No	No	Increase
No	No	Yes	Decrease
No	Yes	No	Decrease
No	Yes	Yes	Increase
Yes	No	No	Decrease
Yes	No	Yes	Increase
Yes	Yes	No	Increase
Yes	Yes	Yes	Decrease

The Proposed hybrid MPPT controller works in similar manner as the XNOR gate as illustrated in Table.

Furthermore, the new controller overcomes the drawbacks of P&O and incremental conductance MPPT controllers. It is designed to provide good performance under rapid temperature changes. The output power of proposed controller does not oscillate around the MPP thus, it can actually determine if the output power has reached MPP or not [14]. Thus the hybrid MPPT technique reduces power losses.

Model of the hybrid proposed MPPT controller was simulated in Matlab and compared with the existing MPPT controller's i.e. incremental conductance and perturb and observe techniques. Simulink model of the hybrid controller is shown in Figure 5. The two inputs of the controller are the voltage and current readings from the solar panel as indicated by 'I' and 'V'. These reading are filtered and temporarily stored in the voltage and current storage respectively. Voltage and Current readings are then multiplied to give the initial and final power so that change in power can be calculated. This change in power is used to compare the power readings. Maximum power point is reached when the change in power is equal to zero. If change in power is greater than or less than zero then the controller compares the voltages. Likewise, change in voltage is calculated from the initial and final readings of voltage and respective comparison is made. After a suitable decision is made current readings are compared and duty cycle is increasd or decreased correspondingly to increase or decrease the reference voltage. The proposed MPPT controller is different from other MPPT controllers as it has a better performance in terms of harvesting power from the solar panel when compared to the other two MPPT techniques. The proposed controller also reduces harmonics as shown in Figure 10.
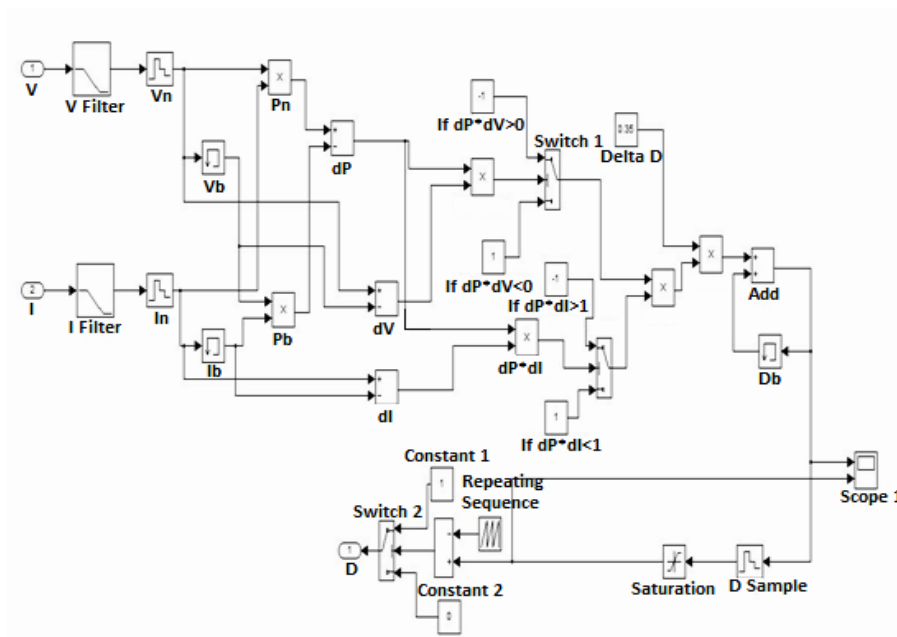

Figure 5. Proposed Hybrid MPPT Model in Simulink

4. Hardware Design

The design is as such that based on the irradiance and temperature, the PV array produces voltage and current. With the proposed hybrid method, current and voltage readings are accumulated and change in voltage and current is calculated through formulas and comparison is made in accordance with greater and less than zero. This comparision decides wheather to decrease or increase the duty cycle to reach the maximum power point. The duty cycle is used to trigger the switch (IGBT) of the DC-DC buck-boost converter and a setpoint is assigned via calculations for the converter to step up and when to step down the voltage level. Figure 6 shows the overall structure of the hardware setup with major components used in testing the new hybrid MPPT controller.
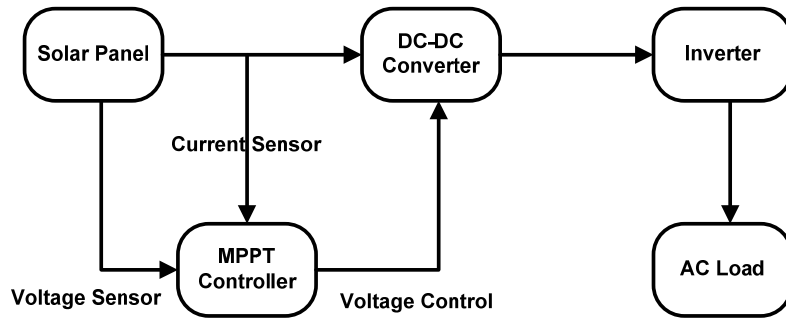
Figure 6. Block diagram of the PV system

The proposed hybrid MPPT controller was also tested using the hardware. A simple buck boost DC-DC converter was designed usingAltium software as shown in Figure 7. A PCB board was then designed in altium and was printed in the lab. After software simulation, a complete hardware circuit was built and tested. The MPPT algorithm was programmed and implemented into arduino board the schematic diagram is shown in Figure 7.
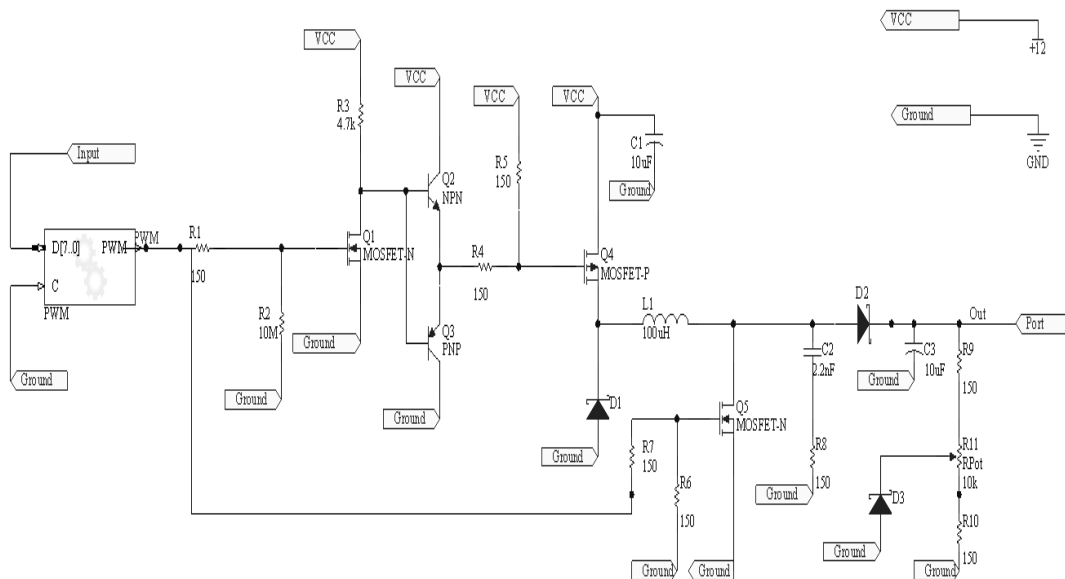
Figure 7. Schematic Diagram

5. Comparison Study and Simulation Results

MPPT algorithm was design and simulated in Matlab-Simulink as shown in Figure 5. The proposed technique was then compared with the commonly used existing techniques P&O and INC MPPT methods. Simulation was carried out by giving a constant temperature of 48 degrees celcius with an irradiation of 1300W/m^2. Simulation results for output voltage, current and power are shown on Figure 8 for P&O, Figure 9 for INC technique and Figure 10 for proposed hybrid controller. A polycrystalline silicon panel of 4.5 watts was used for experimental purpose. Table 2 shows the solar panel specifications.

Table 2. Panel Specifications

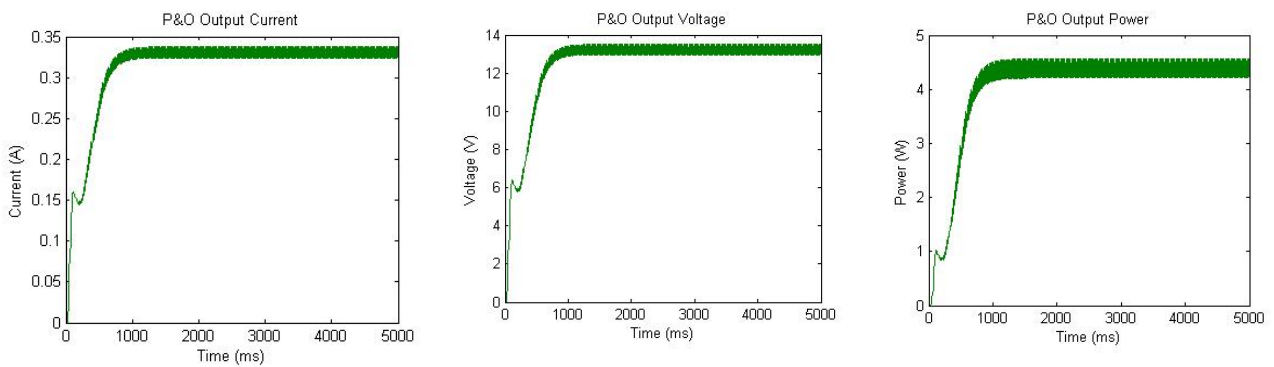| Theoratically |
| --- |
| Maximum Power Pmax 4.5 W |
| Voltage @ max. power Vmax 13.2 V |
| Current @ max. Power Imax 0. 34A |

Figure 8. Simulation Results for P&O Techique;
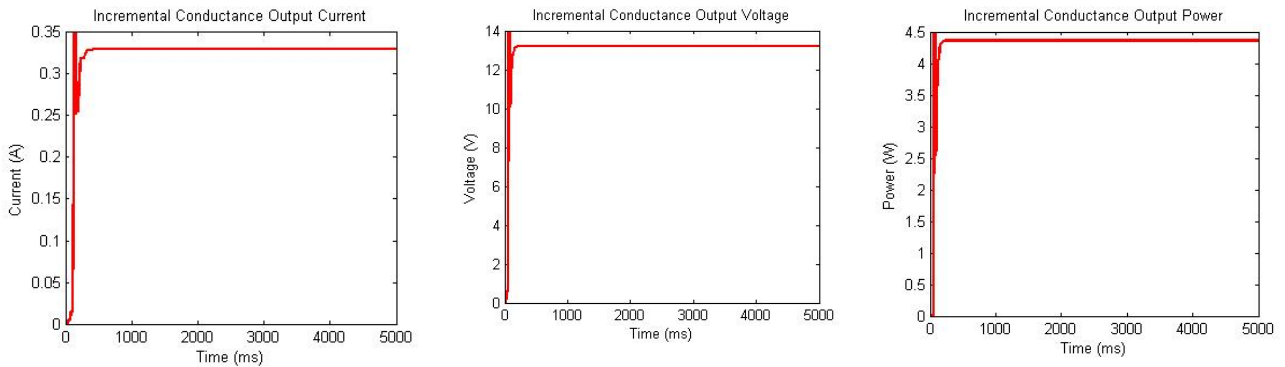Output (a) Current; (b) Voltage; (c) Power

Figure 9. Simulation Results for Incremental Conductance Techique;
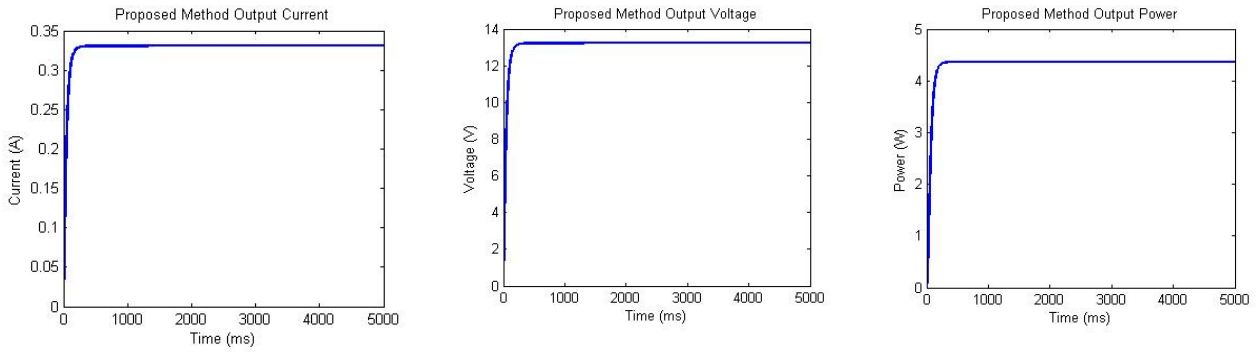Output (a) Current; (b) Voltage; (c) Power

Figure 10. Simulation Results for Proposed Hybrid MPPT Techique;
Output (a) Current; (b) Voltage; (c) Power

From the specification in Table 2, the computed maximum power PMAX for all the techinques was around tracking towards 4.5W

Table 3. Results Comparison

P&O	INC	Hybrid Approach
Maximum Power Pmax 4.2 W	Maximum Power Pmax 4.30 W	Maximum Power Pmax 4.257 W
Voltage @ max. power Vmax 12.7 V	Voltage @ max. power Vmax 13.1 V	Voltage @ max. power Vmax 12.9 V
Current @ max. power Imax 0.33 A	Current @ max. power Imax 0.328 A	Current @ max. power Imax 0.33 A

It is observed that simulated results of proposed control algorithm show the improved convergence speed of output power and hence better tracking efficiency as shown in Table 3. It is graphically proven in Figure 10 that the power output of the proposed controller is more effective in giving quicker response time (stead-state) of the system extracting maximum power from a photovoltaic system, proving the reduced time to track the MPPs due to faster convergence speed. The proposed method has P&O tracking method shows lowest power extraction compared to other methods whereas INC method shows fairly more power extraction but has lower convergence speed compared to the proposed hybrid method. To evaluate the performance of the proposed method, a comparison between theoretical values of PV maximum power and that computed from the proposed hybrid algorithm yields 94.6% of tracking efficiency when carried out under the same temperature and irradiance as P&O and incremental conductance MPPT methods. However, the proposed hybrid alogrthim method has been simulated in MATLAB/SIMULINK environment.

6. Conclusion

The research was targeted to analyse the MPPT implementation using the proposed hybrid technique. The hybrid technique was compared with the two most commonly used methods P&O and Incremental Conductance method. Simulink software was used to simulate the existing and proposed MPPT techniques. The simulation results illustrated that the proposed MPPT technique has better performance than P&O and Incremental conductance as it yield maximum power from the PV systems. The proposed method also reduces oscillation around the maximum power point thus avoiding power loss. The drawback of proposed technique is that it has higher settling time when compared to the incremental conductance method. However, this can be reduced by having further research on filters or tuners to increment or decrement the duty cycle to achieve the optimum output.

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