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# Hybrid Control Method for Maximum Power Point Tracking (MPPT) of Solar PV Power Generating System

[1]D.K.Sharma and [2]G. Purohit

[1]*Department of Electronics & Comm. Engg., Sir Padampat Singhania University, Udaipur (India)*
[2]*Department of Physics, Sir Padampat Singhania University, Udaipur (India)*

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**ABSTRACT**

**Background:** The efficiency of solar PV power generating system is the most important parameter which can be maximized by using an effective Maximum Power Point Tracking (MPPT) technique. For an effective MPPT, an efficient control method (algorithm) is required to efficiently control the operation of MPPT. By using an efficient control algorithm, the wastage of power in tracking the maximum power points (MPPs) and the oscillations of operating point around MPP are reduced. Different variants of characteristic curves (simulated in MATLAB) of solar PV module are presented. Performance parameters of some of the mostly used MPPT control algorithms are summarized. **Objective:** to maximize the efficiency of solar PV power generating system by improving the tracking speed of MPPs and hence reducing the wastage of power by using proposed hybrid control method. **Results:** It is observed that simulated results of proposed control algorithm show the improved convergence speed of output power and hence higher tracking efficiency. The proposed method has been simulated in MATLAB/SIMULINK environment. The result show the reduced time to track the MPPs due to faster convergence speed. **Conclusion:** We have reported the hybrid control method for an improved Maximum Power Point Tracking (MPPT) technique. The proposed hybrid control method is realized using two classical MPPT methods viz. mostly used Perturb and Observe (P&O) method and Constant Voltage (CV) method for better performance of improved MPPT and maximized efficiency of solar PV system. The main requirement for this method is the information about the Voc and Vmp to implement the CV method after P&O method. The easier implementation of P&O method allows combining it with constant voltage method. The constant voltage method works on the fact that ratio of maximum power voltage and open circuit voltage is constant (i.e. VMP / VOC = constant) and usually optimal value of this constant is equals to 0.76. The constant voltage method works more effectively than the P&O and Incremental Conductance (INC) method when solar PV panels are in low insolation. In this proposed hybrid algorithm, the converter is provided with the voltage closer to MPP which is a predetermined fraction of VOC. Using the proposed algorithm, the operation (duty cycle) of boost converter is controlled to optimally operate the MPPT. Consequently the oscillations of MPP around the operating point are minimized and efficiency of the overall solar PV power generating system is maximized.



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## INTRODUCTION

Electricity generation from renewable energy sources (e.g. Solar, wind, fuel cell etc.) is the most effective step towards an eco-friendly sustainable society. Solar photovoltaic (SPV) systems play a foremost role in all renewable energy sources for power generation. The electric power generation from SPV provides non-maintenance, robust and clean operation due to absence of any moving part in these systems. The operating cost (or fuel) for regular generation of electricity is almost zero in SPV, however the cost per watt of power is quite higher than the conventional modes of power generation as from thermal power plants, nuclear power plants or hydro power plants due to its lower conversion efficiency. The efficiency can be considered as the light to electricity ratio for a solar PV system. The efficiency of the SPV system can be substantially increased using Maximum Power Point Tracker (MPPT). MPPT is a power electronic system which tracks the point of maximum power on the characteristic curve of PV module throughout the day in varying solar insolation. MPPT is a highly efficient DC-DC converter which is controlled using a power electronic switch operated by an algorithm. The design of MPPT may be based upon Buck converter, Boost converter, Buck-boost converter etc.

**Corresponding Author:** D.K.Sharma, Department of Electronics & Comm. Engg., Sir Padampat Singhania University, Udaipur (India),
Contact No. +917568912396, E-mail: mail2dksharma@gmail.com

In the case of buck converter the current does not flow constantly, however the constant flow of current may be achieved in boost converter. Many types of algorithms are available to control the operation of switch of boost converter like Perturb & Observe (P&O) algorithm, Incremental Conductance (INC) algorithm, Parasitic Capacitance method etc.

The actual maximum power points vary with conditions such as the surface temperature and the quantity of solar radiation (Mutoh, N *et al*. 2002). The efficient control of MPPT is required for an optimized efficiency of solar PV system. MPPT can be efficiently controlled using a control algorithm for the switch of the DC-DC converter in MPPT circuitry. In all the applications, it is desired that the optimized power should flow from solar PV to the load (Coelho, R.F *et al*. 2010). For this condition it is required to establish the operating point at maximum power point (MPP). MPPT works as an embedded system (combination of hardware and software) in which DC-DC converter works as hardware part and control algorithm acts as software part of MPPT system. This combination of software (control algorithm) and hardware (DC-DC converter) defines the efficiency of solar PV system (Coelho, R.F. *et al*. 2012). Many MPPTs have been designed and developed with new MPPT approaches using various control algorithms.

We present simulation results of hybrid algorithm for an improved MPPT which shows the faster convergence speed and therefore improved efficiency of the whole SPV system for power generation. We have used the boost converter in the present work.

***Solar Photovoltaic (Pv) Power Generating System:***

A typical solar PV power generating system has the following components

Solar PV module (or array for larger power), charge controller, battery, inverter (for ac loads). To maximize the efficiency of this system, MPPT is used between the solar PV module and load. To extract maximum power from the solar PV module, it is needed to track the maximum power points (MPPs) on the characteristics curves of solar PV module. Therefore to obtain the realistic characteristic curve, the solar PV module is to be characterized (modelled) using its characteristic equation. The characterization of solar PV module is described in the next section.

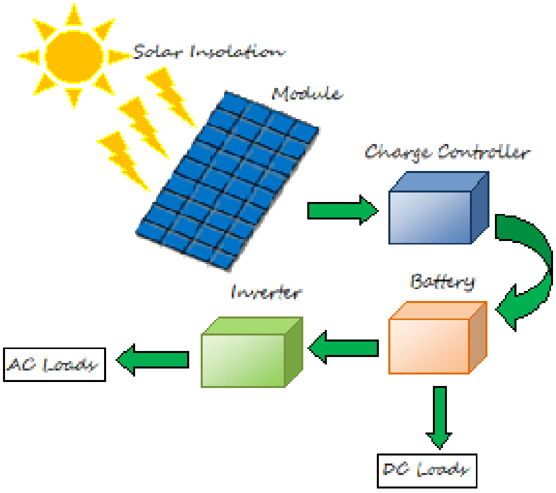



**Fig. 1:** Solar PV Power Generating System

***Solar Pv Module Characterization***

***a) Electrical Equivalent of Solar PV Module:***

To model a solar PV cell (or module), the electrical equivalent circuit of solar PV cell is needed which is shown as in the figure 2. It is obvious from the figure that solar cell is equivalent to a current source with a diode in parallel and two resistors ($R_{SH}$ in parallel and $R_S$ in series) are connected.

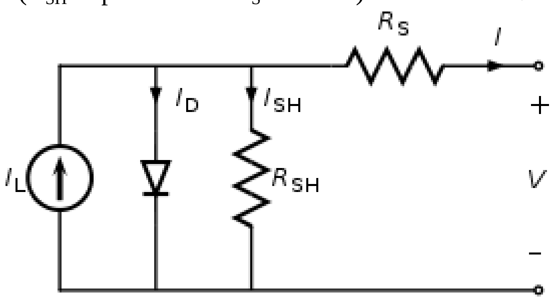



**Fig. 2:** Electrical Equivalent of Solar PV Cell

The characteristic equation of a solar PV cell is given by the following expression which provides the relationship between the output voltage and current and shows the effect of other circuit components.

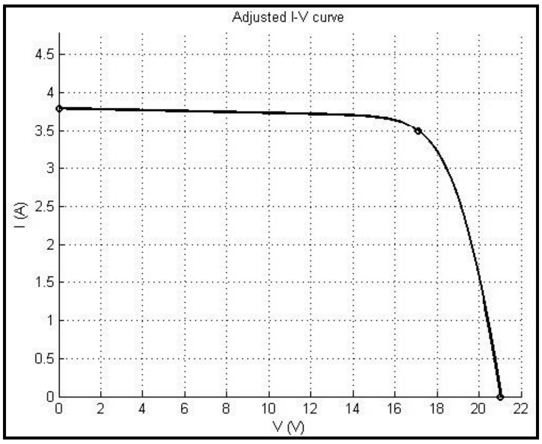
$$I = I_L - I_0 \left\{ \exp\left[ \frac{q(V + IR_S)}{nkT} \right] - 1 \right\} - \frac{V + IR_S}{R_{SH}}$$

Where,

- V is the output voltage of the solar PV cell (Volts)
- I is the output current of the solar PV cell (Amperes)
- $I_L$ is the light generated current of solar PV cell (Amperes)
- q is the electronic charge (Coulombs)
- $R_S$ is the series resistance (Ω)
- $R_{SH}$ is the shunt resistance (Ω)
- n is the diode ideality factor (unit less)
- k is the Boltzmann's constant ($JK^{-1}$) and
- T is the temperature (K)

### b) *Characteristic Curves of Solar PV Module:*

The performance of a Solar PV system depends upon the operating conditions. The maximum power extracted from solar PV system mainly depends upon the insolation and PV cell (module) temperature (ambient temperature) (Garcia, O. *et al*. 2013). The current-voltage and power-voltage characteristic curves for the solar PV module are simulated in MATLAB using the characteristic equation as described in the previous section. The effect of two important parameters ($R_s$ and $R_{SH}$) of electrical equivalent circuit of solar PV module is also shown in the following figures.



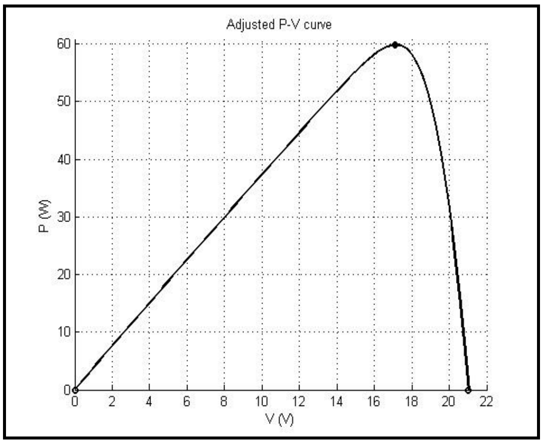
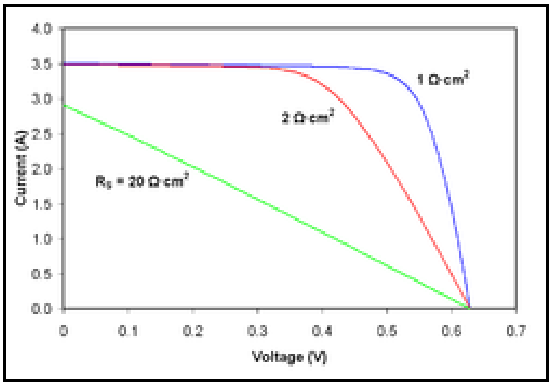




**Fig. 3:** Simulated I-V characeristic curve of solar PV module

Simulated P-V characteristic curve of solar PV module



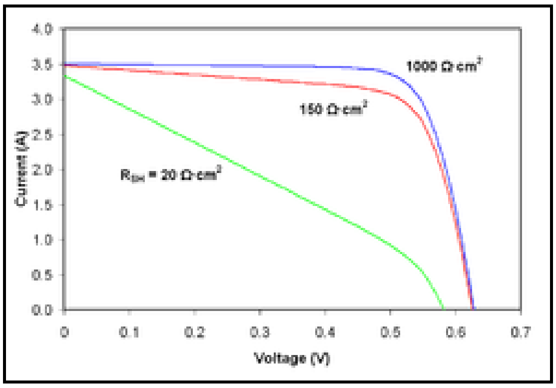
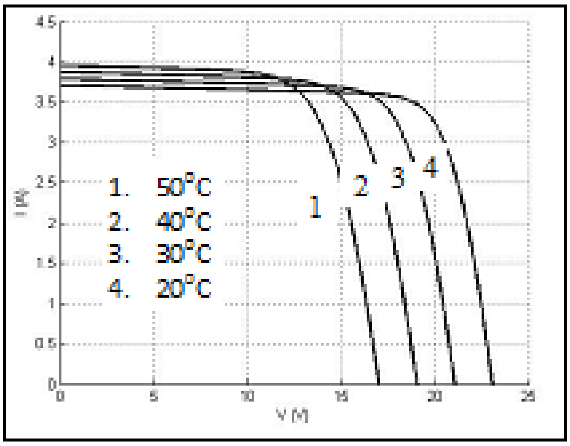




**Fig. 4:** Effect of series resistance on the current-voltage characteristics of solar cell

Effect of shunt resistance on the current–voltage characteristics of solar cell



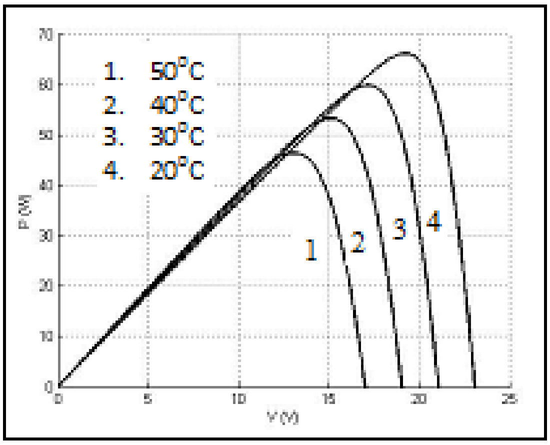
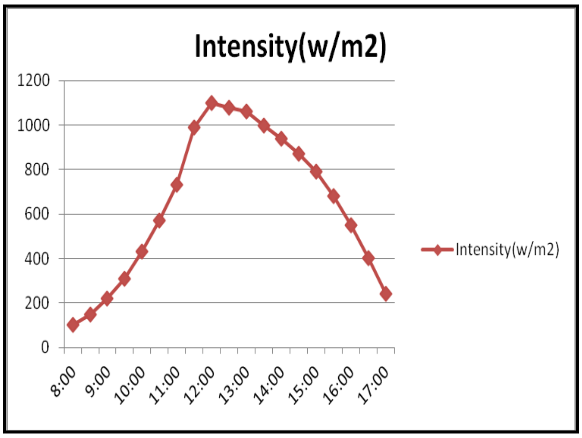




**Fig. 5:** I-V characteristics of solar PV module varying with temperature    P-V characteristics of solar PV module varying with temperature



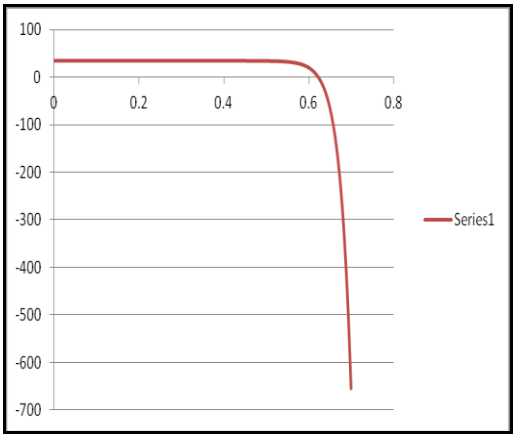




**Fig. 6:** Power-Voltage characteristic curve of solar PV module based on realistic data    Current-Voltage characteristic curve of solar PV module based on realistic data

### *Boost Converter:*

A boost converter is chosen for implementing the MPPT circuitry. A boost converter [Garcia, O. *et al*. 2013] provides the higher voltage at output than the input voltage supplied. As per the law of energy conservation, the output current is lower than the input current.

During the On-state, the switch SW is closed, the input voltage ($V_{PV}$) is fed to the inductor. During this period the diode is reverse biased and the voltage across the inductor is $V_L = V_{PV}$.

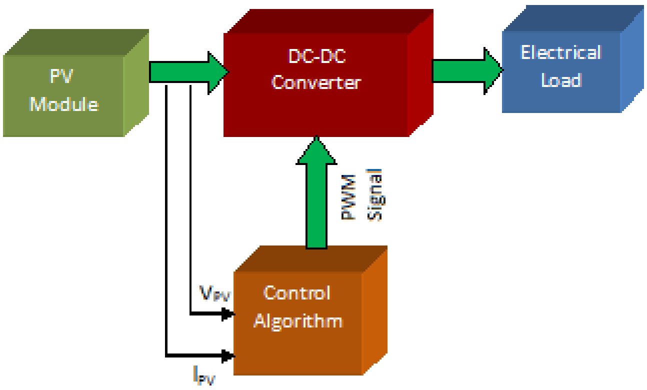



**Fig. 7:** A typical solar PV system with MPPT (DC-DC converter and control algorithm)

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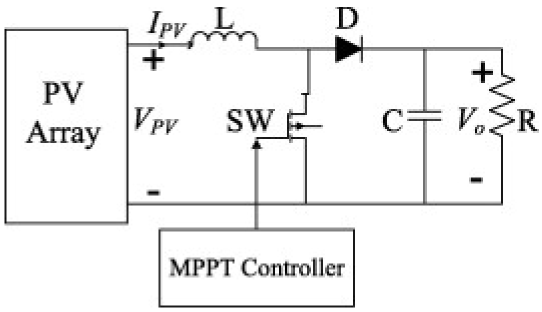


**Fig. 8:** Circuit diagram for a solar PV system with MPPT controller

During the Off-state, the switch SW is open; therefore the inductor current flows through the load as the diode is forward biased in this condition. Now the voltage across inductor is

$$V_L = V_{PV} - V_o$$

By using the two values of voltage across the inductor during $T_{ON}$ and $T_{OFF}$, the relationship between input and output voltage of boost converter can be expressed as:

$$V_o = V_{PV}/1\text{-}D$$

Where D is the duty cycle of the switch of the boost converter and can be defined as $T_{ON}/T$.

***Maximum Power Point Tracking (Mppt) Control Algorithms:***

There are following conditions for the most efficient operation of MPPTs.

1. In winter or in cloudy days: When there is higher demand of electric power for various needs.
2. In the low state charge of battery: When the battery withstands with a low charging status, the MPPT feeds the more current to battery.
3. In cold weather: When the ambient temperature is lower, the solar cells (modules) provide an efficient output to the load and hence MPPT works better.

Various MPPT control algorithms have been designed and developed by many researchers. The performance parameters for some popular control algorithm for MPPT are summarized in the following table.

| S.No. | Algorithm Type | Dependency on PV array | Tracking efficiency | Implementation level | Sensing parameters/ Type |
|---|---|---|---|---|---|
| 1. | Incremental conductance (INC) method (D. P. Hohm and M. E. Ropp 2003; Trishan Esram and Patrick L. Chapman, 2007) | Not dependent | Good | Medium | Voltage & Current |
| 2. | Perturb and Observe (P&O) Method (D. P. Hohm and M. E. Ropp 2003; Marcelo Gradella Villalva *et al*., 2009; Trishan Esram and Patrick L. Chapman, 2007) | Dependent | Good but with unstable operating points | Simple | Voltage & Current |
| 3. | Fuzzy logic controller (FLC) method (D. P. Hohm and M. E. Ropp 2003; Trishan Esram and Patrick L. Chapman, 2007) | Dependent | Good with fast convergence speed | Complex | Digital type |
| 4. | Temperature method (Trishan Esram and Patrick L. Chapman, 2007) | Dependent | Excellent | Medium | Voltage and temperature |
| 5. | Linear current control method (Marcelo Gradella Villalva *et al*., 2009; Moacyr A. G. de Brito *et al*, 2011) | Dependent | Not good | Medium | Irradiance/ digital type |
| 6. | Neural network based method (Trishan Esram and Patrick L. Chapman, 2007) | Dependent | Good with fast convergence speed | Complex | Digital type |

| | | | | | |
|---|---|---|---|---|---|
| 7. | Advanced P&O method (D.K.Sharma and G.Purohit, 2012) | Dependent | Very good | Medium | Voltage & Current |

Apart from the above described control algorithm, the proposed hybrid control algorithm (combining constant voltage and P&O method) is also described for efficiently track the MPP throughout the day with varying insolation condition.

***Proposed Hybrid Control Method For Mppt:***

The proposed hybrid control method combines the features of classical perturb and Observe (P&O) method and constant voltage method. This algorithm provides an easier implementation of P&O method in steady state environmental conditions. In rapidly changing weather conditions, the constant voltage method will be able to approximately track the MPP. P&O method operates in such a way that the output voltage is perturbed with the change in insolation and hence the maximum power is extracted from solar PV system. The constant voltage method works on the fact that ratio of open circuit voltage and maximum power voltage is constant (i.e. $V_{MP}$ / $V_{OC}$ = constant) and ranging from 0.75 to 0.98. In this proposed hybrid algorithm, the converter is provided with the voltage closer to MPP which is a predetermined fraction of $V_{OC}$. Therefore in this manner, the MPPT tracks the MPPs faster after the logic switches over to the P&O algorithm. The disadvantage of this algorithm is that it requires the prior information about the $V_{OC}$ for implementation of constant voltage method before P&O method.

## RESULTS AND DISCUSSION

The solar PV system with MPPT has been simulated in MATLAB/SIMULINK software. The simulated results for MPPT with control algorithm (based upon P&O and constant voltage method) are also been presented here. The results show that MPPT provides the fast convergence speed and hence higher tracking efficiency using the hybrid P&O method (with constant voltage). The simulation results of MPPT control algorithm with involved ripples are also presented. The results also show that the ripples around MPP are minimized which leads to reduce the wastage of power for stabilizing the operating point rapidly.

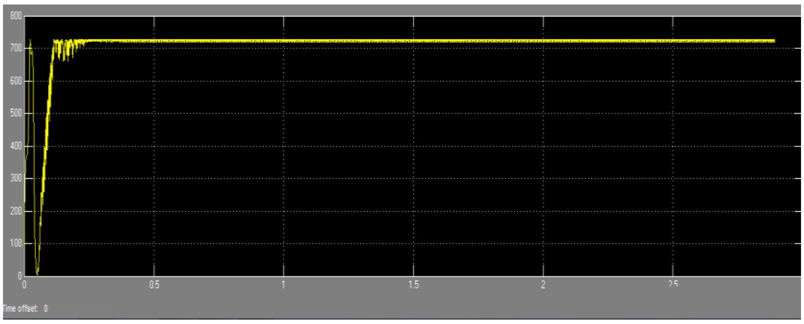

**Fig. 8:** Simulation result of Proposed MPPT with solar PV system

**Fig. 9:** Simulation result of the output of MPPT with proposed hybrid control method

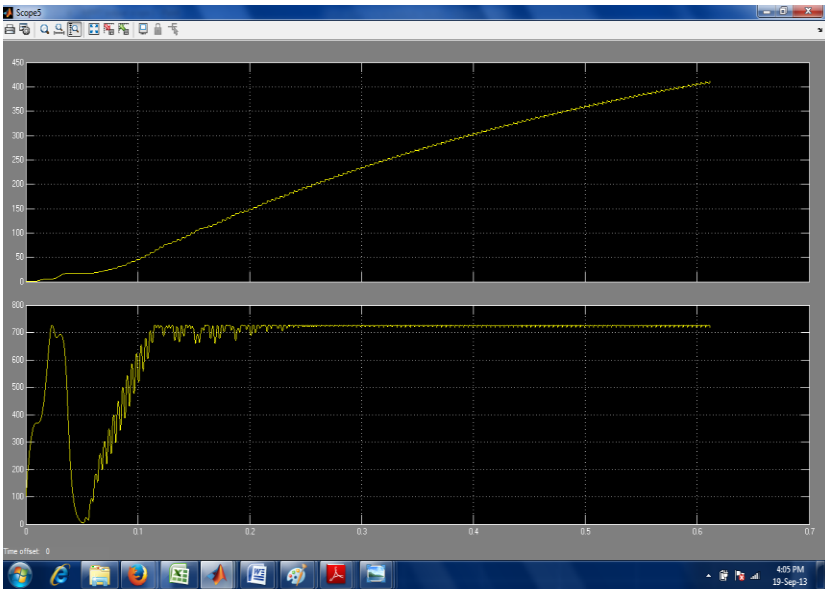

**Fig. 10:** Simulation result of proposed MPPT with involved ripples

***Conclusion:***

The efficiency of solar PV system is the key factor for effective utilization of these systems for power generation. In this paper, the typical solar PV power generating system is investigated with a maximum power point tracker (MPPT). For an efficient operation of MPPT for extraction of maximum possible power from solar PV module, an efficient control algorithm is the basic requirement which functions to control the DC-DC converter circuitry. Various MPPT algorithms are summarized with various performance parameters for their selection for a particular application. Hybrid MPPT algorithm is implemented with and simulated in MATLAB/SIMULINK environment. This hybrid algorithm combines the advantages of P&O method and constant voltage method for an improved operation of MPPT. The simulation results show that the hybrid algorithm provides a fast convergence of constant power to obtain the MPP. Hence the power extracted from the solar PV module is maximized efficiently in order to increase the efficiency of the overall PV system.

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