A Hybrid Variable Step Size MPPT Method Based on P&O and INC Methods

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Abstract

Maximum power point tracking (MPPT) is an essential part of the Photovoltaic (PV) systems to obtain the possible maximum power. Perturb and observe (P&O) is one of the most important MPPT methods because of its simplicity and ease of implementation. In this paper, a modified hybrid variable step size MPPT algorithm based on P&O and incremental conductance (INC) methods is proposed to obtain MPP from the PV system by changing the step size automatically. Proposed algorithm can be an effective solution to the low tracking speed and the oscillations around the MPP problems. Advantages of the proposed algorithm has been verified by the simulation results.

1. Introduction

Factors such as sharply increasing demand for energy, exhaustibility of the fossil fuels and their harmful effects on the environment have been increasing the curiosity about renewable energy sources [1]. Renewable energy is generated from natural resources such as sunlight, rain, wave, wind, geothermal etc. Among these, solar power from sunlight is one of the most promising one for prevailing utilization because of its efficiency and environmentally friendly nature [2].

Solar energy is obtained from Photovoltaic Systems which are made up of solar cells. One solar cell can produce power on very small quantity. To get the desired quantity of power, solar cells usually combined series to form the PV panels. These panels can be put together series or parallel to satisfy the desired power [3]. PV systems are well-accepted because of their convenience for mobile applications, satellite systems, and transportation.

The output power of PV systems varies with solar irradiation, temperature, weather condition, and panel dirtiness. To avoid this, Maximum Power Point Tracking (MPPT) control techniques have been in usage for a long time. MPPT is the indispensable part of PV systems to ensure the operation of converters at the maximum power point of PV Array [4-5].

There are many MPPT methods reported in the literature. Researches dealing with MPPT can be classified mainly into two groups; conventional and soft computing techniques [6-8]. Among the conventional methods, fractional open circuit (FOC) and fractional short circuit (FSC) methods are simple and cost effective but have less accuracy [9-10]. Incremental Conductance (INC) algorithm is based on the slope of P-V curve and it can track the MPP under uniform irradiation only [11].

Perturb and Observe method (P&O) is the most commonly employed MPPT method among all MPPT algorithms due to its simplicity, cost effectiveness and ease of implementation [12]. But this method fails when panels in an array are subjected to different irradiation levels. High tracking time and high steady state oscillations are also major problems for this method. To overcome these problems, soft switching techniques has been developed. Fuzzy Logic Control (FLC), Genetic Algorithm (GA), Particle Swarm Optimization (PSA), Artificial Neural Network (ANN), Fireflies Algorithms are the best known soft switching techniques. Although these methods effectively handle the non-linearities of irradiance and temperature, they are complicated and difficult to implement [13].

There is an alternative way to overcome the problems caused by conventional MPPT methods. Modifying conventional methods by using variable step size remedies the oscillations around the MPP. Main principle of these methods is using higher step sizes when the power is climbing and reducing the step size significantly when the power is around MPP. In literature, a lot of hybrid or modified conventional MPPT methods has been presented [5-8].

In this paper, a modified variable step size algorithm which is based on P&O and INC methods has been proposed. It is a hybrid method since the algorithm uses the ratio of the incremental conductance and the instantaneous conductance as a control variable. Proposed method is shown to improve the tracking speed while providing low oscillation around MPP.

2. Photovoltaic Systems

Photovoltaic panels consist of solar cells connected in series. These cells are semiconductor devices that produce the energy through photoelectric effect. Some semiconductors have photoelectric ability that convert the electromagnetic radiation into electrical current. As long as sunlight is shining, solar cells generates energy.

Photovoltaic panels, batteries, charge regulators, DC-DC converters and inverters connected as grids to form the photovoltaic systems.

2.1. Equivalent Model

Solar cells consist of two or more thin layers of semiconducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated. A PV cell is usually represented by an electrical equivalent one-diode model shown in Fig. 1. The equivalent model contains a current source, shunt and series resistances and a diode inside each cell. Model parameters are the standard PV module datasheet parameters.

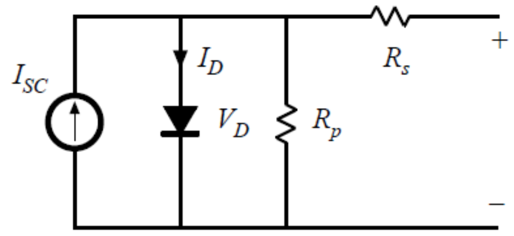

Fig.1. Single PV cell equivalent model

I_{SC} is the maximum value of the current that the solar cell can output under short circuit conditions. In the same way, the maximum voltage at zero current called as open circuit voltage, V_{OC} . From Kirchoff's current law;

$$I_{sc} = I_D + \frac{V_D}{R_P} + I_{PV} \tag{1}$$

and diode characteristic is;

$$I_D = I_0(e^{V_D / V_T} - 1) \tag{2}$$

Lastly from the Kirchoff's voltage law;

$$V_{PVcell} = V_D - R_s I_{PV} \tag{3}$$

Where

I_{PV} PV Current
I_D Diode Current
I_0 Diode Saturation Current
V_{PVcell} Cell Output Voltage
V_D Diode Voltage
V_T Thermal Voltage
R_s Series Resistance
R_p Shunt Resistance

Solar cells produce different power values depending on the solar irradiance and the temperature. Power vs voltage characteristic curves of a typical PV panel are given in Fig. 2. Relationship of the voltage and the current under different irradiance values are shown in Fig. 3. These curves show that there is a unique voltage and current values which supply the maximum power for each irradiation level. This is called as maximum power point (V_{MPP} , I_{MPP}).

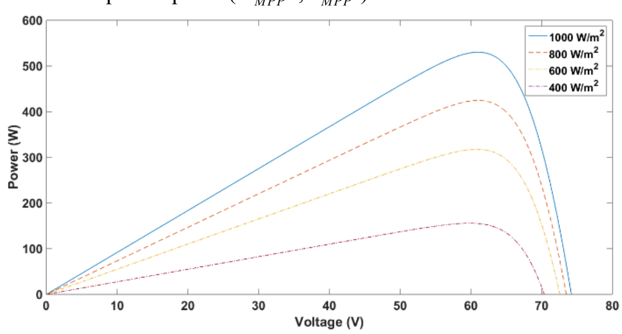

Fig. 2. Effect of irradiance on voltage-power characteristic

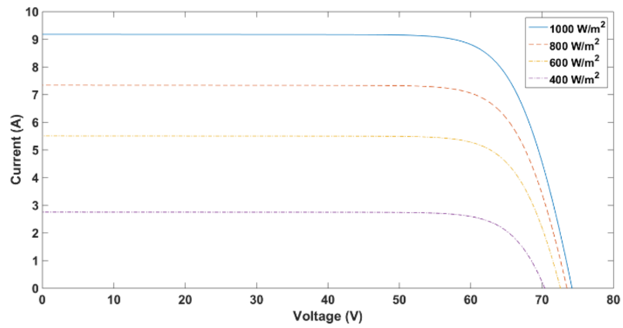

Fig. 3. Effect of irradiance on voltage-current characteristic

To reach this maximum power point, various control techniques has been developed. Maximum Power Point Tracking technique is the most popular control technique because of its safety, cheapness and ease of implementation.

2.2. The Perturb and Observe (P&O) Method

Perturb and observe (P&O) is the best-known and most commonly used MPPT algorithm. This algorithm is simple and easy to implement. P&O algorithm is based on the calculation of PV array output power change. Fig. 4. shows the flowchart of the P&O method.

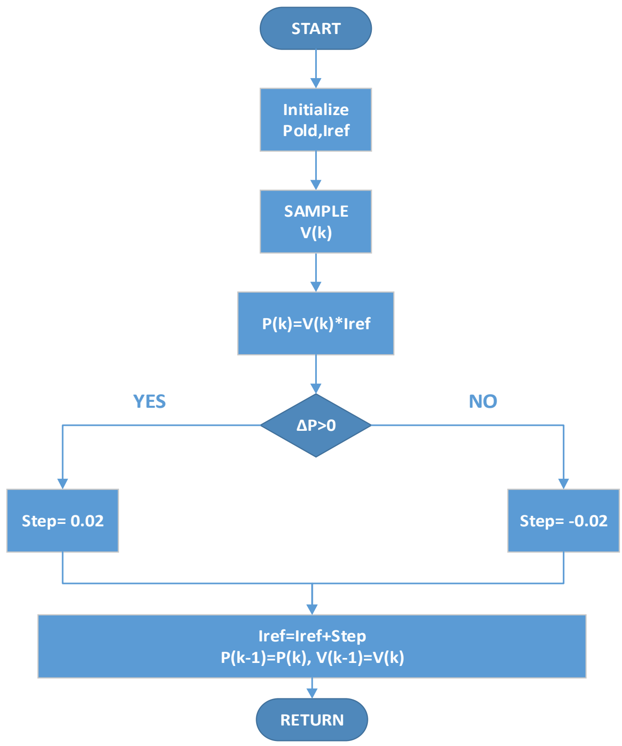

Fig.4. Flowchart of P&O method

Calculation of output power is done by measuring both the PV current and voltage. PV array's current output power value P(k) is compared with the previous perturbing cycle value P(k-1). Based on the outcome of this comparison, the controller decides to whether increase or decrease the current. If the output power is increasing, then the current change direction is kept same as the previous direction. When the stable condition on the power reached, voltage begins to change in the opposite direction to the previous one and oscillates around the peak power.

Besides its simplicity, P&O has some drawbacks. Because of its fixed step size, oscillations occur around the MPP. Reaching the MPP quickly and minimizing oscillations around the MPP are two conflicting objectives when the step size is fixed. Using a larger step size ensures reaching the MPP quickly but the power loss caused by oscillations in steady state also increases. On the other hand, using a small step size can reduce the power loss around the MPP but the tracking time increases. If both fast tracking and low oscillation around MPP are needed, then fixed step P&O algorithms need to be modified.

2.3. Proposed Variable Step Size P&O Method

To overcome challenges mentioned in the previous subsection, a variable step size MPPT algorithm is proposed here.

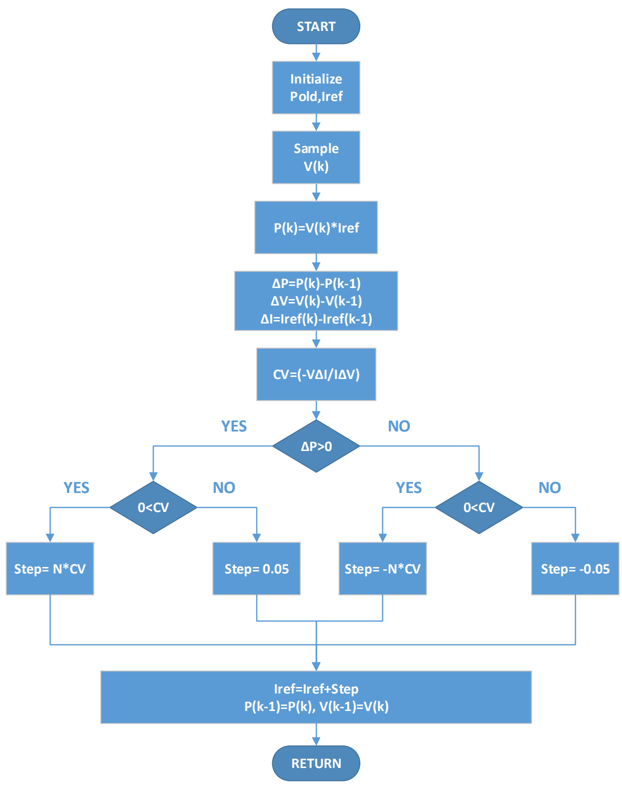

Fig. 5. Flowchart of proposed variable step size P&O

Fig. 5. shows the flowchart of the proposed variable step size algorithm. Proposed method is basically a modification of P&O method by using the ratio of the incremental conductance and the instantaneous conductance as a control variable to allow variable step size. In that regard this is a hybrid method based on P&O and INC methods.

In this method, step size is automatically tuned for the PV operating points. If a change in solar irradiation occurs, step size is also changed quickly for the new power point. The algorithm detects whether the power point is climbing or at the steady state. When the operating point is far from the MPP, the algorithm tunes the step size to a larger value to enable faster tracking.

According to INC method, MPP can be tuned by the ratio of instantaneous conductance and incremental conductance [14]. Suggested algorithm uses this ratio as a control variable (CV). When the system is in climbing position, current value increases as voltage values drops. The value of the CV is greater than 1 in this region. Hence larger step sizes must be picked for fast tracking. When at steady state, both the voltage and the current values has just small changes resulting a CV value of 1. In this case, smaller step sizes are required to have less oscillations around MPP. If CV value becomes negative or undefined as a result of a calculation mistake, system continues to work as fixed step P&O to protect itself.

$$\left\{ \begin{array}{ll} \frac{\Delta I}{\Delta V} > -\frac{I}{V} & \text{climbing position} \\ \frac{\Delta I}{\Delta V} = -\frac{I}{V} & \text{steady state position} \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V} & \text{climb down position} \end{array} \right\} \qquad (4)$$

$$CV = -V\Delta I / I\Delta V \qquad (5)$$

Step= N*CV

where

CV control variable

N scaling factor

ΔI differentiation of current

ΔV differentiation of voltage

Scaling factor is an essential part of the algorithm to appoint the performance of the MPPT. It can be tuned manually. For this system, scaling factor determined as 0.001.

3. Simulation and Results

Simulation of the proposed system is performed on SimPower System toolbox of Matlab /Simulink. Block diagram of the system is shown in Fig. 6. The system consists of a PV array, resistive load, boost converter and the MPPT controller. For this simulation, Lexron 265W mono crystalline PV panel has been chosen. Parameters for this panel is given in Table 1. Two PV panels are connected in series to form the PV array.

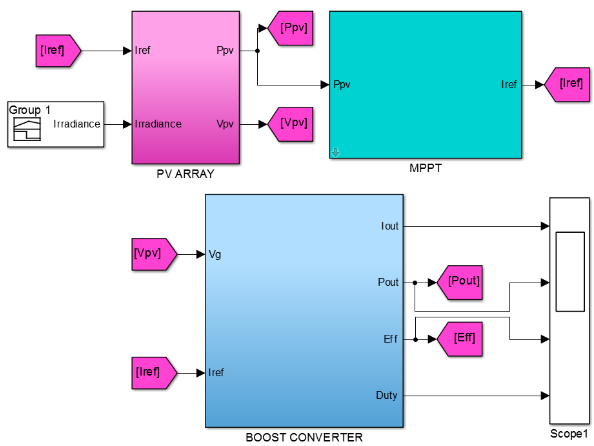

Fig. 6. Simulink Block Diagram of the Proposed System

Table 1. Lexron 265W Monocrystalline Solar Panel Parameters

Parameter	Name	Value
Open Circuit Voltage	V_{oc}	37.5 V
Short Circuit Current	I_{sc}	9.08 A
Max power point voltage	V_{mpp}	30.5 V
Max power point current	I_{mpp}	8.69 A
Module Efficiency (STC)	Eff	18.60 %
Cell Arrangement	Ns	60 (10*6)

A boost converter is connected to the PV array to provide the maximum power to the load. Parameters of the boost converter are given in Table 2.

Table 2. Boost converter parameters

Parameter	Name	Value
MPPT frequency	f	10 kHz
Inductance	L	200 µH
Capacitance	C	10 µF
Resistance	R	200 Ω
Switching Equipment	S	Mosfet

The proposed algorithm was tested under three different solar irradiation conditions to prove its effectiveness. Solar irradiation levels were determined according to the European Efficiency Test, EN50530 [15]. Solar irradiation profiles included step up, step down, ramp up, ramp down and trapezoidal shapes. During all tests, temperature was fixed to 25 ^{o}C. Simulation results are compared with fixed step P&O method. For the P&O method two different step sizes (a large one and a small one) were chosen in order to show the dependence of response speed and the oscillation level to step size.

A step input is applied as the irradiance profile first. As it is shown in Fig. 7, the proposed algorithm is faster than unmodified P&O method to track the reference. Response of the proposed method has also less oscillations at steady state.

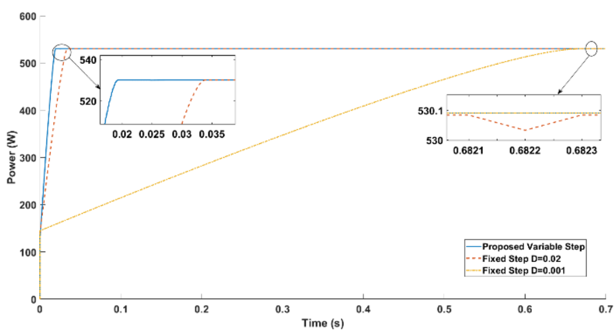

Fig 7. Tracking speed test between proposed algorithm and conventional algorithm

Fig. 8 shows the second irradiance profile consist of ramp up and down functions applied. Ramp slopes were determined as 100 W/m^2s. Simulation results are given in Fig. 9. Proposed algorithm is slightly faster than the P&O method with step size D=0.001 in ramp up region. The response of P&O method with step size D=0.02 is significantly slow in this region. But it has less oscillation under constant irradiance. Oscillation of the proposed method's response is notably less than that of P&O method with smaller step size under constant irradiance. In ramp down region, responses showed similar patterns; P&O with smaller step size has fast and oscillatory response, P&O with larger step size has slow and less oscillatory response, the prosed method has fast and less oscillatory response.

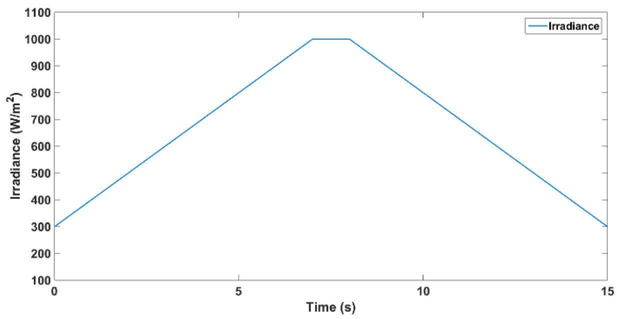

Fig. 8. Ramp up-down irradiance profile

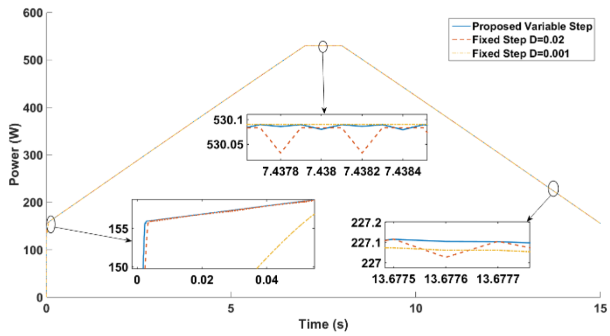

Fig. 9. Comparison of proposed algorithm and original algorithm under ramp up-down irradiance condition

Third irradiance profile is the step up and step down function as it is shown in Fig. 10. For this test, irradiance starts from 300 W/m^2 and suddenly jumps to 1000 W/m^2 at t=1 s. After that, it is suddenly changed back to 300 W/m^2 at t=2 s. As it is seen from Fig. 11, response of the proposed algorithm successfully tracks the reference before that of the fixed size P&O algorithms do.

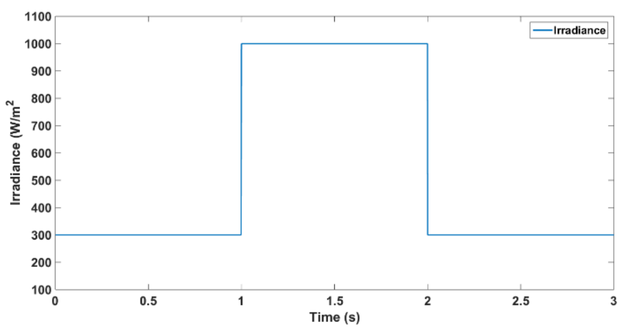

Fig. 10. Step up-down irradiance profile

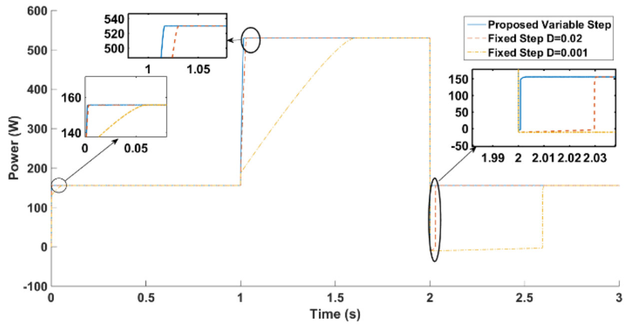

Fig. 11. Comparison of proposed algorithm and original algorithm under step up-down irradiance condition

4. Conclusions

In this paper, a new hybrid MPPT algorithm has proposed and simulated. Modification on the conventional MPPT algorithm provided a faster tracking time for MPP and low steady state oscillation around MPP. Simulation of the proposed system was performed on SimPower System toolbox on Matlab /Simulink. Simulation test conditions and irradiance profiles were prepared according to European Standard Test EN 50530.

Simulations show that the proposed algorithm have advantages over the conventional algorithm and provides solution to the conventional algorithm's drawbacks. Simulations prove that proposed algorithm has faster tracking time and lower oscillations around MPP.

To future work, proposed algorithm will be implemented experimentally to verify simulation results. Also, the proposed algorithm will be improved for working under partial shading conditions.

5. Acknowledgement

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