Drift Free Variable Step Size Perturb and Observe MPPT Algorithm for Photovoltaic Systems Under Rapidly Increasing Insolation

Deepthi Pilakkat and S. Kanthalakshmi

***Abstract*—The characteristic of a Photovoltaic (PV) panel is most affected by the incident solar insolation temperature, shading, and array configuration. Maximum power point tracking (MPPT) algorithms have an important role in harvesting maximum power from the solar PV arrays. Among the various MPPT methods Perturb and Observe (P&O) algorithm is the simple and efficient one. However, there will be a drift problem in case of increase in insolation. This drift will be more under rapid increase in insolation. To improve the speed of tracking the Maximum Power Point (MPP), a variable step size P&O (VSSPO) is developed. The drift problem will be more in the case of VSSPO as it will have a larger step size for an increase in insolation. In this paper, the maximum output power extraction from Solar PV under rapidly increasing insolation conditions by a drift free P&O (DFP&O) as well as drift free VSSPO (DFVSSPO) method is presented.**

***Index Terms*—Drift Free Analysis, Drift free Variable step size P&O, Maximum Power Point Tracking, Perturb and Observe algorithm, Solar PV Systems.**

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1. Introduction

Because the global warming is increasing and conventional fossil-fuel energy sources are reducing, renewable energy sources like solar, wind, geothermal etc. are attracting more consideration as alternate energy sources. Among the renewable energy sources, the solar photovoltaic (PV) energy has been widely utilized in many applications due to its advantages such as direct electric power form, easy maintenance, no noise, etc. With a surge in the use of non-conventional energy sources, PV installations are being increasingly employed in several applications. Paper [1] discussed how the solar energy utilization can improve the quality and quantity of products while reducing the greenhouse gas emissions. The output characteristics of PV panel will vary with the temperature and solar insolation and the foremost confront in using a PV supply is to get to work at its nonlinear output characteristics [2].

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There are a lot of MPPT algorithms available in literatures such as Perturbation and Observation (P&O), Incremental Conductance (INC), fuzzy logic, Particle Swarm Optimization (PSO), Artificial Bee Colony etc [3]-[7]. The P&O method is the simplest method which can be implemented in real time. Even though P&O method is the simplest among all the MPPTs, it has one major disadvantage of oscillations around MPP, and hence wastage of power. By minimizing the fixed perturbation step size, these oscillations can be reduced. The problem with the small step size is, it will take more time to reach MPP [8]. If the tracking time of MPPT can be successfully minimized, more energy can be gathered from PV at MPP [9]. Numerous improvements for the P&O algorithm have been proposed one by one to diminish the number of oscillations around MPP in steady state, but the response is time-consuming under the rapidly changing atmospheric conditions. This will reduce the efficiency of algorithm and hence the PV systems. A modified variable step size P&O MPPT algorithm is proposed in [10], where the step size is automatically tuned according to the operating point. Variable step size P&O (VSSPO) has better steady-state and dynamic performance than the conventional P&O, and will obtain better efficiency of PV power generation system [11]. Another drawback of P&O method is the presence of drift in case of an increase in insolation (G), and this drift effect is severe in case of a rapid increase in insolation [12]. More over a comparative study of different MPPT algorithms are presented in [13] and [14].

Paper [15] presented a step-by-step process for the simulation of PV cells/modules/arrays with Tag tools in MATLAB/SIMULINK. A complete modeling practice for the circuit model with statistical dimensions is offered using power system block set of MATLAB/SIMULINK and the simulation results are validated with experimental set up in [16].

As the demand for PV electricity generation is increasing day by day, research is going on how to improve the efficiency of the PV systems and thereby reducing the overall cost. In this paper, a drift free variable step size P&O algorithm along with a boost converter is designed and simulated to extract maximum power from the PV panel under the rapidly increasing insolation conditions.

The design of PV system using mathematical model with simulation in MATLAB/SIMULINK environment is presented in Section 2. The P&O MPPT algorithm is used as closed loop control and is integrated with DC/DC boost converter. The algorithm has been analyzed for different irradiation levels. The boost converter adjusts its impedance value by changing duty ratio in order to match the load side impedance with panel's impedance. Section III describes about design of the boost converter used for this study and its specifications in detail. In Sections IV and V, the drift analysis and drift free analysis respectively with P&O and VSSPO MPPT algorithms are explained. Section VI delivers simulation results and Section VII presents the conclusion.

II. Modeling of PV Panel

A. Equivalent Circuit and Mathematical equations of Solar Panel

Fig. 1 depicts the equivalent electrical circuit of an ideal solar cell. The PV module can be modeled mathematically as given in equations below. These equations describes about the V-I characteristics of the PV cell and module.

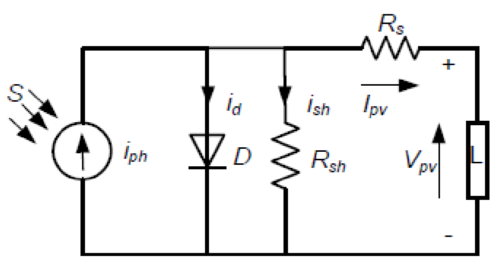


Fig. 1. Equivalent circuit of a solar cell.

The basic equation which describes the PV module output current I_{PV} is given by (1). Sections

$$I_{PV} = N_P.I_{ph} - N_P.I_0\left[\exp\left\{\frac{q(V_{PV}+I_{PV}R_s)}{N_S.A.k.T_{op}}\right\} - 1\right] \quad (1)$$

The module photo current I_{ph}, depends on both temperature and irradiance as shown in equation (2).

$$I_{ph} = [I_{sc} + K_i(T_{op} - T_{ref})]\frac{G}{1000} \quad (2)$$

The module saturation current, I_o varies with the cell temperature, which is given by

$$I_o = I_{rs}\left[\frac{T_{op}}{T_{ref}}\right]^3 \exp\left\{\frac{q.E_g}{k.A}\left(\frac{1}{T_{ref}} - \frac{1}{T_{op}}\right)\right\} \quad (3)$$

Module reverse saturation current I_{rs} is defined by

$$I_{rs} = \frac{I_{SC}}{[\exp\left(\frac{q.V_{OC}}{N_s.A.k.T_{op}}\right) - 1]} \quad (4)$$

The symbols and its values used in equations are described in Table I.

TABLE I
Symbols And Descriptions In PV Module

Symbol	Description	Value	Unit
N_P	Number of parallel connected cells		
N_S	Number of series connected cells		
q	Electron charge	$1.6*10^{-19}$	C
V_{PV}	Output voltage of PV module		V
R_S	Series resistance of PV module		Ω
A	Ideality factor	1.5	
K	Boltzman constant	$1.3805*10^{-23}$	J/K
T_{op}	Module operating temperature		K
T_{ref}	Reference temperature		k
K_i	Short circuit current temperature coefficient		A/K
G	Irradiance		W/m^2
E_g	Band gap energy	1.1	eV
I_{SC}	Short Circuit current of PV module		A
V_{OC}	Open circuit voltage of PV module		V

B. Reference PV Module

MAS SPV-P-100 solar module is used as reference module for simulation. The data sheet details are stated in Table II. The electrical specifications are under Standard Test Conditions (STC), with an irradiation of $1000W/m^2$ at temperature 25^0C and air mass 1.5.

TABLE II
Specifications of MAS-SPV-P100 Module

Description	Specification
Maximum Power (P_{max})	100W
Open circuit voltage (V_{OC})	20.59V
Short circuit current (I_{SC})	5.92A
Maximum Power Point voltage (V_{mpp})	18.9V
Maximum Power Point Current (I_{mpp})	5.44A
Module Efficiency	16.8%
Short Circuit Current Temperature Coefficient	0.06%/K

III. Boost Converter

The DC/DC boost converter is used as an interface between the PV array and the load to provide load impedance matching with the PV source.

To track the maximum operating point for certain irradiance and weather conditions a DC-DC converter is inserted between PV module and load. In order to drive the solar panel continually at the maximum power point (MPP), the duty cycle of the switch of DC-DC converter is always tuned with the help of MPPT algorithms. Fig. 2 shows the circuit diagram of a DC-DC boost converter.

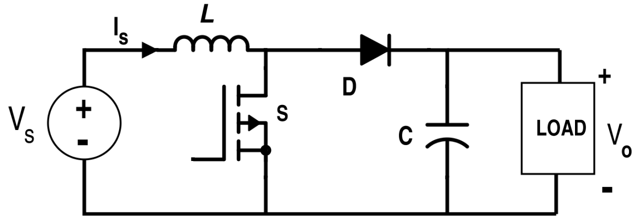


Fig. 2. Circuit diagram of a boost converter.

A. Design of Boost Converter

The design of the boost converter is done with the necessary parameters of the power stage, as follows. The values of the components for boost converter used in the present work are given in Table III.

TABLE III
SPECIFICATIONS OF BOOST CONVERTER

Components	**Specification**
Input Voltage (V_{in})	19V
Output Voltage (V_o)	150V
Output Current (I_o)	1A
Output capacitance (C)	90µF
Load Resistance (R_L)	150Ω
Nominal duty ratio (D)	0.873
Inductance (L)	530µH

a. Design of Duty Ratio:

The duty ratio is calculated by the equation (5).

$$D = 1 - \frac{V_s}{V_o} = 1 - \frac{19}{150} = 0.873 \quad (5)$$

b. Design of Inductor:

The inductor is designed based on the following equation.

$$L = \frac{V_s * (V_o - V_s)}{\Delta I_L * f * V_o} \quad (6)$$

Where, ΔI_L is inductor ripple current which is 20% to 40% of the output current.

$$\Delta I_L = (0.2 \text{ to } 0.4) * I_o * \frac{V_o}{V_s} \quad (7)$$

$$\Delta I_L = 0.2 * 1 * \frac{150}{19} = 1.57A$$

Therefore, $L = \frac{19*(150-19)}{1.57*20K*150} = 528\mu F$

c. Design of Capacitor:

The capacitor value can be calculated using equation (8). The duty ratio is taken as 0.9

$$C = \frac{I_o * D}{f * \Delta V_o} \quad (8)$$

$$= \frac{1 * 0.9}{20K * 0.5} = 90\mu F$$

IV. MPPT AND DRIFT ANALYSIS

A DC/DC boost converter is used as an interface between the PV array and the load to provide load impedance matching with the PV source. To track the maximum operating point for certain irradiance and weather conditions, a DC/DC converter with MPPT is inserted between PV module and load. The duty cycle of the switch of DC/DC converter is always adjusted in such a way as to operate the PV panel at its MPP.

While considering the MPPT methods under a given temperature and irradiance, the main objective is to automatically find the current IMPP or voltage VMPP at which a PV array delivers maximum power [17]. Drift problem is due to the lack of knowledge in knowing whether the increase in power (ΔP>0) is due to perturbation or due to increase in insolation [12]. If the insolation is increased, the power also will increase (ΔP>0). If there is a rapid increase in insolation the drift problem will be more. Drift can occur from any of the three steady state points as shown in Fig. 3 (a) and (b) depending on the instant of change in insolation in between the perturbation time interval (Ta). Suppose there is an increase in insolation while operating at point 1 as shown in Fig. 3 (a), the operating point will be then moved to a new point 4 in corresponding insolation curve for the period of the same kTa perturbation interval.

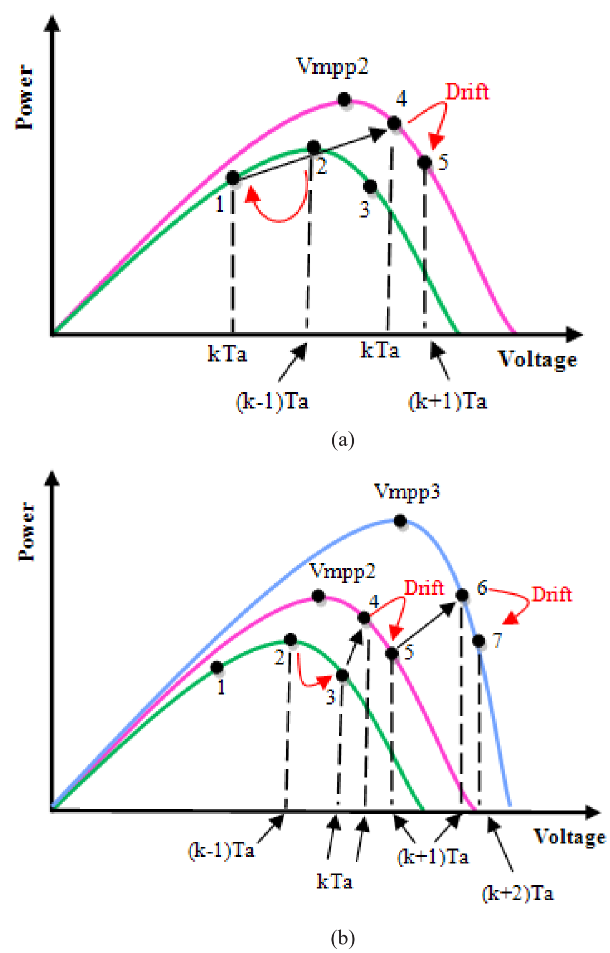


Fig. 3. (a) Drift analysis for one time increase in insolation and (b) rapid increase in insolation.

Now at point 4 as $\Delta P = P_4(kTa) - P_2((k-1)Ta) > 0$ and $\Delta V = V_4(kTa) - V_2((k-1)Ta) > 0$ the algorithm decreases the duty cycle and thereby moving to point 5 away from the MPP in the new curve which is called drift. Likewise for an increase in insolation at point 2 and point 3, the drift problem occurs due to uncertainty of this conventional P&O MPPT technique.

A. Conventional Perturb and observe (P&O) MPPT

The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle [18]. Then the PV voltage and current are measured and the corresponding power is calculated. Considering a small perturbation of voltage (ΔV) or duty cycle (ΔD) of the DC/DC converter in one direction, corresponding power is calculated and compared with the previous value. If change in power, ΔP is positive then the perturbation is in the correct direction; otherwise it should be reversed.

The flowchart shown in Fig. 4 describes the P&O algorithm in detail. The main drawback of P&O algorithm is that it fails to track true power peak in a PV system under partial shading conditions (PSC) and hence settles to local power peak. This results in reduced energy extraction and hence the efficiency of system gets decreased.

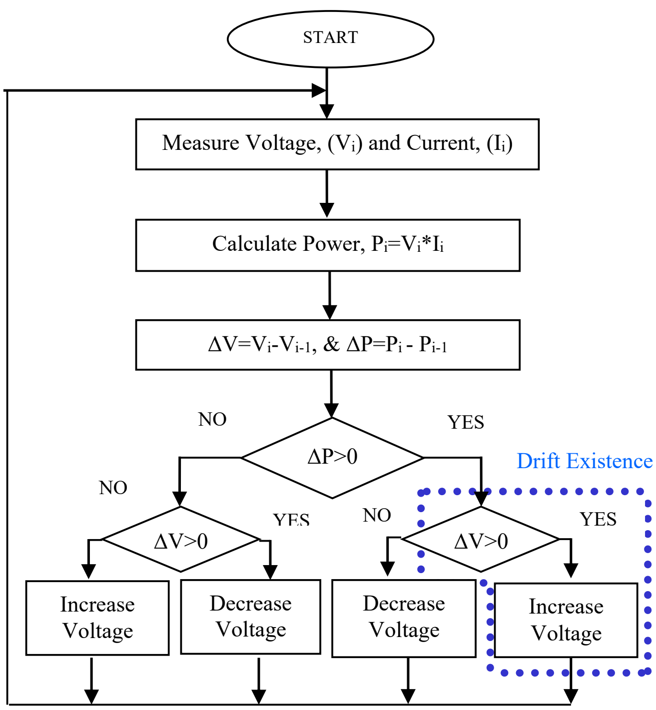


Fig. 4. Flow chart of conventional P&O algorithm.

Another disadvantage of P&O method is its oscillation around MPP. This oscillation can be minimized by reducing the perturbation step size. However, small step size slows down the MPP. To mitigate this problem, a variable step size P&O method can be used, in which step size gets smaller towards MPP.

B. Variable Step size P&O (VSSPO) MPPT

The conventional P&O MPPT method uses fixed step size in order to track the MPP. The VSSPO is a variation of the conventional P&O method. In this algorithm, the step size is automatically tuned to achieve fast and accurate tracking. The dynamic performance is improved by using a large perturbation value, whereas steady state performance can be improved by smaller values [19]. The duty ratio with adaptive step size is given as follows.

$$\Delta D = D(k) - D(k-1) = \pm M * \left|\frac{\Delta P}{\Delta V}\right| \quad (9)$$

Where M is the scaling factor, which is to be tuned at the time of design. For an increase or decrease in insolation, the adaptive technique generates large value of ΔD depending on the value of $\frac{dP}{dV}$. Thus, the effect of drift will be more on VSSPO for an increase in insolation due to the large value of generated ΔD [12]. The VSSPO algorithm with the drift existence loop is shown in Fig. 5.

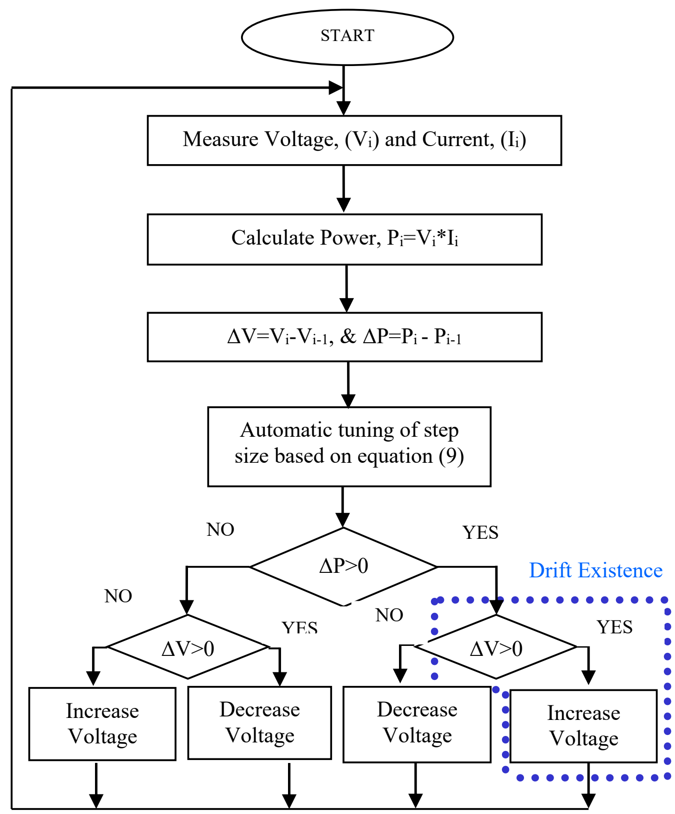


Fig. 5. Flow chart of VSSPO algorithm.

V. Drift Free Analysis

As mentioned before, the conventional P&O has a drift in case of rapid increase in insolation and this is due to lack of knowledge about increase in insolation. This drift can be eliminated by analysing another parameter ΔI (change in current) rather than considering ΔV and ΔP as in conventional P&O. By analysing the PV characteristics, one can see that the increase in power is due to increase in perturbation or due to increase in insolation. The insolation change can be detected by determining ΔI.

From the I-V characteristics shown in Figure 6 one can observe that both ΔV and ΔI will never have the same sign for a single insolation. It is also observed from the same figure both ΔV and ΔI will be positive only for an increase in insolation. Thus it can conclude that, by analyzing ΔI and controlling ΔD the problem of drift can be avoided. A modified drift free P&O algorithm including ΔI is proposed in the next section.

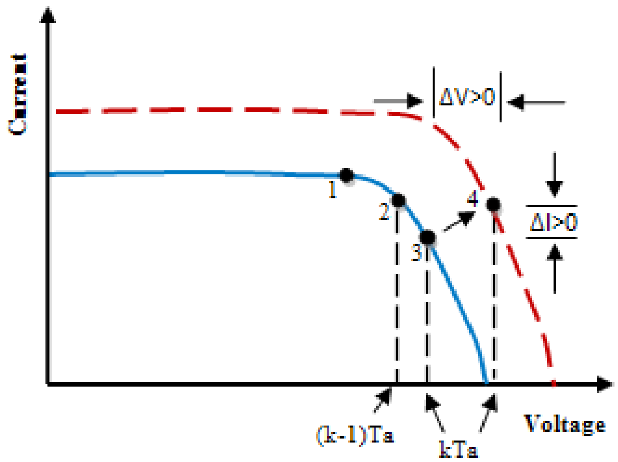


Fig. 6. I-V characteristics for analyzing the change in current with increase in insolation.

A. Drift Free Perturb and observe (DFP&O) MPPT

The basic principle of conventional P&O is controlling duty cycle based on considering ΔV and ΔP. In order to avoid drift free problems during large change in insolation, researchers have already developed some drift free algorithms such as optimized dP-P&O [20] and optimized P&O [3]. According to [20], in order to avoid drift, there is some criteria for setting threshold values. The dP-P&O method uses an additional sampling instant in every iteration, which increases the complexity of the system. The other method optimized P&O uses a higher value of perturbation step size ΔD, for avoiding drift. In such cases drift can be avoided under rapid insolation changes, but the large perturbation step size will result in power loss due to the oscillations around MPP.

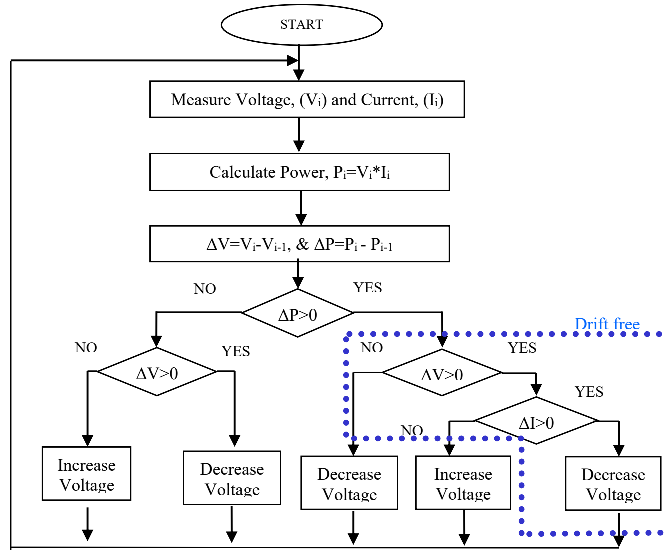
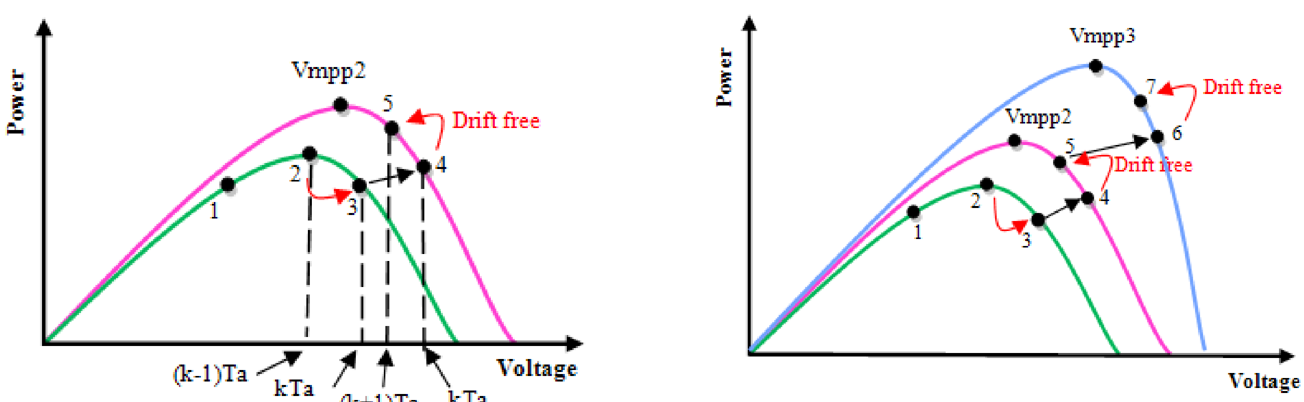


Fig. 8. Flow chart of DFP&O MPPT algorithm.

The remarkable advantage of the proposed DFP&O is, there is no such restraint on ΔD or sampling time as on the above mentioned methods. Here, in DFP&O, one more parameter, ΔI is analyzed in order to avoid the drift problem. Fig. 7(a) and (b) shows the P-V characteristics with drift free P&O MPPT. From these figures it is clear that the drift is avoided as the MPPT understands the change in power is due to increase in insolation and not due to change in perturbation.

When operating at point 3, suppose an increase in insolation occurs and the operating point is shifted to point 4. As the DFP&O understands both ΔV and ΔI are positive, the duty cycle increases and hence voltage decreases. Thus the new operating point is shifted to point 5 as shown in Fig. 7(a). Drift free analysis in case of rapid increase in insolation is shown in Fig. 7(b). The flowchart of DFP&O MPPT is shown in Fig. 8. The drift avoidance loop can be seen in flowchart separately.



(a) (b)

Fig. 7. Drift free analysis with DFP&O MPPT. (a) One time increase in insolation and (b) rapid increase in insolation.

B. Drift Free Variable Step Size P&O (DFVSSPO) MPPT

In addition to the automatic tuning of step size, the DFVSSPO MPPT uses drift analysis along with VSSPO. As mentioned before, the effect of drift will be more on VSSPO for an increase in insolation due to the large value of generated ΔD. This drift problem can be eliminated with the help of DFVSSPO MPPT. The Fig. 9 depicts the flowchart of DFVSSPO algorithm.

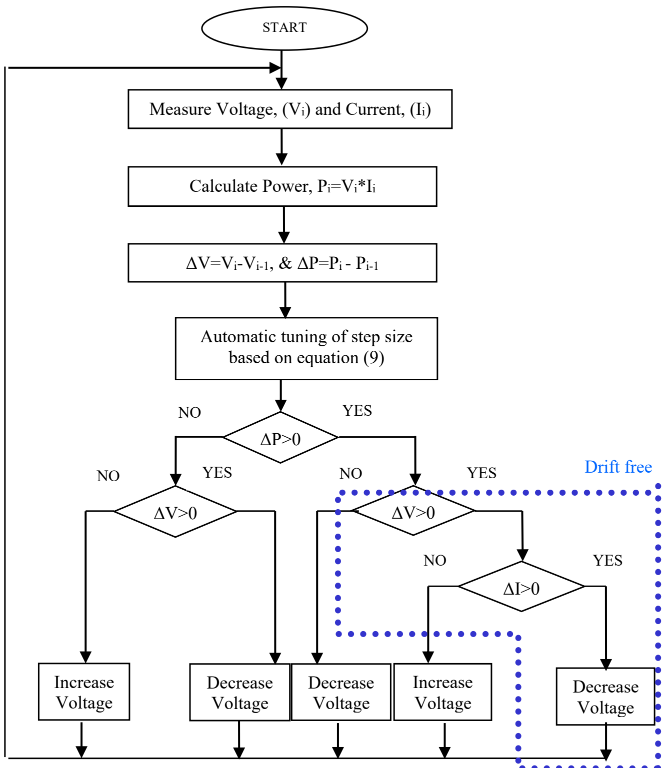


Fig. 9. Flow chart of DFVSSPO MPPT algorithm.

VI. Simulation And Results

This section describes about the simulation of PV module integrated with boost converter along with MPPT algorithms in MATLAB/SIMULINK environment. The MAS-SPV-P-100W PV panel is used for reference.

Fig. 10 represents the MATLAB/ SIMULINK model of the proposed system. Fig. 11 (a) and (b) depicts the P-V (power-voltage) and I-V (current-voltage) characteristics of MAS-SPV-P100 solar panel for varying irradiation and constant temperature of 25^{0}C respectively. As it is a 100W PV panel, at STC, the maximum available power is 100W as shown in Fig. 11 (a). Also it is clear that the output power gets reduced as the irradiance decreases. The output power is reduced to 800W and then to 500W for an irradiation decrease of 800W/m^2 and 500W/m^2 respectively.

Similarly from Fig. 11(b) it is clear that as the irradiation decreases the short circuit current also decreased. From both P-V and I-V characteristics it is seen that there is a slight decrease in open circuit voltage of PV panel as the irradiation gets reduced.

A. Drift analysis with conventional P&O and DFP&O MPPT

The proposed MPPT algorithm has been tested for a step change in insolation level from 500W/m^2 to 800W/m^2 at 1.5s and from 800W/m^2 to 1000W/m^2 at 3s. The perturbation step size is chosen as 0.002. The duty cycle, voltage, and power waveforms with the help of P&O and DFP&O are shown in Fig. 12. Both the MPPT methods are tracking the equivalent MPP efficiently, but the drift in P&O is eliminated in DFP&O method. From Fig. 12 (d) it is clear that the conventional P&O method has a power loss of around 1W when compared to that of a DFP&O.

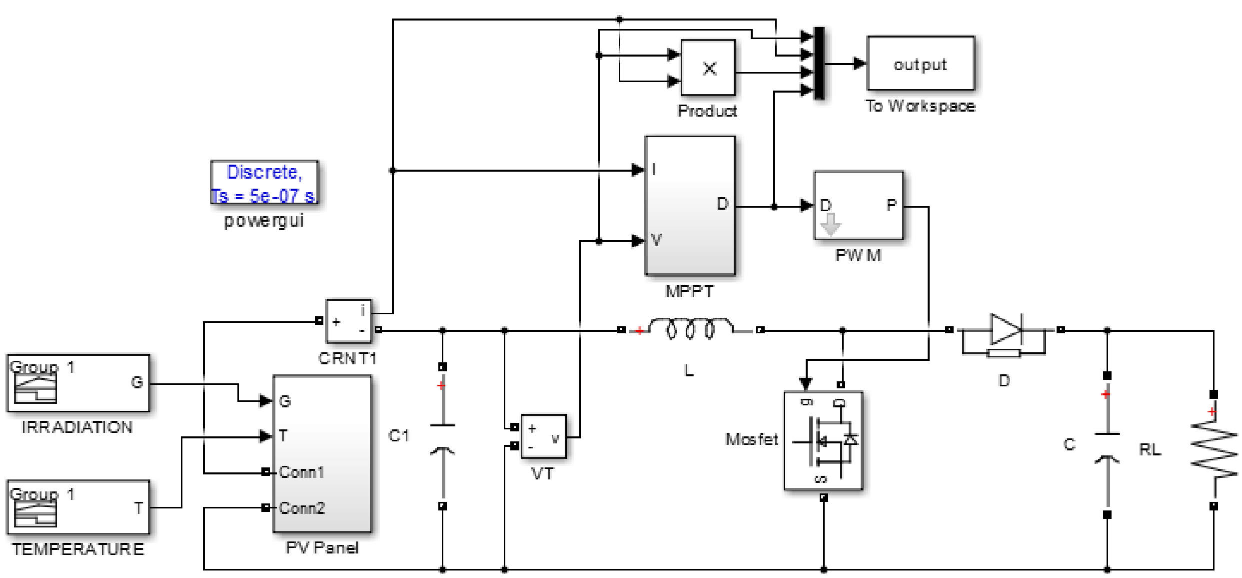


Fig. 10. MATLAB/SIMULINK model of the PV system.

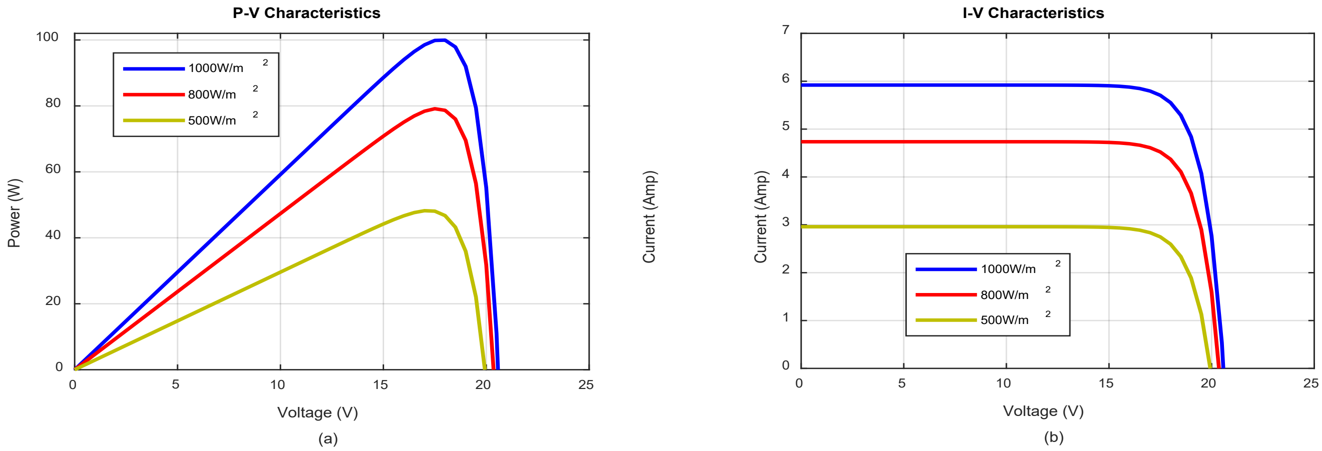


Fig. 11. (a) P-V characteristics and (b) I-V characteristics of MAS-SPV-P100 solar panel for varying irradiation and constant temperature of 25^0C.

B. Drift analysis with VSSPO and DFVSSPO MPPT

Fig. 13 shows the duty cycle, voltage and power output of PV panel using VSSPO and DFVSSPO. When the insolataion changed from 500W/m^2 to 800W/m^2 at 1.5s, the VSSPO method tracks the output power of 78W at 1.67s. At the same time DFVSSPO was able to track 78.5W within 1.52s. From Fig. 13(d) it is clear that the VSSPO method suffers a lot from drift problem, whereas the DFVSSPO is free from drift. Almost 13W power loss is obtained in VSSPO at the time of insolation increase at 1.5s as shown in Fig. 13(d). This power loss will result in reduction in efficiency. With the help of DFVSSPO this drift is eliminated.

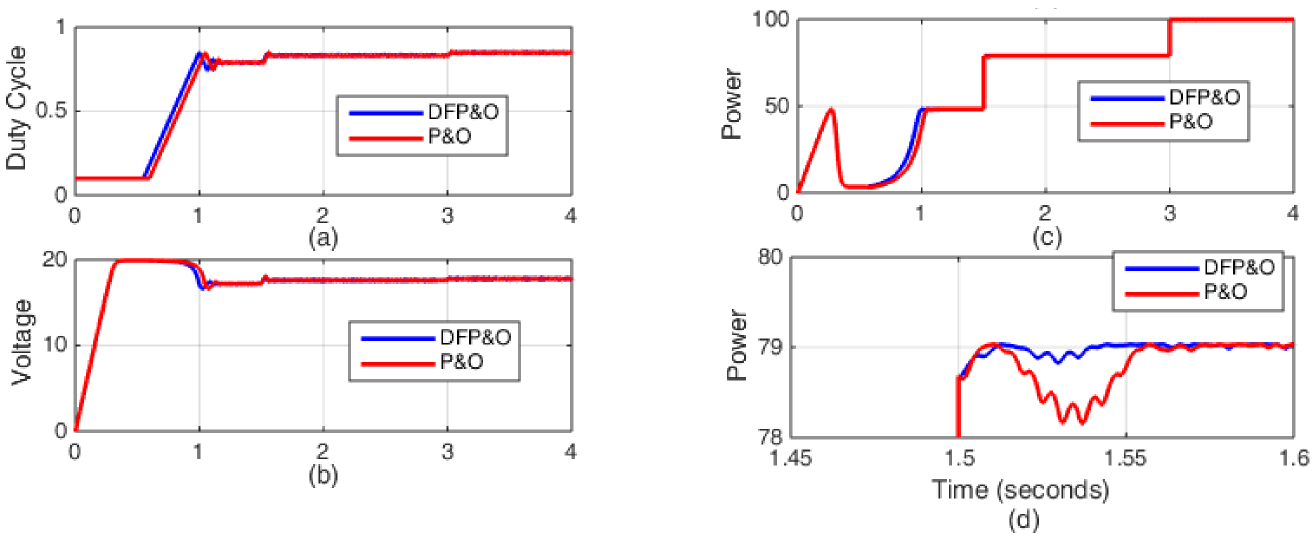


Fig. 12. With conventional P&O and proposed DFP&O for rapid increase in insolation (a) duty cycle, (b) voltage, (c) power and (d) zoomed portion of power at 1.5s.

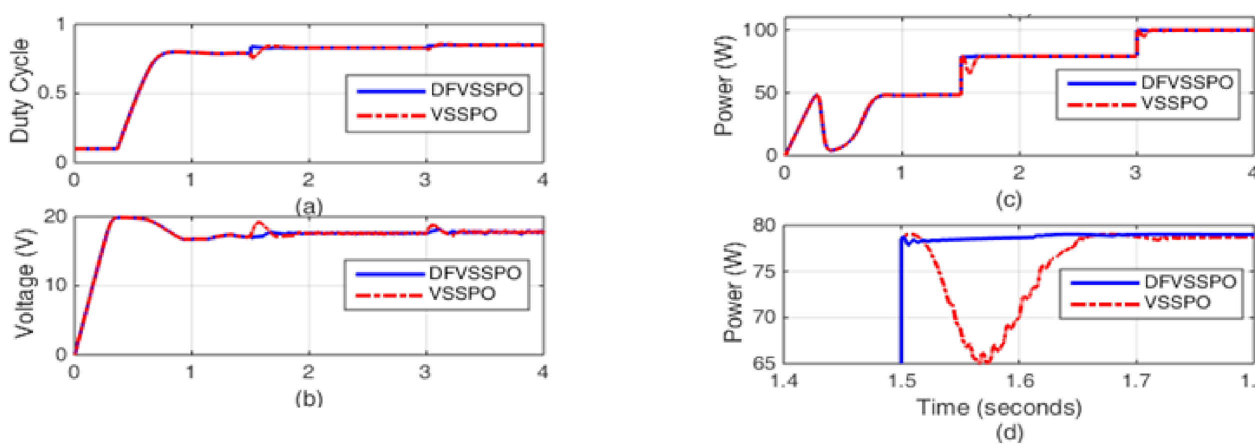


Fig. 13. With VSSPO and proposed DFVSSPO for rapid increase in insolation (a) Duty cycle, (b) Voltage and (c) Power (d) zoomed portion of power at 1.5s.

VII. Conclusion

This paper initially explains the modeling and simulation of a PV panel along with the design of a DC-DC boost converter. The reason for drift phenomena and modifications to avoid drift problem is also explained with the help of conventional P&O and variable step size P&O algorithms. The comparison of conventional P&O with drift free P&O has done and corresponding waveforms are obtained. Similarly, variable step size P&O and modification to VSSPO in order to avoid drift is also proposed and simulated. The basic idea of avoiding drift problem is to include an additional loop and analyze change in current in the conventional P&O algorithm.

The simulation has been done by incorporating a DC/DC boost converter with MPPT control. The simulated results show that the drift free MPPT algorithm reduces the power loss as well as the tracking time when compared to the conventional P&O and VSSPO. This improves the efficiency of the system by gaining a significant amount of power over the complete life cycle of the PV panel. When considering the overall life span of a PV system, drift free operation has an important role in reducing power loss.

The future enhancement of this project can be incorporated along with the merging of IoT (Internet of Things) with the solar system. The voltage and current ratings of the solar plant can be accessed by the owner across the globe.

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