Different Maximum Power Point Tracking Methods and their study for different ambient conditions

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***Abstract*—This article brings together a study of important maximum peak power tracking (MPPT) practices used for photovoltaic systems. Different techniques were taken from various articles on MPPT and are contemplated and compared. This paper offers the Simulink PV system model using P&O (Perturb and Observe) method of MPPT and its characteristics for different varying ambient conditions.**

Keyword- MPPT, PV, P&O, PV array

I. INTRODUCTION

Chasing the maximum power point (MPP) on the P-V curve of a photovoltaic (PV) array is typically an indispensable part of a PV system. The two main problems with PV source is its meager efficiency (almost less than 19%) and its output power variation due to change in atmospheric conditions like insolation and temperature. Apart from this, its nonlinear I-V characteristic compels the user to use something to chase the MPP. MPP is an exceptional point on the P-V curve with the associated power (at a particular temperature and insolation) having maximum value. This MPP also varies with the atmospheric condition. To elicit maximum power, MPPT is done so as to track the MPP. Until now different MPPT schemes have been used but most of them are derived from P&O method [1,3,5,6].

II. MAXIMUM POWER POINT (MPP)

A PV array or generator will have one point on its current/voltage characteristic that corresponds to maximum power output. This is referred to as the maximum power point or maximum power tip or MPP. Figure 1.1 shows a maximum power tip for certain values of temperature and irradiation. It can be observed from the figure that the maximum power tip lies near the knee-point of the I-V curve.

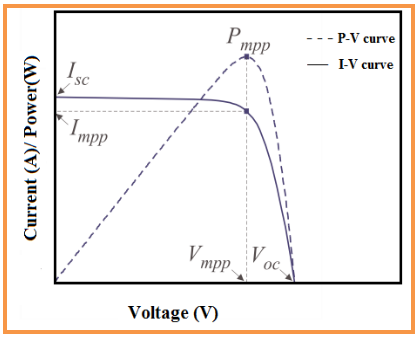


Figure 1.1 Identification of Isc, Voc, Impp, Vmpp and Pmpp on the I-V and P-V curve.

III. DIRECT COUPLING

When a PV unit is coupled to a load directly, the PV module's operating point will be at the intersection of its *I–V* curve and load line, which is the *I-V* relationship of load. For example, a resistive load gives a straight line slope of *1/R* as presented in Figure 1.3.

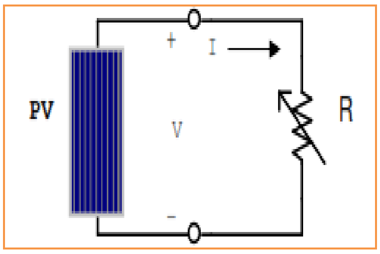


Figure 1. 2 PV module directly with resistive load.

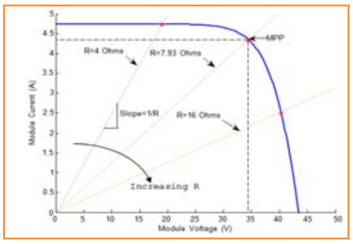


Figure 1. 3-I-V of PV module Curve With various resistive loads.

In other hand, the load impedance orders the operation state of PV unit. In common, this operating state lies rarely at the MPP, consequently not producing the maximum power. A review demonstrates that majority of direct-coupled framework uses a mere31% of the peak PV capability [2,4,7,16]. A PV set is commonly oversized to pay off for low power delivered during winter season. This incongruousness of PV set and load necessitates added over-sizing of the PV set and accordingly upsurges the whole arrangement cost.

For exploiting the PV set, the incoming sun's energy must be converted to electricity with the highest efficiency, done when the photovoltaic module operates on the maximum power point. Nevertheless, since this working point is sturdily affected due to solar fallout and temperature intensities, it may arbitrarily fluctuate on the I-V curl (illustrated Figure 1.4).

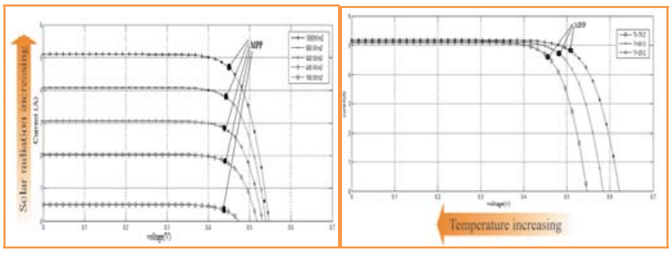


Figure 1.4 MPP across the I-V plan in view of solar fallout and temperature deviations.

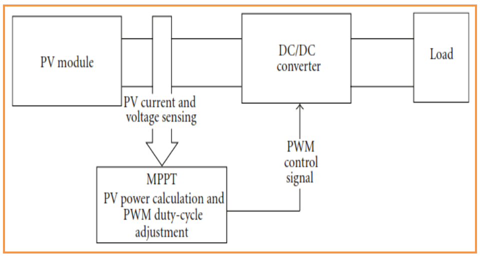


Figure 1.5 block diagram for DC-DC convertor for operation of MPPT.

Thus, to dynamically set the MPP as an action point for a extensive range of solar radiation and temperature, specific circuits, known in the literature by Maximum Power Point Trackers (MPPT),are employed. If properly adapted, MPPT can quote exceeding 90% of PV power [17,18,19,20].

IV. Maximum Power Point Tracking

The efficiency of a solar cell is very low. To upsurge the efficiency, approaches are embarked on to pair the source curve and load curve appropriately. This practice is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum potential power from a varying source. In photo voltaic sets the I-V curve is non-linear, thus is problematic to power a certain load. This is done by way of deploying a DC-to-DC converter whose duty is controlled via MPPT procedure. A DC-to-DC converter is deployed before the allied load and a solar panel is used to power this converter. In fact DC-to-DC converter is the heart of MPPT. Figure 5 shows a simple block figure of usage of MPPT algorithm and DC-DC convertor.

V. MPPT Methods

There are sundry methods used for maximum power point tracking, few are enumerated below:

- Constant Voltage method
- Constant Current method
- Perturb and Observe method
- Incremental Conductance method

A. Constant Voltage

"A percentage of PV panel's voltage at open circuit gives the voltage corresponding to MPP" this fact governs this MPPT scheme. The PV plate is usually disconnected from the load after regular intervals, to record open circuit voltage. Constant voltage mechanism can be effortlessly instigated through analog hardware. Nonetheless, its MPPT chasing efficiency is poor relative to new procedures [20, 36].

B. Constant current

It is likewise probable to employ a fixed current centered MPPT process that estimates MPP current equal to a fixed fraction of short-circuit current [21,22,24]. This is implemented via a switch employed to short the input side of converter transitorily. The current at short-circuit is noted and the current for MPP is mathematically obtained, thereby altering the PV set output current till the obtained MPP current is touched.

C. Perturb and Observe Method

As is clear from the name that a disturbance (i.e a perturb) is given and the result is then analyzed (i.e observed). Here (in P&O or Hill climbing MPPT) duty or voltage or current is disturbed (perturbed) and the resultant change in power is w.r.t the disturbance given is analyzed (observed).

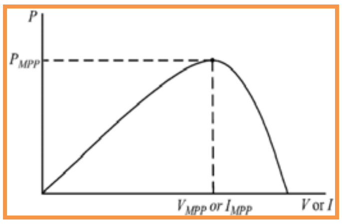


Figure 1.6 Characteristic power curve of PV array

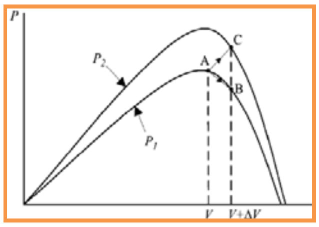


Figure1.7 Divergence of hill climbing/P&O from MPP

It is vibrant from the P-V curve of Fig. 1.6 that any disturbance in the voltage results in some disturbance in power which when observed can help in tracking the peak power. This perturbation is done in a unique manner and is repeated in a passion to reach at MPP. After approaching MPP, the power point oscillated near this point. The size of oscillation is large for big disturbance steps and small for small paces in disturbance. Big steps results in fast chasing while small step results in slow tracking. A smart way is to have mutable step size i.e. large steps for far away points from MPP and small steps for points near MPP.

A two-phase procedure is projected that gives faster chasing in first phase. Hill climbing and P&O methods may be unsuccessful in swiftly altering atmospheric environments (as exemplified in Fig. 1.7, beginning from a working location A, i.e. P1 curvature is exploited, if atmospheric environments remains nearly persistent, a change of ΔV will transport the working location to B and consequently disturbance will be retreated due to a reduction in power. Perturb and Observe (P&O) is one of the most diffused MPPT algorithms, whose tracking response is independent on the environmental conditions, however, its implementation requires a voltage and a current sensor, increasing the cost and complexity [6-10].

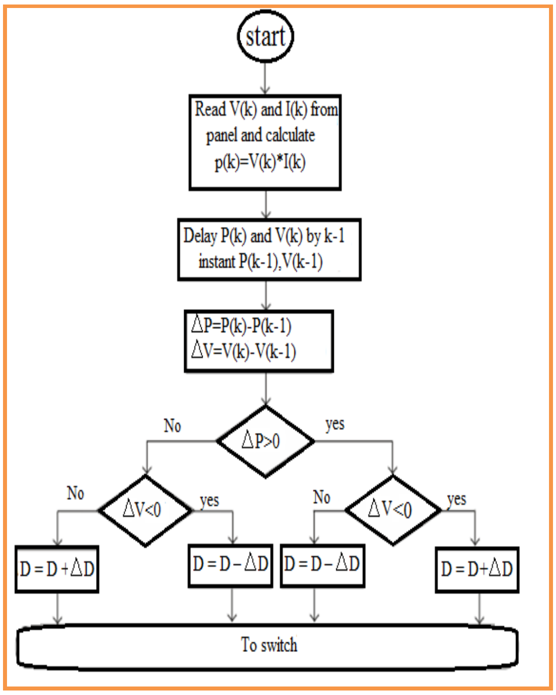
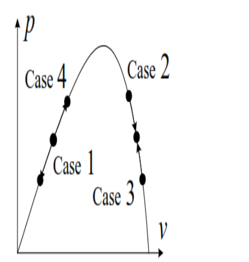


Figure 1.8 Flow Chart of Perturb & Observe.



Case	dP	dV	Action
1	<0	<0	+
2	<0	>0	-
3	>0	<0	-
4	>0	>0	+

Figure1.9 Perturb & Observe (P&O) control action

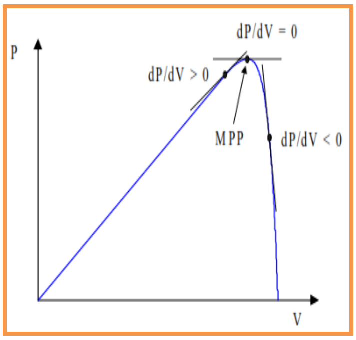


Figure 1.10 Summarization of Perturb & Observe Method

When in operation, the P&O algorithm estimates the PV output power and perturbs the converter duty cycle (increasing or decreasing it). After perturbation, the PV production power is recalculated and, if it was increased, the perturbation is repeated on the same direction, otherwise, it is inverted. However, if the antitrust increases the power curve from P1 to P2 within a sample period and changes, then the functional point will exit from the point A to C. This new curve represents the increase in power due to P2, while the problem is kept the same. Subsequently, the functioning point is separated from the MPP and if the deviation increases rapidly, many research is carried out in the literature, not only cover two methods recently, but also outlines other MPPT techniques.Fig. 1.8 shows the block diagram of the PV system using the hill climbing and P&O methods, while Fig. 4b shows the algorithm flowchart of the technique [12-15].

Summarized the control action of the P&O method

The value of the reference voltage, Vref, will be changed according to the current operating point. When the controller senses that the power from solar set upsurges (dP> 0) and the voltage decreases (dV< 0), it will decrease (-) Vref by a step size C1, so Vref is closer to the MPP. The swaying about a maximum power point roots a power loss that is governed by the step girth of a particular perturbation. The ideal step girth is system reliant and needs to be obtained experimentally to follow the trade-off of increased losses under stable or slowly changing conditions. In fact, as the AC constituent in output power signal is far lesser than the DC constituent and comprises a great noise caused by the switching DC-DC converter, an increase in the amplitude of modulating signal had to be implemented to mend the signal to noise ratio (SNR)[7,11]. Yet, this will give higher swinging at the MPP and consequently upsurges the power losses even in unchanging environmental circumstances.

D. Incremental Conductance

The Incremental Conductance (IncCond) method is featured for combining both, tracking speed and accuracy. From the voltage V_{PV} and current I_{PV} measurements, the algorithm computes the photovoltaic yield power P_{PV} and its derivative in function of the voltage dP_{PV}/dV_{PV}, using both results to define if the duty must be decreased or increased, in command to execute the system operating point on the MPP. Generally the Inc-Cond method is applied digitally, and the derivative is calculated by the micro controller according to (a).

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} = 0 \qquad \text{(a)}$$

$dP_{PV}/dV_{PV}>0$ (left of MPP), the duty is changed for increasing the output voltage; $dP_{PV}/dV_{PV}<0$ (right of MPP), the duty is alternated for decreasing the output voltage; $dP_{PV}/dV_{PV}=0$ (at MPP), the duty is remained unchangeable. Thus MPP can be compared with the instant conduction period (I / V) and with the incremental conduction period (ΔI / ΔV) as revealed in the flow alignment of fig.5. The Vref is the reference voltage on which the PV array is required to operate. In MPP, Vref is equivalent to voltage value on MPP, Vmpp, once reaching the MPP, the operation of PV array is upheld at this point, unless there is no modification in ΔI or modification in atmospheric situations, this MPPT technique is also commonly used and many researches explain it deeply in the details [25-28].

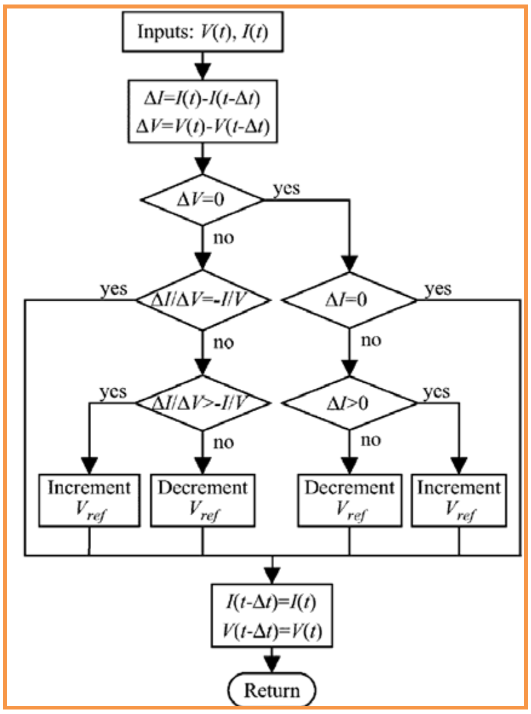


Figure 1.11 The Inc-Cond flowchart

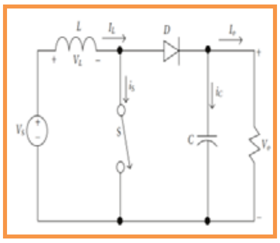


Figure 1.12 Configuration of DC to DC boost converter.

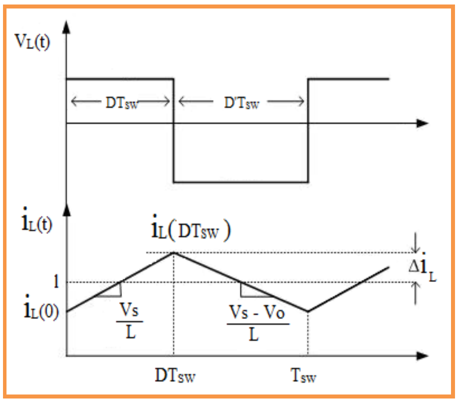


Figure1.13 Steady-state inductor voltage and current waveform, boost converter.

E. Fractional Open-Circuit Voltage

Near linear relationships flanked by VMPP and open circuit voltage of PV array, in different insolation and temperature intensities, gave birth to partial Voc method; The relationship between Vmpp and Voc is almost linear thus equation (b) is obtained.

$$V_{mpp} = k_1 \times V_{oc} \tag{b}$$

Where k_1 is proportionality constant, since k_1 is reliant on the features of the PV array being used, it regularly has to be worked out in advance by determining V_{mpp} and V_{oc} for the specific PV array at different irradiance and temperature levels. The factor k_1 has been stated to be in between 0.71 and 0.78 [3]. Once k_1 is recognized, V_{mpp} can be figured with V_{oc} obtained at times by transitorily shutting down the power converter. Nevertheless, this sustains some weaknesses, including transitory loss of power. To obviate this, it can use pilot cells from which V_{oc} can be attained. These pilot cells must be sensibly picked to closely represent the features of the PV set [3]. Once *Vmpp* is guessed, a closed-loop mechanism on the converter is used to touch this preferred voltage. Since the relationship is only an approximation, the PV arrays have not technically operated on the MPP [21-23].

F. Fractional short-Circuit Current

Fractional short circuit current consequences from the information that, in changing atmospheric conditions,Impp and Isc is almost linearly linked (equation (c)).

$$I_{mpp} = K_2 \times I_{sc} \tag{c}$$

Where K2 is proportional stability, like partial V_{oc} technic, K_2 should be determined according to PV array in use. The stable K2 is usually found between 0.78 and 0.92. To measure. An supplementary switch customarily has to be added to the converter to at times short the PV array so that *Isc* can be measured using a current sensor. This increases the number of components and costs, it is vibrant that this method and the previous major drawbacks are; Power generation is not merely low in search of the Isc, but also because MPP does not counterparts perfectly [18-20, 29-31].

DESIGN OF DC-DC BOOST CONVERTER

The boost converter configuration, as accessible in Figure 1.12, entails of a DC input voltage source V_S, boost inductor L, controlled switch S, diode D, filter capacitor C, and load resistance R.

When the transistor S is ON, the current in inductor L, augments linearly and the capacitor C, deliveries the load current, and it is somewhat discharged. In the second interval when transistor S is OFF, the diode D, is ON and the inductor L, supplies the load and, additionally, recharges the capacitor C. Steady state inductor current and voltage waveform is presented in Figure 1.13.

Using inductor volt stability rue (the steady state output equation are attained (d) and (e)):

$$V_S.T_{on} + (V_S - V_O).T_{off} = 0 \tag{d}$$

$$\frac{V_o}{V_s} = \frac{T_{SW}}{Toff} = \frac{1}{1 - D}(e) \tag{e}$$

If the switch operates with a duty ratio D, the DC voltage gain of the boost converter is given by (f).

$$M_v = \frac{V_o}{V_s} = \frac{1}{1 - D} \tag{f}$$

Where V_S is the input voltage, V_O is the output voltage, and D is the duty cycle of the pulse width modulation (PWM) signal used to control the MOSFET ON-OFF states.

The boost converter runs in the continuous conduction mode for the value of inductance $L > L_m$ where:

$$L_m = \frac{(1 - D^2)DR}{2f} \tag{g}$$

Where Lm is the least value of inductance for continuous conduction (g).

The current to output RC circuit is discontinuous. Thus, filter of lager capacitor is required to limit the output ripple. Cmin the least value of the filter capacitance, that provides the output DC current to the load when the diode D is OFF, that results in ripple voltage V_r, is given by (h).

$$C\min = \frac{DV_O}{V_r RF} \qquad \text{(h)}$$

VI. SIMULINK MODEL FOR P&O MPPT ALGORITHM

The Simulink prototype for P & O MPPT algorithm is shown in Figure 6.8. V_{in} and I_{in} are taken as input for the P&O block and duty cycle is obtained as the output. The P&O block has been taken V and I as an input then send it to sample and hold block, which is used as a delay block because in actual measurement, the system has a measurement delay, therefore, it will be used for mentioning this delay. Moreover, at the output of the sample and hold circuit, the present state voltage signal is V (n). After this step, signal goes to memory block, where the memory block holds and delays its input by one integration time step, this block accepts and outputs continuous signals. Likewise, the product of V_{in} and I_{in} will be processed to provide p where P_n and P_{n-1} represent power at the current cycle time and pervious cycle time of MPPT, respectively. By subtracting P_n and P_{n-1}, is created ΔP and subtracting V_n and V_{n-1}, is created ΔV. In the next step, by using product block and multiplying ΔV and ΔP, if both have, a same sign the output will be positive and if the sign of one of these two signals were, a negative the output will be negative. Afterwards by the usage of switch block, which the Switch blocks, passes through the first input or the third input based on the value of the second input. The 1st and 3rd inputs are the data inputs. Second input is called the control input. In the subsequent step if Δ P* ΔV <0 output of the switch will be negative and ΔD will be negative by multiplying the output of switch by a constant value of perturb step and in the next step value of D get added to previous value, which is stored in memory block and will be decreased and vice versa. This new value of D will be directed to the next block for creating PWM signal [2, 32-35].

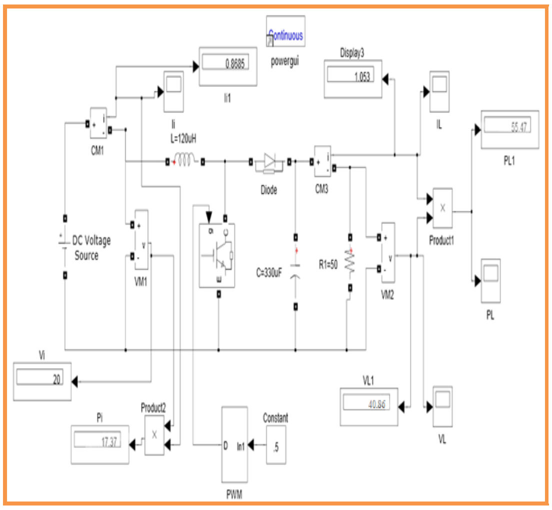


Figure 1.14 Boost converter circuit with DC supply.

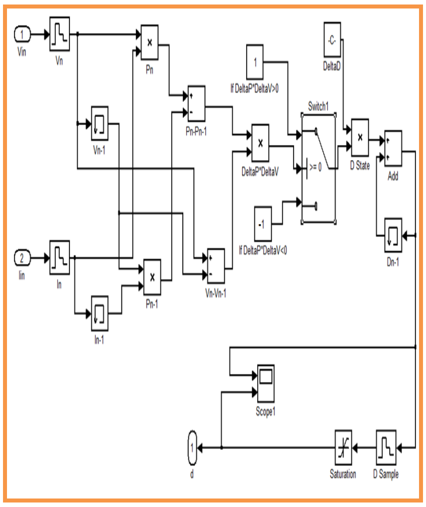


Figure 1.15 Simulink Model for P & O MPPT Algorithm.

VII. SIMULATION RESULT

Figures 1.16 to 1.24 shows different simulation results.Figure 1.16 shows the PV panel voltage when insulation is 200W/m^2 and load value is 200Ω and T=25ºc. Initially the input capacitor virtually short-circuits the PV source. When the capacitor is charged, the PV panel voltage reaches close to its open-circuit voltage (69.16 V) at t = 0.85 sec, PV panel open circuit voltage at G=200 $W/m^2$is 71.21V.

At t = 1 sec, operations of the MOSFET begins and the PV panel voltage start to oscillate finally settles to the MPP voltage, which is 56.98 V at t=3sec.

By zooming in on the curve around t=3sec (steady-state), it shows an oscillation around final value. Figure 1.17 shows the PV panel current for P&O algorithm under low irradiation condition where insolation is 200 $W/m^2$and load resistor is 200Ω, T=25ºc. This figure shows that pv panel output which initially will reach to short-circuit value of current because the capacitor virtually short-circuit pv panel output.

At t=0.7sec output current is 0.342A, which is very close to open-circuit value.

At t=1.29sec the operation of MPPT will start and send duty cycle to MOSFET switch thenthe output will start to increase and oscillating, finally at t=3 sec maximum value of current will reach to 0.955A that is $I_{MPP.}$

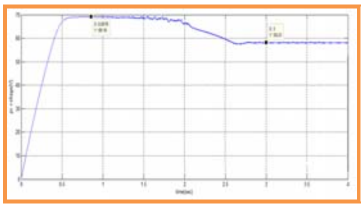


Figure 1.16 V_{pv}–t at G=200W/m^2 and R=200 Ω T=25ºc.

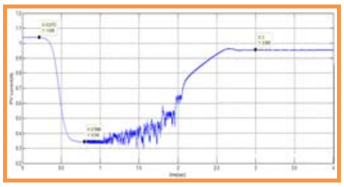


Figure 1.17 PV Current under Condition of G=200W/m^2 and R=200Ω and T=25ºc.

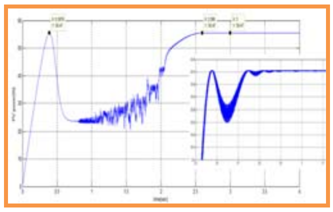


Figure 1.18 PV Power under Condition of G=200W/m^2 and R=200Ω and T=25ºc.

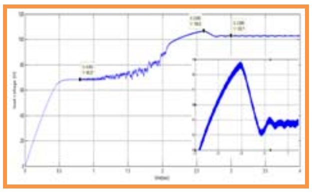


Figure 1.19 Load Voltage G=200W/m^2 and R=200Ω and T=25ºc.

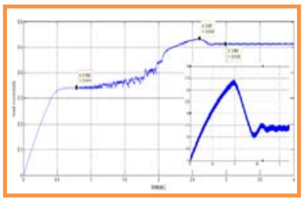


Figure 1.20 Load Current G=200W/m^2 and R=200Ω and T=25ºc.

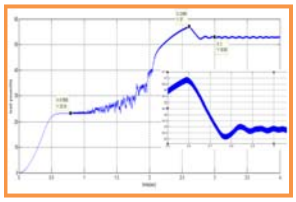


Figure 1.21 Load Power G=200W/m^2 and R=200Ω and T=25ºc

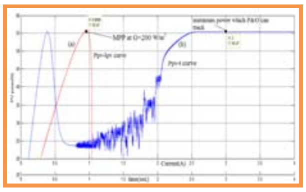


Figure 6.12 G=200W/m^2 and R=200Ω and T=25ºc.

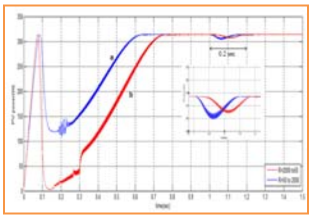


Figure 1.23 Change in Output Power of PV at t=1sec at T=25ºc and G=1000W/m^2 .

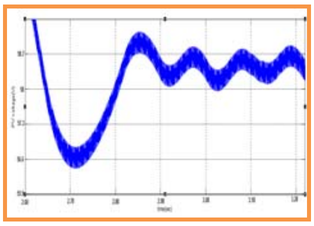


Figure 1.24 PV Voltage for P&O Technique G=200W/m^2 .

VIII. CONCLUSION

This paper has analyzed the expansion of a method for the mathematical modeling of P&O MPPT procedure and explanation of other methods of MPPT. Currently, the commonly employed PV tracking procedure is Perturb and Observe. Perturb and Observe is simple compared to IC method. However, it may have failures to chase the MPP under swift vagaries in solar radiation and present oscillations nearby the MPP at steady-state. In this algorithm, it is obligatory to measure the PV produced voltage and current. P&O method has more precise control, but it doesn't have faster response, but has correspondingly higher hardware requirement which decreases speed and makes it complex to implement. Results show that tracking time in P&O method depends on irradiation. Tracking time will decrease by increasing on insolation. Oscillation nearby the MPP on steady-state will increase, by decrease in radiation, Therefore power losses will occur. P&O has a number of problems, including: (1) PV system cannot always operate on the maximum power point owed to the slow trial and error process, and hence the PV yield is not totally utilized;(2) PV set may continuously run in an vacillating mode even under steady-state sunshine condition, leading to fluctuating inverter output; and (3) the working of the PV set may perhaps flop to chase the maximum power point owing to the abrupt variations in the sunshine. As revealed, the usage of P&O technique is not reasonable because its low speed for chasing maximum power point, which is 0.3sec after changing on irradiation and 0.3sec after changing on load, and also it has a fluctuation around maximum power point.

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