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Global Maximum Power Point Tracking Algorithm for Photovoltaic Systems under partial Shading Conditions

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***Abstract*—This paper presents a novel algorithm for tracking the true maximum power point for a photovoltaic (PV) system under partial shading conditions using variable step size. At uniform irradiance, due to nonlinear VI characteristics of PV array, there exists a unique maximum power point (MPP) at which the solar array produces the maximum output power. However, under partial shading conditions, there exist multiple peaks on VI and PV characteristics that give rise to local and global MPP's. In order to obtain the optimum output, global MPP must be tracked via an intelligent algorithm capable of distinction between local and global maximum power points. Further, the proposed algorithm must be robust and exhibiting fast response to ambient conditions. In this paper, a Photovoltaic system is explicitly modeled and by modifying the existing Perturbation and Observation (P&O) algorithm, a robust, optimized and efficient algorithm for the global maximum power point tracking (GMPPT) is formulated. Conventional Perturbation and Observation (P&O) method carries the advantages of simplified implementation, less computational complexity and reduced computational cost. However, P&O method is not robust and vulnerable to errors at varying weather conditions and changing irradiance levels. Further, the convergence time to MPP is high which leads to slow MPPT. The proposed algorithm is an extension of commonly used P&O method in which variable step size ensure fast convergence to GMPPT and power measurement of the PV array avoids false readings. Simulation results show that the newly formed algorithm has a greater degree of accuracy at constant and varying changing irradiance level under partial shading. The proposed scheme ensures the highly optimized operation of PV systems and efficient extraction of available solar energy.**

Keywords*—*Maximum Power Point Tracking (MPPT); Partial Shading; Perturbation and Observation (P&O); Rapidly Changing Irradiance

I. INTRODUCTION

With the rapid increase in the demand of energy, fossil fuel utilization is at peak and their depletion is inevitable. Alternate and renewable energy resources are playing an important part in order to reduce the gap between supply and demand of energy. Being environment friendly and abundant in nature, solar energy is considered as the most promising technology for the future energy demands. However the output power of a PV array is a nonlinear and depends upon the incident solar irradiation, temperature and the load profile [1]. The efficient extraction of solar energy from existing and developing photovoltaic arrays is the challenge of the hour. MPPT techniques ensure the active and effective operation of PV systems with maximum possible harvesting of incident solar energy. In a direct load and battery connected PV system, load impedance, battery voltage and current levels force the array to operate below the maximum power point. A DC-DC converter along with an intelligent controller fed with the proposed algorithm is used to ensure the maximum power point operation as shown in figure 1. PV arrays are commonly designed to operate at maximum power at any given temperature and irradiance. DC-DC converter is used to separate the PV array operating voltage and load/ battery voltage while controller fed with the seeking algorithm ensures that PV array is always operating on or near the MPP [2, 3, 4].

Various algorithms are used for MPPT and their classification is presented in [5-7]. An improved P&O algorithm with variable step size to achieve fast tracking response is discussed in [8]. [9] Presents the modified P&O algorithm for robust tracking under rapidly varying ambient conditions. In [10], the effect of physical properties of PV array on the generation of multiple MPP is explained. Partial shading results in the production of multiple peaks on VI and PV characteristics. Multiple peaks result in local Maximum Power Points (LMPP) and global maximum power points (GMPP). In order to get the optimized performance, PV array must be operated at GMPP rather than LMPP, and therefore, proposed P&O methods for tracking the global peak for photovoltaic systems under partial shading conditions are drafted in [11, 12].

In this research paper the modifications in [8, 9 and 11] are combined to formulate the robust algorithm which shows improved dynamic response under varying ambient conditions and tracks the GMPP under partial shading conditions. PV array model is developed using diode model and the effect of varying isolation and temperature on the output VI characteristics is illustrated. The effect of partial shading and resulting number of MPPs generated are detailed. Variable step size modification and Power measurement modifications are made in the P & O method. Then the improved P&O is utilized to track the global maximum power point of VI characteristics.

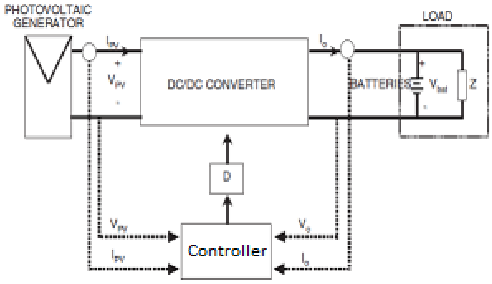

Figure 1: Generalized Scheme of MPPT for PV Systems

II. Diode Model of PV Array

The output VI and PV characteristics of a single PV cell are given by the electric equivalent circuit shown in figure 2 and are governed by the following equations [1].

$$I_{PV} = I_{\lambda} - I_d - I_p \quad (1)$$

$$I_{PV} = I_{\lambda} - I_s\left[\exp\left(\frac{q(V_{PV} + I_{PV}R_s)}{\eta KT}\right) - 1\right] - \frac{(V_{PV} + I_{PV}R_s)}{R_p} \quad (2)$$

Where,

I_{PV} = Output current of PV cell
V_{PV} = Output voltage of PV cell
I_{λ} = Light current
I_d = Diode current
I_p = Current in parallel path
I_s = Reverse saturation current
q = Charge on a single electron
R_s = Series resistance
R_p = Parallel resistance
η = Ideality Factor
K= Boltzman constatnt

The output characteristics of PV cell and corresponding PV modules and arrays are nonlinear in nature. It depends upon the incident light intensity and the ambient temperature. Output characteristics as a function of irradiance and temperature are shown in figure 3-a, 3-b and figure 4-a, 4-b. There exists a MPP against each incident irradiance and ambient temperature and are marked as MPP in the figures.

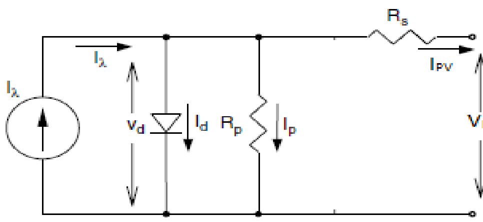

Figure 2: Single Diode Model of a PV Cell

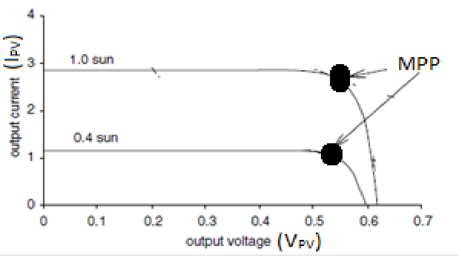

Figure 3-a: V-I characteristics as a function of Irradiance

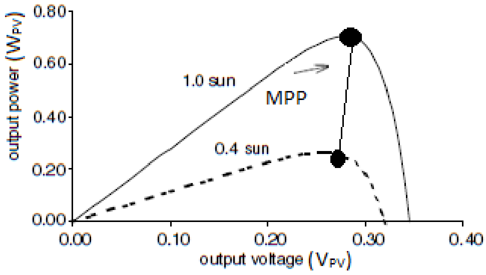

Figure 3-b: P-V characteristics as a function of Irradiance

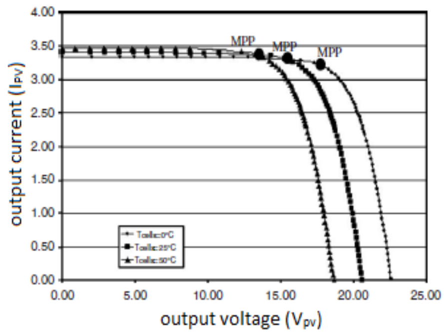

Figure 4a : V-I characteristics as a function of temperature

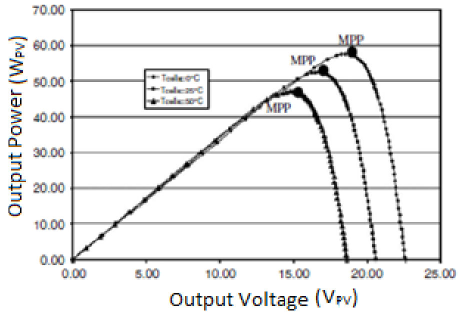

Figure 4b : P-V characteristics as a function of temperature

III. Characteristics of PV Array Under Partial Shading Conditions

PV array consist of series and parallel combinations of PV modules depending upon the output voltage and current requirements. When such a PV array is exposed to uniform irradiance, the output characteristics contain only one MPP and all the modules have same output current. However, if one of the modules in the array is shaded, it will generate less current and will cause power dissipation. Such modules are bypassed using reverse diodes in parallel and power of that particular module is dissipated in the form of heat. So bypass diodes are connected in parallel to avoid the formation of hotspots and subsequent deteriorations in PV array. Blocking diodes are connected at the end of each series array to restrict the backward flow of power and surges from external storage systems. A PV array (shown in figure 5) consisting of parallel interconnection of 3 modules in each row with blocking and bypass diodes, when exposed to partial shading conditions will give rise to multiple MPP's. These MPP's are classified as LMPP and GMPP as shown in figure 6 [13, 14].

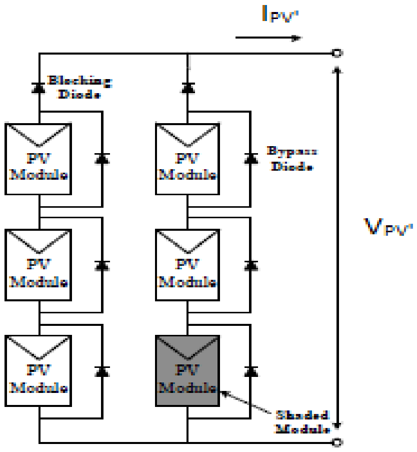

Figure 5: A PV array containing Blocking and Bypass diodes Under Partial Shading Conditions

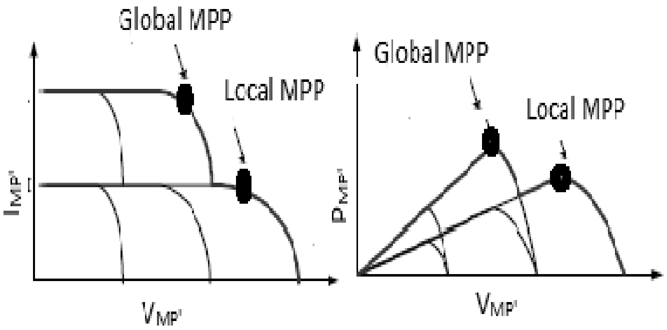

Figure 6 : VI and PV Characteristics of PV array Under Partial Shading Conditions

Conventional MPPT algorithms [5-7] are vulnerable to false tracking as they may track LMPP rather than GMPP which is necessary to be tracked for optimal power output [13,14]. So, appropriate modifications are required in the conventional algorithm to make it more robust, fast and precise for GMPPT tracking.

IV. Modifications in P&O Algorithm

Conventional Perturbation and observation method is mostly used for MPPT due to its simplicity and cost effectiveness. But there are two major problems with its simplified form

I) Under rapidly changing ambient conditions and irradiance levels its tracking becomes unreliable as explained in [5, 15 and 16] and shown in figure 7.

II) The algorithm takes too long to traverse the whole PI and PV curve to obtain MPP. This causes slow dynamic performance and more computational time for tracking.

The following two modifications as delineated in [8, 9 and 11] are made in the conventional P&O method to compensate the above stated shortcomings.

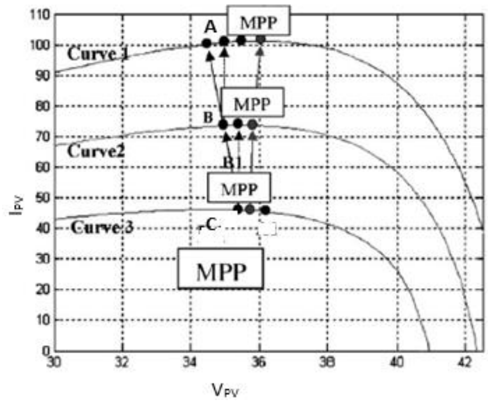

Figure 7: False Tracking in case of Rapidly Varying Irradiance

A. Robustness Enhancement

The main drawback of conventional P&O algorithm is shown in figure 7. In the case of sudden increase in irradiance, the algorithm falsely determines that the increase in power is due to perturb applied, without considering the effect of change in irradiance [13]. Therefore, dP-P&O method is employed to avoid this false tracking [9]. An additional measurement of power without applying perturb ensures that the increase in the output power of the panel is purely due to the change in the irradiance level. Thus, the effect of change in power due to incident light intensity, is separated from the effect of change in power, due to MPPT perturb [9].The improved dP-P&O algorithm is shown in figure 8. This additional measurement during the sampling period results in correct tracking, even with the rapidly varying irradiance and is evident from figure 9.

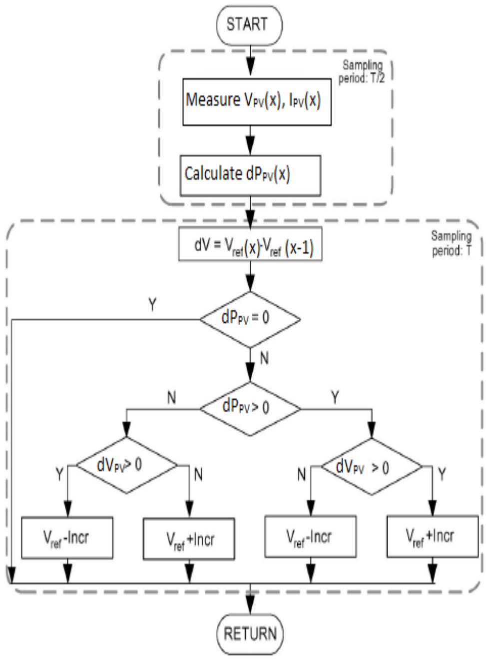

Figure 8: dP-P&O algorithm for Robustness Enhancement

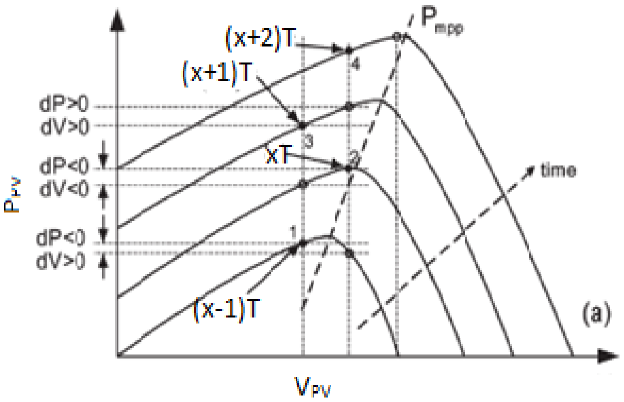

Figure 9 : PV characteristics and MPPT tracking with dP-P&O algorithm

B. Variable step size

Due to fixed step size in conventional P&O algorithm, the operating point oscillates around the MPP. Further, it traverses the whole PV curve to reach the MPP. All this process takes quite long and dynamics of the system becomes poor. The oscillations around MPP results in the loss of the output power and this loss can be effectively reduced by varying the step size. During the traversal on PV curve, the step size is adjusted as it has higher value in the start and lower values near the MPP as show in figure 10 and explained in [8]. These characteristics may are achieved using the duty cycle based variable step size algorithm [8]. For a DC-DC converter based PV system having the battery storage voltage V_B, the power can be expressed in terms of duty cycle D through the following equations [8].

$$V_B = \frac{1}{1-D} V_{PV} \tag{3}$$

$$P_{PV} = V_{PV} * I_{PV} \tag{4}$$

By putting the value of (3) in (4)

$$P_{PV} = V_B (1-D) * I_{PV} \tag{5}$$

$$MPP = G^* = \max[P_{PV}] = \max[V_B (1-D) * I_{PV}] \tag{6}$$

Defining, Q as a measure of the trade-off between the transient and the steady state performance and M as scaling factor for variable size. D will converge to its minimum value on MPP and is given by the equation

$$D(x+1) = D(x) + M * Q \tag{7}$$

Where,

D(x) = duty cycle at instant x

D(x+1) = duty cycle at instant x+1

Various methods for selecting scaling factor M and Q has been discussed in [8]. The algorithm to achieve the desired characteristics (shown in figure 10), with variable step size and reduced oscillations around maximum power point is given in figure 11 [8]. The variable step size technique [8] along with dP-P&O [9] is used to track the GMPPT as explained in the next section.

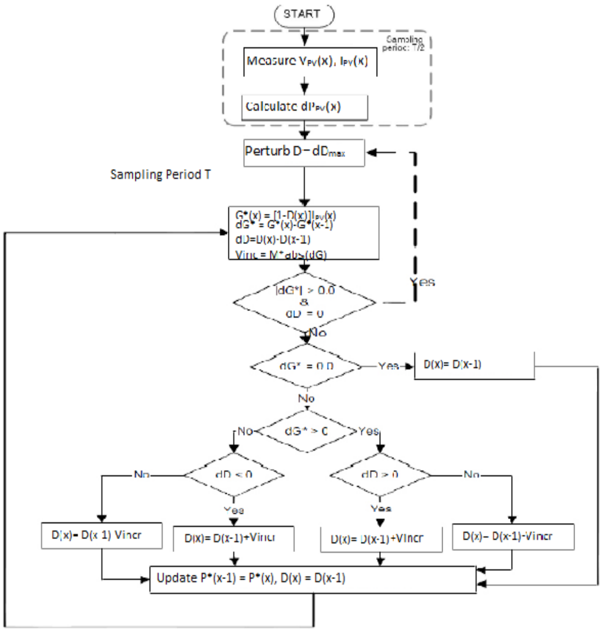

Figure 10: Variable Step Size dP-P&O MPPT Algorithm for Oscillation Control

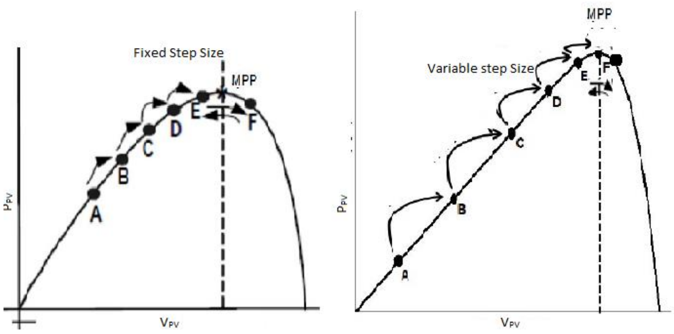

Figure 11: Comparison for Oscillations around MPP b/w Fixed Size and Variable Step Size Tracking

V. GMPPT TRACKING USING IMPROVED P&O

Under partial shading due to shadows, clouds, buildings and flying species, the PV array does not receive non-uniform Irradiance. VI and PV characteristics under such conditions exhibit MPP out of which only one is GMPP and rest are LMPP [13, 14]. A GMPPT algorithm depending upon the electrical characteristics of the panel i.e. open circuit voltage V_{oc} is presented in [12], however the disadvantage of [12] is that the proposed algorithm may track falsely when the GMPP is among two LMPP's. In order to avoid false tracking under such conditions, an Improved GMPPT is presented in [17], however the drawback of this particular scheme is that it is not universal in nature as it also depends upon the panel V_{oc} and configuration of the panels in the array. A generic GMPPT algorithm independent of the panel electrical characteristics and configuration nature has been presented in [11]. This paper uses the universal GMPPT algorithm [11] in conjunction with the improved variable step size dp-P&O algorithm presented in figure 9 to track the GMPP. Reference voltage V_{ref} to start the tracking [12, 17] is preset to 85% V_{oc}, that makes it panel specific, however the proposed GMPPT algorithm in this paper calculates its own reference voltage independent of the panel characteristics. The difference between array voltage under shaded conditions V_{sc} and the calculated V_{ref} is fed to the controller to improve the tracking dynamics and accuracy. The output voltage of controller is compared with the triangular waveform that operates the boost converter. The novel algorithm as shown in figure 12 is used to track the GMPPT under partially shaded conditions. Initially the GMPPT routine is called, which is responsible to calculate the global maximum point. The power of the intermediate converter as shown in figure is iteratively increased by intelligently varying the voltage of the converter V_c and is given by (8)

$$V_c(x) = V_c(x-1) + \Delta V_c(x) \tag{8}$$

Where, $V_c(x)$, $V_c(x-1)$ are converter voltage at step x and x-1 and $\Delta V_c(x)$ is the variable step size perturbation based on the change in duty cycle ΔD and is calculated using (7). Once GMPPT is calculated, variable step size dp- P&O routine comes into action and ensures the fast and accurate convergence to GMPPT.

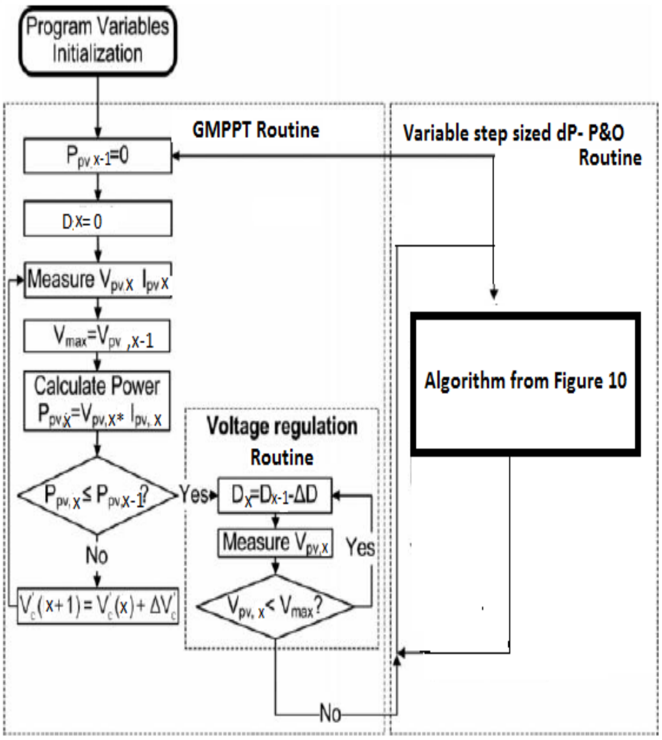

Figure 12: Improved GMPPT Algorithm with dP-P&O Algorithm

VI. Results and Discussions

The proposed GMPPT algorithm is fed into the controller shown in figure 1 and implemented on Matlab/Simulink. Different shading patterns and the resulting GMPP and LMPP are observed. As described earlier, the most critical conditions occur when GMPP comes in between two LMPP. The performance of the proposed algorithm is tested on the shading conditions at which GMPP is in the medium voltage range of PV and VI curve.

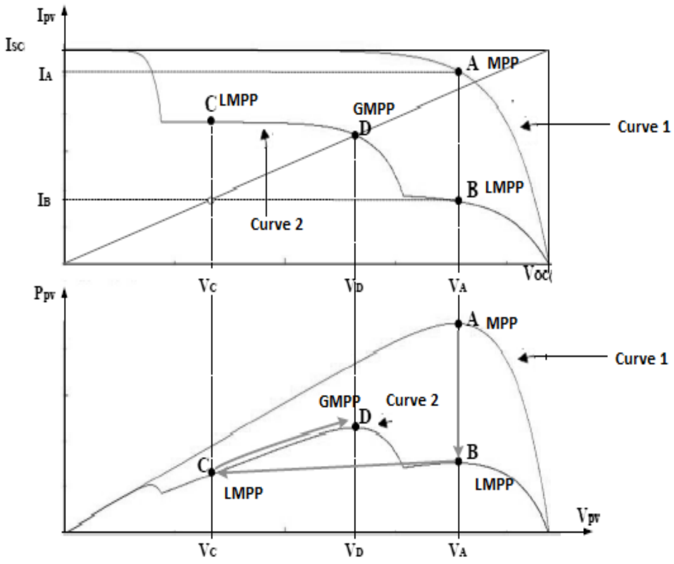

Figure 13: GMPPT using Improved GMPPT Algorithm with dP-P&O Algorithm

In figure 13, the point A on the curve 1 corresponds to MPP under uniform illumination conditions. B and C on curve 2 correspond to LMPP under partial shading conditions while D is GMPP in between B and C. The GMPPT routine in the proposed algorithm calculates D as MPP, while dP-P&O algorithm optimally converges the MPP from B and C towards D with reduced oscillations. Thus the algorithm presented here is capable of accurate tracking with enhanced discrimination capability between LMPP's and GMPP.

The effectiveness of the proposed algorithm under varying irradiance levels is also observed as shown in figure 14. Point A corresponds to the MPP under uniform Irradiance. Point B corresponds to falsely tracked LMPP in the conventional GMPP Schemes. The proposed algorithm accurately tracks the C point which GMPP under changing insolation levels. Thus the proposed algorithm is effective and useful in rapidly varying insolation levels.

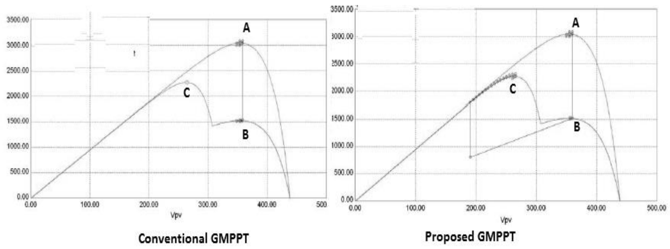

Figure 14: Improved GMPPT under varying Irradiance

VII. CONCLUSION

Under partial conditions, the output VI and PV characteristics of a solar array exhibit multiple maximum power points namely Global and Local maximum power points. Conventional tracking algorithms fail to track the global maximum power points under partial shading conditions. Further, the conventional tacking techniques are vulnerable to error and show poor dynamic performance in rapidly varying irradiance levels. In order to cope up with these issues, a novel GMPPT algorithm capable of discrimination between local and global power points is presented. The proposed algorithm is based upon perturbation and observation method, while variable step size and power changes measurement modifications are introduced in conventional P&O. As a result of these modifications, the proposed algorithm exhibits better dynamic performance, optimum convergence with improved robustness, less oscillations and enhanced reliability. Simulation results validate the effectiveness of the proposed algorithm under varying isolation conditions. Thus the proposed algorithm is an optimal and effective method to track the Global maximum power point under partial shading conditions.

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