

# PSO Based MPPT of PV System under Partial Shading Condition

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**Abstract**— This paper reports the improvement of a most extreme power-point following (MPPT) strategy for photovoltaic (PV) frameworks under in part shaded conditions utilizing firefly calculation. In the proposed system, the particle position is defined as the duty cycle value  $d$  of the dc–dc converter, and the fitness value evaluation function is chosen as the generated power  $P_{PV}$  of the whole PV system. In PSO initialization phase, particles can be placed on fixed position or be placed in the space randomly. In this work the particles are initialized on fixed positions which cover the search space  $[D_{min}, D_{max}]$  with equal distances. The goal of the proposed MPPT algorithm is to maximize the generated power  $P_{PV}$ . After the digital controller output, the PWM command according to the position of particle  $i$  (which represents the duty cycle command), the PV voltage  $V_{PV}$  and current  $I_{PV}$  can be measured and using voltage and current sensor. These values can then be utilized to calculate the fitness value  $P_{PV}$  of particle  $i$ . If the fitness value of particle  $i$  is better than the best fitness value in history  $p_{best,i}$ , set current value as the new  $p_{best,i}$ . Then, choose the particle with the best fitness value of all the particles as the  $g_{best}$ . After all the particles are evaluated, the velocity and position of each particle in the swarm should be updated with the help of eqn. 5.1 and 5.2. In this work two convergence criteria are utilized. If the velocities of all particles become smaller than a threshold, or if the maximum number of iterations is reached, the proposed MPPT algorithm will stop and output the obtained  $g_{best}$  solution. Typically PSO method is used to solve problems that the optimal solution is time invariant. However, in this application, the fitness value (global maximum available power) often changes with environments as well as loading conditions. In such cases, the particles must be reinitialized to search for the new GMPP again. If following criteria is met the particles are reinitialize.

$$\frac{|P_{PV,new} - P_{PV}|}{P_{PV}} \geq \Delta P(\%)$$

## 1. INTRODUCTION

With developing world vitality request and taking off costs of petroleum products together with worry about ecological issues have created colossal enthusiasm for the use of

sustainable power sources. The photovoltaic (PV) control age has seen a fast development over the most recent couple of years prompting broad utilization of sun powered vitality; a PV framework has the upsides of low upkeep cost, nonappearance of moving or pivoting parts and flexibility from natural contamination [1], [2]. Numerous nations give liberal money related plans, for example, feed-in levy [3], sponsored approaches [4], and so forth., prompting fast development of PV influence age frameworks. Because of high beginning expense of PV control age frameworks and its low vitality transformation proficiency, a PV framework is for the most part worked to extricate greatest power from the PV source. With a specific end goal to advance the usage of PV frameworks, most extreme power-point following (MPPT) is for the most part utilized, which requires control electronic interfaces, for example, dc– dc converter and additionally inverter. The target of MPPT is to extricate greatest power created by the PV frameworks under changing state of temperature and sunlight based insolation. A noteworthy test in PV frameworks is to handle its nonlinear current– voltage (I–V) qualities, prompting a one of a kind greatest power point (MPP) on its power– voltage (P–V) trademark bend. The procedure of MPPT is muddled by the way that the P–V bends fluctuate to a great extent with sun based insolation and temperature. By and large, the PV boards are associated in arrangement and parallel in order to take care of the heap control demand. At the point when climatic conditions shift, the MPP of the PV framework likewise changes its position and a few strategies have been exhibited for following the MPP and are accessible in [5]– [11]. These strategies incorporate annoy and watch (P&O) [5], incremental conductance [6], hamper [7], open circuit voltage [8], stack current/stack voltage expansion procedure [9], fluffy control [10], neural system based plans [11], and so on. A nitty gritty examination of different strategies for following MPP in PV frameworks is widely talked about in [12]– [15]. The following techniques talked about in these papers are viable and time tried under uniform sun based insolation, where there is just a single MPP in the P–V bend of the PV framework for a given temperature and insolation. In huge PV frameworks, incompletely shaded condition (PSC) happens wherein PV modules get distinctive sun oriented insolation because of shadow of building, moving mists, and other neighboring

items. The yield intensity of the PV exhibit diminishes to a great extent because of PSC and the quantum of intensity lost rely upon framework arrangement, shading design and the detour diodes fused in the PV modules. The impact of PSC on PV framework has been examined in a few productions [16]–[18]. The prompt impact of PSC is that the subsequent PV trademark bend ends up complex with different pinnacles. Ordinary strategies for following MPP depend on "slope climbing" strategy and these techniques are not compelling in coming to the worldwide optima, when the PV framework under PSC shows different pinnacles; fairly the vast majority of the customary techniques may meet to neighborhood MPP prompting power misfortune. Removing most extreme power from in part shaded PV exhibits can be arranged into four gatherings [19]. In the primary gathering, changed MPP systems which are fit for joining to worldwide most extreme power point (GMPP) are utilized and the second class uses distinctive exhibit reconfigurations. The third gathering depicts diverse PV framework structures and the fourth class includes distinctive converter topologies, for example, staggered inverters. Despite the fact that not featured, a closer examination of the work in [19] obviously demonstrates that the last three classes are costlier, require more segments, and include complex control and higher exchanging misfortune in correlation with changed MPPT methods that fall under first classification. When all is said in done, altered MPP calculations dependably ensure combination to GMPP, framework freedom, and higher following effectiveness For the situation of a shaded PV framework, the PV bend has various pinnacles and union to worldwide MPP is compulsory for separating most extreme power from the PV framework. The enhancement calculation chose for MPPT ought to in a perfect world have the properties of basic computational advances, quicker combination, and ensured assembly to GMPP together with the practicality of execution in an ease computerized controller. Naturally motivated streamlining calculations, for example, hereditary calculations (GAs), subterranean insect province frameworks (ACS), fake safe frameworks (AIS), molecule swarm improvement (PSO) strategies, and so forth., have been widely utilized for different building applications. Among these techniques, PSO is basic in structure, computationally more affordable, and simple to fuse for online applications. Promoting the inalienable properties of PSO, a few researchers have recently employed PSO for GMPP tracking under partial shaded conditions [20]–[24]. These works employ conventional PSO and/or improved versions of PSO for enhanced tracking efficiency. It is shown that the proposed methods based on PSO guarantee convergence to GMPP and is far superior to conventional P&O method. While conventional PSO yields promising results [23], it causes oscillations in output power before reaching GMPP. An improved PSO where the duty cycles are initialized in two phases is reported in [22] which results in reduced steady state oscillations; however, the work in [22] does not compare the performance of the system with conventional PSO and its improved version. Furthermore, the two-stage initialization process may lead to increased computational burden and reduced tracking speed which are

not deliberated in [22]. It is important to mention that while most of the works [23], [24] claim that the PSO-based approach is superior to conventional methods of tracking, a comparison between PSO and conventional methods in terms of tracking speed through simulated and/or measured results is not available under identical conditions of partial shading; such a comparison of MPPT tracking could have highlighted the superiority of PSO. The PSO method for MPPT in PV systems under PSC is preferred by the researchers over other evolutionary algorithms because of its simple computation steps, easy of experimental implementation and increased tracking speed. The application of other evolutionary algorithms for MPPT under PSC is not available in the reported literature. Recently, Yang has developed ametaheuristic algorithm known as firefly algorithm (FA) and is available in [25], [26]. This algorithm is inspired by the flashing behavior of fireflies to attract other fireflies for mating purpose. It is shown in [26] that PSO is a special category of FA. The work in [26] compares PSO with FA by employing several multimodal optimization test functions. The statistical analysis of the comparison clearly indicates that FA is potentially more powerful in finding global optima with least computing time. A closer examination of the results presented in [26] highlights the superiority of FA over PSO in terms of convergence rate and computational burden. This aspect has been further verified in [27]. Recent works also confirmed the superiority of FA in solving complex optimization problems. The objective of this paper is to develop an FA-based scheme for tracking GMPP under PSC in a PV system. The proposed method is shown to be accurate, converges faster to GMPP and is system independent.

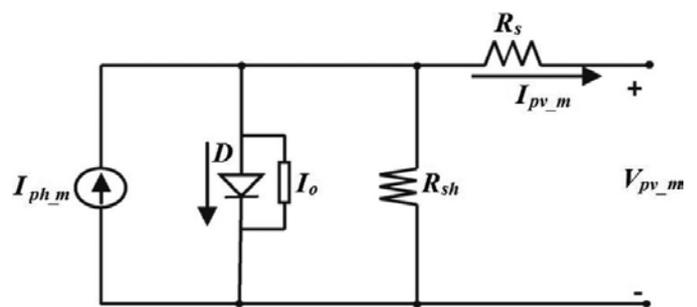


Fig. 1. Single diode model of PV module

Several case studies under different PSC conditions are considered, and the proposed scheme is developed to track the GMPP. This paper also reports the application of conventional P&O and PSO methods for MPPT under identical conditions, and through simulation and experimental studies, it is shown that the FA-based tracking is superior to the existing methods in terms of reduced computational complexity and tracking speed. The transients in power, voltage and current before reaching GMPP are shown to be very least with the proposed in comparison with P&O and PSO methods. The computed results are validated with experiments carried out on two different configurations of PV arrays. Examination of extensive simulation results together with measurements carried out on the two prototypes show that FA-based MPPT always converge to GMPP irrespective of the location of GMPP. The tracking efficiency in all test cases is shown to be

higher than 99.5%. The new MPPT scheme is simple, fast converging, does not require *priory* knowledge of the system. Further, the scheme is easily realized using a low-cost PIC16F876 microcontroller. One major highlight of this paper is that comparative evaluation of P&O, PSO, and FA methods have been experimentally carried out and presented, which is not available in the earlier publications.

## 2 Perturbations and Observation (P&O) And/Hill-Climbing Technique

In this technique, first the PV voltage and current are measured and hence the corresponding power  $p_1$  is calculated. Considering a small perturbation of voltage ( $\Delta V$ ) or perturbation of duty cycle ( $\Delta d$ ) of the dc/dc converter in one direction corresponding power  $P_2$  is calculated.  $P_2$  is then compared with  $P_1$ . If  $P_2$  is more than  $P_1$ , then the perturbation is in the correct direction; otherwise it should be reversed. In this way, the peak power point  $P_{mpp}$  is recognized and hence the corresponding voltage can be calculated [18]–[20]. The major drawbacks of P&O/hill-climbing are occasional deviation from the maximum operating point in case of rapidly changing atmospheric conditions, such as broken clouds. Also, correct perturbation size is important in providing good performance in both dynamic and steady-state response [21].

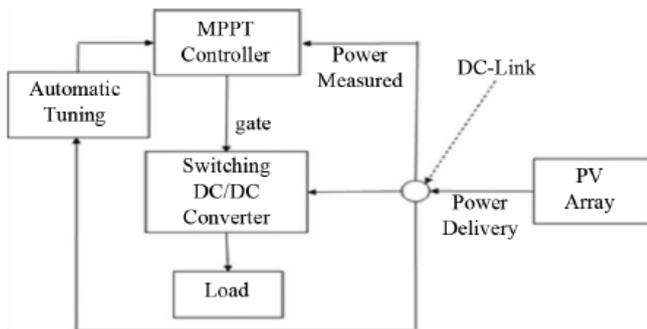


Fig. 2. Block diagram of adaptive Hill-climbing technique.

To solve this problem, a modified adaptive hill climbing technique (Fig. 2) with a variable perturbation step size can be used [22], where an automatic tuning controller varies the perturbation step size to a large value when the power changes in a large range primarily due to environmental variation, to satisfy the fast response requirement during the transient stage. Further, the controller is formulated in such a manner that when the power change is less than or equal to the set lowest limit, the controller assumes that the system enters the steady state and the value of perturbation becomes small. In similar context, one Adaptive P&O technique [23] and another Predictive and Adaptive MPPT P&O technique [24] have been introduced. In the Adaptive P&O method, instead of, the main emphasis has been given on the voltage perturbation. In Predictive and Adaptive MPPT P&O method, a constant duty cycle perturbation that linearly reduces with increase of power drawn from PV panel has been taken.

## 3. PROPOSED SYSTEM

*Step 1 (Parameter Selection):* In the proposed system, the particle position is defined as the duty cycle value  $d$  of the dc–dc converter, and the fitness value evaluation function is chosen as the generated power  $P_{PV}$  of the whole PV system.

*Step 2 (PSO Initialization):* In PSO initialization phase, particles can be placed on fixed position or be placed in the space randomly. In this work the particles are initialized on fixed positions which cover the search space  $[D_{min}, D_{max}]$  with equal distances.

*Step 3 (Fitness Evaluation):* The goal of the proposed MPPT algorithm is to maximize the generated power  $P_{PV}$ . After the digital controller output, the PWM command according to the position of particle  $i$  (which represents the duty cycle command), the PV voltage  $V_{PV}$  and current  $I_{PV}$  can be measured and using voltage and current sensor. These values can then be utilized to calculate the fitness value  $P_{PV}$  of particle  $i$ .

*Step 4 (Update Individual and Global Best Data):* If the fitness value of particle  $i$  is better than the best fitness value in history  $p_{best, i}$ , set current value as the new  $p_{best, i}$ . Then, choose the particle with the best fitness value of all the particles as the  $g_{best}$ .

*Step 5 (Update Velocity and Position of Each Particle):* After all the particles are evaluated, the velocity and position of each particle in the swarm should be updated with the help of eqn. 5.1 and 5.2.

*Step 6 (Convergence Determination):* In this work two convergence criteria are utilized. If the velocities of all particles become smaller than a threshold, or if the maximum number of iterations is reached, the proposed MPPT algorithm will stop and output the obtained  $g_{best}$  solution.

*Step 7 (Reinitialization):* Typically PSO method is used to solve problems that the optimal solution is time invariant. However, in this application, the fitness value (global maximum available power) often changes with environments as well as loading conditions. In such cases, the particles must be reinitialized to search for the new GMPP again. If following criteria is met the particles are reinitialize.

$$\frac{|P_{PV, new} - P_{PV}|}{P_{PV}} \geq \Delta P(\%)$$

## 4. CRITICAL OBSERVATIONS UNDER PARTIALLY SHADED CONDITIONS

Utilizing a recreation demonstrate created in the MATLAB/SIMULINK programming [20], the creators have led a complete investigation of the I–V and P–V attributes of the somewhat shaded PV exhibit. This model uses an extraordinary phrasing to portray the in part shaded exhibit, as delineated in Fig. 1. The wording helps in rearranging the

unpredictable shading example of the vast PV cluster and, thus, to examine the qualities of the huge half-way shaded PV exhibit. A PV module [Fig. 1(a)] is thought to be shaded if at least three of its cells are accepting lower than typical insolation.

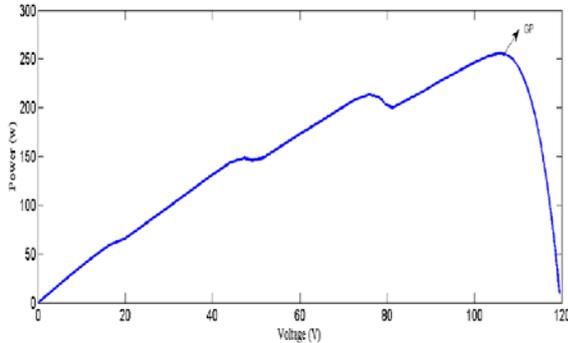


Fig.3. PV Curve

Arrangement associated PV modules, accepting comparable insolation, form a "subassembly" [Fig. 1(b)]. A few arrangement associated subassemblies, each with an alternate level of insolation, shape a "arrangement get together" [Fig. 1(b)]. A "gathering" is comprised of a few comparative arrangement gatherings (having indistinguishable P–V attributes) associated in parallel [Fig. 1(c)]. Different parallel-associated gatherings, with various shading designs constitute a PV exhibit [Fig. 1(d)]. Fig. 2 demonstrates the P–V bends, got utilizing the created display, for a PV cluster having 900 modules (10 in arrangement × 90 in parallel) with a mind boggling shading design (having a few gatherings).

Fig. 3 shows the P–V curves for the array at different insolation levels. For further discussion, the simpler example of the shaded PV array shown in Fig. 1(d), having only three distinct groups, is considered. It is observed that the peaks PS1, PS2, and PS3 occur at  $V_1 = 65$  V,  $V_2 = 114$  V, and  $V_3 = 163$  V, respectively. It is important to note that since four modules are unshaded in each series assembly of group 1, the peak PS1 occurs nearly at voltage  $V_1 = 4 \times 16.3 = 65$  V, where 16.3 V is 80% of the open-circuit voltage of the module (VOC\_module) considered. A similar reasoning can be applied to PS2 and PS3, which occur at nearly  $V_2 (= 7 \times 16.3 = 114$  V) and  $V_3 (= 10 \times 16.3 = 163$  V), respectively. Hence, the peaks PAm<sub>ax1</sub>, PAm<sub>ax2</sub>, and PAm<sub>ax3</sub> occur nearly at the voltages  $V_1$ ,  $V_2$ , and  $V_3$ , respectively. A significant outcome of this observation is that the array power peaks are displaced from each other by an integral multiple of 80% of VOC\_module ( $n \times 0.8 \times$  VOC\_module), where "n" is an integer. As the minimum integral difference in the number of shaded modules between the series assemblies of two groups is one, the minimum possible displacement between two consecutive peaks is  $0.8 \times$  VOC\_module. In Figs. 1(d) and 2, the number of shaded modules in the series assemblies decreases as one moves from the first series assembly to the last one (i.e., from left to right).

### 5. DUTY CYCLE COMPUTATION FOR DC–DC CONVERTER CONTROL

Fig. 4(a) shows the circuit schematic of a boost-type dc–dc power converter whose duty cycle is modulated as per the algorithm used for electrical tracking of the MPP. In a conventional controller working with the P&O method, duty cycle ( $D^*$ ) is generated as follows [22]:

$$D^* = 1 - (V_{ref}/V_o) \tag{1}$$

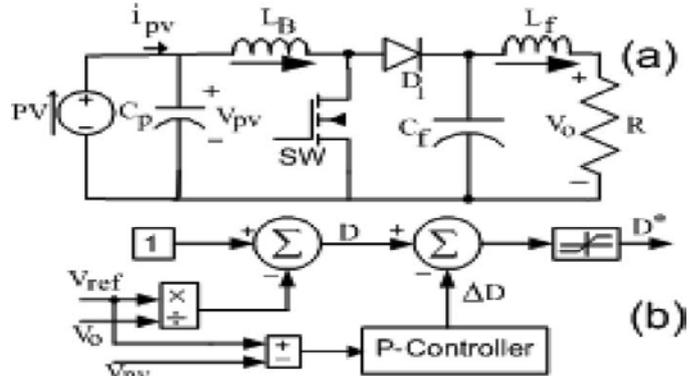


Fig. 4. (a) Circuit schematic for boost converter used for tracking MPP. (b) Proposed control scheme for the dc–dc converter. ( $L_B = 5$  mH,  $C_p = 2000$   $\mu$ H,  $C_f = 1000$   $\mu$ H, and  $L_f = 0.1$  mH).

where  $V_{ref}$  is the reference voltage obtained using the MPPT algorithm described in Section 3, and  $V_o$  is the output voltage of the dc–dc converter. It is observed that such a controller is slow to respond. The proposed controller overcomes this drawback. Here, the control signal for dc–dc converter is obtained in a feedforward manner, as shown in Fig. 3(b). The controller is fast to respond and can quickly track the MPP. The principle involved in this controller can be mathematically explained as under. If  $\Delta D$  is the perturbation in the actual duty cycle  $D$ , then

$$D + \Delta D = 1 - (V_{pv} + \Delta V_{pv}) / (V_o + \Delta V_o) \tag{2}$$

where  $V_{pv}$  is the PV array voltage, while  $\Delta V_{pv}$  and  $\Delta V_o$  are changes in PV array and output voltages of the dc–dc converter, respectively.

If  $\Delta V_o \ll V_o$ , then (2) leads to (3) as follows:

$$\Delta D = -\Delta V_{pv} / V_o. \tag{3}$$

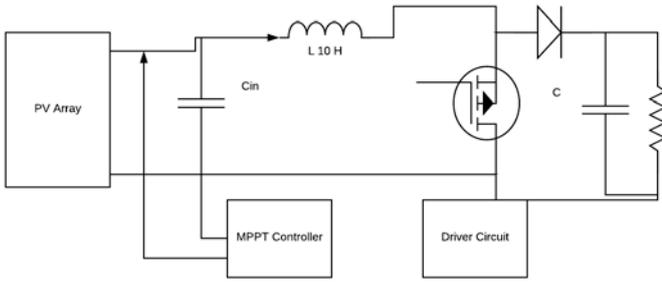


Fig. 5 Proposed Circuit Diagram

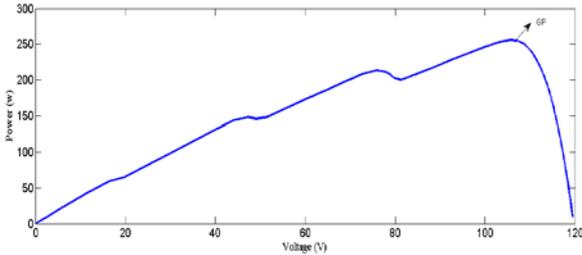


Fig. 5.  $P-V$  characteristic for the array of Fig. 1(d), with solar insolation of  $1000 \text{ W/m}^2$ .

This additional disturbance  $\Delta D$ , when subtracted from the actual duty cycle  $D$ , amplifies the disturbance toward the MPP, and therefore, the MPP is attained quickly. The above mathematical analysis is explained with the help of Fig. 4, which shows the  $P-V$  curve of the array represented by Fig. 1(d). Point A indicates the initial operating point for which the PV array output voltage is  $V_{in}$ . To reach the MPP, the conventional controller sets the reference voltage  $V_{ref}$  by giving a perturbation (here, reduction in the operating voltage) in such a way that the movement is toward the MPP.  $V_{ref}$  is then used to calculate the new duty cycle  $D^*$ . As  $V_{ref} < V_{in}$ , the new duty cycle,  $D^* = 1 - (V_{ref}/V_o)$ , increases. As a result, the same output voltage  $V_o$  can be obtained by having a smaller PV array voltage. Thus, the operating point moves toward the MPP. In the proposed controller, an additional disturbance  $\Delta D = k \times (V_{ref} - V_{in})$  is introduced in the duty cycle computation, where “ $k$ ” is a positive constant.

At  $V_{ref} < V_{in}$ ,  $\Delta D$  is negative. The duty cycle for the next switching cycle is determined by two terms, namely

- 1)  $1 - (V_{ref}/V_o)$  and

- 2)  $\Delta D$ , as given in the following:

$$D^* = 1 - V_{ref}/V_o - \Delta D. \quad (4)$$

Similar to a conventional controller, the first term’s effect is an increase in the duty cycle for the next switching cycle. In addition, as  $\Delta D$  is negative, the second term also increases the duty cycle. Hence, for the same output voltage  $V_o$ , the decrease in PV array voltage is much more than the previous case, which restores the MPP much faster than the conventional method.

## 6. SIMULATION RESULTS

This section presents the simulation results with the proposed algorithm. Fig. 6 shows the PV output current

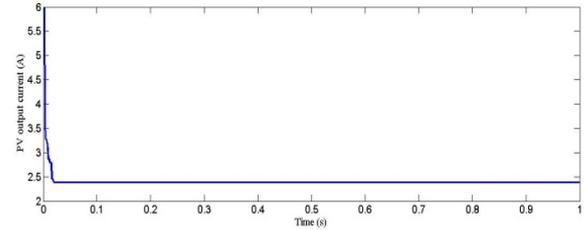


Fig.6. PV Output Current

Figure 7 shows the PV output power.

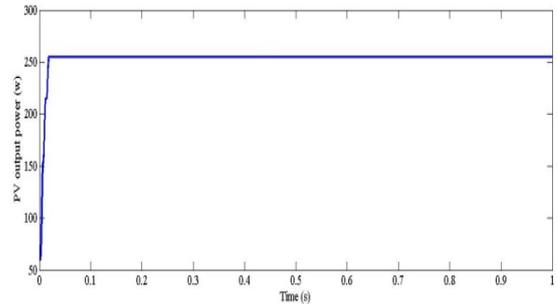


Fig.7. PV output Power

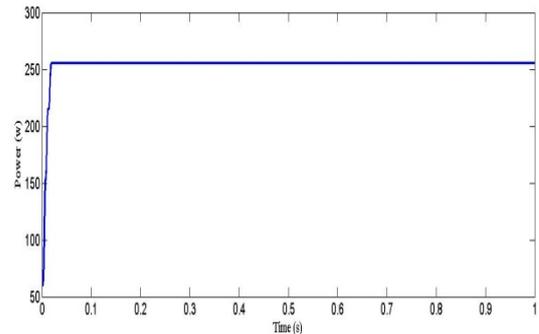


Fig.8. Power PSO

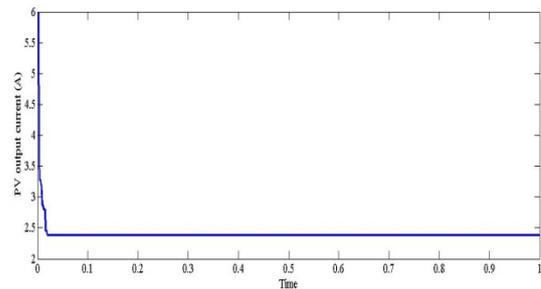


Fig.9. PSO Current

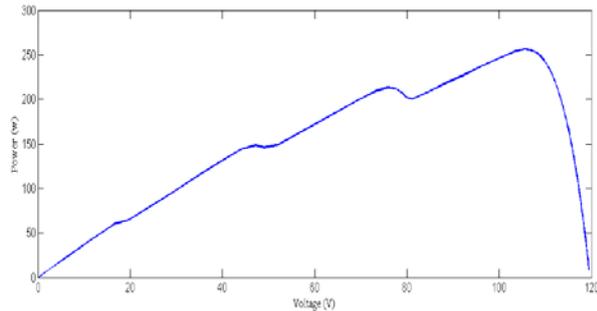


Fig.10. PV curve

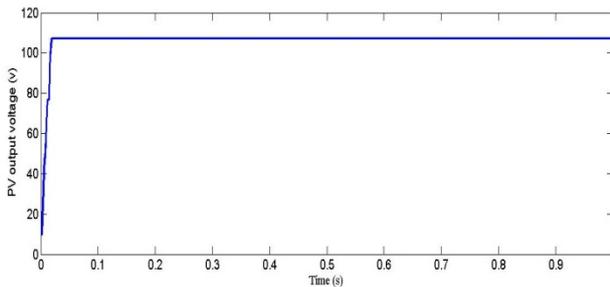


Fig.11. Voltage PSO

## 7. CONCLUSIONS

The main aim of the present work is to develop an accurate MPPT algorithm for PV system under partial shading condition. The PSO based MPPT algorithm is implemented and a comparative study is done with the existing P&O MPPT algorithm. From simulation results, it is found that the proposed PSO based MPPT algorithm is capable of tracking multiple global peaks under partial shading condition. To verify the reliability of proposed PSO based MPPT, the results comparison is drawn with P&O MPPT. It is found that under partial shading condition and varying solar radiation the tracking efficiency of PSO based MPPT shows better results than that of P&O MPPT.

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