# Spider Monkey Based Improve P&O MPPT Controller for Photovoltaic Generation System

Tanmaya Kumar Behera
*Dept. of Electircal & Electronics Engineering*
*ITER, SOA Deemed To Be University*
Bhubaneswar, Odisha, India
tanmayakumarb56@gmail.com

Manoja Kumar Behera
*Dept. of Electrical & Electronics Engineering*
*ITER, SOA Deemed To Be University*
Bhubaneswar, Odisha, India
manoj04manoj04@gmail.com

Niranjan Nayak
*Dept. of Electrical & Electronics Engineering*
*ITER, SOA Deemed To Be University*
Bhubaneswar, Odisha, India
niranjannayak@soa.ac.in

***Abstract*—Photovoltaic (PV) system uses maximum power point tracking (MPPT) technique to maximize its power output. This paper presents a swarm inspired optimization based control method for the MPPT of a PV system. In particular, control methods of perturb and observe (P&O)-proportional integral (PI) and optimisation of this controllers using spider monkey optimisation (SMO) for MPPT control of PV generator are proposed. A well known PI controller is tuned using spider monkey algorithm and tested on a simulated stand alone PV system with local load. The proposed SMO based PI controller enhances the P&O MPPT technique to track the maximum power point (MPP) more rapidly and accurately. The design algorithm of this controller is presented with its simulation results. Simulation results under different environmental conditions are presented and discussed to verify the satisfactory performance of the proposed control, in which the optimised P&O-PI controller by SMO algorithms gives the better performance technique over the traditional control methods.**

***Keywords*—Photovoltaic (PV), maximum power point tracking (MPPT), perturb and observe (P&O), PI controller, spider monkey optimization (SMO)***

## I. INTRODUCTION

Renewable source like solar energy generation is widely gaining importance because of various advantages like no fuel cost, less maintenance, no noise and wear. The efficiency of the PV cell is low and is mostly affected due to various atmospheric conditions and load. Hence in order to counter these problems and maximise the efficiency, all the design parameters of the PV system are needed to be optimised. The I–V and P-V characteristics of PV array are usually very nonlinear. They vary with temperature and solar irradiance that extensively affects the PV power output [1]. At particular irradiance and temperature, there is only one operating point of PV array at which it gives maximum power. Therefore, to maximize its efficiency and power generation, it is needed to coincide the PV generation to the load such that the operating point matches with the MPP of the PV array. The MPPT controller is very much vital for PV system. In addition, the MPP of PV array changes with change in irradiance and temperature. As a result, the tracking of MPP is a difficult problem. To overcome these problems, various tracking technique have been proposed such as perturb and observe (P&O), incremental conductance (IC) and constant voltage etc. These techniques have some demerits for example high cost, complexity and instability. In order to overcome these demerits, researches have used artificial intelligence (AI) technique like fuzzy logic controller (FLC) and artificial neural network (ANN). Even if these methods are very much efficient in dealing with nonlinear I–V and P-V characteristics of the PV array, but still they need complex calculations. For example, FLC has to tackle with various operations like fuzzification, rule base, inference mechanism and defuzzification. And for ANN, a huge number of data is required for training [2].

Also simple PI feed-back control has been used due to its easy structure and better robustness. A linear relationship always exists between $I_{MPP}$ and irradiance. Based on this fact, the current $I_{MPP}$ is found by sensing the irradiance and the PI controller is used to bring the PV current to $I_{MPP}$ [3]. Whereas $I_{MPP}$ and $V_{MPP}$ are calculated from equations that involves irradiance and temperature. After obtaining $I_{MPP}$ and $V_{MPP}$, PV array is forced by the feedback control to operate at the MPP. The INC technique has been presented in such a way that the instantaneous conductance and the incremental conductance are added so as to generate an error signal. So a basic PI controller has been used to bring e to zero.

The conventional approach for such application needs to implement PI controller which has two main drawbacks i.e. slow transient response and oscillations around the MPP [4]. Especially, PI controller needs some time to reach up to steady state which increases the time interval within 2 consecutive reference outputs of MPPT controller and hence it deteriorates the dynamic performance. Also, the nonlinearities in the PV power may degrade the PI controller's performance due to its improper gain parameters that leads to loss of energy from also cause instability. Various solutions have been proposed in literature to rectify this problem. PI regulator is used in robust control to track this MPP. Predictive controller is implemented in fixed step model which is based on modified IC algorithm [5]. Even though these techniques help in solving the problems which are associated with the conventional approaches, still there are various limitations like it requires complex computational effort to implement control techniques.

EA is known to be very effective in dealing with MPPT problem due to its capability to handle nonlinear objective functions. Between the EA techniques, particle swarm optimization (PSO) and bacteria foraging (BF) etc bring attention in design of the controller [6]. However, these

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algorithms are very much effective for design problem but have various limitations like slow convergence, weak local search ability and may get entrapped in local minimum. A relatively new evolutionary algorithm called spider monkey optimization (SMO) has been presented by [7]. SMO algorithm is population based optimization algorithm as well as its very simple and robust and requires very less control parameters to get tuned. Hence, this optimization tool is very much suitable for MPP regardless of atmospheric condition.

Many researchers have got attracted towards the auto tuning of PI controller using AI such as fuzzy systems [8]. However, fuzzy controller has a common disadvantage in designing i.e. it is difficult to derive of fuzzy rules as well as its time consuming and based on expert knowledge. Recently, optimization algorithms have been one of the best alternatives to tune the PI controllers. These new methods have been very useful in finding out the global optimal solutions of the optimized control scheme [9]. One of such approach has been taken into account like SMO which is actually based on the social behaviour of SM i.e. spider monkey optimization algorithm. SMO has been used for various combinatorial problems like in job scheduling, routing optimization in data communication networks etc.

In this paper, a simple implementation of MPPT technique has been presented. The initial starting point of the traditional P&O MPPT algorithm gets enhanced by the proposed MPPT technique using PI controller. In order to optimize the PI controller gains, SMO has been employed. In this paper, the main objective of SMO is to get improvement in both the design efficiency of PI control as well as its performance in order to get optimal PI parameters. Design procedure of a spider monkey model has been presented in this paper that is based on PI controller.

The main objective of this paper is to optimize P&O-PI controller via SMO technique to increase the tracking response of MPP with high efficiency. This paper has 3 different contributions. 1stly, a modified technique has been presented that improves the limitations of the traditional MPPT techniques. 2ndly, a design of an optimized PI controller based on MPPT has been done for standalone PV system using SMO. Depending upon these 2 improvements, at last a satisfactory PV performance has been achieved with respect to the different irradiance and temperature.

The rest part of this paper is given as: section II presents the idea of PV system having PV modeling and boost converter. MPPT techniques describe in section III. Spider monkey optimized PI controller is presented in section IV. Section V shows the simulation results of PV system using the proposed technique. Finally, a conclusion is drawn in section VI.

## II. SYSTEM MODELING

### A. *PV Single Diode Model*

The single diode model of PV cell as shown in "Fig. 1", has been used to model and simulate the PV system. The basic equations that are necessary to model a PV cell are as follows [10].

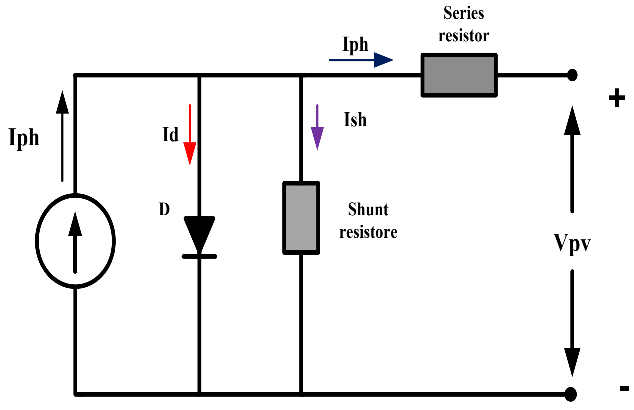



Fig. 1. Single diode circuit for PV cell.

PV current using Kirchhoff's law the relationship represented as follows:

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

The photo current is dependent on the irradiance (λ) and solar cell temperature (T). The $I_{ph}$ equation can be mathematically expressed by the following "(2)":

$$I_{ph} = (I_{sc} + K_i(T - T_r))\ \lambda / \lambda_r \tag{2}$$

While the current is flowing through the diode $I_d$, as shown in the "(3)":

$$I_d = I_o(\exp(q(V_{pv} + R_s I_{pv}) / dkT) - 1) \tag{3}$$

Saturation current $I_0$ of solar cell can be expressed in a mathematical equation that has a relationship with the temperature of the solar cell as follows:

$$I_0 = I_{rs}\left(\frac{T}{T_r}\right)^3 \exp\left[qE_g\left(\frac{1}{T_r} - \frac{1}{T}\right)/kd\right] \tag{4}$$

Where,

$$I_{rs} = \frac{I_{sc}}{\left[\exp\left(\frac{qV_{oc}}{kTd}\right) - 1\right]} \tag{5}$$

The current $I_{sh}$ in a closed loop can be determined by using Kirchhoff's voltage law analysis, which is expressed in "(6)":

$$I_{sh} = (V_{pv} + I_{pv}R) / R_{sh} \tag{6}$$

Therefore, the output current ($I_{PV}$) were previously expressed by "(1)", can be restated by equation "(7)":

$$I_{pv} = I_{ph} - I_0[\exp(q(V_{pv} + I_{pv}R_s) / kTd) - 1] - (V_{pv} + I_{pv}R_s) / R_{sh} \tag{7}$$

Collection of several PV modules are electrically connected in series ($N_s$) and parallel ($N_p$) for generating more power in a PV array. Equivalent current expression of PV array is expressed as follows:

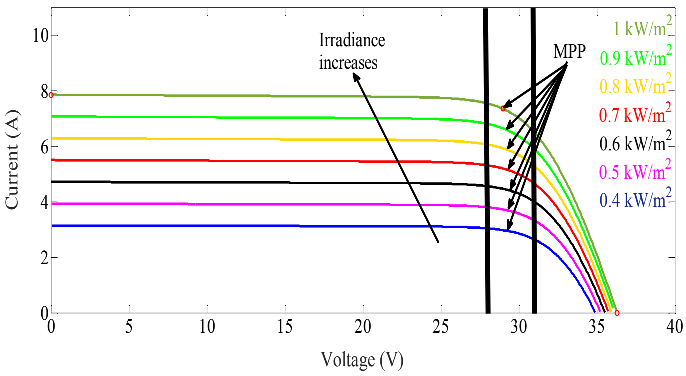
$$I = N_p I_{ph} - N_p I_0[\exp(q(V_{pv}/N_s + R_s I_{pv}/N_p/dkT) - 1] \\ -V_{pv} N_p/N_s + R_s I_{pv}/R_{sh} \tag{8}$$

Where $I_{pv}$ is the solar cell output current (A), $I_{ph}$ is solar cell photo current (A), $I_0$ is saturation current of the solar cell (A), $V_{pv}$ solar cell output voltage (V), $I_{sc}$ is short circuit current (A), $\lambda$ is irradiance (kW/m$^2$), $\lambda_r$ is irradiance reference (kW/m$^2$), T is the temperature (Kelvin), $K_i$ is temperature coefficient, $T_r$ is the reference temperature of solar cell (Kelvin), $I_{rs}$ is reverse saturation current (A), k is Boltzmann's constant, d is ideality factor of the PV, q is electron charge, and $V_{oc}$ is open circuit voltage (V). The specifications of the PV module are given in Table I.

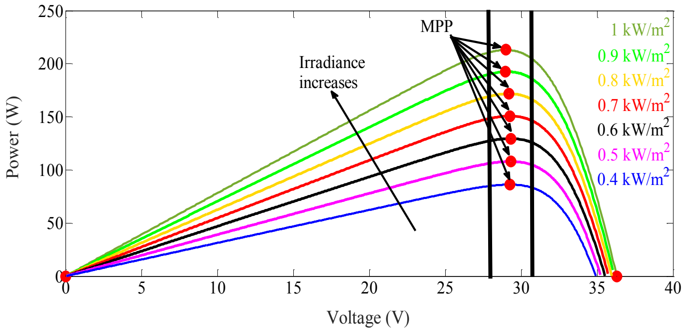
TABLE I. SOLAR MODULE PARAMETERS

| Specification | Value |
|---|---|
| Number of Cell ($N_s$) | 60 |
| Maximum power ($P_m$) | 213.15 W |
| Voltage ate $P_m$ | 29 V |
| Current at $P_m$ | 7.35 A |
| Open circuit voltage ($V_{oc}$) | 36.3 V |
| Short-circuit current ($I_{sc}$) | 7.84 A |
| Temperature coefficient of $V_{oc}$ | -0.36099 %/$^O$C |
| Temperature coefficient of $I_{sc}$ | 0.102 %/$^O$C |

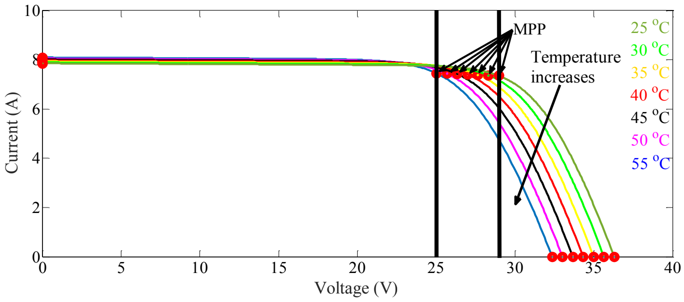
The PV array was designed using 48 PV panels which were connected in series and parallel arrangement. The characteristics of PV modules shown in "Fig. 2", in which the bond between the electrical power, voltage and current is clarified in P-V and I-V curves of the PV module. Initially the simulation were done at a constant temperature of 25°C at seven different irradiance value of 400W/m$^2$, 500W/m$^2$, 600W/m$^2$, 700W/m$^2$, 800W/m$^2$, 900W/m$^2$ and then keeping irradiance constant at 1000W/m$^2$ at seven different temperature value of 25°C to 55°C and to detect the MPPT response of the system when responding to a change in the irradiation which has a direct impact on the power produced by the PV module. A nonlinear single diode model I-V characteristic of PV cell represents the deviation of the current providing by the cell as a function of the voltage represents in equation.



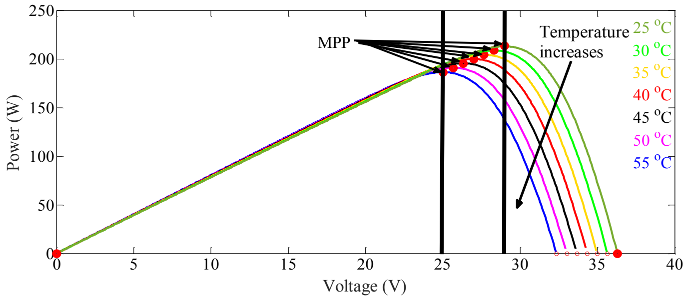

(a)




(b)




(c)




(d)

Fig. 2. The I–V, P–V curves of PV panel: (a) T = 25°C, the I–V curves under various irradiance, (b) T = 25°C, the P–V curves under various irradiance, (c) $\lambda$ = 1000W/m$^2$, the I–V curves under various temperature, and (d) $\lambda$ = 1000 W/m$^2$, the P–V curves under different temperature.

## *B. DC-DC Boost Converter*

DC-DC converter is one of the most essential components of the system, as it controls the DC output by varying its duty cycle. Here the converter approves that this system will give more than the DC-DC converter input voltage. Boost converter consist of combined inductor and capacitor, when converter switch is open the voltage across this elements gives the converter a boost output voltage [11]. The duty cycle of converter is given by "(9)". Using this expression the desired output voltage can be correcting the converters duty cycle [9].

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{9}$$

where D= duty cycle, $V_{in}$= input voltage and $V_{out}$=output voltage.

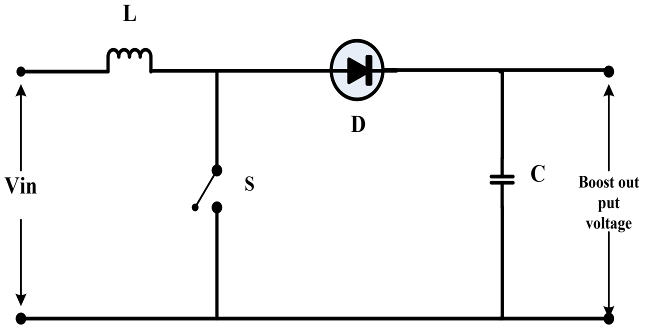



Fig. 3. Boost converter.

## III. MPPT (Maximum Power Point Tracking) Requirement

Maximization of PV output power can be done by a maximum power point tracker. Maximum available power is drawn by the MPPT controller by imposing the PV array to drive closer to MPP. Power output of the PV array changes if there are changes in solar radiation and temperature. MPPT techniques help in fast and accurate tracking. The purpose or role of various algorithms, proposed till date is to control the duty ratio (D) of the converter. This is done in such a manner that the actual load line seen by the PV array coincides with that of a load at which maximum power in extracted from the panel [12]. The basic types of DC-DC converter are mainly used for this purpose is boost converter. $R_{in}$ is the input resistance of the converter and $R_o$ is the load resistance. In “Fig. 4”, the approximate range of $R_{in}$ for boost DC-DC converters has been shown. The input and output impedances are compared by the following expression.

$$R_{in} = (1 - D^2) R_O \tag{10}$$

where D is the duty cycle, $R_{in}$ is the PV impedance and $R_o$ the load impedance.

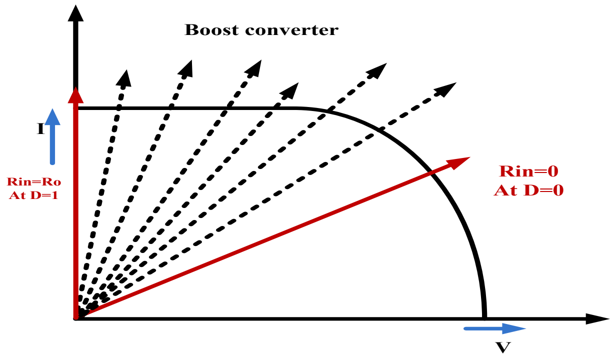



Fig. 4. Approximate range of $R_{in}$ for boost converter.

### A. *Perturb and Observe (P&O) Algorithm*

Among all the MPPT method for rapidly changing weather condition, simplicity, relatively, accuracy and rapid response P&O MPPT becoming more useful as compare to other MPPT techniques. P&O techniques says that in order to generate a reference signal for the outer control loop, a fixed perturb value is technologically advanced. The perturb signal can be either an array reference current or a voltage. “Fig. 5”, shows the flowchart of P&O method. The new perturbation direction can be fixed for the PV array output power for each and every cycle by comparing before and after the perturbation. By small perturbation, the PV output power can come closer to the MPP and also to the operating point into steady state. New perturbation direction can be decided by comparing previous and current PV output power. Perturbation size is diminished during tracking process. The perturbation size is initialized with 10% of open circuit voltage and it is cut up at each perturbation [13].

- If, ΔP*ΔV>0, the operating voltage must increase.
- While, ΔP*ΔV<0, the operating voltage must decrease.
- At, ΔP*ΔV=0, it’s the maximum power point.

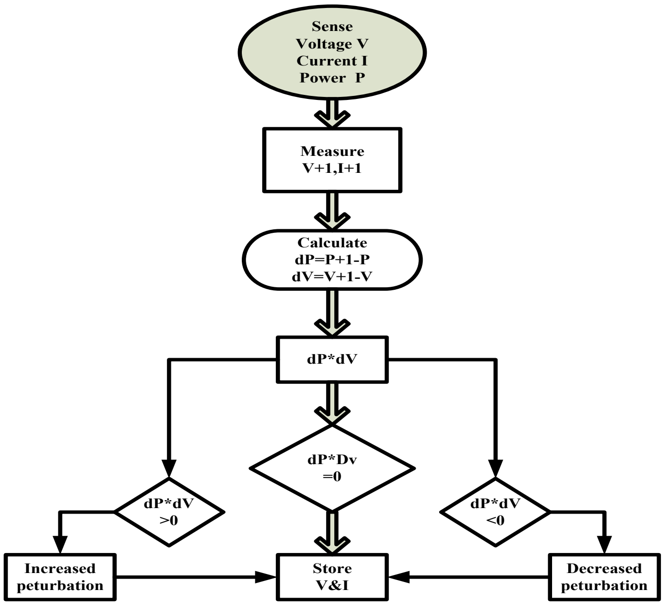



Fig. 5. The flowchart of P&O algorithm.

The changes in the operating voltage of a DC-DC converter have been done by varying a step size, ΔD (0.01) to the duty cycle D. The two parameters that are important in this model are the step size, ΔD and the time between iterations. Smaller the P&O step size, higher is the rate of accuracy and longer is the tracking time. Here our P&O algorithm reduced the perturbation if ΔP*ΔV <0 and increased the perturbation if ΔP*ΔV>0. We use a boost converter for the voltage shifting.

## IV. Proposed MPPT technique

Many MPPT techniques are actually used to extract the maximum power from the PV generator. In this section, the effectiveness of two different control algorithms is studied, which are P&O-PI and P&O-PI with SMO. The upcoming subsections will explain the used algorithms. “Fig. 6”, depicts the proposed MPP control used in this paper.

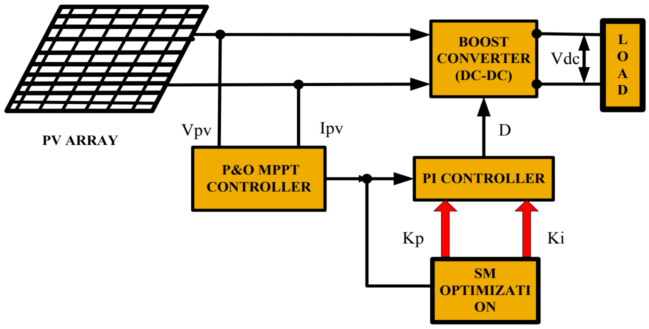



Fig. 6. Proposed MPPT controller.

### A. PI Controller

The PI controller expression for a continuous time system is given as:

$$U(t) = K_p e(t) + K_i \int_0^t e(t)dt \tag{11}$$

where e(t) is the system error between input and output, U(t) is PI controller generated control action, $K_p$ is the proportional gain and $K_i$ is the integral gain.

### B. Spider Monkey Optimization (SMO)

In the field of numerical optimization, swarm intelligence is one of the most difficult areas to work on for the researchers. Many algorithms have been developed by the researchers by doing simulations on the swarming behaviour of various creatures like ants, fish and birds. But a new optimization has been done in this paper that is based on the foraging behaviour of spider monkeys. Spider monkeys have been categorized as one of the fission fusion social structure based animals. Such type of animals usually follows fission fusion social systems where they themselves split from larger to smaller groups and vice versa depending on the scarcity or availability of food [14]. The proposed spider monkey optimization (SMO) algorithm is inspired by intelligent foraging behaviour of fission fusion social structure based animals, and the algorithm of SMO is given below:

- Assign all parameters: population, local leader (LL) limit, global leader (GL) limit, perturbation rate (pr).
- Compute fitness.
- Choose both local and global leaders using greedy selection.

**Do** till the stopping criterion isn't reached.

*1)* Generate the new position for every group members by using experience of self knowledge, local leader and group member's to find the objective for food source.

*2)* Apply greedy selection process between curent position and new position based on fitness and choose the superior one.

*3)* Determine the probability $p_j$ for entire group members using equation.

$$p_j = 0.9 * \frac{fitness_j}{fitness_{max}} + 0.1$$

*4)* Generate new position for entire group members, chosen by $p_j$,by using experience of self knowledge, global leader and group member's.

*5)* Update the local and global leader's new position by using greedy selection process for entire group.

*6)* If any local group leader position isn't updated after the local leader limit then all members of that particular group are redirected for foraging by local leader decision phase algorithm.

*7)* If any global group leader position isn't update after global leader limit then she splits the group in to smaller groups by global leader decision phase algorithm.

**End**

### C. Spider Monkey Based PI Optimization

Generally, the process of optimization focuses on finding out the controller parameters in order to optimize a given cost function of the system. The main aim of this work is to optimize the system under control by minimizing up to a suitable performance standard consisting of a spider monkey based PI controller and an unknown system. The effectiveness of the proposed spider monkey P&O-PI MPPT is computed by the following performance criteria. The performance criterion of the system is designed as follows.

### D. Objective Function

In order to find out the parameters of PV cell models, the cost function that is to be optimized must be defined. The root mean square error (RMSE) that is used as an objective function is written in "(12)" and the error between the measured value of current $I_{pv}$ and the calculated value has to be minimized by using "(7)" [15].

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n} f(I_{pv}, V_{pv}, Y)} \tag{12}$$

n is the number of measured I-V data, each solution is represented by the vector Y, for the single diode model $Y = [I_{ph}, I_0, d, R_s, R_{sh}]$ as defined in "(13)".

$$f(I_{pv}, V_{PV}, Y) = I_{ph} - I_0[\exp(q(V_{pv} + I_{pv}R_s)/kTd) - 1] - (V_{pv} + I_{pv}R_s)/R_{sh} \tag{13}$$

## V. Simulation Results

The proposed MPPT method has been compared with P&O-PI MPPT at various atmospheric conditions and the results shows that the proposed MPPT method used for the PV simulation system tracks the maximum power effectively and accurately. MATLAB/Simulink has been used for simulation. The gating signal that is used to drive the switch of boost converter is nothing but the output of the MPPT control block.

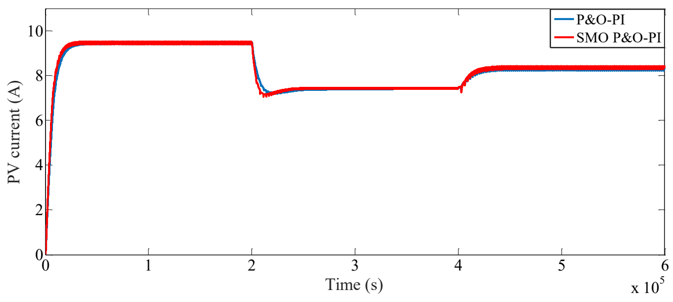



Fig. 7(a). Comparison between PV output current of P&O-PI and SMO P&O-PI MPPT controller.

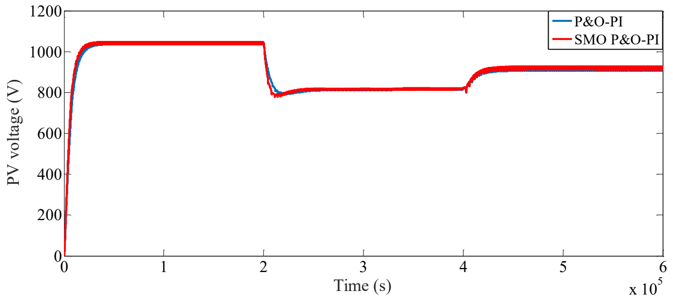



Fig. 7(b). Comparison between PV output voltage of P&O-PI and SMO P&O-PI MPPT controller.

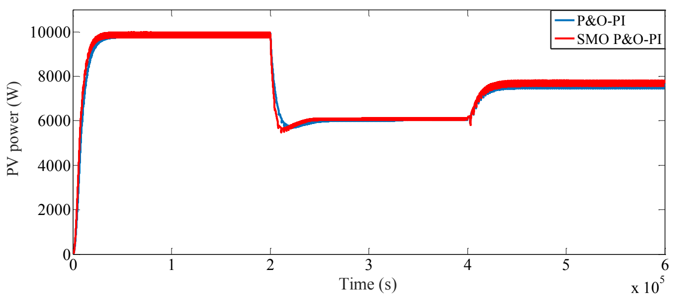



Fig. 7(c). Comparison between PV output power of P&O-PI and SMO P&O-PI MPPT controller.

In this above comparison the output voltage, current and power results graph clearly show that the proposed method works effectively to maximize the stability of the voltage and reduce fluctuation, power and current of a PV system. It is observed in Fig. "7(a)", "7(b)" and "7(c)" that by optimizing gain value $K_p$ and $K_i$ of PI controller by SMO give better tracking with less steady state oscillation.

TABLE II. GAIN OF PI CONTROLLER

| **MPPT Technique** | **$K_p$** | **$K_i$** |
|---|---|---|
| P&O-PI | 0.5 | 0.03 |
| SMO P&O-PI | 2.5 | 0.116 |

## VI. CONCLUSION

In this paper, the performance of the traditional P&O MPPT technique has been improved by the optimized PI controller that has been designed. The optimization is based on the spider monkey algorithm and a good response has been achieved by the enhanced controller for different atmospheric condition. The MPPT technique that has been proposed is very easy to implement. It has a good convergence property and an efficient searching ability for the optimal MPP in the PV power voltage curve.

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