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# Sliding Mode based PSO MPPT for Solar PV System

***Abstract**. This paper presents a novel Sliding Mode based Particle Swarm Optimization (PSO) Maximum Power Point Tracking (MPPT) algorithm for Solar Photovoltaic (PV) systems. The proposed algorithm aims to optimize the power output of the PV system by continuously tracking and maintaining the maximum power point (MPP) under varying environmental conditions. the proposed algorithm shows superior robustness against variations in solar radiation and temperature, making it suitable for real-world applications. The effectiveness of the algorithm is verified through comparative analysis with other existing MPPT techniques, validating its superiority in achieving optimal power generation for Solar PV systems.*

***Streszczenie.** W artykule przedstawiono nowy algorytm śledzenia maksymalnego punktu mocy (MPPT) oparty na trybie przesuwania dla systemów fotowoltaicznych (PV). Proponowany algorytm ma na celu optymalizację mocy wyjściowej systemu fotowoltaicznego poprzez ciągłe śledzenie i utrzymywanie punktu maksymalnej mocy (MPP) w różnych warunkach środowiskowych. proponowany algorytm wykazuje doskonałą odporność na zmiany promieniowania słonecznego i temperatury, dzięki czemu nadaje się do zastosowań w świecie rzeczywistym. Skuteczność algorytmu jest weryfikowana poprzez analizę porównawczą z innymi istniejącymi technikami MPPT, potwierdzającą jego wyższość w osiąganiu optymalnego wytwarzania energii dla systemów fotowoltaicznych. (**PSO MPPT oparty na trybie ślizgowym dla systemu fotowoltaicznego**)*

**Keywords:** Maximum Power Point Tracking (MPPT), Sliding Mode Control, Particle Swarm Optimization (PSO), Solar Photovoltaic (PV) System
**Słowa kluczowe:** Śledzenie maksymalnego punktu mocy (MPPT), sterowanie trybem ślizgowym, optymalizacja roju cząstek (PSO), system fotowoltaiczny (PV)

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## Introduction

After a dramatic growth in the usage of electrical systems, one of the most important areas of research for this century will be the study of energy resources and how they are used. It has been discovered that one of the more extensively utilised types of energy is renewable energy.The use of renewable energy systems gives rise to a wide variety of problems. The efficiency of solar panels, as well as reaching their full potential efficiency, is one of the most significant challenges. To solve the issue, it is necessary to make sure that the design of every component of the photovoltaic system is as good as it can be [1].For the purpose of maximising the amount of power that can be extracted, it is essential to optimise the DC/DC converters that are utilised as the scheme in the middle between the photovoltaic (PV) generator and the load. Therefore, it causes the GPV to function at its utmost capacity. As a consequence, it is able to provide the highest possible electric current despite the variable loads and environmental circumstances. Many researchers will find this to be helpful in their efforts to further the development of photovoltaic (PV) systems that can collect solar power and transform it into electricity. As a consequence of this, several suggested methods have been presented in order to estimate and evaluate various MPPT algorithms under a variety of meteorological situations. These strategies are able to be categorised based on the degree of difficulty involved in their execution, as well as the rate of converging and the precision of the monitoring system [5].

## Proposed System

Figure 1 is an illustration of the schematic representation of the Sliding Mode based PSO MPPT (MPPT) for a Solar PV System. The diagram highlights the key components and their interconnections in the planned MPPT algorithm. The PV system is the primary input to the block diagram, which comprises of the PV panels, a DC-DC converter, and a load. The solar panels convert solar radiation into electrical energy, which is then fed to the DC-DC converter. The DC-DC converter adjusts the voltage and current levels to match the load requirements. The Sliding Mode Control block is an essential component of the MPPT algorithm. It continuously monitors the operating conditions and calculates the sliding surface, which represents the deviation between the actual power output and the maximum power point (MPP) reference. The sliding surface is utilized to generate the control signal that drives the DC-DC converter towards the MPP. The Particle Swarm Optimization (PSO) block is responsible for optimizing the control signal generated by the sliding mode controller. It employs a population-based optimization technique, where a group of particles iteratively searches for the optimal control parameters. The PSO algorithm updates the particle positions based on their individual and collective experiences, aiming to converge towards the optimal solution. The MPPT Controller block integrates the outputs of the sliding mode controller and the PSO algorithm to generate the final control signal. It combines the advantages of both techniques to achieve accurate and robust MPP tracking The electrical output of the MPPT Controller is fed to the DC-DC converter, which then adjusts the current and voltage levels in order to continue the operation of the PV system at the MPP. Finally, the electrical energy is supplied to the load, enabling efficient power utilization. The block diagram demonstrates the sequential flow of operations in the Sliding Mode based PSO MPPT algorithm, showcasing its ability to optimize power extraction from solar panels and enhance the performance of Solar PV systems

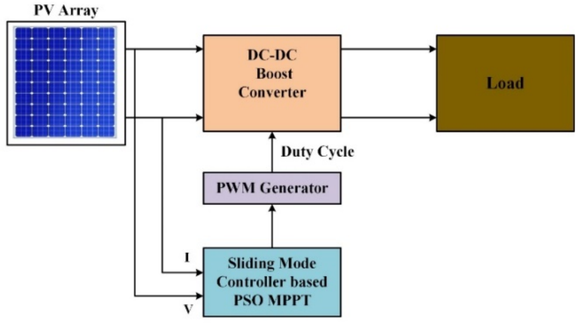



Fig.1. Schematic representation of the SMC based PSO MPPT

**PV Array**

When a solar cell is exposed to sunshine, the light energy that strikes it is converted into an electrical charge. This is the fundamental concept that underpins the operation of solar photovoltaic systems. The similar representation of a solar photovoltaic (PV) system that resembles the sole diode model is shown in Figure.2. It is composed of a photo current referred to as Iph that vary with the temperature and irradiance, an array of resistance that stands in for the resistance within the device that is the root cause of the passage of current I, and a shunt resistance that defines the movement of a current known as Ish, which is a current that leaks. Additionally, it has a parallel resistance that represents in for the internal resistance that is the lead to of the flow of current I [9]-[10]. The following presents the mathematical formulas for the load current, photo current, and any additional equations that are pertinent to the discussion

(1) $I = I_{ph} - I_o - I_{sh}$

(2) $I_{ph} = [I_{sc} + K_i(T_k - T)] \times \frac{G}{1000}$

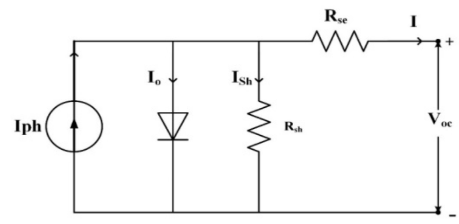



Fig.2. Equivalent Circuit of PV Cell

(3) $I_{RS} = \frac{I_{sc}}{[\exp\left(q \times \frac{V_{oc}}{N_S} \times k \times A \times T\right) - 1}$

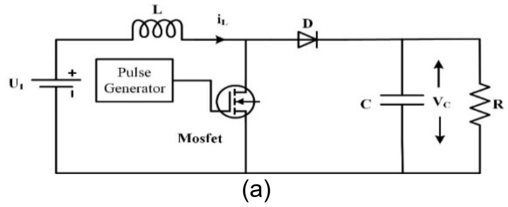
(4) $I_o = I_{RS}[\frac{T}{T_r}^3]exp\left[\frac{q \times E_{go}}{Ak}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right]$

(5) $I_{PV} = N_p \times I_{ph} - N_p \times I_o\left[\exp\left\{\frac{q \times V_{PV} + I_{PV}R_{se}}{N_S \times AkT}\right\} - 1\right]$

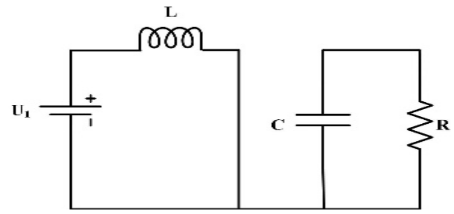
where $I_{PV}$ stands for the photo current of the diode measured in (A), $I_0$ stands for the opposite saturation current diode's reverse saturation current measured in (A), and $I_{sh}$ stands for the current leakage of the diode measured in (A). $I_{sc}$ is the short circuit current measured in amps, q is the electron charge, k is the Boltzmann constant, A is the diode ideality factor, T is the junction emperature measured in kelvins, NP is the number of cells linked in parallel, and Ns is the number of cells linked in series. All of these values are denoted using the letter "A." Vpv is the voltage across a diode measured in volts, whereas Voc is the voltage across an open circuit measured in volts.

**Boost converter**

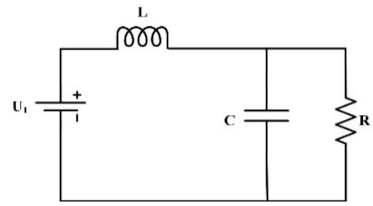
Figure 3 illustrates the basic boost converter circuit as well as its 'ON' and 'OFF' state circuits respectively.




(a)




(b)




(c)

Fig.3 a) Fundamental Circuit of Boost converter b) ON State Equivalent Circuit c) OFF State Equivalent Circuit

When in the 'ON' state, the inductor receives a charge through the u1 value described in equation (6). When the circuit is in this condition, where iL has been specified as being zero, there is no flow of current to the capacitor or the resistor.

(6) $u_1 = L\frac{di_L}{dt}$

(7) $0 = C\frac{dV_C}{dt} + \frac{V_C}{R}$ (7)

It is possible to derive the state derivative of x1' and x2' in equations (8) and (9) by rearrangement of the components in equations (6) and (7). Using equations (8) and (9), one can build the state space matrix A and B that is used in (10) for a boost converter that is in the "ON" state.

(8) $x_1' = \frac{1}{L}u_1$

(9) $x_2' = -\frac{x_2}{RC}$

(10) $\begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}u_1$

The analogue circuit of the boost converter's circuit is exactly the same as that of a Buck converter when it is in the "ON" state. As a result, the state space matrices A and B for the 'OFF' state of a boost converter is comparable to that of a buck converter. In a similar fashion, the formula for the average value of the converter state space A and B matrix for its 'ON' and 'OFF' state may be constructed with the switching duty cycle d taken into consideration. The arithmetic mean of the A and B matrices are shown at 11 and 12, respectively.

$$\bar{A} = A_{(ON)} + A_{(OFF)}(1-d)$$

(11) $\bar{A} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix}d + \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}(1\text{-d}) = \begin{bmatrix} 0 & -\frac{1-d}{L} \\ \frac{1-d}{C} & -\frac{1}{RC} \end{bmatrix}$

(12) $\bar{B} = B_{(ON)} + B_{(OFF)}(1-d)$

$$\bar{B} = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}d + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}(1-d) = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$$

To finish up the boost converter model, we are going to insert the average matrix from equations 11 and 12 into equation 1. The finished modelling of the boost converter may be seen in equation (13).

(13) $\begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{(1-d)}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} u_1$

In order to acquire the output state of VC and iL, the output state space for C and D matrices should be analogous to the expression (13).

**MPP Control Strategy**

Maximum Power Point Control, often known as MPPT, is a technique that is utilised in solar power systems in order to maximise the amount of electricity that may be drawn from photovoltaic panels. It does this by making dynamic adjustments to the load impedance in order to maintain the panels' ability to function at their maximum power point (MPP) in spite of changes in external circumstances such as temperature and the amount of sunshine that is present. The MPPT algorithm continually monitors and changes the voltage at which it operates and current to meet the MPP. This matches the MPP, which increases the efficiency of the system and maximises the energy harvest. The Maximum Power Point Tracking (MPPT) technology provides optimum power production and enhances the overall efficiency of PV systems by keeping the panels at their MPP.

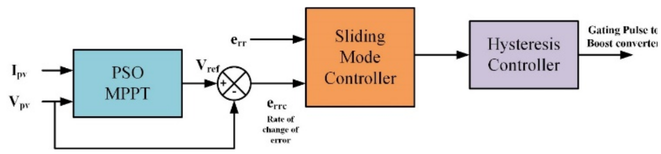



Fig.4. PSO MPPT & Sliding Control Strategy

**PSO MPPT**

The PSO method is a bio-inspired method that is created on the social behaviour of animals. The procedure starts with an assortment of random particles, each of which represents a possible resolution. This will continue until the problem has been solved. The history of individual and communal events, or the experiences of both each individual particle and the population as a whole, are taken into justification by update equations in order to modify the velocity of each individual particle. These equations take into account the history of both the individual particles and the population as a whole.

The primary objective is to design the particles in such a way that they will proactively explore throughout the search space for the most appropriate response. The method uses a fitness function to estimate the performance of each particle at the end of each iteration. The programme then modifies the velocity of each particle such that it corresponds to both the particle's best performance up to that point ($P_{best}$) as well as the highest average score of all other particles ($G_{best}$). The topological layout of the algorithm, which refers to the method in which the particles communicate with one another, is an essential module that play an important role in the algorithm's overall efficiency. The usual PSO method may be defined with the help of the equations that are provided below.

(14) $v_i(k+1) = wv_i(k) + c_1r_1.\left(P_{best} - x_i(k)\right) + c_2r_2.\left(g_{best} - x_i(k)\right)$

(15) $x_i(k+1) = x_i(k) + v_i(k+1)$

i= 1,2,3……, N

In this equation, xi and vi represent the velocity and location of particle I, correspondingly; k signifies the number of iterations; w represents the inertia weight; r1 and r2 are arbitrary variable quantity whose values are unvaryingly distributed within the range [0, 1]; and c1 and c2 signify the reasoning and communal coefficients, respectively. The optimal location of particle i is denoted by the symbol $p_{best}$, but the best place for the whole swarm is denoted by the symbol gbest, i

(16) $p_{besti} = x_{ik}$

(17) $f(x_{ik}) > f(p_{besti})$

where f stands for an objective function that has to be optimised to its full potential.

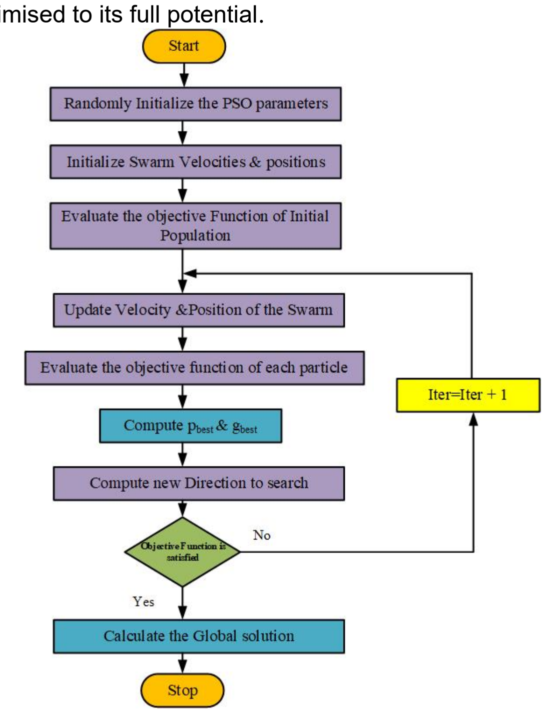



Fig.5. Flowchart of Particle swarm optimization MPPT

**Sliding Mode control MPPT**

Sliding mode control is an instance of dynamic structure control, which is one of the primary families of control rules [3]. Sliding mode control was developed in the 1950s. In most cases, the needed modifications to the structure are made by an element in the structure control system via the process of switching at the controller. This method's purpose is to ensure that the path of the scheme is constrained by means of discontinuous control so that it may develop and remain, for an extended period of time, on a surface referred to as the "sliding surface," (x), where the ensuing behaviour is in accordance with a anticipated dynamic. SMC is a kind of nonlinear control that is used mostly for systems with changeable structure. As a result, the sli1ding mode command has been introduced to our arsenal. Therefore, the output voltage is denoted by x2, while the intended output voltage is denoted by K. The sliding surface is specified in the state space by the x2 = K, and it corresponds to the control surface of the sliding mode that is denoted by., the sliding surface may be defined as having

(18) $\dot{x_2} < 0 \; if \; x_2 > k$

(19) $\dot{x_2} > 0 \; if \; x_2 > k$

Equation 20 is a useful tool for defining the route that a first-order system will take. As a direct result of this, the rate of converging will be regulated.

(20) $\dot{x_2} = -\lambda\,(x_2 - k)$

By combining the information in the preceding paragraphs, we are able to locate our service sequence equation d, which enables us to regulate the output variable. The boost chopper's duty cycle will be denoted by the letter d.

(21) $d(t) = 1 - \frac{v_{pv} + \sqrt{v_{pv}{}^2 + a x_2 (x_2 - k)}}{2x_2}$

Where

(22) $a = -4\lambda(LC\lambda - \frac{L}{R})$

After we have finished implementing the system on Simulink, which gives us the opportunity to evaluate the system's speed and resilience, we will continue. It has a high degree of consistency even while operating in a steady state and is very effective [4]. The sliding mode control is an easy way to build, and it is resilient despite the fact that disturbances are present in the system. The most significant qualities of this approach are as follows

- The dynamic behaviour of the system was made possible by the selection of the switching strategy. A reaction from the closed loop that is unresponsive to disturbances and changes in the parameters (this ensures the resilience of the system)..
- Depending on the circumstances, the choice of the location is rather extensive.
- It is quick while at the same time having the potential to develop into an unstable condition.

**Simulation Results**

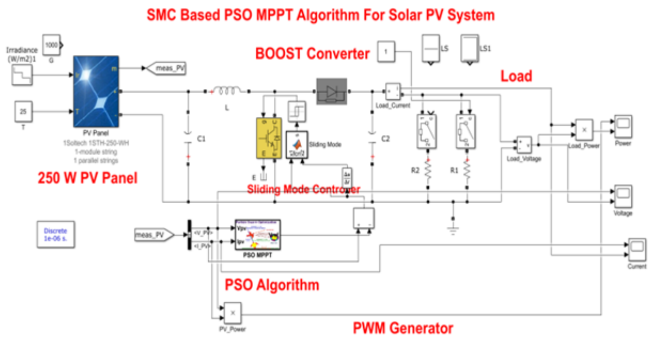



Fig.6. PSO Sliding Mode MPPT for PV system

Using the software MATLAB Simulink, a simulation model of a PSO-based sliding mode Maximum Power Point Tracking (MPPT) driven solar PV system was constructed. A boost converter is used to link the photovoltaic system, which has a rating of 250 watts and runs at a voltage of 29 volts, to the load. The outcomes of the simulation were studied for a number of different scenarios. Figure 6 depicts the PSO Sliding mode MPPT controller of the PV scheme as it appears in the Simulink modelling environment.

The irradiance level of the photovoltaic (PV) system undergoes periodic changes every 0.2 seconds. Specifically, for the first 0.2 seconds, the irradiance is set at 1000 W/m². From 0.2 to 0.4 seconds, it decreases to 800 W/m², and from 0.4 to 0.6 seconds, it further decreases to 600 W/m². During each time interval, the corresponding measurements of PV voltage, current, power, load voltage, current, and power are recorded and analyzed using the Particle Swarm Optimization (PSO) sliding mode MPPT algorithm.To visually represent the data, Figure 7 displays the variations in PV and load voltage over time. Figure 8 illustrates the changes in PV and load current, while Figure 9 depicts the fluctuations in PV and load power. These figures provide a graphical representation of the dynamic behavior of the PV system and its associated load under the varying irradiance conditions. Analyzing these figures enables a better understanding of the system's performance and helps optimize the MPPT control strategy for improved power generation and efficiency

Tale.1. Performance of the PSO Sliding mode MPPT

| Irradiance | Voltage (V) | | Current (A) | | Power (W) | |
|---|---|---|---|---|---|---|
| | PV | Load | PV | Load | PV | Load |
| 1000 | 31 | 120 | 8.06 | 2.04 | 250 | 245 |
| 800 | 30.5 | 110 | 6.55 | 1.77 | 200 | 195 |
| 600 | 30.2 | 90 | 4.96 | 1.61 | 150 | 145 |

Table 1 shows the performance of a PSO sliding mode Maximum Power Point Tracking (MPPT) method under varying irradiance conditions. The table provides detailed information on voltage, current, and output power for both the photovoltaic panel and the load connected to it. The first column of the table represents the irradiance levels in units of W/m². Irradiance is a measure of the solar energy incident on the PV panel's surface and has a direct impact on the system's performance. The table examines three irradiance levels: 1000 W/m², 800 W/m², and 600 W/m². The second and third columns display the voltage values for the PV panel and the load, respectively, measured in volts (V). The voltage indicates the electrical potential difference across the components and plays a crucial role in determining power generation and consumption.

The fourth and fifth columns present the current values for the PV panel and the load, respectively, measured in amperes (A). Current represents the flow of electric charge and influences the power generation and consumption within the system. The final two columns provide the output power for both the PV panel and the load in units of watts (W). Power is the product of voltage and current and represents the actual electrical energy being generated or consumed. For each irradiance level, the corresponding values of voltage, current, and power are recorded for both the oad and the Photovoltaic system. This data allows for an analysis of the system's performance and efficiency under different irradiance conditions.

Analyzing the table, we observe that as the irradiance reduce from 1000 W/m² to 600 W/m², the voltage values for both the PV panel and the load show a slight decrease. This decrease in voltage can be attributed to the reduced availability of solar energy. Additionally, the current values for both components also decrease, indicating a decrease in the flow of electric charge. The power output for the PV panel follows a similar trend, decreasing as the irradiance level decreases. This reduction in power output is expected since the PV panel generates electricity based on the incident solar energy.

Consequently, the power output for the load also decreases accordingly. Overall, the table demonstrates how the PSO sliding mode MPPT system performs under varying irradiance conditions.

The recorded values of voltage, current, and power allow for a comprehensive evaluation of the system's efficiency and effectiveness in maximizing power generation and ensuring optimal performance. By analyzing this data, researchers and engineers can further enhance the design and control strategies of MPPT systems to improve their performance under different operating conditions, leading to increased energy harvesting from solar sources.

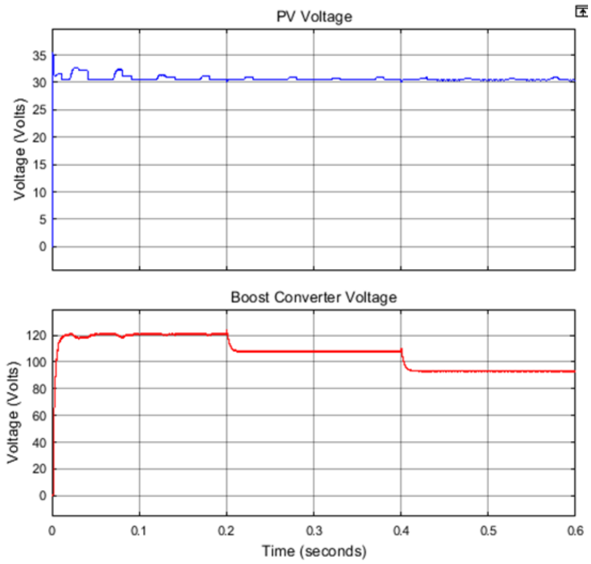



Fig.7. PV Voltage and Load Voltage

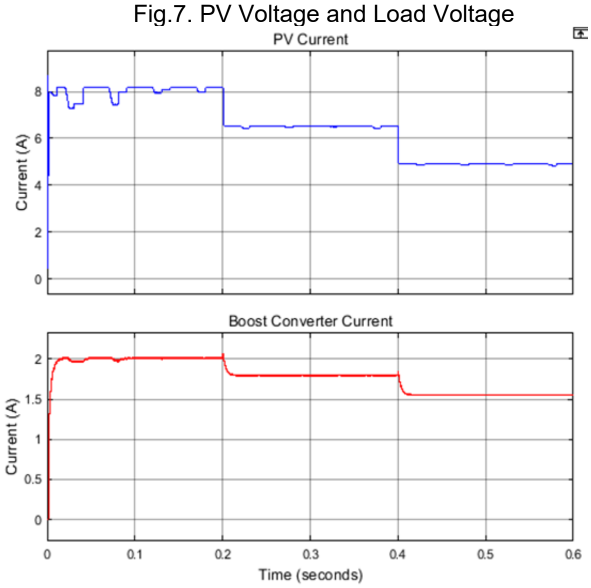



Fig.8. PV Current and Load current

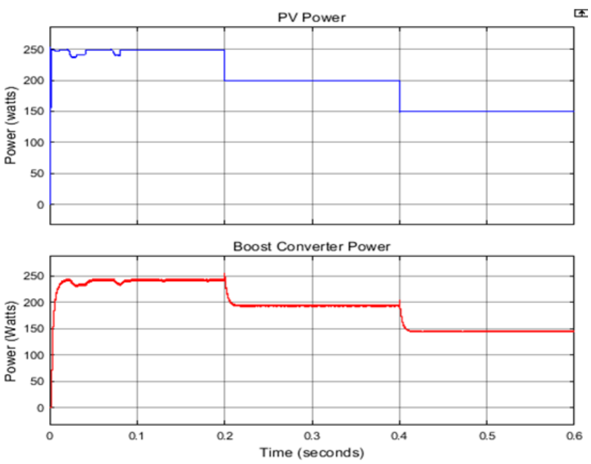



Fig.9 PV Power and Load power

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**Conclusion**

In conclusion, this study proposed a novel Sliding Mode based Particle Swarm Optimization (PSO) Maximum Power Point Tracking (MPPT) algorithm for Solar PV systems. The algorithm combines the robustness of sliding mode control with the optimization capabilities of PSO to achieve efficient and precise chasing of the maximum power point (MPP) under varying ecological conditions. The simulation results demonstrated that the proposed algorithm outclasses conventional MPPT techniques in terms of tracking accuracy, response time, stability, and steady-state error reduction. It effectively adapts to changes in solar radiation and temperature, making it suitable for real-world applications By continuously adjusting the functioning point of the PV system, the algorithm maximizes power extraction from the solar panels, resulting in improved energy conversion efficiency. The integration of sliding mode control and PSO provides a robust and efficient solution for achieving optimal power generation in Solar PV systems. The proposed algorithm contributes to the advancement of MPPT techniques, offering a promising approach to improve the presentation and reliability of Solar PV systems. Future research can focus on implementing the algorithm in hardware prototypes and conducting field tests to validate its effectiveness in practical applications.

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