

## Sliding Mode Control based Maximum Power Point Tracking of PV System

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**Abstract:** Solar Energy is the clean and renewable source of energy. Solar PV systems are gaining attraction for energy generation in these days of increasing energy demand due to its reducing cost and new researches carried on its efficient use. The solar cell is always operated at its Maximum Power Point for better results. There are different methods to search the maximum power point of PV system. In this paper, a Maximum Power Point Tracking method for Solar PV system using Sliding Mode Control is proposed. The PV system modeling practice under standard test conditions is discussed. The proposed controller strategy is robust technology in steady state and during varying environmental conditions. A DC/DC boost converter is utilized as a control actuator for the MPP tracking using PWM control on the switches. Simulation results in MATLAB/SIMULINK and discussion are provided to demonstrate the effectiveness of the proposed controller design.

**Keywords:** Solar PV System, Maximum Power Point Tracking, Sliding Mode Control, Boost Converter, PWM (Pulse Width Modulation).

### I. Introduction

In today's life, electricity plays an important role. In electrical power system, consumers require uninterrupted power at rated frequency and voltage. Due to advantages of electrical energy over other energy sources, its demand is increasing rapidly. But due to limits of available conventional energy sources, we have to use the non-conventional energy sources effectively and efficiently to fulfil the increasing energy demands.

Solar energy is the clean and renewable source of energy. It is widely available and free. Solar energy offers a very promising alternative because it is free, abundant, pollution free and distributed throughout the earth. Electrical energy can be obtained from sun using Solar PV technology. The PV devices has many advantages as, i) short time for designing and installation, ii) matching of output power with peak load demand, iii) static structure as it doesn't contains any moving part [1].

A photovoltaic system directly converts energy from sunlight into electricity [2]. The basic element of PV system is the PV cell. The PV cell is a semiconductor device exposed to sunlight. The number of solar cells are connected in series and/or parallel to obtain the desired voltage and current and the grouping is called PV module. The number of modules are grouped together to form solar array. The voltage and current available at the terminals of PV devices can be directly fed to small loads such as calculators, DC motors, lamps etc [1]. Generally the output of PV system is processed using electronic converters for more sophisticated applications. For efficient use of PV system the PV cells are always operated at maximum power point.

Nowadays, more research works has been focussed on how to extract maximum power effectively from the PV cells. There are so many algorithms have been developed for extracting the maximum available power in the panel such as P&O method, Incremental conductance method, Fractional  $V_{oc}$  method, fractional  $I_{sc}$  method. There are two ways to extract such as using solar tracking system and Maximum Power Point Tracking (MPPT). The Maximum Power Point Tracking (MPPT) is usually used as online control strategy to track the maximum output power operating point of the Photovoltaic system for different operating conditions of insolation and temperature of the PV system. MPPT with the PV system increases the power extraction efficiency to 97%. There are several methods to determine the Maximum Power Point of PV cell and control the converter output corresponding to the MPP (Maximum Power Point) to extract maximum power from cell. In this paper a Sliding Mode Controller based MPPT method is discussed.

### II. Modeling of PV System

The basic unit of PV system is solar cell or PV cell. An individual solar cell produces direct current and power typically between 1 and 2 Watts, hardly enough to power most applications [5]. The numbers of pre-wired cells are connected in series to form a PV module. Modules are then connected in series to increase the voltage rating and in parallel to increase the current rating. Such a series and parallel combination of modules are called PV array [1]. The general structure of PV array is shown in Figure 1. Solar Cell or Photovoltaic (PV) cell is a device that is made up of semiconductor materials such as silicon, gallium arsenide and cadmium telluride, etc. that converts sunlight directly into electricity. The voltage of a solar cell does not depend strongly

on the solar irradiance but depends primarily on the cell temperature [5]. PV modules can be designed to operate at different voltages by connecting solar cells in series. When solar cells absorb sunlight, free electrons and holes are created at positive/negative junctions.

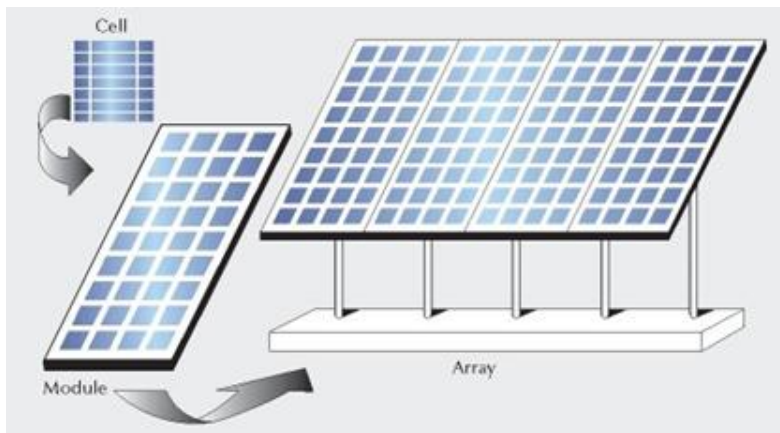


Fig. 1 General Structure of PV Array

If the positive and negative junctions of solar cell are connected to DC electrical equipment, current is delivered to operate the electrical equipment. The behaviour of PV cell can be shown by its equivalent circuit. Various equivalent circuits of the PV cell are shown in Figure 2.

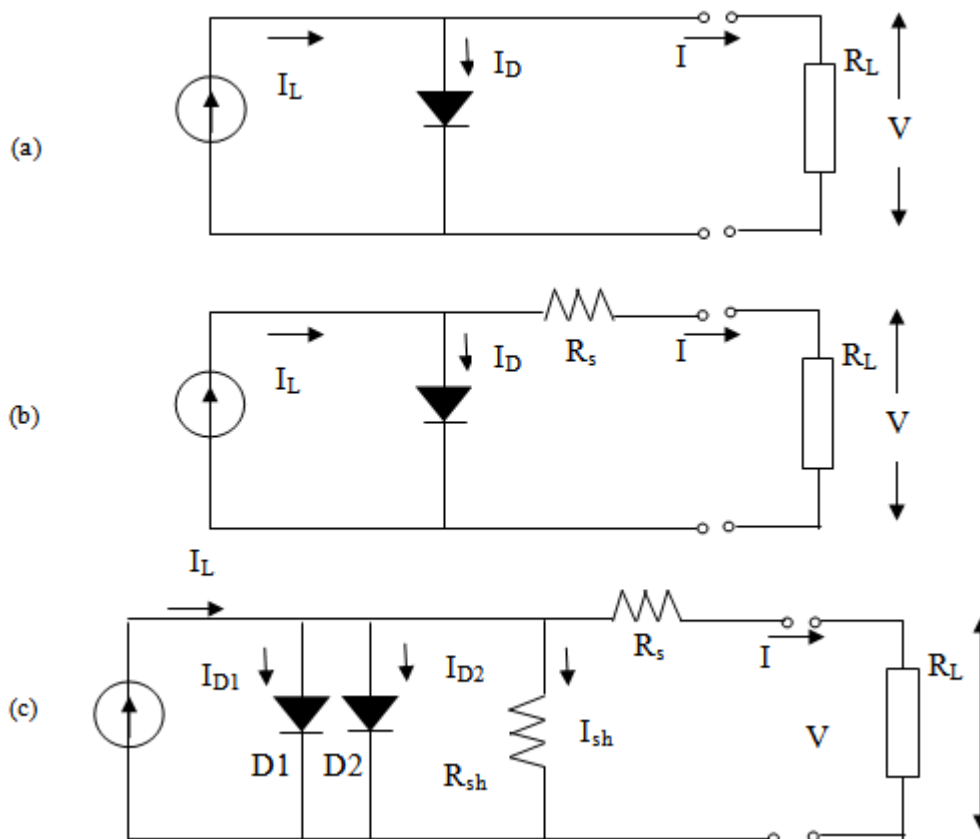


Fig. 2 Equivalent circuit of PV model (a) Ideal model (b) Single diode model (c) Double diode model

The ideal model of PV module as shown in Figure 2(a) does not include the parasitic resistances accounted for the cells power loss. The single-diode model in Figure 2(b) is the traditional PV model known as the five parameters model. The double-diode model as shown in Figure 2(c) is having better accuracy [3] [4] because it takes into account some physical phenomena of semiconductor, viz., charge diffusion and recombination in the space charge layer.

In the generalized model of PV module as shown in Figure 2, the current source is used to model the incident solar irradiance, a diode for the polarization phenomena, a series and parallel resistances to represent the power losses [1]. The mathematical equations describing the behaviour of cases in Figure 2 are given respectively by the equation (1) - (3) as:

$$I = I_{ph} - I_{sat} \left( e^{\frac{V}{N_s A V_T}} - 1 \right) \quad (1)$$

Where,

$$I_D = I_{sat} \left( e^{\frac{V}{N_s A V_T}} - 1 \right)$$

$$I = I_{ph} - I_{sat} \left( e^{\frac{V+I R_S}{N_s A V_T}} - 1 \right) - \frac{V+I R_S}{R_p} \quad (2)$$

$$I = I_{ph} - I_{sat_1} \left( e^{\frac{V+I R_S}{N_s V_T}} - 1 \right) - I_{sat_2} \left( e^{\frac{V+I R_S}{N_s 2 V_T}} - 1 \right) - \frac{V+I R_S}{R_p} \quad (3)$$

Where,

- I : Terminal current of PV module (A)
- $I_{ph}$  : Photo generated current (A)
- $I_{sat}$  : Saturation current of Diode (A)
- V : Terminal voltage of PV module (V)
- $R_S$  : Equivalent series resistance of PV module ( $\Omega$ )
- $R_p$  : Equivalent parallel resistance of PV module ( $\Omega$ )
- A : Diode ideality factor
- $N_s$  : Number of cells connected in series in PV module
- $V_T$  : Diode thermal voltage  $= \frac{kT}{q}$
- k : Boltz Mann's constant  $= 1.3806503 \times 10^{-23}$  J/K
- T : Temperature ( $^{\circ}$ K)
- q : Charge of electron  $= 1.602 \times 10^{-19}$  C

Among above three models the single diode model is simple for modelling of PV system. This model provides more accurate results with simplicity [2].

A typical I-V and P-V characteristics of a PV module at certain solar irradiation G and temperature T are shown in Figure 3 and Figure 4 respectively.

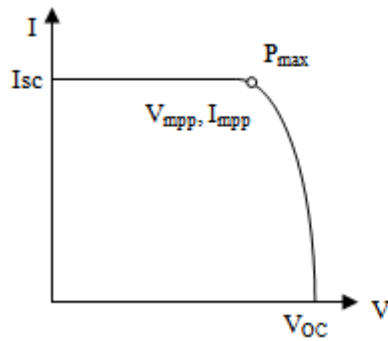


Fig. 3 I-V characteristics of PV model

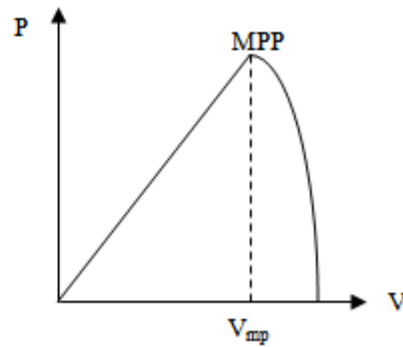


Fig. 4 P-V characteristics of PV model

The PV modules are characterized by the some important parameters such as:

1. Short circuit current ( $I_{sc}$ ): The maximum value of the generated current when the terminals of PV module are short circuited i.e  $V=0$ . While modelling any PV system generally it is assumed that,  $I_{sc} \approx I_{ph}$ .
2. Open circuit voltage ( $V_{oc}$ ): The terminal voltage of PV module with open terminals i.e  $I=0$ .
3. Maximum Power Point: this is the point at which the power generated is maximum i.e  $P_{max}$ . The voltage corresponding to MPP is  $V = V_{mp}$  and the current corresponding to MPP is  $I = I_{mp}$ .

The short circuit current and open circuit voltages are given by:

$$I_{sc}(G) = \left( \frac{G}{G_{stc}} \right) I_{sc}(G_{stc}) \quad (4)$$

$$(G) = V_{oc}(G_{stc}) + N_s G V_T \log \left( \frac{G}{G_{stc}} \right) \quad (5)$$

Here G is the solar irradiance, hence from above equations 4 and 5 the performance of PV module can be affected by change in irradiance.

### III. Control Strategy

There are different techniques of extracting Maximum Power from PV array as Hill Climbing or Perturb and Observe, Incremental Conductance, Fractional Open Circuit Voltage method, Fractional Short Circuit Current method etc. But they are having some limitations [2]. To get more accurate results the MPPT using Sliding Mode Controller is used here.

#### 3.1 PV System:

The general block diagram of control system is shown in Figure 5. The block diagram consisting of the PV array, DC-DC Boost Converter, SMC based MPPT Controller and load.

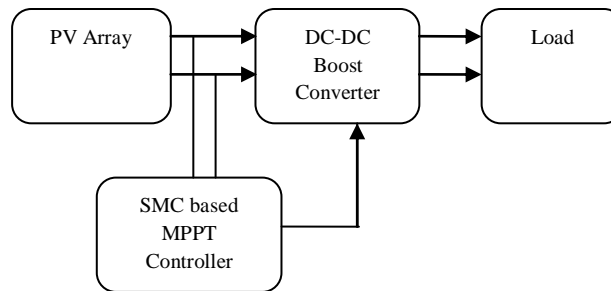


Fig.5 MPPT using Sliding Mode Control.

A single diode model of PV Module is used here as it is relatively simple compared to double diode model. The modelling of the PV module is done in MATLAB/Simulink using the following equations: The Terminal current of PV module is given as:

$$I_m = I_{pv} \cdot N_{pp} - \left\{ \left[ \left( \frac{N_{ss}}{N_{pp}} \cdot R_s \cdot I_{meas} + V_{meas} \right) \cdot \frac{V_{ta}}{N_{ss}} \right] - 1 \right\} \quad (6)$$

Where,

$$I_{pv} = I_{sh} \cdot \left( \frac{R_s + R_p}{R_p} \right) \quad (7)$$

The Open circuit current is given by:

$$I_o = \frac{K_i dT + I_{ph}}{\left[ e^{(V_{ocn} + K_v dT) \cdot V_{ta} - 1} \right]} \quad (8)$$

The data used for the PV model is as tabulated in Table.1.

**Table 1.** Parameters used in PV module

$I_{sh} = 2.55 \text{ A}$	$I_{mp} = 2.25 \text{ A}$	$K_v = -0.123$
$V_{oc} = 21.24 \text{ V}$	$V_{mp} = 16.56 \text{ V}$	$K_i = 0.00318$
$N_s = 36$	$N_{ss} = 2$	$N_{pp} = 2$
$R_p = 145.67 \ \Omega$	$R_s = 0.47 \ \Omega$	$k = 1.38065e^{-23} \text{ J/K}$
$q = 1.602e^{-19} \text{ C}$	$A = 1.5$	

#### 3.2 Sliding Mode Control:

The control algorithm using Sliding Mode Controller is used for Maximum Power extraction from PV Array at various operating conditions. This control strategy provides accurate estimation of point corresponding to maximum power on PV curve and helps to increase its efficiency.

The designing of SMC includes two main steps such as designing a Switching function called Sliding Surface and a Control law. The slope of PV characteristics is considered as a sliding surface  $s$ . The control law is designed to switch the duty cycle of Boost converter as per the requirement automatically. The control law used is:

$$u = \begin{cases} 1 & \text{if } s > 0 \\ 0 & \text{if } s < 0 \end{cases} \quad (9)$$

#### 3.3 Boost Converter:

A DC to DC boost converter is simply a power converter that regulates the average output voltage at a level higher than the input or source voltage. For this reason the boost converter is often referred to as a step-up converter or regulator. The general circuit of Boost Converter is shown in Figure 6.

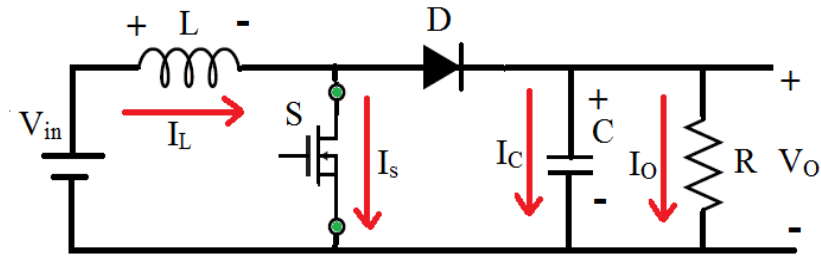


Fig.6 General Boost Converter

The DC input voltage is in series with a large inductor acting as a current source. A switch in parallel with the current source and the output is turned off periodically, providing energy from the inductor and the source to increase the average output voltage. The boost converter is commonly used in regulated DC power supplies.

In this paper the DC/DC converter is designed such that a dc link maintains a nearly constant voltage of 180V at the output of the converter as shown in Figure 6. The DC/DC boost converter parameters are designed based on the values of the input voltage from the PV module, 5% input ripple current, and switching frequency of 10 kHz. The dc voltage transfer function for the boost converter can be modelled by the static relation as:

$$V_{pv} = V_o(1 - D) \tag{10}$$

Where,

$V_{pv}$  is the voltage across the PV module that is changing with the irradiance variation,

$V_o$  is the nearly constant output voltage, and

$D$  is the duty ratio which serves as a control input or controller output.

Here the Sliding Mode Controller strategy adjusts the DC/DC converter duty ratio to steer the operating point to the maximum output power delivered from the PV module.

#### IV. Result

To demonstrate the performance of SMC based MPPT technique the SIMULINK model of a system is developed in MATLAB/Simulink and simulation results are obtained at various operating conditions.

At first, the simulation is run under Standard Test Condition with irradiance  $G=1000 \text{ W/m}^2$  and operating temperature of  $25^\circ\text{C}$ . The results obtained at STC are as shown in Figure 7.

Then the same model is simulated with irradiance changed from  $1000 \text{ W/m}^2$  to  $400 \text{ W/m}^2$  at time 1second. The results obtained are as shown in Figure 8.

Further to validate the robustness of control algorithm the same model is simulated with irradiance changed from  $1000 \text{ W/m}^2$  to  $600 \text{ W/m}^2$  at time 0.5 second and again changed from  $600 \text{ W/m}^2$  to  $1000 \text{ W/m}^2$  at 1 second. The results obtained are as shown in Figure 9.

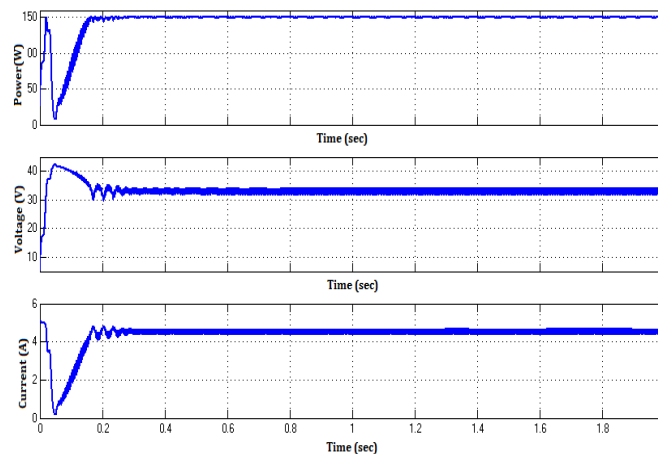


Fig. 7 PV system parameters under STC( $1000 \text{ W/m}^2$ )

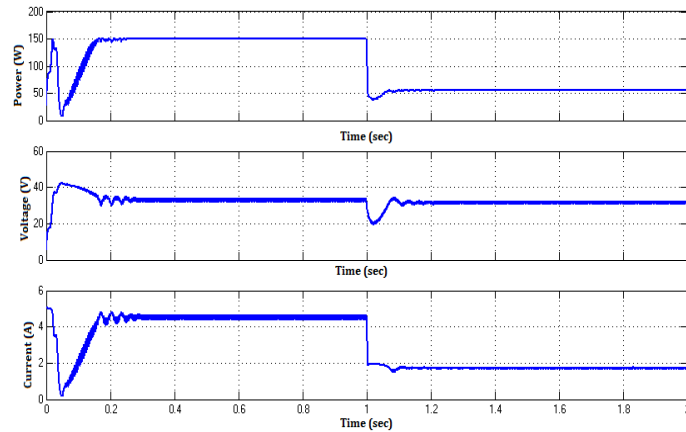


Fig. 8 PV system parameters under irradiance change from(1000 W/m<sup>2</sup>) to (400 W/m<sup>2</sup>)

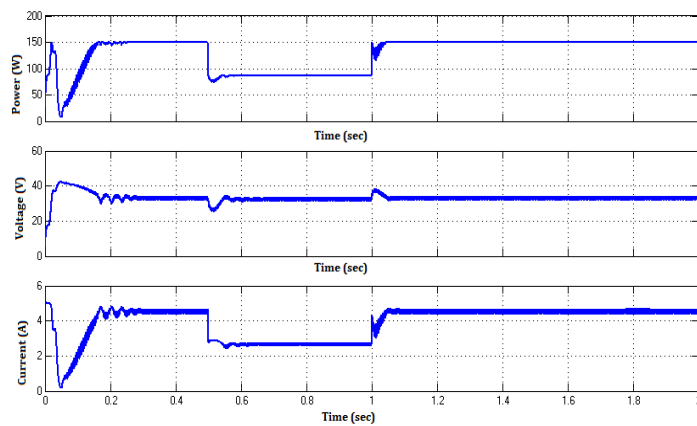


Fig. 9 PV system parameters under irradiance change From (1000 W/m<sup>2</sup>) to (400 W/m<sup>2</sup>) to (1000 W/m<sup>2</sup>)

## V. Conclusion

The results show the robustness of the proposed MPPT using SMC. The control law used in this paper is easily implemented and also it is clear that for this technique the exact model of system is not necessary.

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