Performance Analysis of Slide Mode Control based MPPT Controller for Photovoltaic Applications

Saravana selvan.D, Harikrishnan.V, Umayal.V, and Indumathy.M

***Abstract*—**Photovoltaic (PV) is a technical name in which radiant (photon) energy from the sun is converted to direct current (dc) Electrical Energy. Photovoltaic generators have a nonlinear voltage current characteristic with a unique Maximum Power Point (MPP), which depends on the temperature and irradiance condition. When these conditions are changed, the operating point and MPP will be changed. Therefore, maximum Power Point tracking (MPPT) controller is required to ensure that the maximum available power is obtained from the panel. In this paper, a sliding mode control is proposed by defining a new formulation for sliding surface which is based on Incremental conductance (IC) algorithm. IC method is functioned by using the slope of the derivative of the voltage with respect to the current in order to reach the maximum power point. It can be experimentally verified by modelling the PV system with the proposed MPPT algorithm in Matlab /Simulink Software. The stability and robustness of the proposed controller are investigated to load variations and environment changes.

***Keywords*---** PV Module, MPPT, Incremental Conductance (IC) Algorithm, Sliding Mode Control**.**

I. Introduction

SOLAR Energy is the ultimate source of energy, which is naturally replenished in a short time period of time, for this reason it is called "Renewable Energy" or "Sustainable Energy". Due to the severity of the global energy crisis and environmental pollution, the photovoltaic (PV) system has become one kind of important renewable energy source. Solar energy has the advantages of maximum reserve, inexhaustibleness, and is free from geographical restrictions, thus making PV technology a popular research topic. Currently more research works has been focussed on how to extract more power effectively from the PV cells. There are so many algorithms has been developed for extracting the maximum available power in the panel. Now a days a very efficient Incremental conductance algorithm is developed and implemented by so many researchers [1-2]. Among with this complex algorithm, artificial intelligence based Mppt controller have been reported in the literature [3-5].

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There are two ways such as solar tracking system and Maximum Power Point Tracking (MPPT) [6, 7]. In the literature survey show that there will be an increasing percentage of 30-40 % of energy will be extracted compared to the PV system without solar tracking system [8, 9]. The Maximum Power Point Tracking (MPPT) is usually used as online control strategy to track the maximum output power operating point of the Photovoltaic generation (PVG) for different operating condition of insolation and temperature of the PVG. The author [10, 11] compares and evaluates the percentage of power extraction with MPPT and without MPPT. It clearly shows that when we use MPPT with the PV system, the power extraction efficiency is increase to 97%. The study of developing a PV charging system for Li-ion batteries by integrating MPPT and charging control for the battery is reviewed [12]. The author [13] reviews the various types of non isolated Dc-Dc converters for the photo voltaic system. Optimal operating performances by different converter topologies are one of the main points which can be summarized in this research work. [13] It concludes that the best type of converter for PV system is the buck-boost Dc/Dc converter. The overall block diagram of PV panel with Dc-Dc converter and MPPT is shown in Fig.1

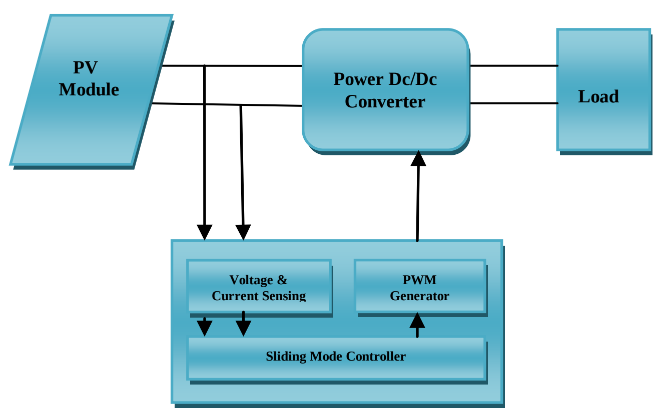

Fig.1 Overall Block Diagram

This paper reviews the basic characteristics of the PV cell and the simulation model of the circuit with the help of Matlab/simulink software. The MPPT Controller is necessary for any solar systems need to extract maximum power from PV module. It forces PV module to operate at close to maximum power operation point to draw maximum available power. The MPPT algorithm used in this paper is of slide mode control based fixed step size Incremental Conductance (IC) Method. But the optimal performance of the PV system mainly depends on the power converter. The simulation model of the PV based system with slide mode MPPT controller will be implemented in the Matlab/Simulink.

II. MODELING OF PV CELL

The solar cell is the basic unit of a PV system. An individual solar cell produces direct current and power typically between 1 and 2 W, hardly enough to power most applications. 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. 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. If the positive and negative junctions of solar cell are connected to DC electrical equipment, current is delivered to operate the electrical equipment. The equivalent circuit of the PV cell is shown in fig. 2

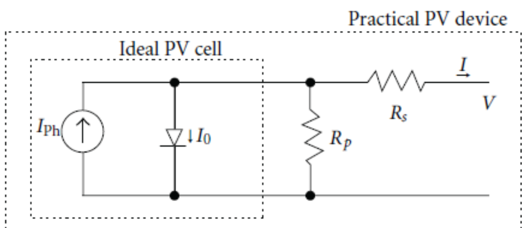

Fig. 2 PV cell Modeled as a diode circuit

For simplicity, the single-diode model of Fig.2 is used in this paper [14]. This model offers a good compromise between simplicity and accuracy with the basic structure consisting of a current source and a parallel diode. In Fig.2, I_{ph} represents the cell photocurrent while *R*sh and *Rs* are, respectively, the intrinsic shunt and series resistances of the cell. The module photocurrent I_{ph} of the photovoltaic module depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation:

$$I_{ph} = [I_{SC} + K_i(Tk - T\text{ref})] * \lambda / 1000$$

Where, I_{ph} [A] is the light-generated current at the nominal condition (25∘C and 1000W/m^2), K_i is the short-circuit current/temperature coefficient (0.0017A/K), T_k and T_{ref} are, respectively, the actual and reference temperatures in *K*, λ is the irradiation on the device surface (W/m^2), and the nominal irradiation is 1000W/m^2. The value of module short-circuit current is I_{SC} taken from the datasheet of the reference model. The detailed simulink model of PV cell is presented in Fig.3. Iph for different values of insolation and temperature is shown in Table 1.

TABLE.I
IPH FOR VARIOUS INSOLATION AND TEMPERATURES

S. No	Insol W/m^2	Value of Iph (A)			
		20^{o}c	30^{o}c	40^{o}c	50^{o}c
1	1000	2.54	2.557	2.578	2.593
2	500	1.278	1.279	1.288	1.299
3	100	0.252	0.254	0.257	0.259

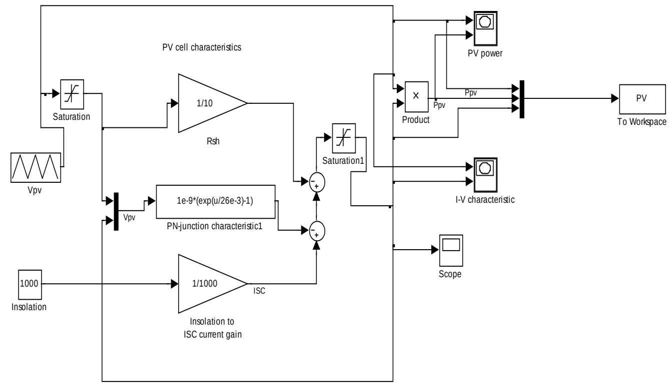

Fig.3 Simulink Model of PV cell

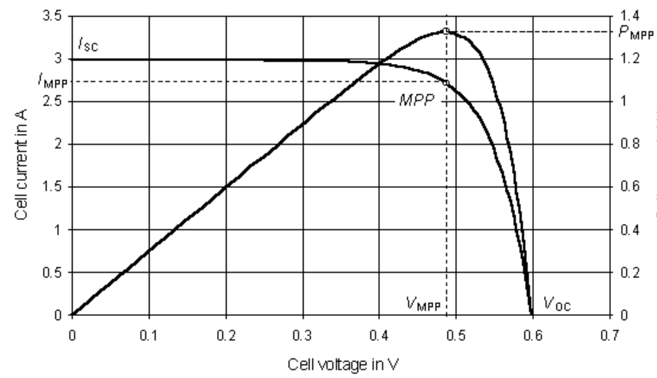

Fig.4 I-V & P-V Characteristics of PV cell

III. INCREMENTAL-CONDUCTANCE MPPT ALGORITHM

MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature. Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day. MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery. MPPT algorithm can be applied to both buck and boost power converter depending on system design. Normally, for battery system voltage is equal or less than 48 V, buck converter is useful. On the other hand, if battery system voltage is greater than 48 V, boost converter should be chosen. In this investigation buck-book converter is used for the analysis for various load conditions.

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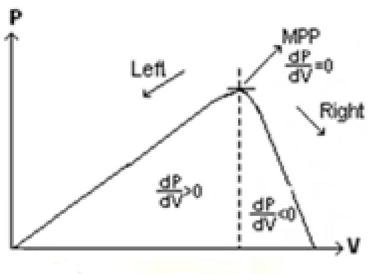

Fig.5 Basic Concept of Incremental Conductance on a PV Curve

The basic concept of Incremental conductance on a PV curve of a solar module is shown in Fig.5. The slope of the P-V module power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$dP/dV=0$ at MPP

$dP/dV>0$ left of MPP

$dP/dV<0$ right of MPP

$dP/dV = d(VI)/d(V)= I *dV+ V*dI$

The dP/dV is defined as Maximum power point identifier factor. By utilizing this factor, the IC method is proposed to effectively track the MPP of PV array [15]. The following definitions are considered to track the MPP.

$\Delta I/\Delta V = -I/V$ *at MPP,* $\Delta V_n=0$

$\Delta I/\Delta V > -I/V$ *left of MPP,* $\Delta V_n= +\delta$

$\Delta I/\Delta V < -I/V$ *right of MPP,* $\Delta V_n= -\delta$

$$(dI/dV) + (I/V) = 0 \quad (1)$$

The MPPT regulates the PWM control signal of the dc to dc power converter until the condition of equation no.1 is satisfied. Consider the n^{th} iteration of the algorithm as a reference, and then n+1 iteration process can be determined by using the above equations. The Flow chart of incremental conductance MPPT is shown in Fig.6. The output control signal of the IC method is used to adjust the voltage reference of PV array by increasing or decreasing a constant value ($\Delta V=\delta$) to the previous reference voltage. In this method the tracking of MPP is accomplished by a fixed step size ($\pm\ \delta$) regardless to the gap between the operating point of PV and MPP location. In this method the peak power of the module lies at above 97% of its incremental conductance.

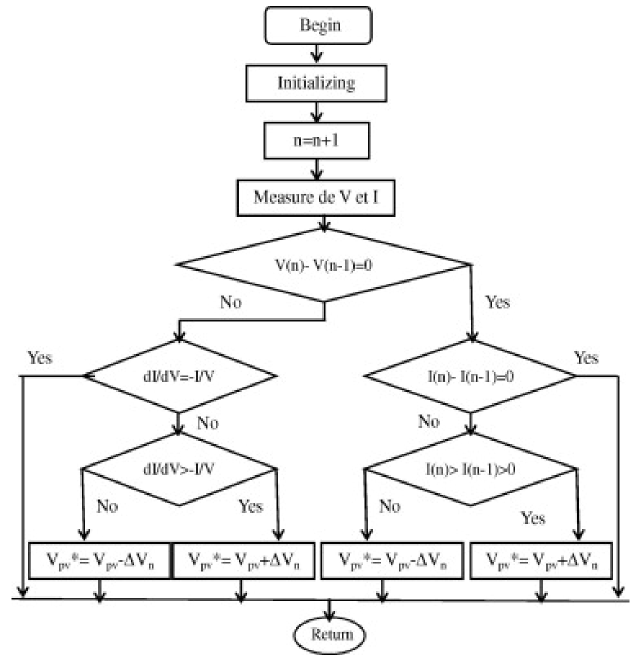

Fig.6 Flow chart of MPPT Incremental Conductance

IV. DC-DC POWER CONVERTER

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT.

There are several different types of dc-dc converters, buck, boost, buck-boost and cuk topologies, have been developed and reported in the literature to meet variety of application specific demands. In this proposed system, Buck- Boost converter is used since it can accomplish the Maximum power point from the PV panel under the dynamic behaviour of load. The fig.7 show the basic Buck-Boost converter circuit diagram. It can able to regulate the voltage level at load terminal. The following equations represents the state equation s for the Buck-Boost converter.

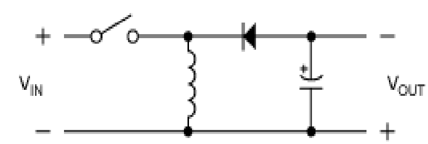

Fig.7 Buck- Boost Converter

$$\frac{dI_L}{dt} = \frac{D.V_p}{L} - \frac{(1-D)V_o}{L} \quad (2)$$

Where, I_L is the inductor current, V_p is the PV panel voltage, D is the duty ratio of the switch, V_o is the ouput voltage.

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V. Sliding Mode Control

The sliding mode control consists of sliding surface and control law design. The sliding surface is defined based on Incremental Conductance (IC) MPPT algorithm. The inversion of the equation (1) is given by

$$-dV_p/dI_p = V_p/I_p \tag{3}$$

In the equation (3), the parameter $-dV_p/dI_p$ is called as instantaneous resistance (R_p) and V_p/I_p is called as incremental resistance (r_p). so the equation no.3 can reformulated as

$$\delta = R_p - r_p \tag{4}$$

The difference of these resistance value is defined the sliding surface of MPPT. Whenever δ value becomes zero which indicates the achievement of maximum power point (MPP). The control law input [17] for MPPT can be defined by the following equation.

$$X(t) = X_{eq}(t) + X_n(t) \tag{5}$$

Where $X_{eq}(t)$ is defined as the system behaviour on sliding surface. $X_n(t)$ is known as non linear switching inputs. $X_{eq}(t)$ is obtained from invariant condition and it is given as

$$(\delta = 0,\ d\delta = 0) \text{ is biequivalent to } (X = X_{eq}) \tag{6}$$

The derivative of equation (4) with respect to time can be written as

$d\delta = dR/dt - dr/dt$, then

Multiply both sides by dI_p/dt, becomes

$d\delta = (dR/dI_p - dr/I_p).\ dI_p/dt$

$$d\delta = \omega\, dI_L/dt \tag{7}$$

where $I_L = K.\ I_p$

where k is proportional constant.

By substituting equation (2) in equation (7), the time derivative of sliding surface is obtained as

$$d\delta = \omega\left[x(t).\frac{V_p}{L} - (1 - x(t)).\frac{V_o}{L}\right] \tag{8}$$

Considering equation 8 and equation 6, the equivalent control input is obtained as

$$X_{eq}(t) = V_o / (V_o + V_p) \tag{9}$$

Now $X_n(t)$ is choosen so that the Lyapunov stability criteria ($d\delta\ .\delta < 0$) is met

The choosen $X_n(t)$ as

$$X_n(t) = -\frac{V_o}{V_o + V_p} + \frac{1}{(1+M)} \tag{10}$$

Where M is the control signal which is calculated through Lyapunov stability criteria. Then adding the equation (9) &(10)

$$X(t) = 1/(1+M) \tag{11}$$

By considering the operating point of system is 'a' which is shown in figure no. since the gradient is negative , moving the operating point to the right side causes increasing in the current of PV array, which results in decreasing of R_p and increasing of r_p, therefore, ($\partial R_p/\partial I_p<0$, ($\partial r_p/\partial I_p>0$). Also, moving the operating point to the left side causes decreasing in the current of PV array, which results in increasing of R_p and decreasing of r_p, therefore, ($\partial R_p/\partial I_p>0$, ($\partial r_p/\partial Ip<0$). for positive sliding surface ($\delta>0$);

$$\frac{V_p}{V_o} > \left[\frac{V_p^{(1-\alpha)}.(I_p)^{\alpha}}{V_o}\right]\left|\frac{dV_p}{dI_p}\right|^{\alpha} \tag{12}$$

when ($\delta<0$),

$$\frac{V_p}{V_o} < \left[\frac{V_p^{(1-\alpha)}.(I_p)^{\alpha}}{V_o}\right]\left|\frac{dV_p}{dI_p}\right|^{\alpha} \tag{13}$$

From the equation (12) & (13), the control law M can be choosen as

$$M = \left[\frac{V_p^{(1-\alpha)}.(I_p)^{\alpha}}{V_o}\right]\left|\frac{dV_p}{dI_p}\right|^{\alpha} \tag{14}$$

Substituting equation (14) in equation (11), the control input is obtained as

$$X(t) = \left[1 + \left[\frac{V_p^{(1-\alpha)}.(I_p)^{\alpha}}{V_o}\right]\left|\frac{dV_p}{dI_p}\right|^{\alpha}\right]^{-1} \tag{15}$$

The duty cycle must be lie in $0<D<1$,

$$D = \begin{cases} 0, X(t) \le 0 \\ X(t), 0 < X(t) < 1 \\ 1, 1 \le X(t) \end{cases}$$

VI. Simulation Results & Discussions

The Matlab/simulink model of the PV system with Slide mode controller has been designed which is shown in Fig.8 simulated in Matlab/ Simulink. In this model, Buck –Boost converter is used in between the PV panel and a dynamic load. The Fig.9 illustrated the simulation results the Slide mode controller PWM output and the PV panel output power waveforms under the resistive load of 100 ohm with irradiation 400Watt/m^2. . The Fig.10 represents the PV panel output voltage, Buck-Boost converter output voltage and current waveforms with the irradiation of same 400Watt/m^2 of resistive load of 100 ohm.

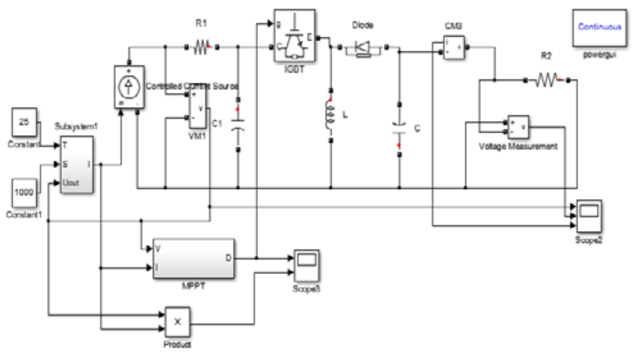

Fig. 8 Simulink Model of PV system with Slide mode controller

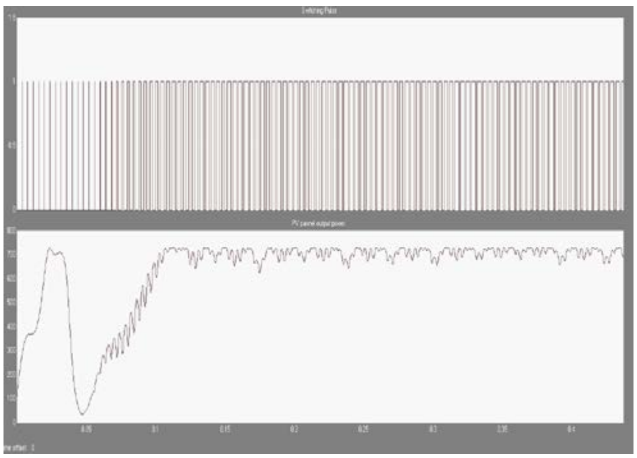

Fig. 9 PWM output & PV Output Power waveforms (400W/m2, 100Ω)

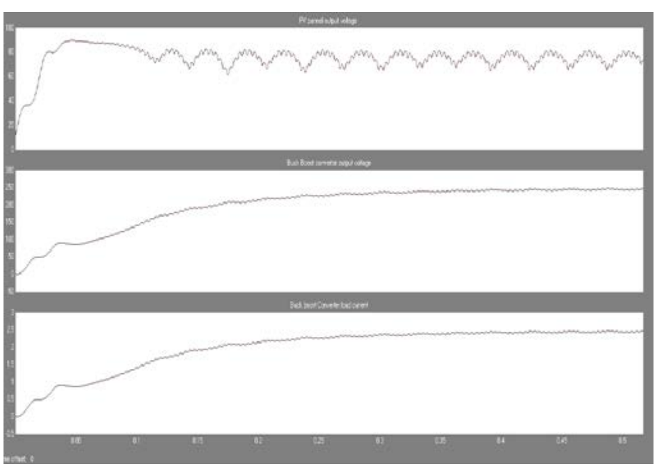

Fig.10 PV Panel Output voltage, Buck Boost Converter Output voltage and current waveforms (400W/m2, 100Ω)

The Fig.11 illustrated the simulation results the Slide mode controller PWM output and the PV panel output power waveforms under the resistive load of 50 ohm with irradiation 1000 Watt/m^2.

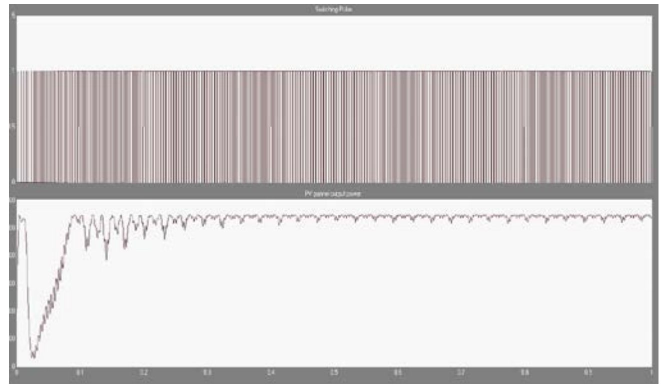

Fig.11 PWM Output and PV Output Power waveforms (1000W/m2, 50Ω)

The Fig.12 represents the PV panel output voltage, Buck-Boost converter output voltage and current waveforms with the irradiation of same 1000Watt/m^2 of resistive load of 50 ohm. The specifications of the Buck Boost converter used for experimental analysis is shown in the following table 2.

TABLE II
BUCK BOOST CONVERTER SPECIFICATIONS

Parameter	Value
C1	2x10^{-3}F
L	0.01H
C	2x10^{-3}F
RL	50ohm

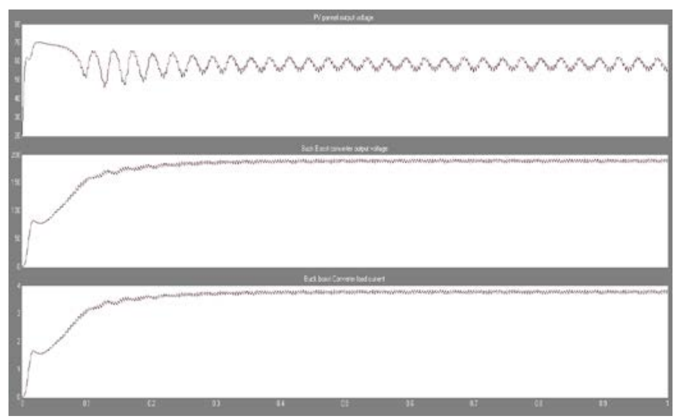

Fig.12 PV Panel Output voltage, Buck Boost Converter Output voltage and current waveforms (1000W/m2,50Ω)

VII. CONCLUSION & FUTURE WORK

This study proposes the slide mode control based MPPT controller for photovoltaic application. In this investigation, the Buck Boost converter topology is used. The proposed system is simulated by using Matlab/Simulink and its performance analysis has been investigated under various load conditions and different irradiations of solar rays. The simulation result shows that it performs very well in the extraction of available maximum power. In this proposed system, the fixed step incremental conductance algorithm has been incorporated, in future, the variable Incremental conductance with optimized slide mode controller will be designed and developed for better results.

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