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A MPPT WITH SLIDING MODE CONTROL FOR PV SYSTEM

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ABSTRACT

DC-DC power converters are added for matching the load to the photo voltaic modules (PVM) because of the nonlinear behavior of the photo voltaic cells. A maximum power point tracker for PV cells, PVM and PV arrays are presented using a dynamic optimal voltage estimator to estimate the voltage at which a PV cell generates its maximum power and the dynamic voltage estimator force the PV cell to reach and operate at that voltage in a finite time and to stay there for all future time so that the maximum power is available to the load. This is obtained by controlling the duty cycle of a DC-DC converter using sliding mode control (SMC). The load will be composed of a battery bank. A sliding mode controller is given the estimated maximum power point as a reference for it to track that point and force the PV system to operate in this point. This method has the advantage that it will guarantee the maximum output power possible by the array configuration while considering the dynamic parameters such as temperature and solar irradiance and delivering more power to charge the battery. SMC is designed and simulated using MATLAB/SIMULINK environment. The simulation results show that the maximum power is obtained from PVM at all the operating conditions using SMC.

Keywords

Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Sliding Mode Control (SMC), Dc-Dc Converter

1. INTRODUCTION

Renewable energy sources play an important role in the current scenario. Various renewable sources such as solar energy, wind energy, geothermal etc. are harness for electric power generation. Among the renewable energy sources**,** solar PV energy has been drawing increasing interest in recent years as an alternative and important source of energy for the future. The solar energy is directly converted into electrical energy by solar photovoltaic module. The photovoltaic modules are made up of silicon cells. The silicon solar cells which give output voltage of around 0.7V under open circuit condition [13]. Many such cells are connected in series to get a solar PV module. Normally in a module there are 36 cells, which give an open circuit voltage of around 20V. The current rating of the modules depends on the area of the individual cells, if the cell area is large; the current output of the cell is high. For obtaining higher power output, the solar PV modules are connected in series and parallel combinations forming solar PV arrays.

PV systems constitute an environmental friendly alternative way for energy production using the energy from the sun. They operate quietly without emissions, can be installed quickly and are modular which has the advantage that the more units can be added if the load increases. PV system has long lifetime and less maintenance requirements make them an ideal solution for remote applications when used as autonomous (stand-alone) systems. Solar PV systems can be designed and put in operation for both autonomous and grid connected application. Stand-alone PV systems are commonly encountered in developing countries and remote locations. Photovoltaic cells have a single operating point where the values of the current and voltage of the cell result in a maximum power output [1]. These values correspond to a particular resistance which is equal to the division of the maximum voltage and maximum current. By connecting the PV cell directly to a load or a battery, the output power can be severely reduced due to load mismatching or, in case of a battery, load voltage mismatching. Since this operating point depends on factors like temperature, solar irradiance and load impedance, a device capable of tracking the maximum power point and force the PVM to operate at that point is required [3]. A maximum power point tracker (MPPT) is a device capable of search for the point of maximum power and, using DC-DC converters, extracts the maximum power available by the cell. By controlling the duty cycle of the switching frequency of the converter we can change the equivalent voltage of the cell and by that, its equivalent resistance into the one in which the PVM is in the maximum power operating point.

Several methods have been designed and implemented to search for this operation point are Perturb & Observe, Hill Climbing Method, Incremental conductance algorithm, neural network, Linear reoriented method. Some of the disadvantages with these methods are that some of them require doing a

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lot of iterations to calculate the optimal steady state duty ratio. Some of them use approximate values that do not guarantee near maximum power output. Some of them can be very complex, can be slow and can become instable if the MPP moves abruptly.

2. PROPOSED SYSTEM

Figure 1 shows the proposed scheme for the MPPT.

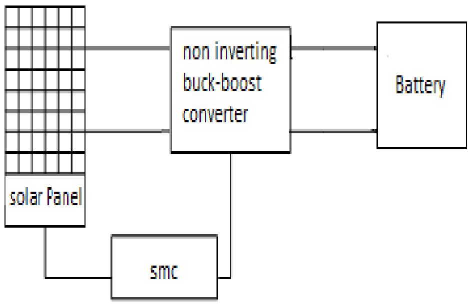

Fig 1: Proposed System Scheme

This system use a PV array (*s* x *p*) composed of *s* in series cells and *p* in parallel cells. It is then connected to a DC-DC converter in order to increase or decrease the desired voltage. It is then connected directly to the load, which is composed of a 12 V battery. The duty cycle of the converter is controlled by a sliding mode controller.

The proposed model will guarantee the extraction of the maximum power that can be produced by the PVM while regulating the load voltage to the battery's voltage [3]. That way we can have a workable load voltage that can be connected to an inverter while matching the load resistance to the PV optimal resistance.

3. MODELLING OF PV PANEL

A photovoltaic PV Generator is the whole assembly of solar cells, connections, protective parts, supports etc. Solar cells are made of semiconductor materials(usually silicon),which are specially treated to form an electric field, positive on one side (backside) and negative on the other (towards the sun).When solar energy (photons) hits the solar cell, electrons are knocked loose from the atoms in the semiconductor material, creating electron-hole pairs. If electrical conductors are then attached to the positive and negative sides, forming an electrical circuit, the electrons are captured in the form of electric current I_{ph} (photocurrent). During darkness, the solar cell is not an active device, it works as a diode. That is a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates a current I_d, called diode current or dark current [2]. A PV module, which converts light into electricity, can be modeled as a single diode model, as shown in figure 2

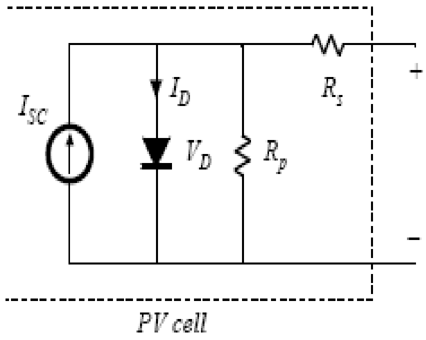

Fig 2: Equivalent Circuit Model of PV

The relationship among different currents and voltages of the equivalent circuit model of PV module is given by,

KCL

$$I_{sc} - I_D - I_{pv} - \left(\frac{V_D}{R_p}\right) = 0 \quad (1)$$

Diode Characteristics

$$I_D = I_o \left\{ \exp\left(\frac{V_D}{V_T}\right) - 1 \right\} \quad (2)$$

KVL

$$V_{PVcell} = V_D - R_s I_{pv} \quad (3)$$

$$I_{PV} = I_{ph} - I_0 \left\{ \exp\left[\frac{q(V + R_{se} I_{PV})}{A k_B T}\right] - 1 \right\} - \frac{V + R_{se} I_{PV}}{R_{sh}} \quad (4)$$

$$I_d = I_0 \left[\exp\left\{ \frac{q}{A K_B T}(V + R_{se} I_{PV}) - 1 \right\} \right] \quad (5)$$

A real solar cell can be characterized by the following fundamental parameters,

- Short circuit current: $I_{sc}= I_{ph}$. It is the greatest value of the current generated by cell. It is proposed under short circuit condition: V=0.
- Open circuit voltage: corresponds to the voltage drop across the diode, when it is traversed by the Photocurrent Iph, namely when the generated current is I=0.It reflects the voltage of the cell in the night and it can be mathematically expressed as

$$V_{oc}= V_t \ln (I_{ph} / I_o) \quad (6)$$

Where Vt= mkTe/e is known as thermal voltage and Te is the absolute cell temperature.

- Maximum Power Point is the operating point, at which the power dissipated in the resistive load is maximum

$$P_{max}= I_{max} \cdot V_{max} \quad (7)$$

- Maximum efficiency is the ratio between the maximum power and the incident light power

$$\eta=P_{max}/P_{in}= I_{max} V_{max} / AG_a \quad (8)$$

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Where G_a is the ambient irradiation and A is the cell area,
Solar cell I-V and P-V characteristics are shown in Figure 3 and Figure 4 respectively

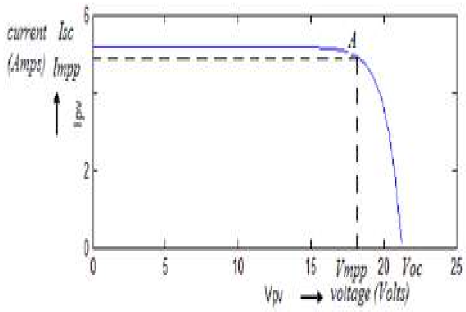

Fig 3: I-V Characteristics of solar cell

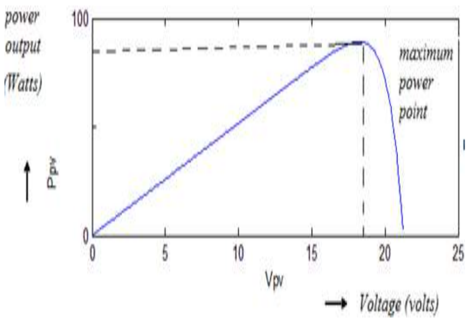

Fig 4: P-V Characteristics of solar cell

4. NON INVERTING BUCK BOOST DC-DC CONVERTER

The diagram in Figure 5 shows the structure of the modified buck-boost converter.

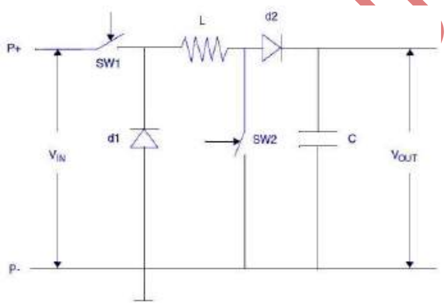

Fig 5: Modified buck-Boost converter circuit

You can use this converter as buck-boost converter, as a buck converter or as a boost converter by selecting different combinations of switches SW1 and SW2 driven by the PWM1 and PWM2 signals output by the microcontroller [10]. This converter can be used as a non inverting buck-boost converter by selecting the operating mode from Table 1 which briefly describes the converter modes.

Table 1. Operating Modes Based On Switch Combinations

Phase	SW1 (PWM1)	SW2 (PWM2)	Operating modes
1	OFF	OFF	BUCK
2	OFF	ON	N/A
3	ON	OFF	BUCK-BOOST
4	ON	ON	BOOST

5. MAXIMUM POWER POINT TRACKING

When a solar PV system is developed for practical applications, the I-V characteristics keeps on changing with insolation and temperature. In order to receive the maximum power, the load must adjust itself accordingly to track the maximum power point. The I-V characteristics of PV system along with some common loads are shown in fig 5. An ideal load is one that tracks the maximum power point.

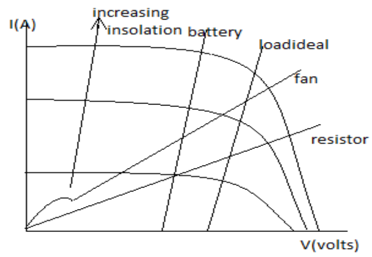

Fig 6: Characteristics of PV and some loads

If the operating point departs significantly from the maximum power point, it may be a desire to interpose an electronic maximum power point tracker (MPPT) between is an adaptation of DC-DC switching voltage regulator. Coupling to the load for maximum power point transfer may require either providing a higher voltage at a lower current or lower voltage for higher current.

The PV panel gives maximum power P_{max}, at a particular voltage Vmp and current Imp. Now it can be interpreted that, the PV panel R_{rmax}, becomes equal to the load resistance. There are several methods of MPP tracking to ensure maximum output from the PV panel.

5.1 Existing topologies employed for PV system

Several methods have been designed and implemented to search for the maximum power operation point.

5.1.1 Constant Voltage Method

In a very simple MPP tracking technique, the PV panel voltage is compared with a constant reference voltage that corresponds to the MPP voltage under specified ambient conditions. The error signal is used to change the duty cycle of a dc-dc converter, interfaced between the PV panel and the load, so as to make the PV panel voltage equal to the MPP voltage. This method is very simple to implement, but is not accurate [3]. There is substantial power wastage, as it does not take into account the effect of changes in solar insolation and temperature.

5.1.2 Perturb-and-observation method

The current drawn from the PV panel is perturbed and the resulting output power is observed. If an increased current results in higher power, it is further increased till the output power begins to decline. On the other hand, if an increase in current results in less power than before, then current is decreased until power output stops increasing and begins to go down. A drawback of PAO method is that the operating point oscillates around the Output Power MPP [4]. Moreover, in rapidly changing atmospheric conditions, the MPPT takes considerable time to track the MPP and during this interval the significant amount of power is wasted.

5.1.3 Incremental Conductance Method

The incremental conductance method, compares the incremental conductance of the PV panel with its instantaneous conductance and changes the duty ratio of the c-dc converter such that

$$\frac{dI}{dV} = -\frac{I}{V} \tag{9}$$

where V and I are PV panel voltage and current respectively. The method is based on the fact that at MPP, dP/dV = 0 hence this method, though accurate, needs complex control circuit [6].

5.1.4 Voltage Based Maximum Power Point Method

The voltage V_{mp} at which the solar panel gives maximum power conditions, the Vmp also changes approximately in same proportion. It has shown that there exists almost a linear relation between V and Voc

$$V_{op} = M_V V_{oc} \tag{10}$$

where M_v is called the voltage factor. M_v has a different value for different solar panels. It is found to be 0.8 for the solar panels used for theoretical and experimental analysis [8].

Other methods that have been used to obtain the maximum power are parameters estimations, neural networks, adaptive hill climbing [12] and linear reoriented method.

5.2 Proposed topology employed for PV system

5.2.1 Sliding Mode Controller

An implementation of a maximum power point tracker, based in reaching a reference open circuit voltage, using a sliding mode controller obtained to control the duty cycle of a DC-DC converter in order to force the PV module to operate at its maximum power point, for a given temperature and irradiance, to improve the utilization of the produced energy when connected to a load. For this case the load it's a battery and a resistance. This SMC employs one reaching phase and another sliding phase. The sliding phase consists of higher switching frequency known as chattering. Though chattering is responsible for the robustness of this technique but it is objectionable because of switching losses and electromagnetic interference.

6. SLIDING MODE CONTROL

A sliding mode controller is a variable structure control where the dynamics of a non linear system is altered via the application of a high frequency switching control. In sliding mode control, the trajectories of the system are forced to reach a sliding manifold of surface, where it exhibit desirable features, in finite time and to stay on the manifold for all future time. It is achieved by suitable control strategy. To apply sliding mode control we have to know if the system can reach the sliding manifold. Once the systems reach the sliding manifold, the controller has to force the system to stay in the manifold for all future time.

Sliding Mode Control is widely use for a lot of applications including control systems for DC/DC converters, power supply, electric grid connections, motors speed regulator, position control system, among others.

To design the sliding mode controller we have to select the desired surface. We want to obtain the maximum power that can be extracted from the PV module at the given temperature and irradiance conditions. Since we know the output voltage we have to have in order to extract the maximum power from the PV system, we choose a surface that will force the system to reach that voltage in a finite time and stay there for infinite time. With that in mind, we chose the following sliding manifold

$$\sigma = V - V_{op} \tag{11}$$

V is the output voltage of the PV cell and V_{op} is the optimal voltage. This sliding manifold will assure us to force all the trajectories of the system to reach the optimal voltage and to keep it in the optimal voltage for all future time. Since the optimal voltage is dynamic since it change when changes occur in the temperature and irradiance this sliding surface is also changing with respect to the temperature and irradiance giving us a dynamic sliding surface. The sliding mode will be controlling the duty cycle of a switching device. So the switching device will have two operation states

$$\begin{cases} \text{On} & V\text{-}V_{op}<0 \\ \text{Off} & V\text{-}V_{op}<0 \end{cases}$$

Now, the controller will behave in the following way:

$$u=\begin{cases} 1 & V\text{-}V_{op}<0 \\ 0 & V\text{-}V_{op}<0 \end{cases}$$

A control law that guarantees us that our controller will behave in that way is given by the following equation:

$$u = \frac{1}{2} + \frac{1}{2}.\text{sign}(V - V_{op}) \quad (12)$$

This law of control also guarantees us that the system trajectories will reach the proposed manifold and will stay there for all future time. This can be explained in a practical way [3]. At first, because the PVM is not connected, the PVM output voltage will be equal to its open circuit voltage. Since the open circuit voltage is greater than the optimal voltage the switching device will be on. When the switch is on, the PVM output voltage will begin to drop because of the load mismatching until it reaches below the optimal voltage. Then the switch will turn off creating an open circuit condition forcing the PVM output voltage to increase up to its open circuit voltage. When the output voltage passes the optimal voltage then the switch will turn off and the sequence will start again and will continue for all future time. This control law works for a variety of DC-DC converters like the Buck converter, SEPIC converter and Buck- Boost converter.

7. SIMULATION

The system was simulated using Matlab's Simulink software with the power system toolbox. With this software we simulate and test the sliding mode controller and the proposed model. The simulink model is shown at figure 8. The solar Cell model was represented by a single block composed by a Sub circuit. The system was simulated under constant ambient temperature and solar irradiance. The simulation results of the PV system with constant ambient conditions Connected to the battery through buck converter are shown in Figure 12.

7.1 Simulation Model of PV Module

7.1.1 Model Description

The standard PV module data-sheet parameters are shown in Table 2

Table 2. The Standard PV Module Data-Sheet Parameters

S.No	Parameters	Values
1	Short circuit current, I_{sc}	5.45A
2	Open circuit voltage, V_{oc}	22.2V
3	Rated current IR at maximum power point(MPP), I_{mp}	4.95A
4	Rated voltage VR at MPP, Vmp	17.2V

These values are calculated under standard test conditions (1kW/m2, 1.5 AM, 25°C). A bypass diode (a single diode across the entire module) can be included. Temperature effects are not modeled.

7.1.2 Sub Circuit Model of PV Module

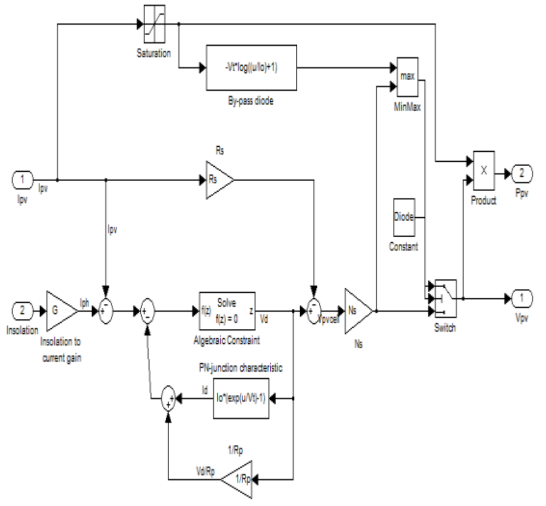

Fig 7: Simulation Scheme for PV Sub circuit

7.2 Simulation Model of PV with FSMC MPPT

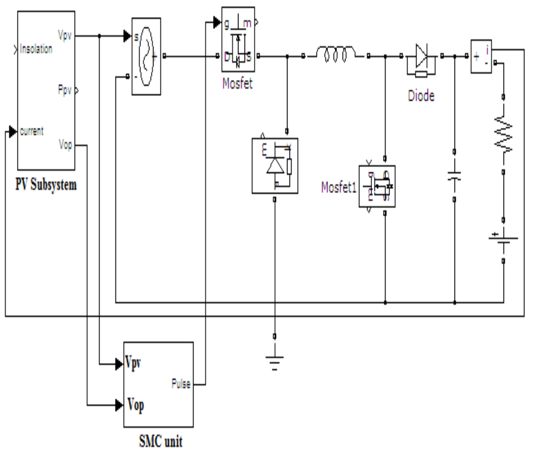

Fig 8: Simulation Scheme for the Proposed Model

8. RESULTS

Table 3 shows the results of the estimated P_{max} for the case of battery connected to PV through converter compared to the values of battery connected directly to the PV. The error percent for the voltage and current stays within acceptable values. Since the estimation is very near to the Optimal values, by forcing the system to operate at the estimated voltage, guarantee us to be working in a near maximum power point.

Figure 12 validate the sliding mode controller and ensure that the PV operates at its maximum power even under standard test conditions (STC) and under varying solar irradiation condition while supplying a higher power to the battery. It can be seen that the proposed method increase significantly the available power delivered to the battery.

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Table 3. Simulation Results of the Estimated Maximum Power

Insolation (W/m²)	Battery Connected Directly to PV	Battery Connected to PV Through Converter
	P_{pv}(W)	P_{max}(W)
100	5.61	5.86
200	14.51	14.56
300	22.5	23.49
400	30.39	32.53
500	38.2	41.58
600	45.93	50.6
700	53.57	59.53
800	61.11	68.31
900	68.55	76.87
1000	75.87	85.14

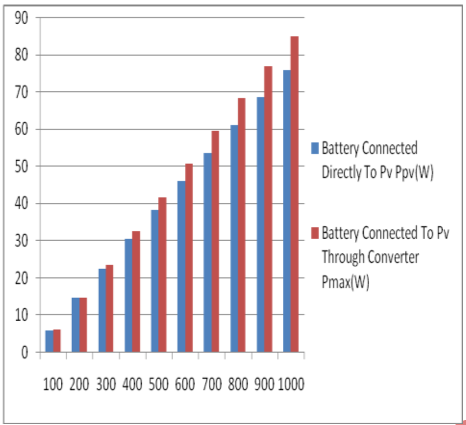

Fig 9: Comparison plot of Actual PV (without MPPT) Power vs. Maximum PV (with MPPT) Power

8.1 I-V and P-V Characteristics waveform

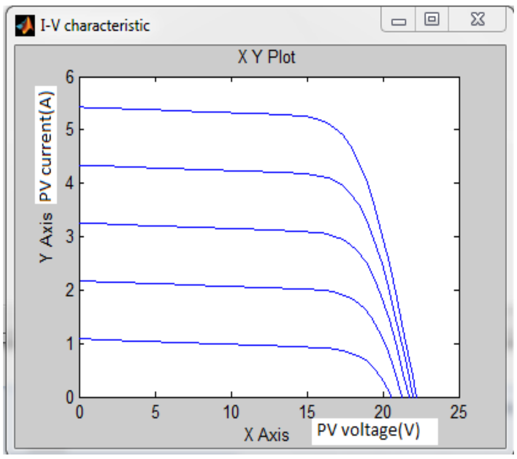

Fig 10: I-V Characteristics of PV Module

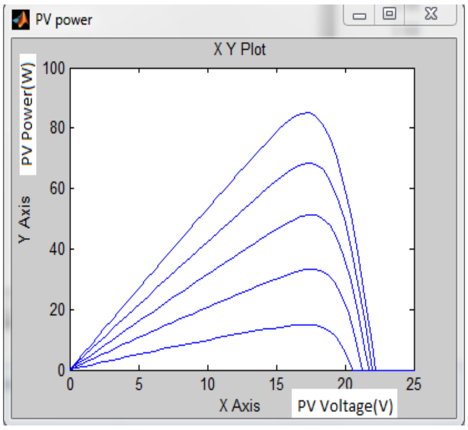

Fig 11: P-V Characteristics of PV Module

8.2 Simulation results of Voltage, current and Power

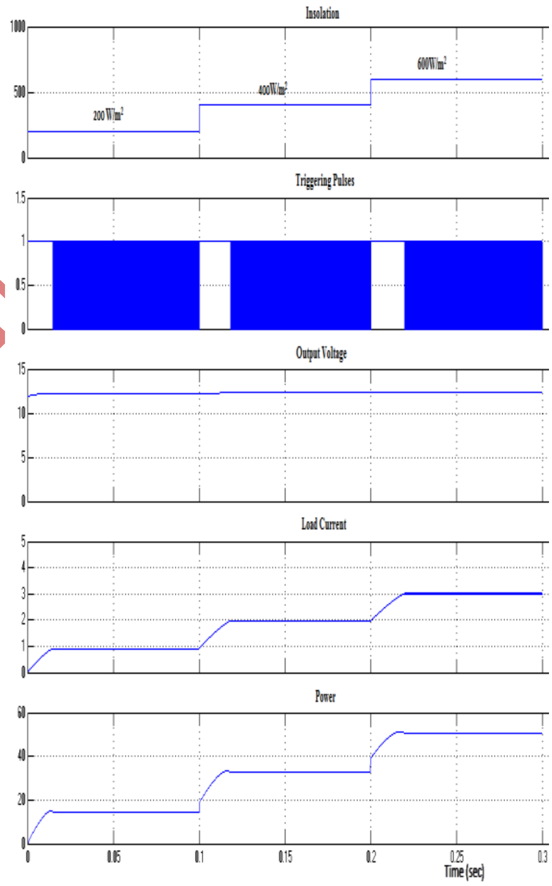

Fig 12: Output waveforms at battery when connected to proposed MPPT at varying Insolation condition

9. CONCLUSION

This paper presents a simple photovoltaic solar cell dynamic sliding mode controlled maximum power point tracker for battery charging applications capable of compute the maximum power point under constant ambient temperature and varying solar irradiation. The proposed Sliding Mode controller only requires the array output voltage and the optimal voltage which is continuously computed. From the simulation results is evident that a maximum power is tracked and achieved under constant ambient temperature and varying solar irradiance.

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