A Solar Photovoltaic Power Harvesting System Using Sliding Mode Controller with Positive Output Luo Converter

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ABSTRACT:

The Solar Photo Voltaic (SPV) power generation is a much preferred renewable source of energy because of its well pronounced advantages The Positive Output Luo Converter (POLC) is a DC-to-DC converter with a buck boost facility and the converter does not exhibit the typical polarity reversal that happens in the generic buck boost converter. In this research the design and development of a POLC along with the Sliding Mode Controller (SMC) is carried out and presented herein. The proposed techniques have been validated using simulations in the MATLAB SIMULINK environment.

Keywords: Solar Photo Voltaic system, Positive Output Luo Converter, Sliding mode controller, Maximum Power Point Tracking (MPPT).

I Introduction

The SPV power generation system does not generate a constant output power like other conventional DC power generating systems like the Battery or the DC generator. Although the SPV system has a rated capacity, as the power production process depends upon the environmental conditions like solar insolation and temperature, the power output of the SPV system is not a constant but changes from time to time. The internal electrical parameters of the SPV panels do change with climatic conditions and it becomes absolutely essential to alter the electrical load connected to the solar panel automatically so that maximum power is transferred from the SPV system to the electrical load. The advent of the modern digital computer, the microprocessors and the microcontrollers have paved the way for soft computing based MPPT techniques.The Sliding Mode Controller (SMC) is a nonlinear control system and is also known as the variable structure controller and it is used to track the maximum power.

II AReview of The Photo Voltaic Power Generation

When certain semiconductor materials are exposed to light they exhibit an electric current. If the terminals of the semiconductor material are terminated across an electrical load, typically a resistor then current flows through the external load.The typical voltage and current generated by a typical solar photo voltaic cell is about 0.7 V and a few micro amps. Therefore in order to get an useful voltage and to drive a potential electrical load many solar photo cells are connected in cascade. Series combinations of solar cells bring out more voltage. Parallel combination of solar cells drives more current to the load. The characteristics of the solar photo voltaic cell can be mathematically modeled and the equivalent circuit of the solar cell is as shown in Figure 1. The equation of the Photo voltaic current is a nonlinear equation and contains exponential terms. This causes the nonlinear behavior of the solar PV cell. The three popular models of the photo voltaic cell are the single diode model, the two diode model and the three diode model. The two and three diode models are more accurate and the single diode model is sufficient for many practical purposes.

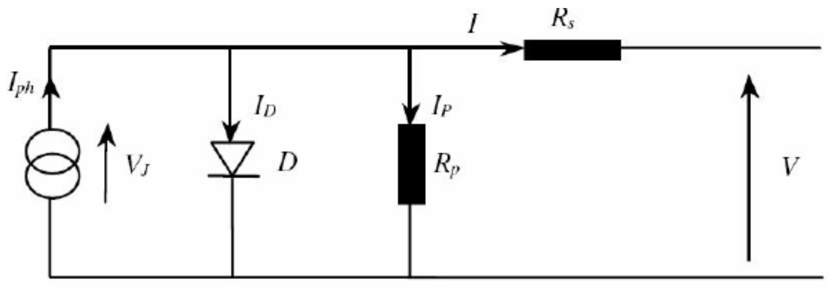


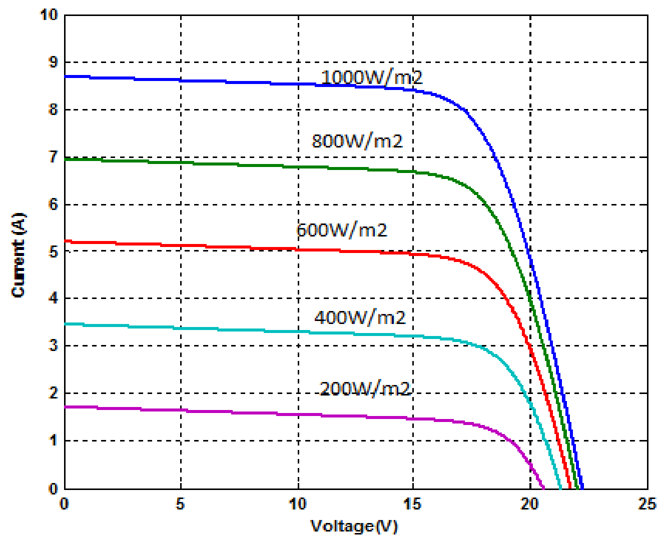
Figure 1 Single diode model of the PV

$$I = I_{ph} - I_o\left\{e^{\frac{q(V+R_sI)}{AKT}} - 1\right\} - \frac{V+R_sI}{R_{sh}} \quad (1)$$

As shown in equation.1, Iph is the photo current generated from the cell and a part of this current is passed through the diode as the forward saturation current. Another part of the Photo current Iph is routed through the shunt resistance Rsh. The shunt component of current is the representation of the recombination effect happening within the photo cell. The remaining part of the photo current flows through the load. The output current flows through the series resistance Rs. With the load terminals open there is no output current and hence no voltage drop across the series resistance. The series resistance represents the ohmic contacts, and the resistance of the bulk of the semiconductoritself. The solar Photovoltaic panel is characterized by a set of four parameters.

They are the open circuit voltage Voc, the short circuit current Isc, the voltage Vpmax while delivering the maximum power output Pmax and the current Ipmax while delivering maximum power Pmax. With reference to the mathematical model and the equivalent circuit of the solar photo voltaic cell, the internal resistances Rsh and Rs play an important role in the operational characteristics of the solar cell. The presence of the diode, series and parallel resistors make the analysis a little complex and especially this problem is more defined when the values of Rs and Rp are variable with respect to the operating conditions of the PV panel in respect of the available temperature, irradiation and the loading condition.

An important challenge in the modeling of the solarcellis the estimation of the values for Rs and Rp which are found by solving the exponential transcendental equation and this is to be done in real time The Newton Raphson method is the most commonly used solution methodology for finding the real time values of Rs and Rp of the solar cell. The complex characteristics of the PV panel can be attributed to the presence of these dynamically altered resistances and the nonlinear nature of the internal diode.



The power versus voltage characteristics and the current versus voltage characteristics of the solar panel are as shown in Figure 2. The families of characteristics are obtained when the characteristics are plotted for various solar insulations.

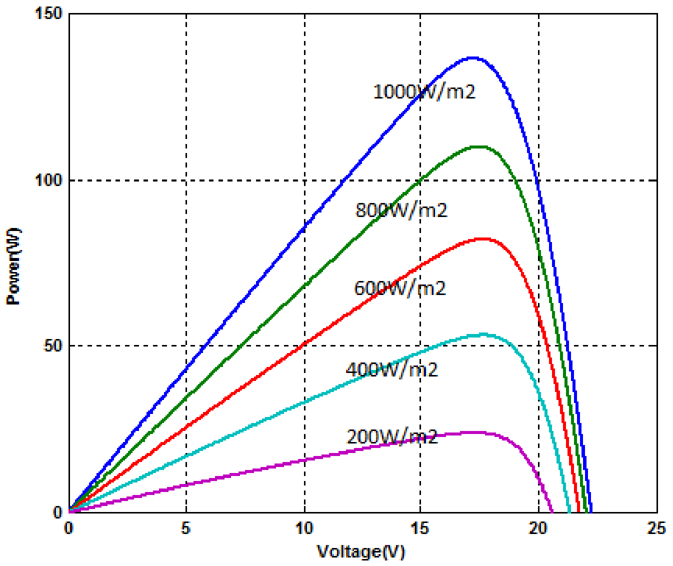


Figure 2 The Voltage V_s Current; Voltage V_s power family of Characteristics for different insolation levels

III The Positive Output Luo Converter

The Positive Output Luo Converter or the POLC is a DC to DC converter with voltage step up and step down features. However, unlike the generic buck boost converter the POLC does not invert the polarity of the DC output voltage with respect to the input voltage. The topology of the POLC is given in Figure 3. The main components are the power control switch S, the boost inductor L1, the intermediate capacitor C1, the diode D and the additional filter inductor L2 and the output filter capacitor C2. Since the power electronic switch S comes in series with the input DC source it can be sure that the converter can give a voltage reduced with respect to the input. In addition there is also the boost capability.

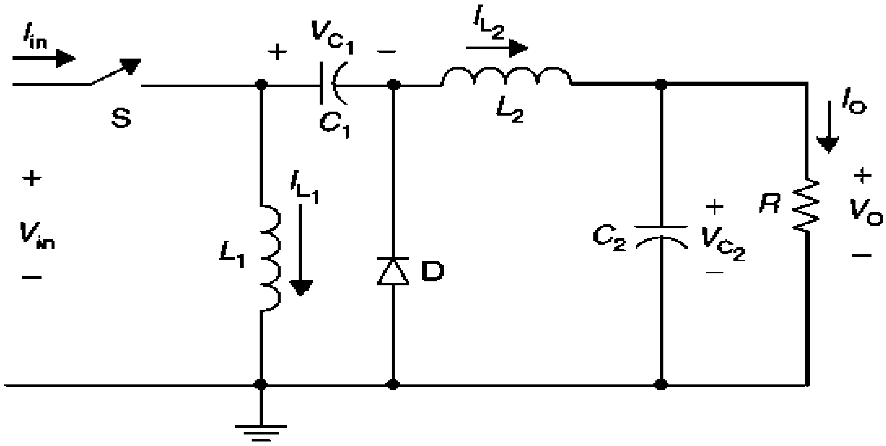


Figure 3 The schematic of the POLC

The functionality of the POLC can be treated as the series combination of a buck converter and a boost converter and the mathematical product of $d$and $1/(1-d)$= $d/(1-d)$ renders the converter the buck boost feature while d is the duty cycle. In the case of the buck operation $V_o = V_{in} \times d$ In the case of the boost operation$V_o = V_{in}/(1-d)$.If the converter as a whole is treated as a buck converter followed by a boost converter then the overall voltage gain will be $d/(1-d)$. The Inductor L1 is the shunt boost inductor and it handles the full power transferred from the source to the load. The inductor L2 is the series filter inductor and this inductor along with the output capacitor C2 take careof supplying a ripple free DC voltage across the load. The inductor L1 draws power from the source and passes it on to the output through the capacitor C1. The output side and the input side of the POLC are coupled through a series capacitor. When the converter is working the actual DC source voltage drops across the series capacitor and the voltage produced above the input voltage is passed on to the output. For example if the source voltage is 20V and the duty cycle is 0.6 then the steady state output voltage as given by the equation $V_o = V_{in} \times d/(1-d)$ andtheoutputvoltagewillthereforebe $V_o = 20 \times 1.5 = 30V$.

The actual voltage, in reality, generated by the boost mechanism will be 50 volts and a voltage equal to the source voltage of 20 volts will be dropped across the series capacitor and the remaining voltage of 30volts will appear across the load. Interestingly if the switch and the front end inductor or the boost inductor are just considered and if the relationship between the input voltage and the output voltage are related as a simple boost converter the boosted voltage will be given by the relationship$V_o = V_{in}/(1-d)$. Substituting the input voltage V_{in} and the duty cycle 0.6 the boost voltage will be 20/(1-0.6) and V_o= 20/0.4 = 50 volts. Out of this 50 volts generated the equivalent of the source voltage of 20 volts drops across the series capacitor and the remaining 30 volts appears across the load. This happens in compliance with the steady state equation for the output voltage of the POLC as given by

$$V_o = V_{in} \times d/(1-d) \quad (2)$$

In real time application the components that cause power losses in the POLC are the power semiconductor switch S, the inductors L1 and L2 and the intermediate and the output capacitors that are respectively series and the parallel in the topology. While going ahead with the mathematical analysis, it is assumed that, the components are ideal and incur no losses and however in the simulation and in the experimental verification these losses will be exhibited.

IV The Maximum Power Point Tracking

The maximum power deliverable from a solar PV is a function of the environmental conditions like temperature and solar insolation. With more solar insolation, the power generated by the PV panel is more and with increased temperature, the electric power generated by the PV panel gets reduced. The internal resistance of the solar panel changes with respect to the prevailing solar insolation and the prevailing temperature. In order that the power produced by the solar panel is fully harvested and delivered to the load the load resistance must be equal to the source resistance. In real time environment, as the solar insolation and temperature changes unpredictably, an automatic means of adjusting the load resistance is required and this arrangement or mechanism is known as the Maximum Power Point Tracking. If the power electronic converter connected to the solar PV is a DC to DC type of converter with variable duty cycle control then MPPT could be achieved bycontrolling the duty cycle of the DC to DC converter. Thus with Positive Output Luo Converter as the power conversion system attached to the solar PV panel the duty cycle is the manipulated parameter. By controlling the duty cycle of the POLC, the MPPT is achieved. It is the duty cycle of the POLC that essentially determine the equivalent resistance of the POLC looking from the source side. Based on the solar insolation the duty cycle will be adjusted and an algorithmic approach is required to manipulate the duty cycle so that the maximum power is harvested at all points of time. Figure 2.3 shows the circuit arrangement of the POLC with the power electronic switch on and off, the circuit topology changes accordingly and the resistance offered by the topology to the source side gets changed alternately. The average resistance over a cycle will match that required for maximum power transfer of power from the solar panel. The traditional MPPT techniques like the Perturb and Observe method or the incremental conductance method requires an explicit carrier. The reference signal to be compared against the carrier is generated by the algorithm and the corresponding switching train is generated.

V The Sliding Mode Controller

The Sliding Mode Controller (SMC) is a nonlinear control system and is also known as the variable structure controller. In any system, if the manipulated variable assumes two or more different but distinct values and if the application of the manipulated variable may cause the system to appear as a different structure depending upon the value of the manipulated variable then such a system is known as a variable structure system. In a POLC, the manipulated variable is the switching pulses and the switching pulse assumes two values of on and off for periods determined by the duty cycle. During the on and off periods the circuit assumes two different equivalent topological structures that make the system a variable structure system.

When the system assumes the first structure the controlled parameter moves in a direction and during the period the other structure is formed the direction of the controlled parameter changes to the opposite direction. Thus it becomes possible to keep the controlled parameter in a predetermined position. The basic information required for the implementation of the sliding mode controlled MPPT are usually available from the name plate details of the PV panel. The four important parameters available from the name plate of the PV panel are the Voc, Isc, Vpmax and Ipmax. These values correspond to the Standard Test Conditions of an insolation of 1000w/m2 and a temperature 25oC. In a solar photo voltaic panel, when subjected to a certain solar insolation and temperature the ratio between the voltage at maximum power point Vpmax and the Open circuit voltage V_{oc} is a constant of the panel. Let this constant be denoted as 'K'. In order that maximum power is harvested from the panel, the terminal voltage of the panel is maintained at an unique voltage that is a multiplication of the constant K and the open circuit voltage V_{oc} for the present solar insolation and temperature.

Whenever the solar insolation falls the value of V_{oc} also falls. For the new Voc, the$V_{pmax} = K \times V_{oc}$

As shown in the circuit diagram of the POLC, to start with, as the switch S is in the Off state, the PV panel is disconnected from the rest of the circuit current and the PV current becomes zero. In this condition, the solar panel delivers zero output power and the PV panel is left open circuited and the voltage across the PV panel is now equal to the open circuit voltage Voc. With the power electronic switch S is closed the solar panel drives a current through the front end inductor L1. The rise of current causes the PV panel terminal voltage to fall and if the switch is maintained in the On state the PV current reaches the short circuit current and at this condition the power delivered by the panel becomes zero as the terminal voltage has now become zero.

Thus the two states of the power electronic switch can drive the PV panel to swing between the open circuit and short circuit states. In these two extreme conditions the power delivered by the PV panel is zero. On the voltage versus current plane of the PV panel, the maximum power point lies between these two extremes. At the point of maximum power harvest, the terminal voltage of the PV panel will be $V_{pmax} = K \times V_{oc}$.

If the operation is started from the switch in the Off state, the initial voltage across the PV panel will be Voc. As the power electronic switch S is closed, the PV current rises and the PV terminal voltage falls eventually reaching the Vpmax. As the PV voltage just reaches Vpmax the power electronic switch S is opened. The PV panel once again gets open circuited. Once again the direction of the change in the terminal voltage of the PV panel now changes and it rises again above the Vpmax level. As the PV panel terminal voltage crosses the Vpmax in its excursion towards Voc the power electronic switch S is closed again. Thus the power electronic switch S is opened and closed repeatedly such that the required PV voltage for the delivery of maximum power output is achieved.

The algorithm for the SMC method of MPPT can be shown as

$$If V_{pv} > V_{pmax}\ then S = 1;$$

$$If V_{pv} < V_{pmax}\ then S = 0;$$

The typical rate of fall of terminal voltage and rise of current through the panel with the POLC connected to the PV panel, when the switch is closed can be observed by a simple MATLAB SIMULINK simulation as shown in the Figure 4.

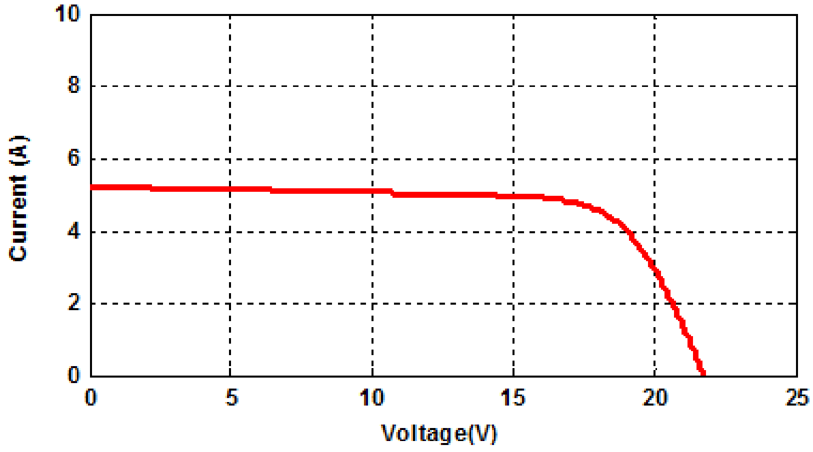


Figure 4 Current V_s Voltage when the switch is closed

The typical rate of rise of power output reaching a maximum and then falling down with the power control switch continuing in the on state with the POLC connected to the PV panel can be observed by a simple MATLAB SIMULINK simulation as shown in the Figure 5.

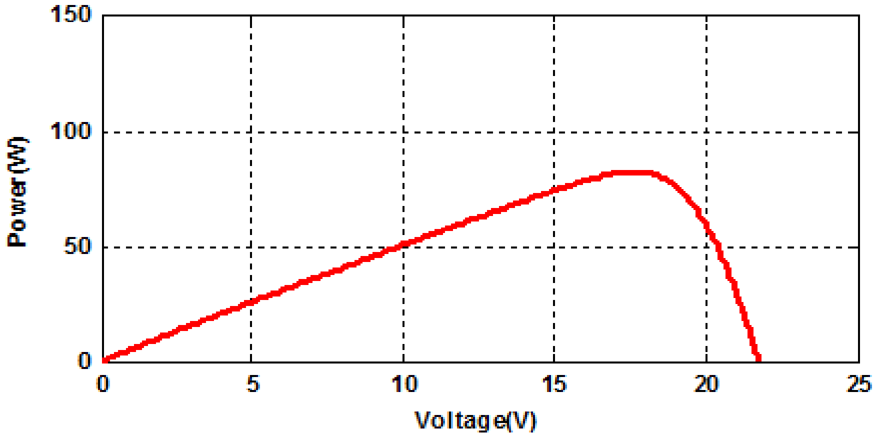


Figure 5Power V_s Voltage when the switch is closed

5.1 Sliding surface and System stability with the SMC

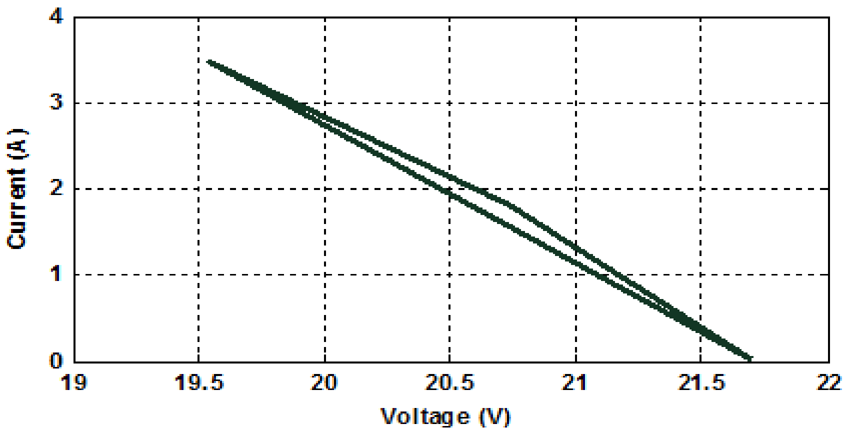


Figure 6 Sliding surface in the Current Vs Voltage curve of the PV panel with insolation 600w/m²

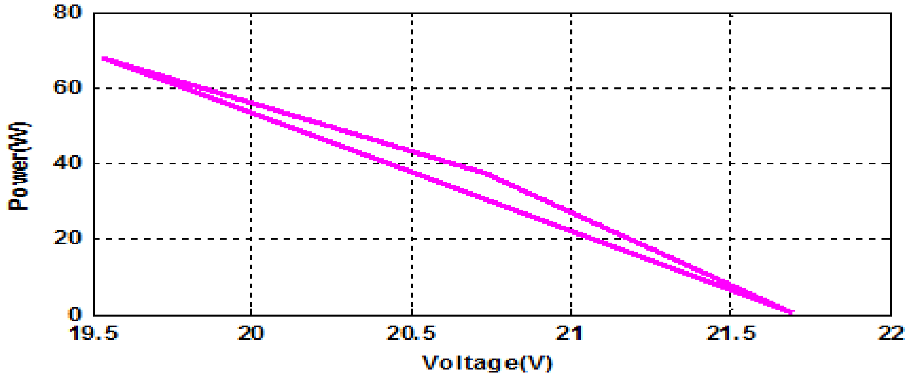


Figure 7 Sliding surface in the Power Vs Voltage curve of the PV panel with insolation 600w/m²

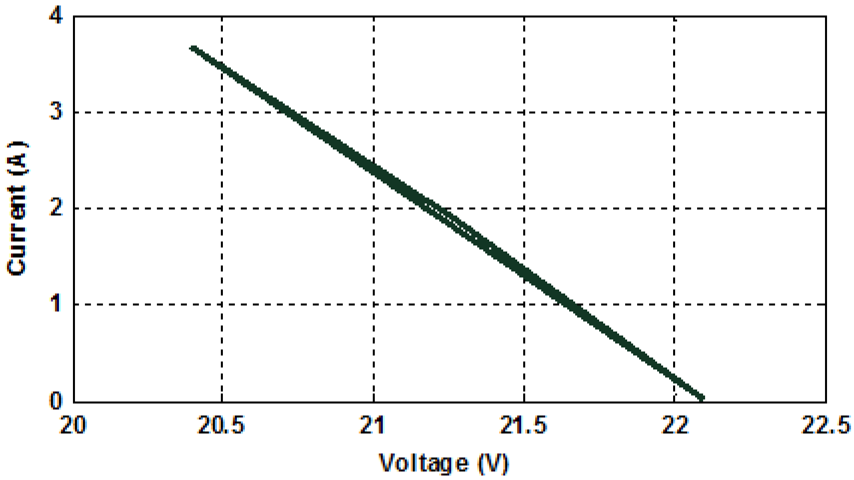


Figure 8 Sliding surface in the Current Vs Voltage curve of the PV panel with insolation 900w/m²

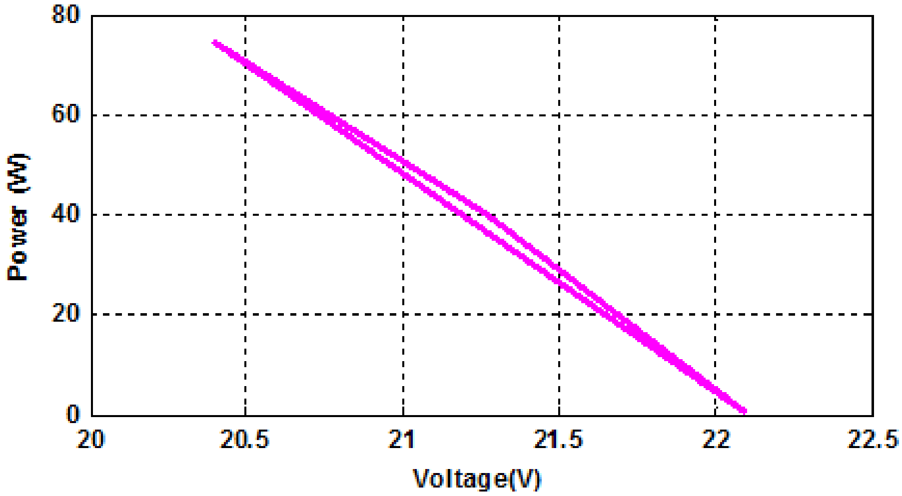


Figure 9 Sliding surface in the Power Vs Voltage curve of the PV panel with insolation 900w/m^2

Thus transient of rise and fall of the panel current do not follow the same path and thus traces a closed curve forming a surface on the Voltage Vs Current plane of the PV panel. This is the surface created by the SMC and this surface varies in accordance with the solar insolation as shown in Figures 6 to 9.

VI Simulations in TheMatlab Simulink Environment

The block schematic in the MATLAB SIMULINK environment is as shown in Figure 10. It consists of the Solar PV panel subsystem and the POLC along with the SMC based MPPT.

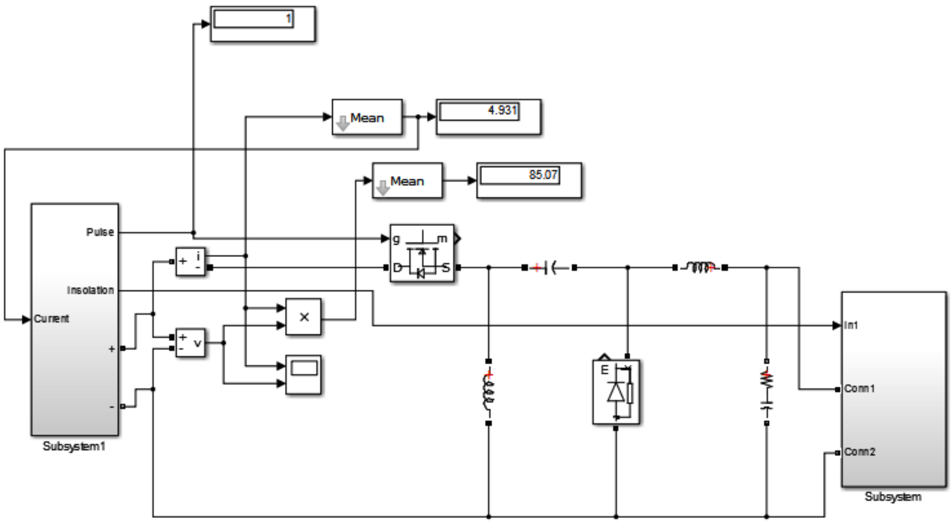


Figure 10 The MATLAB SIMULINK realization of the POLC

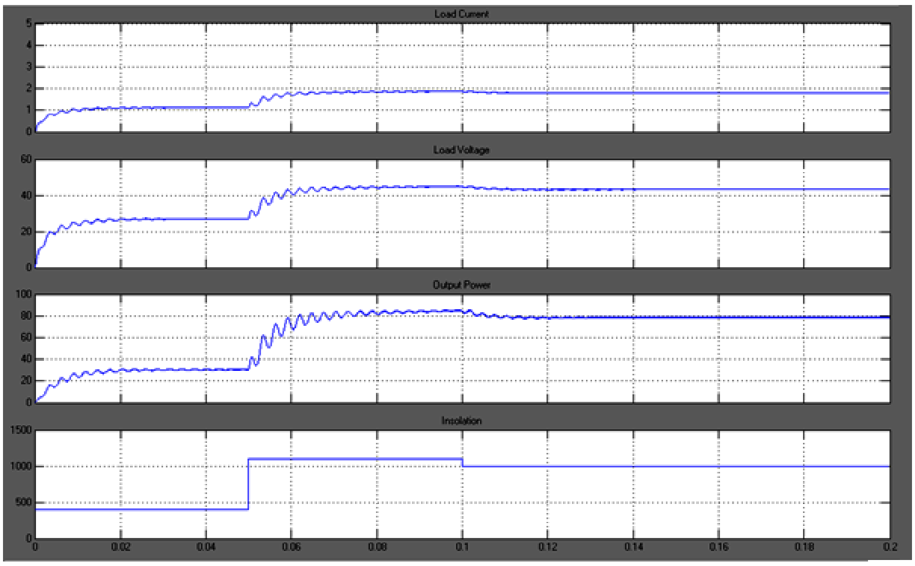


Figure 11 Represents the changes in the load voltage, load current, Output power of solar PV for due to change in insolation level

Table 1 gives the Simulation results for SMC based MPPT in POLC with various MPPT Techniques at Solar Insolation 1000 W/m^2

Table 1 Comparison of SMC with various MPPT Techniques

Method	Output Power in Watt	NS	MC
P and O	121	2	Fair
INC	121.5	2	Fair
SMC	124.5	1	Simple
FLC	122	2	Complex
ANN	122	2	Complex

VII Conclusion

An SMC based MPPT scheme has been designed and developed for the Positive Output Luo Converter. A sliding mode controller has been implemented for the harvest of maximum power when the POLC was used with a 125 W Solar panel. The results of MPPT with SMC have been compared with other MPPT algorithms. It has been concluded that the proposed design the SMC based MPPT for the POLC has proved to be better than the other MPPT algorithms. The proposed methodology has been validated using matlab Simulink.

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