International Journal of Engineering Research And Management (IJERM)
ISSN : 2349- 2058, Volume-01, Issue-07, October 2014

A MPPT with Fuzzy Sliding Mode Control for PV System used in Battery Charging Applications

P.Amuthini, M.Preetha, M.Yuvaleela, E.Mageswari

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 (PV) cells. A maximum power point tracker (MPPT) 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 Fuzzy sliding mode control (FSMC). 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. FSMC 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 FSMC.**

Index Terms— **Maximum Power Point Tracking(MPPT), Photovoltaic(PV),Sliding Mode Control(SMC),Fuzzy Sliding Mode Control(FSMC).**

I. INTRODUCTION

Reason development in the renewable energy sources is due to depliction of fossil fuels.Also this renewable energy sources is available in abundant in nature. One of the main advantage of this resources is that they are pollution free and occupies less space when compared with conventional sources. Various renewable energy available are solar energy, wind energy, geo-thermal energy, bio-mass energy, ocean energy, tidal, etc. Among them solar and pv are more appreciable since they are available in large account.To utilize the available energy. from this resources we are in need of an interface none other than power electronic converters.This converters control flow of power between the source and the load.

Renewable energy sources play an important role in electric power generation. Various renewable sources such as solar energy, wind energy, geothermal etc. are harness for electric power generation. Solar energy is a good choice for electric power generation. 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. Many such cells are connected in series to get a solar PV module.

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. 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. 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 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.

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 lot of iterations to calculate the optimal steady

Manuscript received Oct 10, 2014

P.Amuthini,
M.Preetha,
M.Yuvaleela,
E.Mageswari

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.

II. MODELLING OF PHOTOVOLTAIC 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. A PV module, which converts light into electricity, can be modeled as a single diode model, as shown in Fig. 1

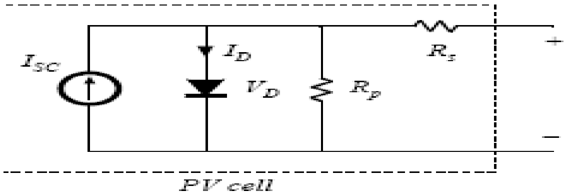

Figure 1 Equivalent Circuit Model of PV

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

KCL

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

Diode Characteristics

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

KVL

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

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

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

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

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

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

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

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

$$\eta = P_{max}/P_{in} = I_{max} V_{max} / A_{ga} \qquad (8)$$

Where Ga is the ambient irradiation and A is the cell area.

Solar cell I-V and P-V characteristics are shown in Fig 2 and Fig 3 respectively

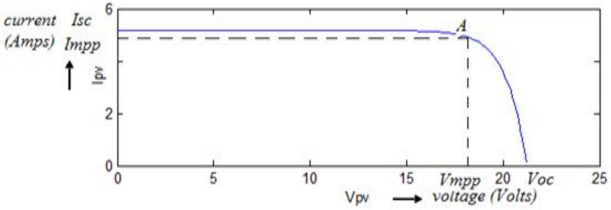

Figure 2 I-V Characteristics of solar cell

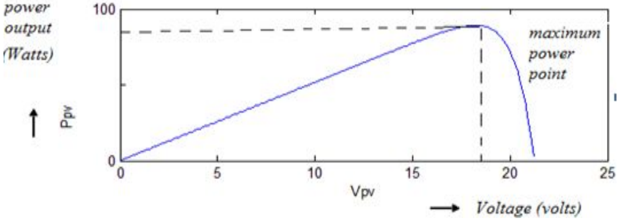

Figure 3 P-V Characteristics of solar cell

III. DC-DC CONVERTER

The step-down dc-dc converter, commonly known as a buck converter, is shown in Fig. 4. It consists of dc input voltage source VS, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. Under the assumption that the inductor current is always positive the state of the converter in which the inductor current is never zero for any period of time is called the continuous conduction mode (CCM). It can be seen from the circuit that when the switch S is commanded to the on state, the diode D is reverse-biased when the switch S is off, the diode conducts to support an uninterrupted current in the inductor.

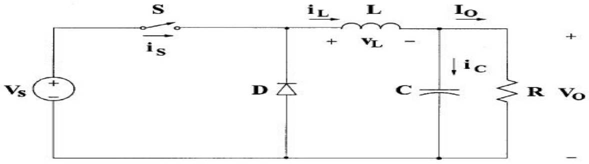

Figure 4 Buck converter circuit

For the buck converter

$$(V_S - V_O)DT = -V_O(1-D)T \qquad (9)$$

Hence, the dc voltage transfer function, defined as the ratio of the output voltage to the input voltage, is

$$M_V = \frac{V_O}{V_S} = D \qquad (10)$$

It can be seen from Eq. (10) that the output voltage is always smaller that the input voltage.

IV. 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.

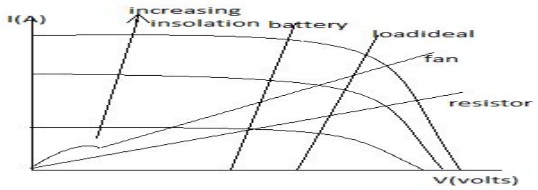

Figure 5 Characteristics of PV and some loads

If the operating point departs significantly from the maximum power point, it may be desires to interpose an electronic maximum power point tracker (MPPT) between are 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.

A. Existing topologies employed for pv system

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

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.

2) Perturb-and-observation (PAO) 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. 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.

Other methods that have been used to obtain the maximum power are parameters estimations, neural networks and linear reoriented method.

B. Proposed topology employed for pv system

1)Fuzzy Sliding Mode Controller: The drawback of SMC is the chattering phenomena. To overcome the chattering problem one solution consists into extending SMC to a Fuzzy Sliding Mode Control (FSMC). FSMC is a non-conventional and robust control law. It is suitable for nonlinear or complex systems characterized by parametric fluctuation or uncertainties. The advantage of the FSMC is that it is not directly related to a mathematical model of the controlled systems as the SMC.

V. FUZZY SLIDING MODE CONTROL

a) Fsmc For Dc- Dc Converters.

Some researchers show that FLC is a general form of variable structure control. Thus, some attempts have been made in order to integrate the SMC and FLC to a FSMC. However, the design of a FSMC for nonlinear system is a difficult problem. There have been quite a lot of researches on the combination of sliding mode control with fuzzy logic control techniques for improving the robustness and the performances of nonlinear systems with uncertainty.

We can distinguish two classes of control algorithms for FSMC. The first class is the fuzzy boundary layer SMC where the signum function is replaced by a fuzzy map so that the control input switch in a smooth manner to the equivalent control component. As consequence chattering is reduced. As an example of this kind of control a FSMC proposed by PALM is adopted. The second class consists of the set of fuzzy control algorithms which approximate the input-output map of traditional sliding mode control.

b) Fuzzy Boundary Layer Smc

Let us consider a second order system and as an example,
The sliding surface defined as follows:

$$S=EY^{T} \quad (8)$$

Where $E=[e,\dot{e}]$ and $Y=[k\ 1]$ with k a constant gain and e the output system error.

The distance between the trajectory error and the sliding surface dsn is defined as follows

$$d_{sn}=\frac{\dot{e}_p+ke_p}{\sqrt{1+k^2}} \quad (9)$$

dsn is the normal distance between the point $P(e_p,\dot{e}_p)$and the sliding surface. Such distance is illustrated graphically in Fig. 9 for an arbitrary point $P(e_p,\dot{e}_p)$.

Let $H(e_n,\dot{e}_n)$ be the intersection point of the switching line and its perpendicular passing through the point $P(e_p,\dot{e}_p)$.d_0 is defined as the distance between the point $H(e_p,\dot{e}_p)$ and the origin O. The distance do is expressed as follows

$$d_o=\sqrt{|E|^2-d_{sn}^2} \quad (10)$$

The presented FSMC has as inputs the two distances d_{sn} and do. The output signal is the control increment ΔU (k) which is used to update the control signal defined as follows

$$U(k)=\Delta U(k)+U(k-1) \quad (11)$$

The control law is equivalent to an integral action allowing a steady state error.

The presented FSMC is a Mamdani fuzzy inference system composed by a fuzzification block, a rule base block and a defuzzification block.

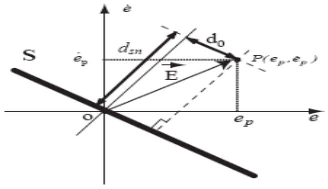

Figure 6 Distances d_{sn} and d_0

Trapezoidal and triangular membership functions, denoted by N (Negative), Z (Zero) and P (Positive), are used for dsn. The same shape of membership functions denoted by Z (Zero), PS (Positive small) and PB (Positive Big) are used for do.dsn and do membership functions are presented respectively in Fig. 7 and Fig. 8 in the normalized domain [−1 1] for dsn and [0 1] for d_o.

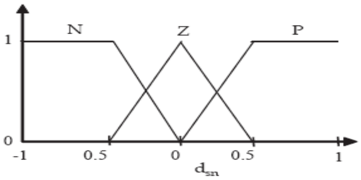

Figure 7 d_{sn} membership functions

For the output signal of the proposed FSMC, fives triangular membership functions, denoted by NB (Negative Big), NM (Negative Middle), Z (Zero), PM (Positive Middle), PB (Positive Big) are used for the output signal Δd. The rule base is given by table 1.

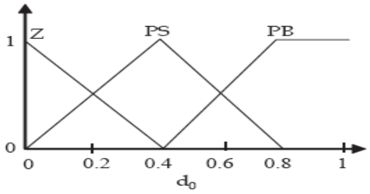

Figure 8 d_o membership functions

Table 1 Rule base of the proposed FSMC.

d_o \ d_{sn}	N	Z	P
Z	PS	Z	NS
PS	PB	PS	NB
PB	PB	NS	NB

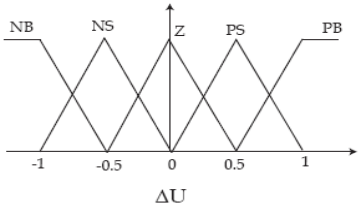

Figure 9 ΔU membership functions

VI. 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 Subcircuit. 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 Fig. 14.

A. Simulation Model Of Pv Module

1) Subcircuit Model Of Pv Module

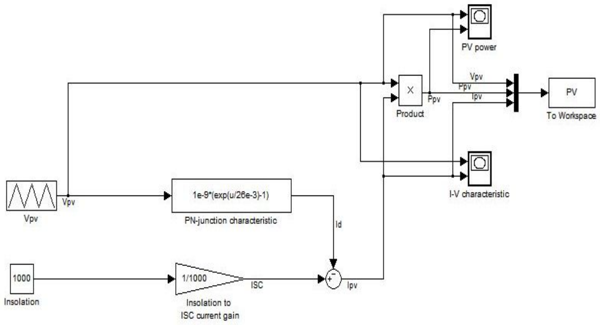

Figure 10 Simulation Scheme for PV Sub circuit

B. Simulation Model Of Pv With FSMC MPPT

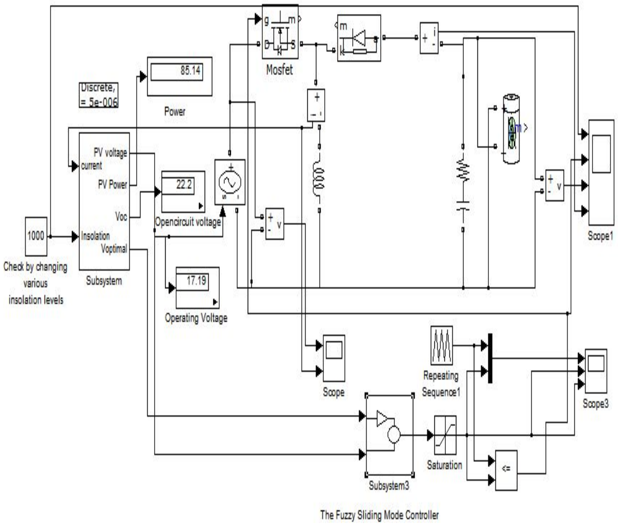

Figure 11 Simulation Scheme for the Proposed Model

C. Simulation Model FSMC

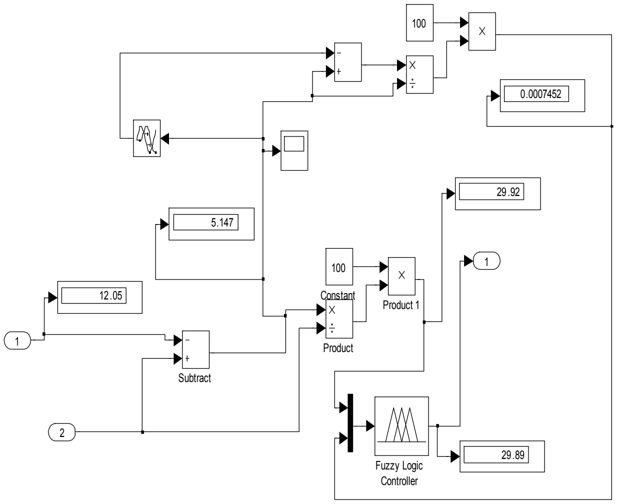

Figure 12 Simulation Scheme for the Proposed Model

VII. RESULTS

Table 2 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.

Fig.14 validate the fuzzy sliding mode controller and ensure that the PV operation point is in the knee point of the power vs. voltage graph were the PV operates at its maximum power even under standard conditions (STC) and under varying solar irradiation condition while supplying a higher power to the battery. Table 3 shows increment in the power given to the battery. It can be seen that the proposed method increase significantly the available power delivered to the battery.

1) I-V and P-V Characteristics waveform

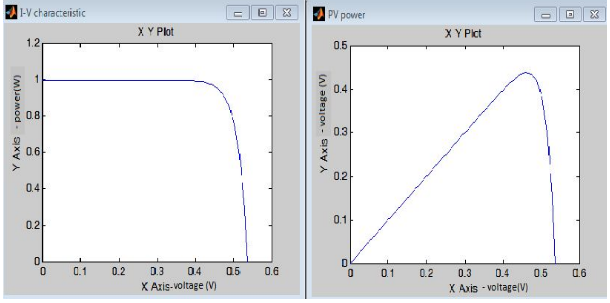

Figure 13 I-V & P-V Characteristics of PV Module

2) Simulation results of Power

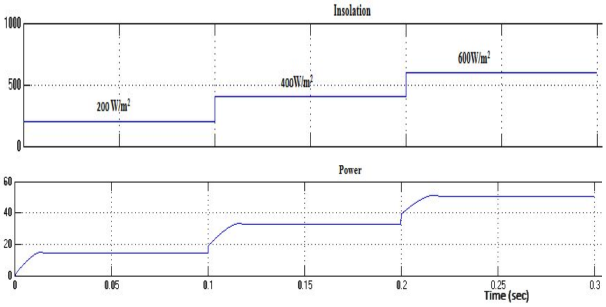

Figure 14 Output Power at battery when connected to proposed MPPT at varying Insolation condition

3) Simulation results of Output Voltage and Current

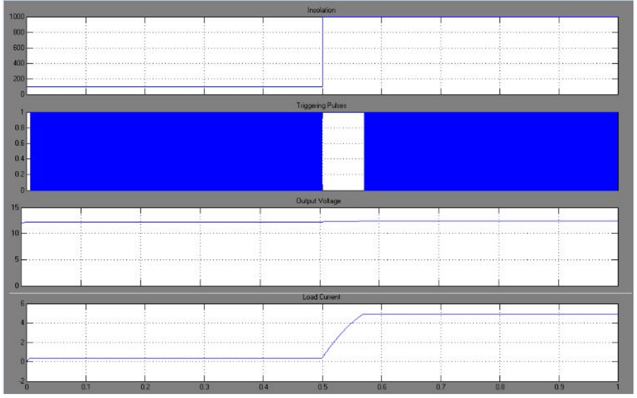

Figure 15 Output Voltage and Current at battery when connected to proposed MPPT

TABLE 2
SIMULATION RESULTS OF THE ESTIMATED P_{MAX}

Insolation (W/m^2)	**P_{pv}(W)**	**P_{max}(W)**
200	14.51	14.56
400	30.39	32.53
600	45.93	50.6
800	61.11	68.31
1000	75.87	85.14

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 Fuzzy 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. The first class of FSMC aimed to reduce chattering by changing the nonlinear component control by a fuzzy function. FSMC is not based on a rigorous analytical study as SMC. Thus, the same FSMC can be applied to Buck and Buck-Boost converters.

REFERENCES

[1] Eduardo Ortiz, Fang Peng, ''A Novel Method To Estimate The Maximum Power For A Photovoltaic Inverter System'', 2000 35th Annual Ieee Power Electronics Specialists Conference.

[2] Eduardo I; Peng, F.Z. Ortiz-Rivera, "Analytical Model For A Photovoltaic Module Using The Electrical Characteristics Provided By The Manufacturer Data Sheet'', Power Electronics Conference, 2005.Pesc'05. Ieee 36th, Vol. Pp 2087-2091, 11-14 Sept.2005

[3] Emil A. Jimenez Brea, I. Ortiz-Rivera, Jesus Gonzalez-Llorente, ''Simple Photovoltaic Solar Cell Dynamic Sliding Mode Controlled Maximum Power Point Tracker For Battery Charging Applications''(2010)Ieee.University Of Puerto Rico, Mayaguez Campus Mayaguez, Puerto Rico.

[4] Hasan. K. N,. Haque. M. E and Negnevitsky. M,'' Control Of Energy Storage Interface With A Bidirectional Converter For Photovoltaic Systems'' 2008 Australasian Universities Power Engineering Conference

[5] Kamel Ben Saad, Abdelaziz Sahbani And Mohamed Benrejeb,'' Sliding Mode Control And Fuzzy Sliding Mode Control For Dc-Dc Converters'' Research Unit Lara, National Engineering School Of Tunis (Enit), Tunis, Tunisia

[6] Myung-Bok Kim, Il-Song Kim, Myung-Joong Youn, ''New Maximum Power Point Tracker Using Sliding-Mode Observer For Estimation Of Solar Array Current In The Grid-Connected Photovoltaic System'', Ieee Transactions On Industrial Eletronics, Vol. 53, No.4, August 2006, Pag.1027-1036

[7] Spiazzi. G, Mattavelli. P, Rossetto. L,''Sliding Mode Control Of Dc-Dc Converters '', Dept. Of Electronics And Informatics Dept. Of Electrical Engineering University Of Padova, Via Gradenigo 6/A - 35131 - Padova (Italy)

[8] Vázquez J. R, Arteaga Orozco M. I, Salmerón. P, Litrán S. P, Alcántara F. J, '' Maximum Power Point Tracker Of A Photovoltaic System Using Sliding Mode Control'' International Conference On Renewable Energies And Power Quality (Icrepq'09) Valencia (Spain), 15th To 17th April, 2009

[9] Website for Pv Module Simulink Models. [Online]. Available: Http://Ecewww.Colorado.Edu/~Ecen2060/Matlab.Html