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MPPT Control Strategies for Solar Energy Harvesting Using SMC Approach

Vishakha S. Chavan
Research Scholar PG (Control System)
Department M. B. E. Society's
College of Engineering
Ambajogai(Maharashtra) [INDIA]
Email: vishakha.chavan8181@gmail.com

S. S. Sankeshwari
Professor & Head of the Department
Department of Electrical, Electronics & Power Engg.
M. B. E. Society's College of Engineering
Ambajogai(Maharashtra) [INDIA]
Email: sankeswari@gmail.com

ABSTRACT

This paper provides a new maximum power point tracking facility for standalone photovoltaic (PV) system. The unique combination of Sliding mode controller (SMC) controller with Voltage Reference Estimator and Partial Shadowing (PS) artistry are occur. The goal of this work is to exalt the solar energy harvesting from the photovoltaic generator (PVG). This goal is achieved with the help of SMC that lift the Boost Converter joined between the PVG and Load. This paper presents the detailed study & MATLAB/SILULIKHK design of MPPT controller to ensure a high PV system performance with the help of partial shadow technique which can also be selected for practical implementation issue. SMC offers fast and accurate convergence to the maximum power point. This performance can evaluate during steady state, load varying and partial shadow disturbance. Significant extracted results and discussion are provided to demonstrate the validity of proposed overall PV system.

Keywords:— *PV System, Sliding Mode Controller (SMC), MPPT, Partial Shadowing, Boost Converter.*

I. INTRODUCTION

The linearly increasing oil praises and fluctuation of rising degree of pollution contrasted with new arrangement of sustainable development make alternative and renewable energy sources more effective. Economic incentives and huge advancement in electric technology promote the use of photovoltaic systems. Many MPPT method have been developed and implemented in previous studies including Perturb and Observe (P&O)[1], incremental conductance (Inc-Cond)[2], fuzzy logic controller (FLC) approaches[3], Adaptive neuro fuzzy inference system[4], fractional open-circuit voltage and short circuit current[5], etc. These algorithms depends on the actual PVG operating point, from previous power point position. The trajectory of the new command value support the algorithm to choose the command output values. These techniques have high tracking accuracy only under stable condition, however it does not provide accurate output values between tracking speed and reliability when load values or weather condition rapidly changes.

Sliding mode controller has recently attracted from researches due to many advantages [6,7], its implementation simplicity and robustness are the main advantages, also it has grate performance in motor control and robotics. SMC used in PV fields by maximizing the power generated from PV panel while maintaining the system stability. To increase the efficiency and reduce the cost an boost converter is connected between PVG and load.

In general, PV system is typically built around the following main components shown in Figure 1:

- PVG to convert solar energy into electric energy.
- DC-DC converter to feed the load voltage demand.
- Digital controller that driver the converter.
- A load.

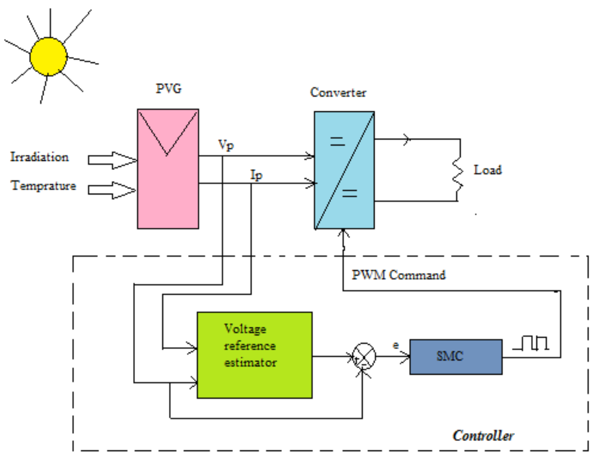

Figure 1: Synoptic Diagram of PVG System

The main objective of this work is to drag the MPP voltage reference estimator that attains the MPP. Due to partial shaded condition performance of photovoltaic module is highly affected to find the solution of this problem. PS algorithm is implemented between the VRE and SMC to reduce the error more effectively.

This paper is structured as follows: A brief description of the of the considered PV model is presented in Section 2, while Section 3 deals with the explanation of the entire proposed MPPT method; a detailed analysis of the voltage reference generator and a sliding mode controller method is described. Section 4 is dedicated to the partial shadowing (PS) study and the description of the PS-SMC algorithm. Simulation results are carried out in Section 5. Finally, some conclusions and future work are described in Section 6.

II. Photovoltaic System Modelling

One can substitute a PV cell to an equivalent electric circuit which includes current sources, diode & resistors.

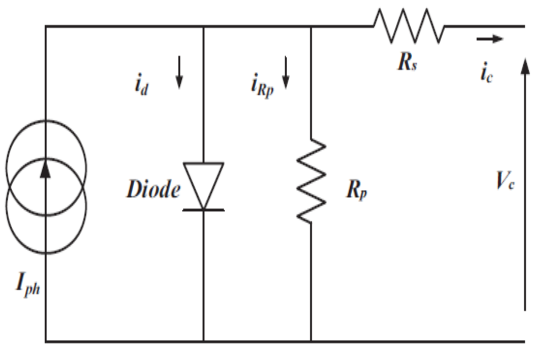

Figure 2: Equivalent circuit of PV cell

Produced Iph current is depends on irradiation intensity. Current Id flows through diode, Ic is the difference between Iph & Id which is feeding the load [8].

Use the node law,

$$I_c = I_{ph} - I_d - I_{sh} \quad (1)$$

The current Iph can be evaluated as,

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{rs-ref} + K_{sct}\left(T_c - T_{c-ref}\right)\right) \quad (2)$$

$$I_d = I_{rs}\left[\frac{\exp\left(q\left(V_c + R_s I_c\right)\right)}{\alpha KT} - 1\right] \quad (3)$$

$$I_{sh} = \frac{V_c + R_s I_c}{R_p} \quad (4)$$

Reverse saturation current at reference temperature can be obtained as,

$$I_{rs} = \frac{I_{rs-ref}}{exp\left[\frac{qV_{oc}}{n_s N \beta T_c}\right]} \quad (5)$$

Finally, Ic can be given by

$$I = I_{ph} - \left[I_{rs}\left[\frac{\exp(q(V_c + R_s I_c))}{\alpha KT} - 1\right]\right] - \frac{V_c + R_s I_c}{R_p} \quad (6)$$

The model of PVG depends on number of series (Ns) & parallel (Np) cells, shown in Figure 3

$$I_p = N_p I_c$$
$$V_p = N_s n_s V_c$$

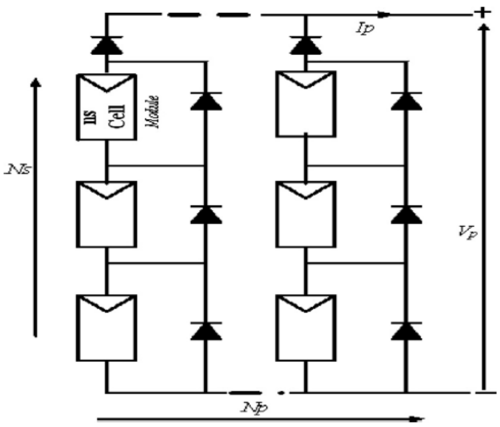

Figure 3: A PVG group of modules

Finally, current Ip can be given as

$$I_p = N_p I_{ph} - N_p I_{rs}\left(\frac{\exp q}{\alpha K_T}\left(\frac{V_p}{n_s N_s} + \frac{R_s I_p}{N_p}\right) - 1\right) - \frac{N_p}{R_p}\left(\frac{V_p}{n_p N_p} + \frac{R_s I_p}{N_p}\right) \quad (7)$$

By assuming Rp>>Rs, The terms containing Rs and Rp parameters could be eliminated.

Here the model is with Rs = 0, Rp = ∞

$$I_p = N_p I_{ph} - N_p I_{rs}\left(\frac{\exp q}{n.KT_c}\left(\frac{V_p}{n_s N_s}\right) - 1\right) \quad (8)$$

Where,

Id- Current through diode (A)

Irs, Iph- Reverse diode saturation current and phase current (A)

K-Boltzmann's Constant=1.381 (10)^(-23) (J/K).*

Tc,Tc-ref - cell temperature and reference temperature) (°C)

A- Ideality factor = 1.3

q = electron charge = 1.602* $(10)^{(-19)}$ (C)

G,Gref – irridation and irridation at STC (1000)) (W/m^2).

Vc, Ic- output voltage and current.

Ksct- Short circuit current temperature = 2.2* $(10)^{(-3)}$

Here, the model has 36 series connected monocrystalline cells n_s=36). Normally the performance of solar cell is evaluated the standard state condition (STC), the irradiance is normalize to 1000 w/m^2 & the cell temperature is 25°C.

Table 1. Specifications of the PV panel.

Cell type	Môn crystalline
Maximum power (W)	55
Open circuit voltage Voc (V)	20.5
Short circuit current Isc (A)	3.7
Voltage, max power V_{MMP} (V)	16.2
Current, max power I_{MMP} (A)	3.4
Number of cells in series	36
Temp. coeff. of Isc (mA/°C)	1.66
Temp. coeff. of Voc (mV/°C)	-84.08

2.2 Power boost converter

DC-DC boost converter is an electronic device which is used to DC electrical power efficiency from one voltage level to another according to duty cycle (D) command signal.

Converter holds the PVG to max working point via a regulator known as MPPT, hence the current of PVG is boosted. In order to step up the voltage, switch IGBT is used which has high commutation frequency with outpour voltage control by varying the switching duty cycle (D). The circuit diagram of converter & load is shown in figure 4 [9].

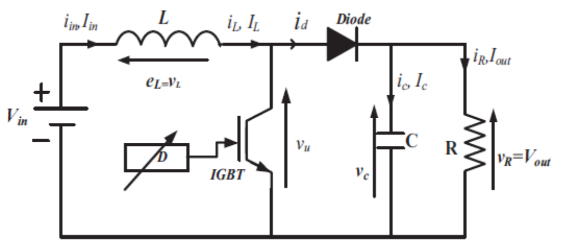

Figure 4. Circuit diagram of the Boost converter

In a continuous conduction mode (CCM) of boost converter, the output voltage is related to input one as follows:

$$V_{out} = \frac{1}{1-D} V_{in} \quad (9)$$

Based on assumption where Pin =Pout it can be obtained as,

$$R_{pv} = (1-D)^2 R_{out} \quad (10)$$

Where Rpv is the equivalent resistance viewed by connected to the PV module and Rout is the load connected to converter.

3. MPPT CONTROL

As the amount of sunlight varies, the load characteristics that gives highest power transfer efficiency changes, so that the efficiency of system is optimized when the load characteristics changes to keep the power transfer at highest efficiency. This load characteristics is called MPPT.

3.1 Sliding mode controller

The method SMC-MPPT algorithm is divided into two steps, first is to draw the actual reference voltage value at which the system will reach its maximum power. The second is to operate the system with this voltage value that gives the max power.

Step 1: Voltage reference estimator

The goal of this is to create a command using voltage reference (Vref) which force the system to work at the MPP. In figure 5, the red curve is indicated as a MPP-VRE constructed using the fitting function F with V_{MPP} = F(P). From Figure 5 after several irradiations for any state, the system will be forced to work with the required voltage V_{MPP} and therefore it meets the MPP. For eg: let the PV system is working at point 'P1', after projection with voltage reference curve, reference voltage move from ' V1 to V2' and operating point will change its position to "P2". Using same strategy, "P2" will projected again on reference curve until it reaches its max point shown in Figure 5. And finally P_3= P_{MPP}. As a result, the constructed red curve can be used as MPP-VRE [10].

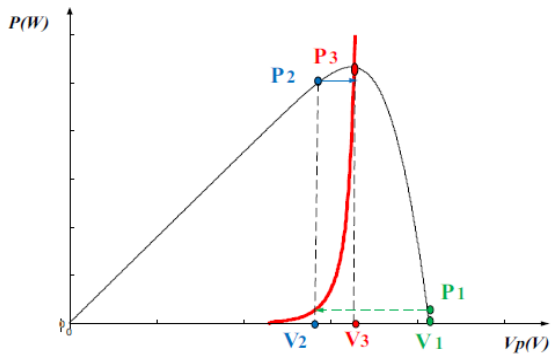

Figure 5 PV characteristics at fixed temperature value of 25 ℃

At a given temperature several tests have been performed, finally it conclude that following function provide better implementation for PV panel.

$$V_{MPP} = F(X, Y)$$

$$= p_{00} + p_{10}{*}X + p_{01}{*}Y{+}p_{20}{*}\,(X)^2 + p_{11}{*}XY + p_{30}{*}X_3 + p_{21}{*}X_2{*}\,Y + p_{40}{*}x^4 + p_{31}{*}(\,X)^3{*}Y{+}\,(p_{50}{*}X^5{+}p_{41}{*}X^4{*}Y \quad (11)$$

With, X = (P - meanX)/stdX and

Y = (T - meanY)/stdY ; meanX =73.38, stdX = 67.38; meanY = 29.7, stdY = 13.05

p_{00}=15.29	p_{10}=0.6488	p_{01}=–1.09
p_{20}=–0.5132	p_{11}=0.01793	p_{30}=0.4582
p_{21}=–0.01153	p_{40}=–0.2286	p_{31}=–0.001497
p_{50}=0.04033	p_{41}=0.001746	

Step 2: SMC

After the estimation of VMPP, the implemented SMC is used to drive the regulation element in such a way to reduce the actual voltage error between the acquired PVG voltage and the target VMPP.

$$S = e = V_p - V_{ref} \quad (12)$$

$$u = \frac{1}{2}(1 + sign(S)) \quad (13)$$

$$u = \begin{cases} 1 & S > 0 \\ 0 & S < 0 \end{cases} \quad (14)$$

Stability demonstration:-

The stability can be analysed based on the Lyapunov theory. A positive definite function V is defined as

$$V = \frac{1}{2}S^2 > 0 \quad (15)$$

Whose time derivative is:

$$V = S\frac{ds}{dt} = S\dot{S}.$$

Considering

$$\begin{cases} S = e = V_p - V_{*MPP} \\ \dot{S} = \dot{e} = \dot{V}P \end{cases}$$

Next, based on the principle of Lyapunov, it is demonstrated that S reaches the state S = 0. Therefore the system reaches the desired voltage value VMPP, and thus reaches the point of maximum power.

When S > 0

The switch will be open; this implies that the duty cycle will increase. From the boost converter model Eq. (14) we have,

$R_{pv}=(1–D)^2R_{out}$ and using this equation, we can observe that:

- If the duty cycle D increases, then Rpv decreases, so based on the PV dynamic given by the I–V characteristic shown in Figure 7, the Ip will increase and Vp will decrease equivalently from Eq. (7). It can be deduced that when the voltage (Vp) increases/decrees, The current (Ip) decreases/increases. So, as a result in this case, this implies

$\dot{V}p$ < 0 and $\dot{S}$ < 0

Finally, < 0.

When S < 0, Using the same method.

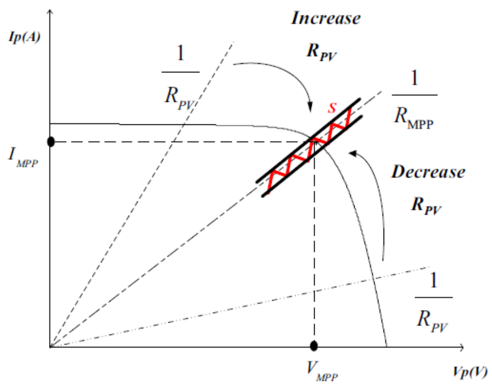

Figure 6 IV characteristics and MPPT process

The switch will be close, this implies that the duty cycle will decrease. If the duty cycle D decreases, then $R_{pv}=((1–D))^2 R_{out}$ increases. Therefore, based on the PV dynamic given by the I–V characteristic shown in Figure 7, the Ip will decrease and Vp increases equivalently from Equation (9). It can be deduced that, when the voltage (Vp) decreases/increases the current (Ip) will increase/decrease, so:

If the resistance connected to the PV panel increases then (Vp) increases and (Ip) decreases, this implies that: *vp* > 0 And> 0

$$\text{So } S\dot{S} < 0$$

Finally, using the Lyapunov stability theory it can be concluded that S reaches the state S = 0, meaning that the system reaches the desired voltage value VMPP and hence the converges to the point of maximum power.

IV. PARTIAL SHADOWING OF PHOTOVOLTAIC ARRAYS (PVG)

The performance of the series connected chain of the solar cells is affected if all its cells are not equally illuminated (partially shaded) Figure 7 shows the characteristics of the PVG in cases of presence of shadow presence or not [11].

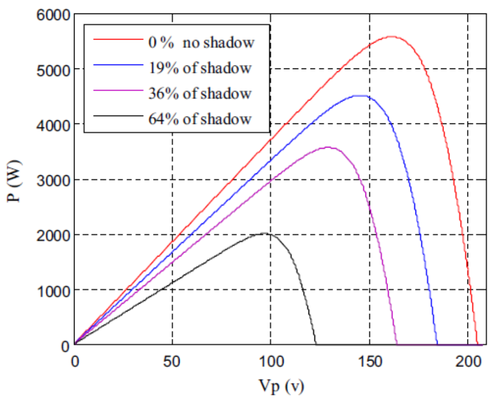

Figure 7 PV Characteristics under constant irradiation (1000 W/m2) and temperature (25 ℃) values.

Partial shadow (PS) is a common reason of power loss in a PV system. This loss of efficiency can occurs in many ways. This paper proposes an additional algorithm is added after the voltage reference estimator and before the SMC controller to correctly track the MPP against PS disturbance occurring.

This work proposes a system based on a simple partial shadow detection method that will be trigged only when PS is detected; in order to check the presence of a PS, this algorithm makes a test every one second; this is accomplished through the test of the power value. As a result, when the power decreases by 10% the correction action will be trigged. This algorithm is called PS-SMC. The flowchart of the PS-SMC concept is shown in Figure 8.

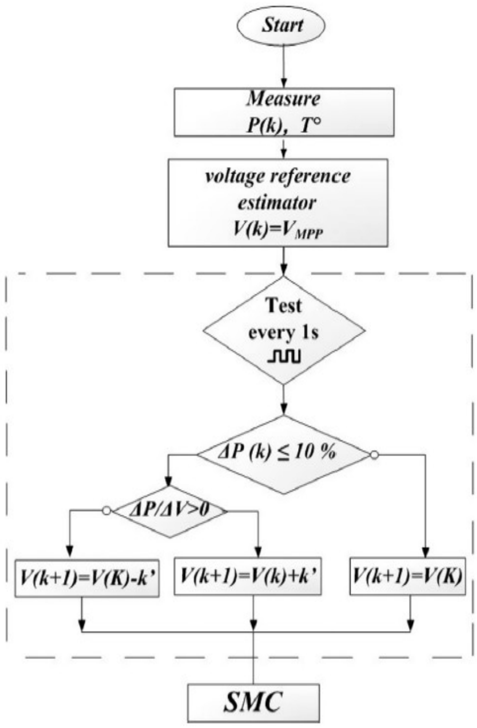

Figure 8 PS-SMC algorithm flowchart

In this algorithm, temperature and current voltage sensors are required for the voltage reference estimator. The same current and voltage will be later used for the calculation of the power values. First, the voltage reference estimator generates the VMMP. After receiving the last value, this algorithm makes a test every period of one second in order to test the existing shadow by detecting a decrease in the power values.

5. Simulation & Simulation Results

Figure 9 shows the Simulink diagram of PS-SMC

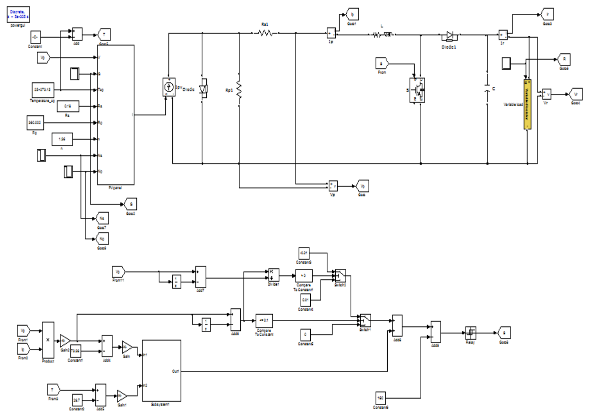

Figure 9 Simulation diagram of proposed system

5.1 Simulation results of SMC

The system is tested over a sudden step irritation and load changes as shown respectively. in output 10, 11 this action is used to provoke the controller robustness and the ability to keep the extracting the maximum power within this abrupt variation.

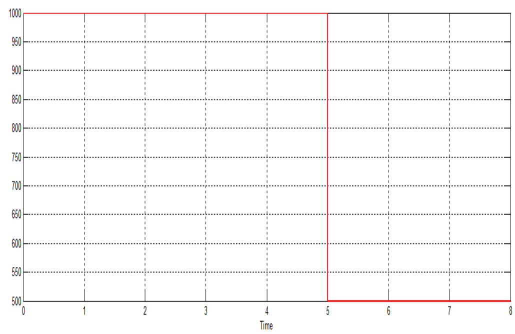

Figure 10 Irradiation abrupt variation

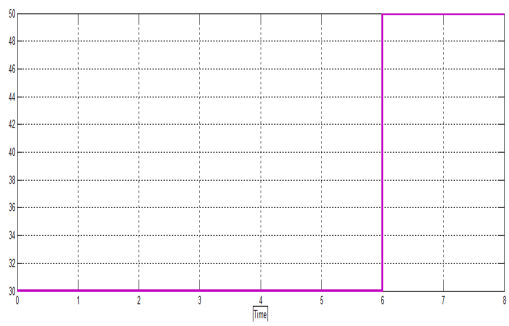

Figure 11. Load abrupt variation

In order to test the PS-SMC robustness against PS the system will suffer 19 % of partial shadowing from 1 to 3 s as shown in Figure 12.

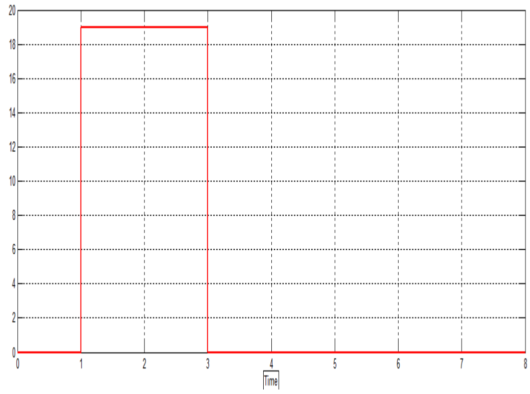

Figure 12 Partial shadow abrupt variation

Figure 13 presents the duty cycle signal delivered by the SMC, which will be used with a reference saw signal to generate a PWM IGBT drive signal. This figure also shows the direct PWM signal generated by the PS-SMC. This has the benefit of avoiding the use of a PWM commutation signal (saw signal). It permits directly constructing the PWM output signal toward the IGBT Gate. In Figure 13 close up (at second 1 and 5), it is clear that the PWM frequency is affected by the condition changes.

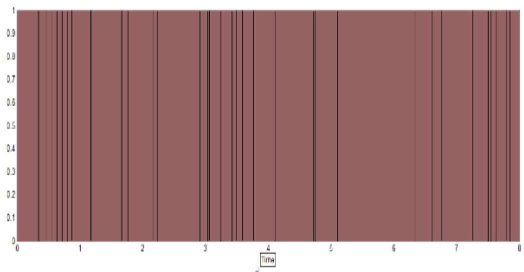

Figure 13 Controller Signal Output

Figure 14 shows the PVG current, voltage and power respectively. As observed in Figure 14 the PS-SMC algorithm tracks the new MPP yet always generates an oscillating signal around the optimal power value. Figure 14(b) shows the output of the voltage reference estimator (VMPP); when the PV system is under partial shadow, this voltage doesn't correspond to the voltage at the correct MPP. In this case, the PS-SMC acts in order to adequately modify the MPP reference voltage using the algorithm presented in Figure 8. it is clear that in the magnified portion of second 2 there is a small perturbation. This perturbation is caused by the PS-SMC test (every second in case of shadow detection) to verify that there is still a partial shadow. At second 5, the irradiation changes, the MPP also changes its position, and so the controllers act in order to track the new MPP.

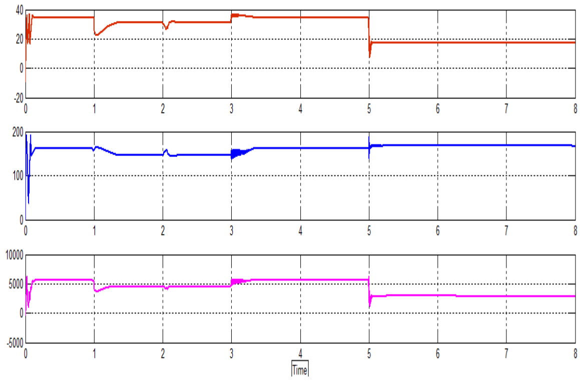

Figure 14 PVG current, voltage and power behavior

Figure 15 show the load voltage and current. The SMC controller presents less oscillations and faster tracking in its response. The algorithm based on a sliding mode control is a robust and efficient algorithm. Indeed, this algorithm works at the optimum point without oscillations. Furthermore, it is characterized by a good behavior in transient state.

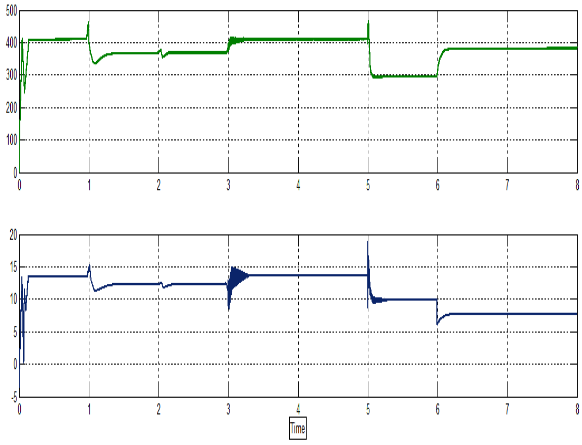

Figure 15. PVG power and Load feeding voltage

This work is focusing on SMC as an MPPT. The main purpose of this thesis is to add a voltage reference estimator that generates the VMMP in ordinary conditions and also add a PS algorithm that detects shadow and generates the adequate voltage value. In order to gain time, The PS algorithm starts the research of the new VMPP from the last value given by the voltage reference estimator. Later, the adequate voltage will be considered as an input for the SMC controller that guarantees the system maximum efficiency and stability. Simulations were performed while rapidly changing shading, load and irradiation disturbances were applied, and the obtained results show that both systems using different controllers present a good maximum power tracking. However, the PS-SMC controllers present lesser oscillations, faster tracking in response and more stability. Moreover, the PS-SMC algorithm has been proved to be effective and sensitive to existing shading.

VI. Conclusion

A PVG system with a passive load type via a Boost converter is reviewed through simulation tests. To boost the system efficiency and performance, a MPPT DC-DC converter driven is synthesized based on the sliding mode theory. Using the Lyapunov theory the stability of the proposed SMC-MPPT system is verified. A simple and reliable estimator was formulated using only temperature and power sensors, for perform of accurate and rapid SMC-MPP. The proposed MPPT algorithm insures high tracking performance and robustness. A new algorithm PS-SMC is proposed to compensate and overcome the PVG shadowing effects and drawbacks. This thesis summarizes the main algorithms driving an entire PVG system obtained after long and extensive work. Acquired results are very encouraging and suggest perspective experimental and theoretical studies for improving PVG system performances.

This paper summarizes the main algorithms driving an entire PVG system obtained after long and extensive work, which dealt with theoretical and experimental efforts. Acquired results are very encouraging and suggest perspective experimental and theoretical studies for boosting PVG system performances. Moreover, this work can be extended to consider dynamic load types.

REFERENCES:

[1] Zakzouk NE, Abdelsalam AKA, Helal A, Williams BW. Modified variable-step incremental conductance maximum power point tracking technique for photovoltaic systems. In: 39th Annual conference of the IEEE industrial electronics society. IECON; 2013. p. 1741–8.

[2] Hadji S, Gaubert J, Krim F. Maximum Power Point Tracking (MPPT) for photovoltaic systems using open circuit voltage and short circuit current. In: Int Conf Syst Control (ICSC). p. 87–92.

[3] El Khateb A, Rahim NA, Slvarj J, Uddin MN. Fuzzy logic controller based SEPIC converter for maximum power point tracking. IEEE Trans Ind Appl 2014;50:2349–58.

[4] Farhat M, Barambones O, Sbita L. Efficiency optimization of a DSP-based standalone PV system using a stable single input fuzzy logic controller. Renew Sustain Energy Rev 2015;49:907–20.

[5] Farhat M, Flah A, Sbita L. Photovoltaic maximum power point tracking based on ANN control. Int Rev on Model Simul (IREMOS) 2014;7:474–80.

[6] Alqahtani A, Utkinin V. Self-optimization of photovoltaic system power generation based on sliding mode control. In: Proceedings of IECON'12. p.3468–74.

[7] Levron Y, Shmilovitz D. Maximum power point tracking employing sliding mode control. IEEE Trans Circuits Syst 2013;60:724–31.

[8] Farhat M, Sbita L. Efficiency boosting for PV systems-MPPT intelligent control based. Energy Efficiency. Intech Publisher; 2015. http://dx.doi.org/10.5772/59399.

[9] Zhou Z, Holland PM, Igic P. MPPT algorithm test on a photovoltaic emulating system constructed by a DC power supply and an indoor solar panel. Energy Convers Manage 2014;85:460–9.

[10] Rújula AAB, Abián JAC. A novel MPPT method for PV systems with irradiance measurement. Sol Energy 2014;109:95–104.

[11] Mathur Badrilal. Effect of shading on series and parallel connected solar PV modules. Modern Appl Sci 2009;3:32 –41.

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