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Principle of Modified Incremental Conductance Sliding Mode MPPT Control Applied of Photovoltaic system

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***Abstract*— In order to operate the photovoltaic generator in its optimal regime, it is necessary to introduce an adaptation stage between the source and the load. This stage is generally in the form of a static converter (DC/DC). To extract the maximum power at each moment from the generator photovoltaic, the control (Maximum Power Point Tracking) acts on the duty cycle of the DC-DC converter to extract the Maximum Power Point . These methods are classified into three categories: indirect, direct and intelligent methods. In this work we will make a combination between a direct method which is characterized by its simplicity of implementation and another method among the intelligent methods which is characterized by a very good response time of the system and offers a minimization of oscillation around the maximum power point. These methods are; the incremental conductance method and the sliding mode method. With this mixture between these two methods, an improvement has been applied which is a starting system which facilitates the attack of the maximum power point during the starting phase through the open circuit voltage. This combination gives a very good extraction of the point of maximum power, this is demonstrated by the simulation results.**

***Keywords*— Incremental Conductance (IC), Modified incremental conductance sliding mode method (MICSM), Maximum power point tracking (MPPT), Sliding mode control (SMC).**

I. INTRODUCTION

The fossil fuels (oil, gas, uranium, etc ...), despite their contributions, have drawbacks in terms of capacity that comes from the degradation of the world's reserves and in terms of impact on the environment. The latter is visible by the rejection of greenhouse gases that causes global warming. These disadvantages give rise to technologies that help exploit the inexhaustible clean natural energies.

The renewable energy penetrates becoming more and more important in national electricity production. The Tunisian strategy plans to bring back the share of renewable energies in electricity production from around 2% in 2010 to 30% in 2030.

In the last decades, following the improvement of the yield of photovoltaic panels as well as the increase of the advantages notably the subsidies, the profitability of a photovoltaic installation became justified. A problem we may encounter is the high dependence of the output characteristics of a photovoltaic generator with the climate conditions (Temperature and irradiation). So we have to find ways to still extract the maximum power of PVG and send it to the load.

To ensure an optimal operation of the photovoltaic generator (For a given illumination and temperature), there is an optimal voltage V_{opt} and an optimal current I_{opt} which generates an optimal power P_{opt} delivered by the photovoltaic generator. As a result, there are different search techniques of the MPP that lead to reducing the error between the voltage of the photovoltaic generator and the optimal reference voltage which varies according to the climatic conditions. Several methods are used to avoid this operating problem by generating a suitable V_{opt} reference voltage. These methods are summarized in three categories: Indirect , Direct and Intelligent methods.

Among these different methods, we have chosen to make a combination between two methods belonging to two different categories; Incremental conductance and sliding mode methods. The purpose of this combination is to take advantage of the advantages of each of these methods to have a very good extraction of maximum power in terms of response time, oscillation minimization and simplicity of implementation.

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The rest of this paper is organized as follows: The modeling of the PV System is introduced in section 2. Section 3 is interested in the description of proposed MPPT algorithm . In section 4, the simulation results are provided.

II. CONFIGURATION OF PV POWER SYSTEM

The system thus synthesized presents a photovoltaic system without storage energy. It consists of a resistive load powered from a renewable energy source (photovoltaic energy). The stage of adaptation between the load and the source is ensured through the addition of a booster chopper. Chopper control is done with a Maximum Power Point Tracking (MPPT) command to extract a maximum power from the load. Fig.1. shows the block diagram of the study system.

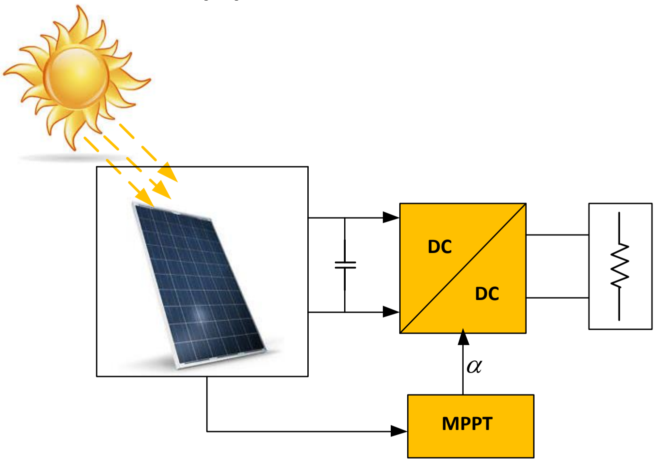

Fig. 1 General structure of the PV system

A. Electrical model of a real solar cell

The equivalent diagram of a photovoltaic cell is given by the Fig.2.

Circuit ideal

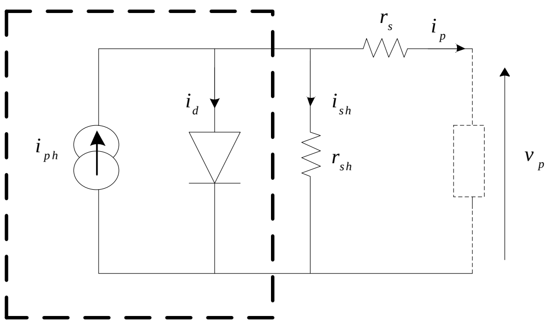

Fig. 2 Equivalent circuit of real solar cell

The mathematical model of a photovoltaic cell is given by the following equation (1):

$$f(v_{pv}, i_{pv}) = i_{pv} - i_{ph} + i_s(\exp(\frac{v_{pv} + r_s i_{pv}}{v_t} - 1) + \frac{v_{pv} + r_s i_{pv}}{r_{sh}} \tag{1}$$

With V_{pv} and I_{pv} are respectively the output voltage and the output current of PV Generator, i_{ph} is the photocurrent, i_s is the reverse saturation current of the diode, v_t is the solar cell thermal voltage, R_s and R_{sh} are respectively the series and shunt resistors of the cell. The PV Generator is constituted by an assembly of photovoltaic panels; the panels in turn are constituted by photovoltaic cells.

B. Modeling of the PVG-BOOST chain

Fig. 3. shows the block diagram of a parallel chopper:

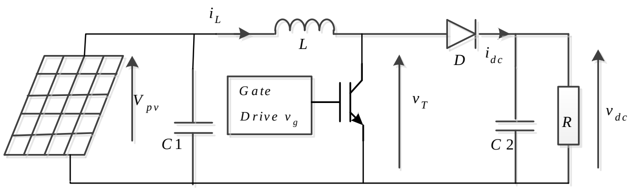

Fig. 3 Block diagram of a parallel chopper

To extract maximum power from PVG, we must act on the chopper by the action of the duty cycle that is given by the following equation:

$$V_{dc} = \frac{V_{pv}}{1-\alpha} \tag{2}$$

Fig.4. and Fig.5. show the structure of the chopper boost in both cases of the controlled switch :

- **Closed switch structure**

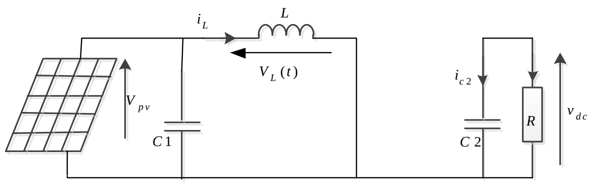

Fig . 4 Block diagram of closed switch structure

$$\begin{cases} \frac{di_L(t)}{dt} = \frac{V_{pv}(t)}{L} \\ \frac{dV_{dc}(t)}{dt} = -\frac{V_{dc}(t)}{Rc_2} \end{cases} \tag{3}$$

- **Structure with open switch**

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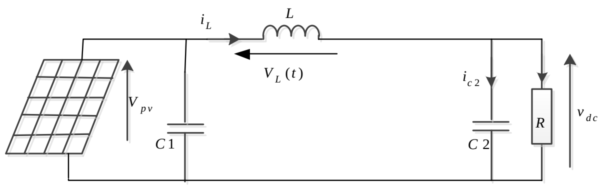

Fig. 5 Block diagram of a structure with open switch

$$\begin{cases} \dfrac{di(t)}{dt} = \dfrac{V_{pv}(t)}{L} - \dfrac{\mathrm{V}_{\mathrm{dc}}(\mathrm{t})}{L} \\ \dfrac{dV_{dc}(t)}{dt} = \dfrac{i_L(t)}{c_2} - \dfrac{V_{dc}(t)}{c_2 R} \end{cases} \tag{4}$$

From (3) and (4), the mathematical model of the PVG-BOOST system is as follows:

$$\begin{cases} \dfrac{di(t)}{dt} = \dfrac{V_{pv}(t)}{L} - (1-u)\dfrac{V_{dc}(t)}{L} \\ \dfrac{dV_{dc}(t)}{dt} = -\dfrac{V_{dc}(t)}{Rc_2} + (1-u)\dfrac{i_L(t)}{c_2} \end{cases} \tag{5}$$

With u is the switching state.

If we ask that: $x = [x_1 \ x_2]^t = [i_L(t) \ V_{dc}(t)]^t$

so, we get the following model:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{x_2}{L} \\ \dfrac{x_1}{c_2} & -\dfrac{x_2}{Rc_2} \end{bmatrix} + \begin{bmatrix} \dfrac{x_2}{L} \\ -\dfrac{x_1}{c_2} \end{bmatrix} u + \begin{bmatrix} \dfrac{V_{pv}(t)}{L} \\ 0 \end{bmatrix} \tag{6}$$

III. PRINCIPLE OF THE PROPOSED MPPT TECHNIQUE

The output characteristics of a photovoltaic generator are influenced by climatic conditions. Therefore, MPPT techniques are required to follow the maximum power point to maximize the extracted power. This MPPT as its name suggests can track the PVG maximum power point.

A. Incremental conductance method

Incremental conductance algorithm is based on the following equation

$$\frac{\partial I_{pv}}{\partial V_{pv}} + \frac{I_{pv}}{V_{pv}} = 0 \tag{7}$$

When the operating point is in the right of the maximum power point, so we have:

$$\frac{\partial I_{pv}}{\partial V_{pv}} + \frac{I_{pv}}{V_{pv}} < 0 \tag{8}$$

If this point is to left of maximum power point, we obtained:

$$\frac{\partial I_{pv}}{\partial V_{pv}} + \frac{I_{pv}}{V_{pv}} > 0 \tag{9}$$

The optimum can be followed by comparing the instantaneous conductance $\dfrac{I_{pv}}{V_{pv}}$ and the incremental conductance $-\dfrac{\partial I_{pv}}{\partial V_{pv}}$. If the optimum is reached, the operation of the PVG is maintained at this point and the disturbance stops until a new change in current level is noted, [1], [2]. In this case, the decrease in the algorithm or the increment is performed to follow the new maximum power point. This method provides a good performance in rapidly changing weather conditions.

B. Modified Incremental Conductance Sliding Mode Control (MICSM)

The variable structure control with sliding mode is a control technique that is essentially characterized by: the robustness of a system in front of parametric variations and external disturbances.
The feasibility of this control technique is validated theoretically as well as the practical plan. The control of variable structure systems occupies a nonlinear control class of systems. It is essentially characterized by a structure that varies with the evolution of the order, [3]-[5].
Sliding mode control is a technique that occupies a large part in different applications (robotics, aeronautics, automobile, electric actuators, etc ...).
The synthesis of the sliding mode control consists essentially of three parts,
• The choice of the sliding surface;
• The establishment of the conditions of existence;
• The determination of the control law.
In this part, we studied the continuous-time Sliding Mode Control (SMC) theory while providing an improvement to it, [6], [7].

MICSM method consists firstly in a combination of the incremental conductance method and the sliding mode. We will choose as sliding surface S the equation that characterizes the IC method:

$$s(x) = \frac{I_{pv}}{V_{pv}} + \frac{\partial I_{pv}}{\partial V_{pv}} \tag{10}$$

At the point of maximum power, We have:

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$$\frac{I_{pv}}{V_{pv}}+\frac{\partial I_{pv}}{\partial V_{pv}}=0 \implies \frac{I_{pv}}{V_{pv}}=-\frac{\partial I_{pv}}{\partial V_{pv}} \quad (11)$$

We will consider $Y=-\frac{\partial I_{pv}}{\partial V_{pv}}$ as incremental inductance and $y=\frac{I_{pv}}{V_{pv}}$ as instantaneous conductance. So we can write the sliding surface in another form according to the current I*pv:*

$$s(x)=y(I_{pv})-Y(I_{pv}) \quad (12)$$

We distinguish three cases of operation:

- To the left of the PPM:

$$y(I_{pv})-Y(I_{pv})>0 \implies y(I_{pv})>Y(I_{pv})$$

- To the right of the PPM:

$$y(I_{pv})-Y(I_{pv})<0 \implies y(I_{pv})<Y(I_{pv})$$

- At the PPM:

$$y(I_{pv})-Y(I_{pv})=0 \implies y(I_{pv})=Y(I_{pv})$$

This principle can be explained by the following figure:

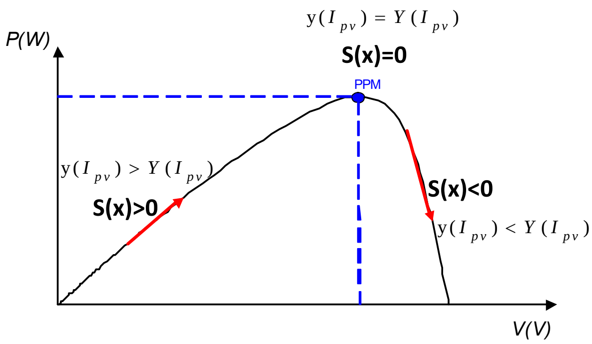

Fig. 6 Cases of operation

Once the sliding surface is chosen. We will determine the control law which is generally constituted by two terms. It is written in the following form:

$$u=u_{eq}+u_{nl} \quad (13)$$

u_{eq} : It is the equivalent command whose operating point remains on the sliding surface. It is determined from the derivative of the switching function which is equal to zero.

u_{nl} : It is the discontinuous term. The operating point must remain in the vicinity of the surface *S*.

During the sliding mode, we have : $s=\dot{s}=0$ et $u=u_{eq}$.

Gold, the sliding surface depends solely on $x_1=i_L$, which gives us,

$$\begin{aligned}\dot{s}&=\frac{\partial s}{\partial x_1}\dot{x}_1=\frac{\partial s}{\partial i_L}\dot{i}_L=\left(\frac{\partial y}{\partial i_L}-\frac{\partial Y}{\partial i_L}\right)\times\left(\frac{Vpv}{L}-(1-u)\frac{Vdc}{L}\right)\\&=A\times\left(\frac{Vpv}{L}-(1-u)\frac{Vdc}{L}\right)=0\end{aligned} \quad (14)$$

The equivalent order is calculated as follows:

$$u_{eq}=1-\frac{V_{pv}}{V_{dc}} \quad (15)$$

The nonlinear component is given by:

$$u_{nl}=-k|s|^{\beta}\operatorname{sgn}(s) \quad (16)$$

With $0<\beta<1$ and K is a constant .

So, finally we get :

$$u=u_{nl}+u_{eq}=1-\frac{V_{pv}}{V_{dc}}-k|s|^{\beta}\operatorname{sgn}(s) \quad (17)$$

The conditions of existence are verified, if there is a function of Lyapunov such that:

$$v=\frac{1}{2}s^2,\ dv=\dot{s}.s<0 \quad (18)$$

This condition is called condition of attractiveness.

After the calculations and simplifications, we obtained

$$\begin{aligned}dv&=\frac{A\times V_{dc}}{L}u_n\times s(x)<0\\&=-\frac{A\times k}{L}\times V_{dc}|s|^{\beta}\times s(x)\times\operatorname{sgn}(s)\\&=-\frac{A\times k}{L}\times V_{dc}|s|^{\beta+1}<0\end{aligned} \quad (19)$$

Thus, the sign of $A=\left(\frac{\partial y}{\partial i_L}-\frac{\partial Y}{\partial i_L}\right)$ is always negative.

So, to ensure the stability of the system : $k<0$

The data cycle of the chopper is given by :

$$\alpha=\begin{cases}0 & u\le 0\\ u & 0<u<1\\ 1 & u\ge 1\end{cases} \quad (20)$$

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Temperature is the second most important parameter in the behavior of a photovoltaic cell. By setting the illumination to a fixed value, the changing of the temperature leads to the change of the MPP. The open circuit voltage decreases by increasing of the temperature which causes a decrease in the maximum power.

We note that the optimum voltage is directly related to the open circuit voltage as shown in equation (3):

$$V_{pv\_opt} = K \times V_{oc} \qquad (21)$$

With $K = 0.77$

We will use these results to improve the proposed method because it is known that at the beginning the photovoltaic system takes a long time to reach the MPP. So we will add a starter system that can find the optimal voltage that corresponds to the MPP which is equal to 77% of Voc .

IV. SIMULATION RESULTS

To compare the performances of the MICSM algorithm and the conventional IC method , a MATLAB-SIMULINK model of a PV system is developed. At the beginning, we will test these two approaches with standard test conditions (INS=1000w/m²c, T=25°C). The results obtained of IC method are presented in Fig. 7, and Fig.8. The results obtained of MICSM method are presented in Fig.9, Fig.10 and Fig.11.

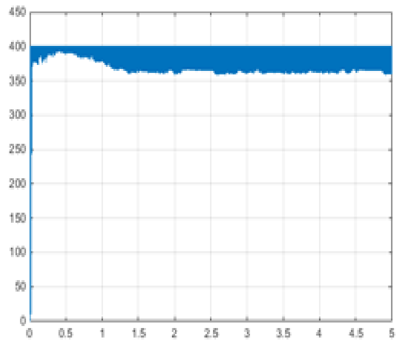

Fig. 7 Evolution of Power

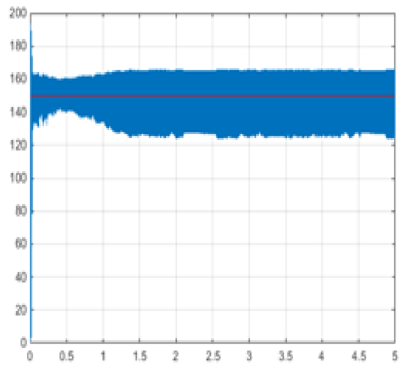

Fig. 8 Evolution of *Vpv* and *Vpv-opt*

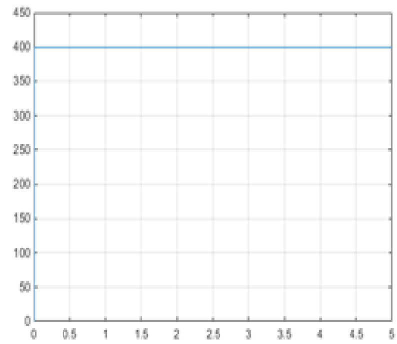

Fig. 9 Evolution of Power

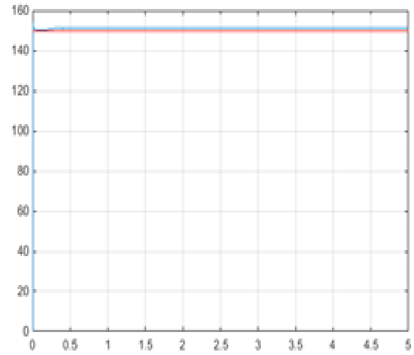

Fig. 10 Evolution of *Vpv* and *Vpv-opt*

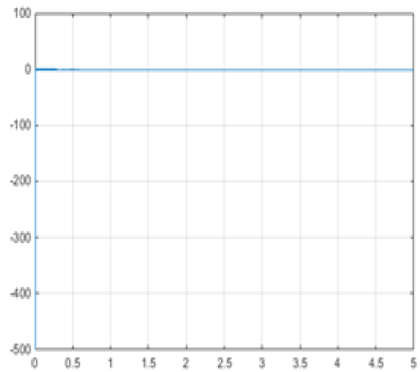

Fig. 11 Sliding surface

The simulation results show the effectiveness of the MICSM method compared to the conventional IC method. the system reaches its maximum power with minimum oscillation and even for the optimal voltage which is on the order of 150V.

In order to validate the proposed method, a test were carried out taking into account an irradiation scenario (800==>900==>1000W/m²). The evolution of powers for IC and MICSM methods are given by Fig.12. and Fig.14. The evolution of the MPP for the two methods are given by Fig.13. and Fig.15.

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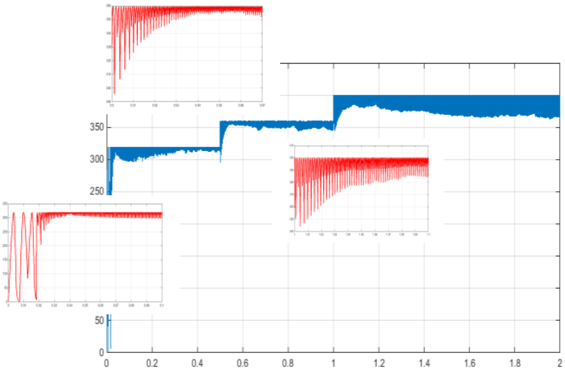

Fig. 12 Evolution of power on IC method

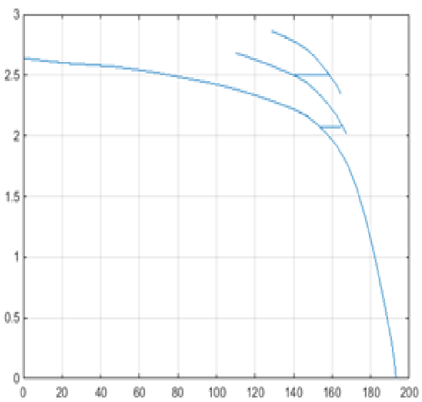

Fig. 13 Evolution of MPP on IC method

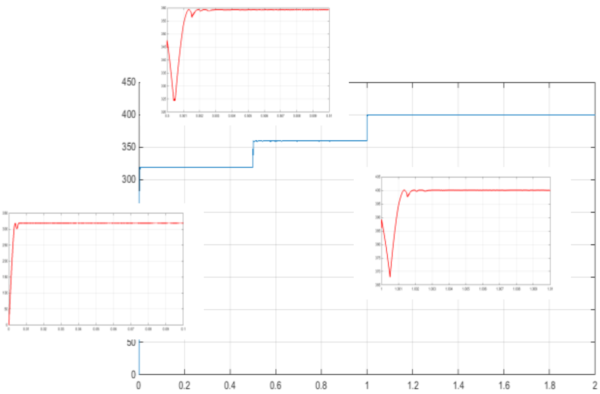

Fig. 14 Evolution of power on M ICSM method

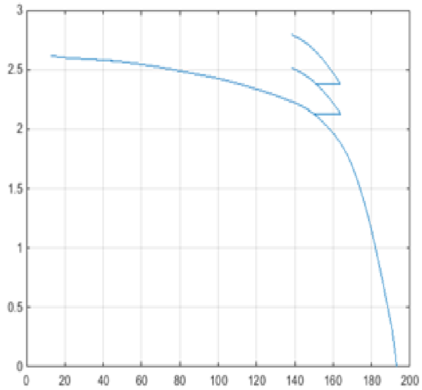

Fig. 15 Evolution of MPP on MICSM method

Table (1) summarizes the results obtained from the previous figures with respect to response time and the speed of tracking of the MPP.

TABLE I

RESPONSE TIME OF DIFFERENT APPROACHES

Methods	**800==>900**	**900==>1000**
IC	0.035s(3500cycles)	0.03s(3000cycles)
MICSM	0.005s(500cycles)	0.005s(500cycles)

The two MPPT techniques are compared in terms of dynamic response and oscillation around MPP, the results show that the MICSM method is much better than the classical method IC. The response time is much better in the case of the modified method and even for the oscillation which is decreased compared to the classical method.

V. CONCLUSION

The control strategy proposed in this work is applied to a photovoltaic system (resistive load). This requires, in the first place, the analysis of the source-side system, that is to say the elaboration of a command that uses the search of the optimal point of the power (MPPT) applied to the association "photovoltaic generator - chopper. The interesting part of this work is devoted to the control of the proposed PV system with a technique that comes from a combination of two different methods (incremental conductance and sliding mode) and with an improvement based on the addition of a starting system which makes it possible to attack the point of maximum power more quickly at the start of control. In this context, we present results based on a comparative study of performances in terms of response time and oscillations. The results of the simulations obtained confirm the validity of the proposed approach (MICSM).

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REFERENCES

[1] Weibing Gao and J. C. Hung, «Variable structure control of nonlinear systems: a new approach», IEEE Transactions on Industrial Electronic, Vol. 40, No.1, pp.45- 55, 1993.

[2] Weibing Gao, Yufu Wang and Abdollah Homaifa, «Discrete time variable structure control systems», IEEE Transactions on Industrial Electronics, Vol. 42, No. 2, pp. 117-122, April 1995.

[3] J. Ghanzanfari and M. M. Farsangi, «Maximum Power Point Tracking using Sliding Mode Control for photovoltaic array», Iranian Journal of Electrical and Electronic Engineering, Vol. 9, No. 3, September 2013.

[4] Mahmoud Ellouze, Riadh Gamoudi and Abdelkader Mami, «Sliding mode control applied to a photovoltaic water pumping system», International Journal of Physical Sciences, Vol. 5, No. 4, pp. 334-344, April 2010.

[5] Asma Chihi, Anis Sellami and Mohamed Abdellatif Khalfa, «Sliding mode control of a photovoltaic pumping system», The 2012 IEEE Mediterranean Electrotechnical Conference (MELECON), 25-28 March, Yasmine Hammamet, Tunisia, pp. 936-939, 2012.

[6] Mohamed Chakib Sosse Alaoui, «Commande et observateur par modes glissant d’un système de pompage et d’un bras manipulateur», Thèse de Doctorat, Faculté des Sciences Dhar el Mehraz Fes, 2009.

[7] Nejib Hamrouni, Moncef Jraidi and Adnène Chérif, « Theoretical and experimental analysis of the behavior of a photovoltaic pumping system, Solar Energy, 83(2009), pp. 1335-1344, 2009.

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