Second Order Sliding Mode Control of DC-DC Converter used in the Photovoltaic System According an Adaptive MPPT

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Abstract- This paper deals with the development of an adaptive maximum power point tracking (MPPT) for Photovoltaic systems, whatever the type of the used converters (Buck, Boost, Buck-Boost). The main goal of the proposed work is to track the maximum power point (MPP) using adaptive algorithm (MPOA). This algorithm generates the output voltage reference V_{ref} which must track the output voltage to reach the Maximum Power Point by modifying duty cycle of the DC-DC converter. In order to do that, second order sliding mode control is used. Furthermore, the use of the second order sliding mode control (SOSMC) can reduce the chattering phenomenon and ensure high transient response for a wide range of desired current or voltage under parameter variations. The proposed control is tested under different operating conditions. All results confirm the effectiveness of our proposed algorithm.

Keywords Second order sliding mode control, Super-Twisting algorithm, DC-DC Converter, adaptive MPPT, photovoltaic systems

1. Introduction

Until the present, most of energy demand in the world is depending on the fossil fuel (coal, petroleum and natural gas ...etc.) which represents different challenge and problems. The global warming appears to be one of the serious problems associated with these resources. This is biggest challenge for preserving the life on our planet.

The most ambitious solution is the renewable energy resources [1-4]. They can be used in remote and rural area applications, where the public grid is not available option or it can be integrated into the grid connected applications [5]. The Photovoltaic system depends on the cell’s temperature and solar irradiance [6].

The maximum power point (MPP) depends on the level of the irradiance and the temperature that varies over time. In order to track the MPP, a large number of algorithms have been proposed. The widely used algorithm is perturb and observe (P&O) method, due to its simplicity and easily implemented [7]. In the classical (P&O), the control voltage is based a fixed step size in the around MPP. The algorithm variable size was suggested in [8] in order to reduce oscillation. However, these algorithms are not accurate and fast because they do not consider the effects of weather change and the parameters variations [9-12].

The P&O algorithms are developed in order to maximize the power Ppv of the panel and minimize the disturbance of the PV system [13-14]. The algorithms should have a high performances to track MPP.

The principal of operation is shows in the figure 1.

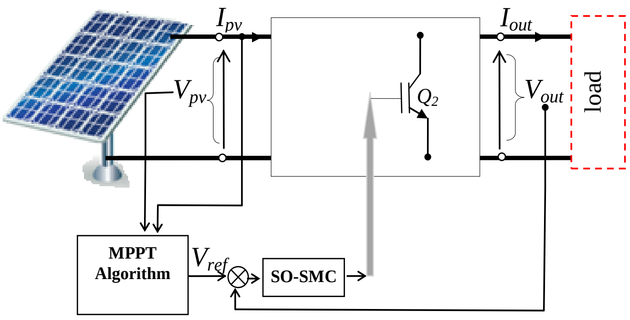

Fig.1. Illustration of proposed control.

The panel voltage and current are used to compute the PV power. The proposed MPOA guarantee that the power PV is maintained all time at its maximum value. The MPOA and SOSMC are chosen for two principal objectives. The first one is the extraction a maximum power Ppv from the panel under any changing radiation (β) and temperature (T). The second one is to obtain a high response of DC converter output voltage.

In this paper we proposed a modified P&O algorithm (MPOA) associated the second order sliding mode control to track MPP of the PV systems.

2. Modelling of Photovoltaic Panel

In the literature many models of the PV systems have been developed. These models may be based on the equivalent circuit or empirically model [15-17]. The equivalent circuit with one diode is chosen as shown in figure 2.

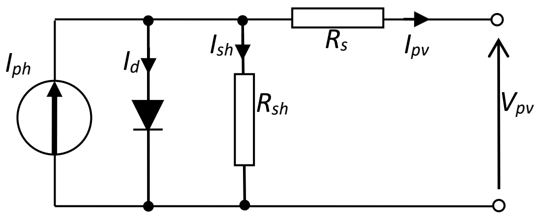

Fig. 2. Equivalent circuit with one diode of PV panel

The standard equation of the PV panel with one diode is given as follows:

$$I_{pv} = I_{ph} - I_s\left(e^{\frac{V_{pv}+R_sI_{pv}}{aV_T}} - 1\right) - \frac{V_{pv}+R_sI_{pv}}{R_{sh}} \qquad (1)$$

where I_{pv} is photovoltaic current, Is is saturation current, R_S is equivalent series resistance of the array, *T* is temperature, *k* is Boltzmann constant, a is diode ideality constant, $VT = k\,T/q$ is thermal voltage of array.

Figures (3) and (4) show the characteristics of the PV panel under changing of irradiation and temperature

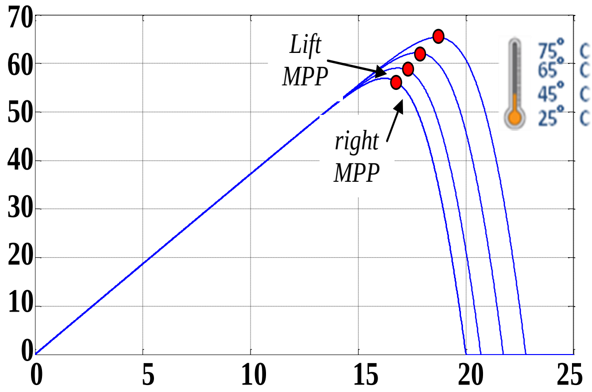

Fig. 3. Operating characteristics P-V of the PV panel under temperature variation.

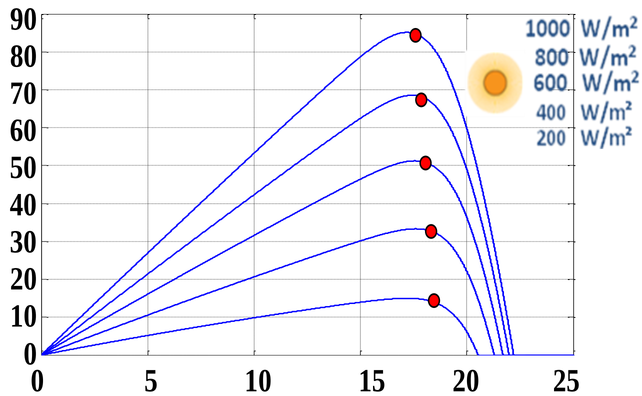

Fig .4. Operating characteristics P-V of the PV panel, under irradiation variation.

The buck and the boost converters are the important devices in power system provides the connection between the PV system and the load[18]-[22].

3. Modelling of the Buck Converter

The scheme of the buck converter is given by the figure 5.

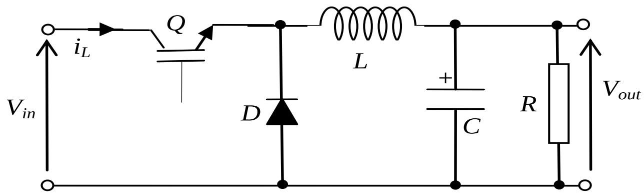

Fig.5. buck converter

Under continuous conduction mode, the average model of buck converter can be written as given by following equations [19].

$$\begin{cases} \dot{x}_1 = \lambda_1 u V_{in} - \lambda_1 x_2 \\ \dot{x}_2 = \lambda_2 x_1 - \lambda_3 x_2 \end{cases} \qquad (2)$$

Where u is a duty cycle.

$\lambda_1 = \frac{1}{L}$; $\lambda_2 = \frac{1}{C}$, $\lambda_3 = \frac{1}{RC}$; $[x_1 \quad x_2] = [i_L \quad V_{out}]$;
$0 \le u \le 1$

4. Boost Converter Modeling

The scheme of the boost converter is given by the Fig. 6.

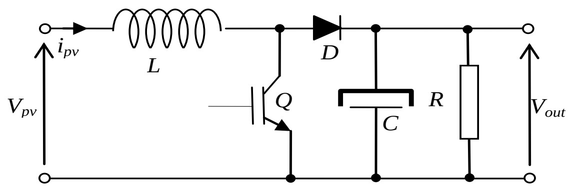

Fig. 6. DC-DC Boost Converter

Under continuous conduction mode, the average model of buck converter can be written as given by following equations

$$\begin{cases} \dot{x}_1 = \lambda_1 V_{pv} - \lambda_1 x_2 u \\ \dot{x}_2 = \lambda_2 x_1 u - \lambda_3 x_2 \end{cases} \tag{3}$$

where $\lambda_1 = \frac{1}{L}$; $\lambda_2 = \frac{1}{C}$; $\lambda_3 = \frac{1}{RC}$; $u = (1-\alpha)$ and $[x_1 \quad x_2] = [ipv \quad V_{out}]$.T is the switching period and α is the duty cycle.

5. Adaptive P&O Algorithm

Generally, precision and speed tracking of MPP are the two requirements of all MPPT algorithms. However, using an MPPT algorithm with fixed step limit the performance of these techniques, for a small step size the oscillations are reduced and slow down tracking. If the step size is bigger the MPP is reached faster, but with more oscillations [20-25]. This algorithm may be given as follows:

$$\begin{cases} V_{ref}(t) = V_{ref}(t-h) - K.sign(\frac{\Delta P_{pv}}{\Delta V_{pv}}) \\ \Delta P = P_{pv}(t) - P_{pv}(t-h) \\ \Delta V = V_{pv}(t) - V_{pv}(t-h) \end{cases} \tag{4}$$

where h is the step time, K is the constant step gain and V is output voltage control.

In this paper, we replace the constant step gain K by another adaptive step gain K_a which depends of state variation of the power and voltage. This algorithm can be written as follows:

$$V_{ref}(t) = V_{ref}(t-h) - K_a.sign(\frac{\Delta P_{pv}}{\Delta V_{pv}}) \tag{5}$$

Where Ka is an adaptive gain and can be given as flows:

if ($\Delta P_{pv}(t-h) > 0$ & $\Delta P_{pv}(t)$) > 0 then $K_a = k_1$

if ($\Delta P_{pv}(t-h) > 0$ & $\Delta P_{pv}(t)$) <0 then $K_a = k_2$

if ($\Delta P_{pv}(t-h) < 0$ & $\Delta P_{pv}(t)$) <0 then $K_a = k_3$

if ($\Delta P_{pv}(t-h) < 0$ & $\Delta P_{pv}(t)$) >0 then $K_a = k_4$

where $\Delta P_{pv}(t-h)$ and q are the PV power variation at $(t-h)$ and (t) respectively.

Figure 7 represents the comparative between classical PO and adaptive MPOA.

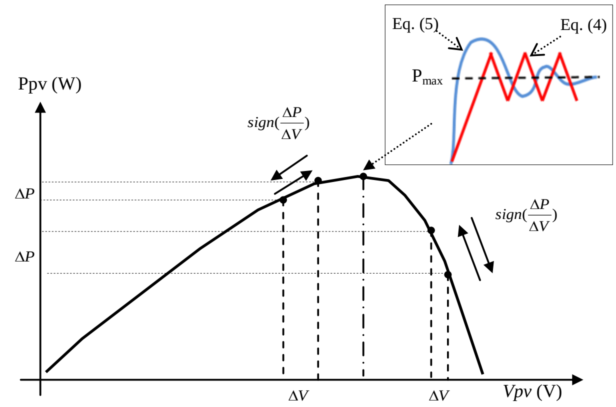

Fig. 7. Comparative between classical PO and adaptive MPOA

K_a is step size of MPOA algorithm, the flow chart of the adaptive MPOA showing in figure 8

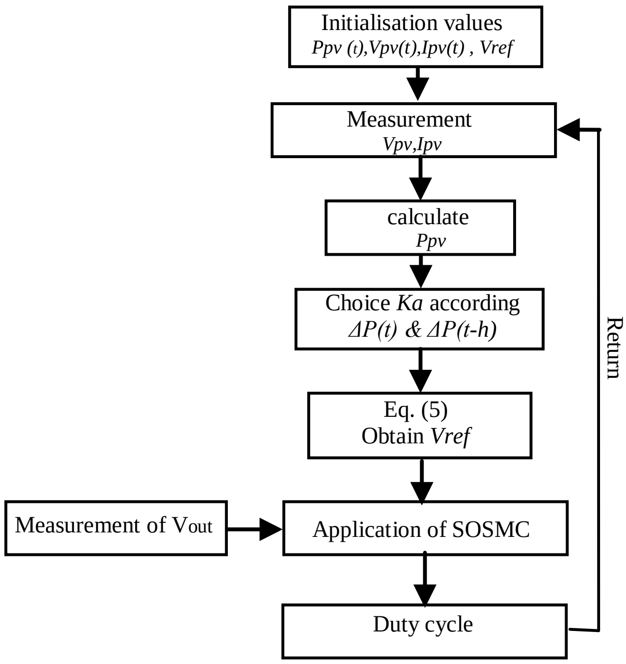

Fig. 8. The flow chart of the adaptive MPOA

6. Theory of the Second Order Sliding Mode Control

It is well known that the drawback of sliding mode control is the chattering phenomenon. In order to reduce the chattering a second order sliding mode control is developed. According to the theory of the sliding mode control, we should determine a sliding surface S and design a control law in order to attract the state trajectory $S=0$ and maintain it there [26-35].

Consider a model of DC converter is given by:

$$\begin{cases} \dot{x} = f_1(x,t) + f_2(x,t)u \\ S = S(x,t) = e(x,t) + \lambda \dot{e}(x,t) \\ e(x,t) = (x_2^* - x_2) \end{cases} \quad (6)$$

where $x \in R^n$ are state of the system, $u \in R$ is the control ,f1 , f2 are functions easily identified from eq. (2)., $S \in R$ is the sliding surface.   .

if we differentiate the sliding surface *S*, we can write:

$$\ddot{S} = \varphi_1(t,S,\dot{S}) + \varphi_2(t,S,\dot{S}).\dot{u} \quad (7)$$

with

$$\varphi_1(t,s,\dot{s}) = \lambda_1\lambda_2 V_{in}u - \lambda_1\lambda_2 x_2 u^2 + \gamma_1\lambda_2 x_i u - \gamma_1\lambda_3 x_v$$
$$-(\gamma_1 \dot{x}_v^* + \ddot{x}_{ve})$$

$$\varphi_2(t,S,\dot{S}) = \lambda_2 x_1$$

The control u is bonded $(0 \le u \le 1)$

We assume that the equation (6) satisfy the following conditions [34]:

$$\begin{cases} 0 < \gamma_i \le \left|\varphi_2(t,S,\dot{S})\right| \le \gamma_e \\ \left|\varphi_2(t,S,\dot{S})\right| \le \varpi_0 \end{cases} \quad (8)$$

where γ_i, γ_e and ϖ_0 are positive gains.

The used control law is the super twisting algorithm given as follow [37-38]:

$$u = u_1 + u_2 \quad (9)$$

where

$$\begin{cases} \dot{u}_1 = -\delta_1 sign(S) \\ u_2 = -\delta_2 |S|^{\rho} sign(S) \end{cases}$$

And δ_1, δ_2 are constant positive and must verify the following inequalities

$$\begin{cases} \delta_{1_i} > \dfrac{\varpi_0}{\gamma_i} \\ \delta_{2_i}^2 \ge \dfrac{4\varpi_0}{\gamma_i} \dfrac{\gamma_e(\delta_1 + \varpi_0)}{\gamma_i(\delta_1 - \varpi_0)} \end{cases} \quad (10)$$

and $0 < \rho \le \dfrac{1}{2}$

The use of the second order sliding mode guarantees the finite time convergence.

7. Experimental Results

The proposed control has been tested in order to verify the performance of the proposed MPOA. Figure 9 shows the experimental setup of the system composed by a PV emulator connected with a buck converter has been used instead of the solar panel. The current *Ipv* and voltage *Vpv* are measured by LA-25NP and LV-25P sensors. The proposed control is realized on the dSAPCE DS1103.

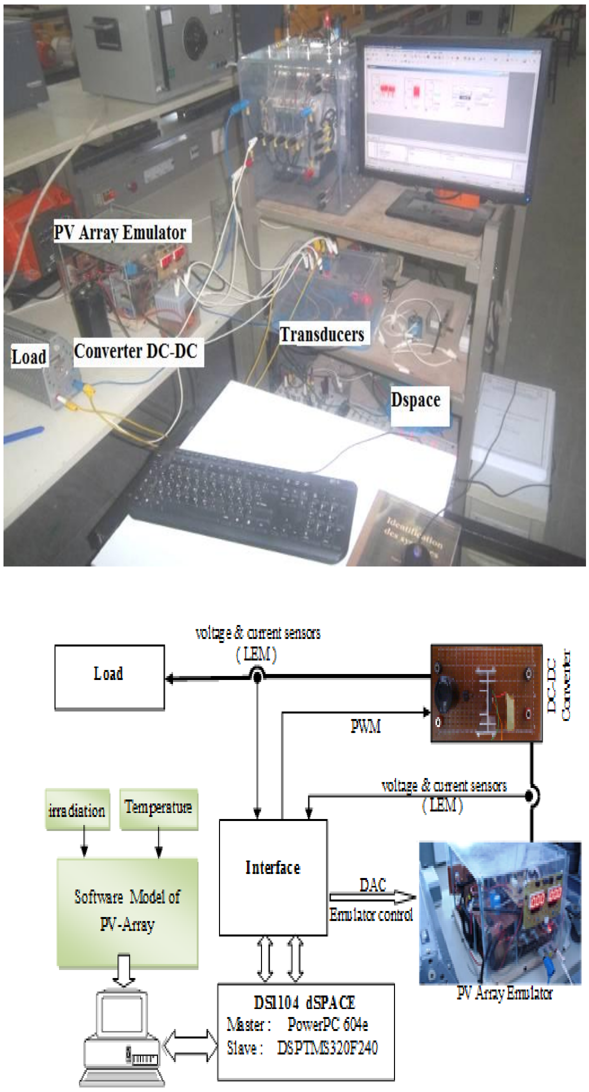

Fig. 9. Structure of the laboratory setup

8. PV with Buck Converter

The experimental investigation of the proposed algorithm is verified with a fixed and variable irradiation. The results are compared with the classical P&O algorithm.

In figure 10, the irradiation value is fixed at *1000 w/m²*. The output voltage follow perfectly the reference voltage which is *27.4 V*. shown in figure 10.b. The figure 10.c shows that the output voltage error value between*+0.2* and *-0.2* errors tend to zero. The MPOA eliminates the oscillation and reduces the output voltage error. The load current and PV current are show in figure 10.d. In this case the PV power is *84.2 W* around maximum point as shown in figure 10.e. The comparison between the MPOA and P&O algorithm is illustrated in figure 10.f.

In second part, the irradiance value is regularly changing between $\beta=200w/m^2$ and $\beta=1kw/m^2$ with sinusoidal function. In figure 11, the output voltage and PV power track their references with good performances and low oscillations.

Table 1. Parameters of experimental test

Parameters	**Symbol**	**Value**
Input voltage	V_{pv}	*27.2V*
Current of panel	I_{pv}	*32 A*
Ambient temperature	T	*25°C*
Open-circuit voltage	V_{oc}	*25V*
Short-circuit current	I_{sc}	*5A*
Switching frequency	f_s	*10 kHz*
Load resistance	R	*11 Ω*
Inductor	L	*0.0022 H*
Gain1 of MPOA	k_1	*0.001*
Gain2 of MPOA	k_2	*0.0005*
Gain3 of MPOA	k_3	*0.002*
Gain4 of MPOA	k_4	*0.001*
Gain 1 of SOSMC	δ_1	*0.003*
Gain 2 of SOSM	δ_2	*0.005*

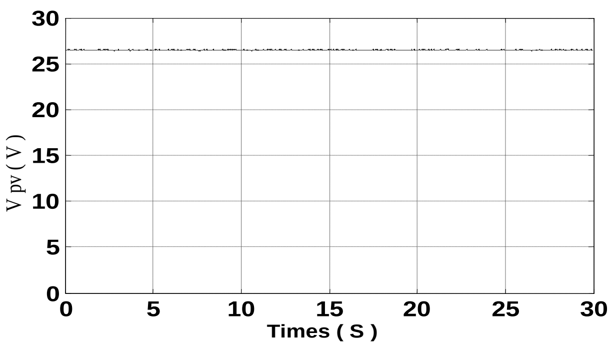

Fig. 10.a.Voltage of the PV panel

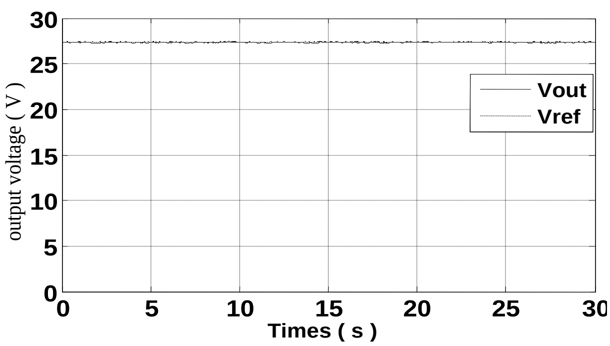

Fig. 10.b. DC converter output voltage.

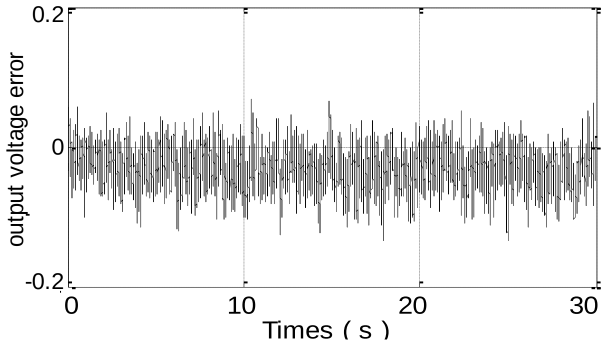

Fig. 10.c. The output voltage error

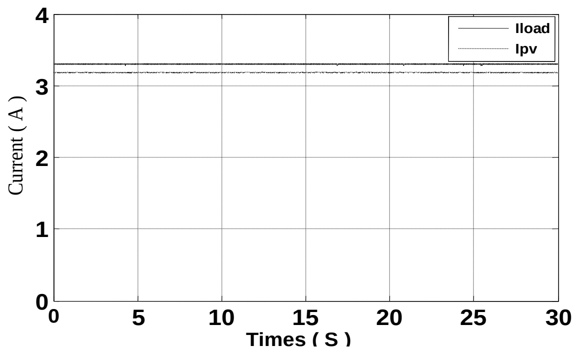

Fig. 10.d. Load current and current of panel

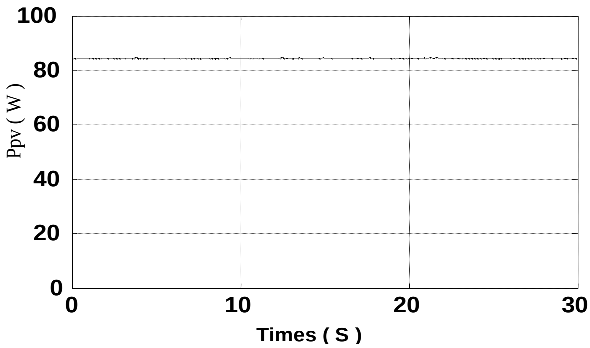

Fig. 10.e. Maximum power of PV panel

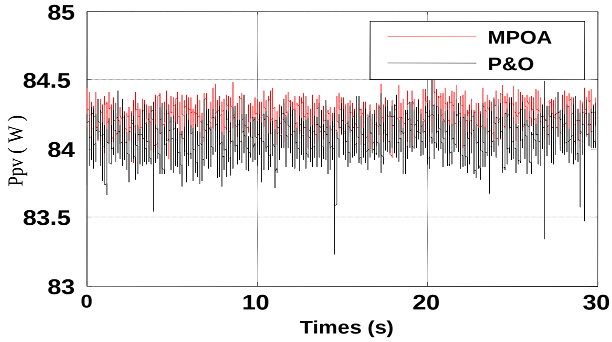

Fig. 10.f. P_{PV} comparison between MPOA and P&O

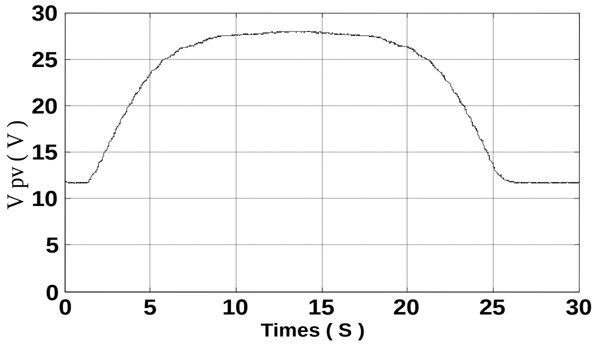

Fig.11.a. Voltage of PV panel

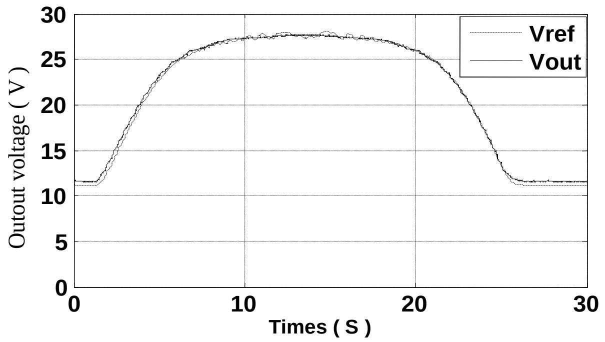

Fig.11.b. DC converter output voltage

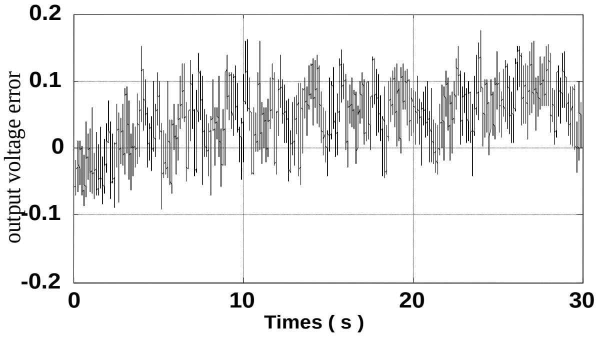

Fig.11.c. Output voltage error

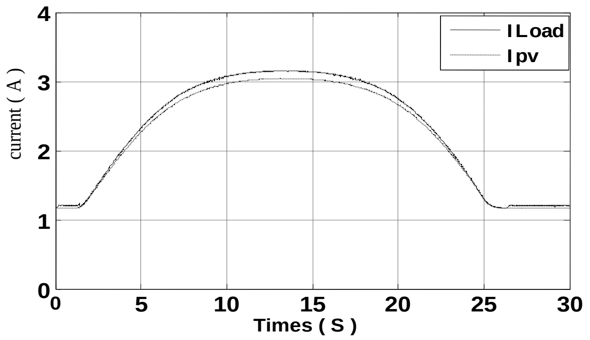

Fig.11.d. load current and current of panel

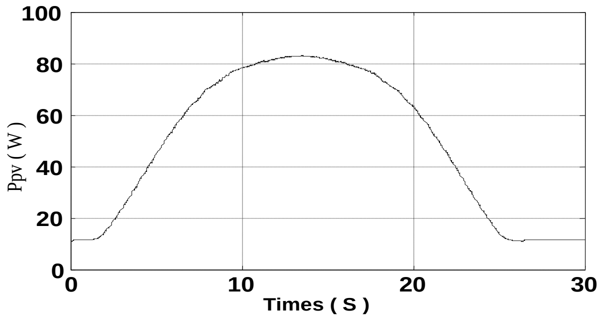

Fig.11.e. P_{PV} of the PV panel

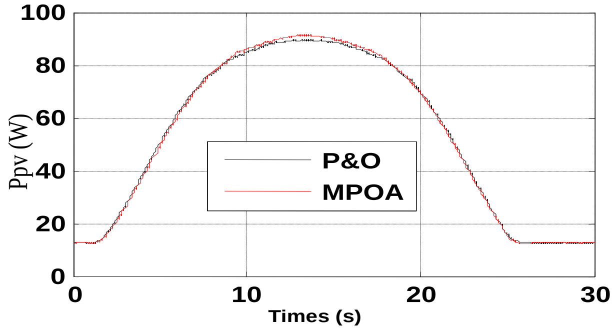

Fig.11.f. P_{PV} comparison between MPOA and P&O (f) load current and current of panel

9. PV with Boost Converter

In order to validate our MPOA with boost converter. The irradiance value is regularly changing between β=*200w/m*^{2} to β=*1kw/m*^{2} with sinusoidal function. The output voltage and PV power track their references with good performances and low oscillations figure 12.

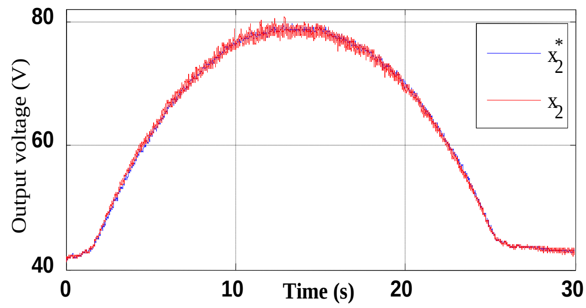

Fig. 12.a. Output voltage

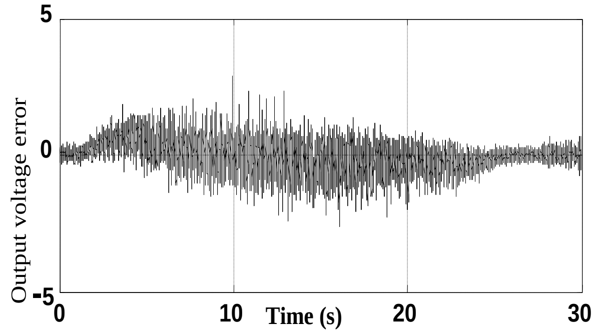

Fig . 12.b. Output voltage error

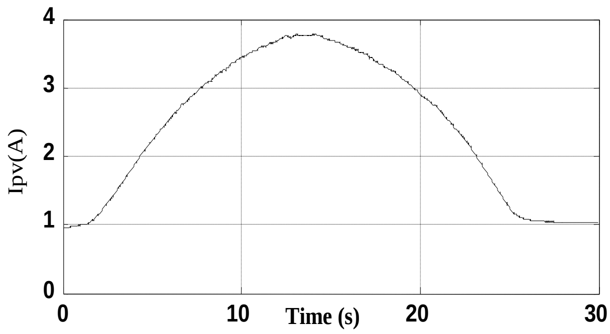

Fig . 12.c. the current of panel

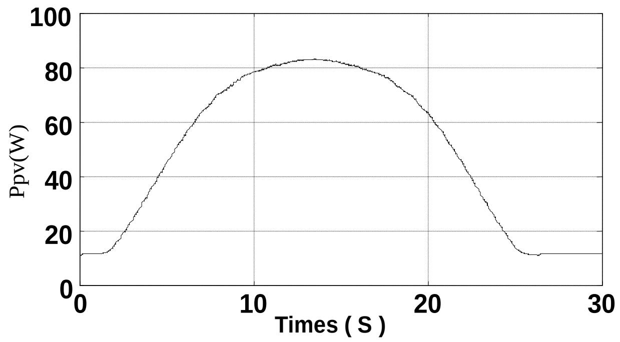

Fig . 12.d. P_{PV} maximum power of PV panel.

From the experimental results shown in figure 12, we can observe that the output voltage *Vpv* and power *Ppv* tracked respectively the reference voltage and the maximum power point with good performances.

10. Conclusions

The In this paper an adaptive MPPT algorithm associated with second order sliding mode control is presented. The main objective of the proposed work is the development of an adaptive maximum power point tracking algorithm for Photovoltaic systems whatever the type of the used DC-DC converters. The secondary aims are to reduce the oscillation and to obtain a high response of the output voltage according to the weather conditions changing and parameter variations. All results prove the effectiveness of the second order sliding mode control and our improved MPPT approach.

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