MAXIMUM POWER POINT TRACKING CONTROLLER BASED ON SLIDING MODE APPROACH

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Abstract

Recently, the solar energy has become an alternative source of energy of great importance. Diverse researches and efforts have been concentrated on the photovoltaic (PV) systems efficiency improvement and the accessibility to this technology. This paper presents an intelligent approach for the improvement and optimization of the PV system efficiency. A PV system topology incorporating a maximum power point tracking controller (MPPT) is studied. In order to perform this goal a special interest was focused on the sliding mode control and the P&O algorithm. This paper presents a detailed study and design of a MPPT controller to ensure a high PV system performance which can be selected for practical implementation issue. A simulation examples shows that the MPPT is achieved using a DC/DC Boost converter between the PV system and the resistive load. Significant extracted results are given to prove the validity of the proposed overall PV system.

Keywords: PV, Boost Converter, MPPT, SMC.

1 INTRODUCTION

This work analyses the control of a stand-alone PV system. However the success of a PV application depends on whether conditions where the power electronics devices helped to extract a high power from the PVG. The extraction of the maximum of power from the PVG is then indispensable. Therefore, maximum power point tracking (MPPT) controller accuracy becomes a key control in the device operation for successful PV applications. In general, the MPPT control is a challenging, because the sunshine condition that determines the amount of sun energy into the PVG may change at any time. Therefore, the PV system can be considered as a non-linear complex system.

Numerous MPPT methods have been developed and implemented in previous studies, for instance, perturb and observe (P&O), fractional open-circuit voltage and fuzzy logic controller (FLC) approaches [7] etc. These techniques have high tracking accuracy under stable internal and external condition, but still reveal some trade-offs between tracking speed and tracking reliability when load values or weather conditions rapidly changes [6]. Sliding mode controller has recently attracted considerable attention of researchers, The main benefit of the sliding sector technique is that it can avoid chattering [1],[8]. Its advantage among, is the simplicity of implementation, robustness, and great performance in different fields such as robotic, motor control, etc. In this paper the interest was focus in the use of SMC in the photovoltaic fields by maximizing the power generated from the PV panels. Moreover, the system stability is demonstrated [2].

The main role of this controller is to generate a command using a voltage reference \( V_{\text{ref}} \) in order to force the system to work at the MPP. The \( V_{\text{ref}} \) is generated online via a voltage reference generator that doesn’t require the irradiation measurement. In this paper, the SMC algorithm generates directly PWM signal. This last has the benefit to avoid the use of a PWM commutation signal (Saw signal). It permits to build directly a PWM output signal toward the converter IGBT gate. Contrariwise, other algorithm such as P&O [7] generates a duty cycle signal that will be used with a reference saw signal to generate a PWM IGBT drive signal.

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

1) A PVG that converts solar energy to electric one,
2) A DC-DC converter that manipulates produced DC voltage by the PV arrays to a load voltage demand,
3) A digital controller that drives the converter operation with MPPT capability.
4) Resistive Load
2 PHOTOVOLTAIC ENERGY CONVERSION

2.1 PVG MODEL

One can substitute a PV cell to an equivalent electric circuit which includes a power supply and a diode. The power source produces the $I_{ph}$ current, which depends on impinging irradiation. Through diode flows the current $I_d$. The current $I_c$ feeding the load is the difference between $I_{ph}$ and $I_d$ which is reduced by the resistance $R_s$. This last represents resistances of cell and connection among cells [5].

By exploiting the node law

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

The current $I_{ph}$ can be evaluated as:

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

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

$$I_{sh} = \frac{1}{R_p} \left(V_c + R_s I_c \right) \quad (4)$$

The reverse saturation current at reference temperature can be approximately obtained as:

$$I_{rs} = \frac{I_{rs \_ ref}}{\exp \frac{qV_{rs}}{n_s n_p \beta T_c} - 1} \quad (5)$$

Finally the cell current $I_c$ can be given by

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

The modeling of a PVG depending on series and parallel number respectively $N_s$ and $N_p$ as:

$$I_p = N_p I_c, \quad V_p = N_s n_p V_c \quad (7)$$

Finally the PVG current ($I_p$) can be given by

$$I_p = N_p I_{ph} - N_p I_{rs} \left( \exp \frac{q(V_p + R_s I_p)}{akT} \left( \frac{V_p}{n_s N_s} + \frac{R_s I_p}{N_p} \right) - 1 \right) - \frac{N_p \left( V_p + \frac{R_s I_p}{N_p} \right)}{R_p \left( n_s N_s + \frac{R_s I_p}{N_p} \right)} \quad (8)$$
The highly \( I-V \) nonlinear characteristics are shown in figure 4 for different irradiation values.

![Figure 4](image1)

![Figure 4](image2)

Figure 4: (a) P-V and (b) I-V characteristics at fixed temperature value of 25.3°C

2.2 BOOST CONVERTER

DC-DC converters are electronic devices used whenever is needed to change DC electrical power efficiently from one voltage level to another. They’re necessary because unlike AC, DC can’t simply be stepped up or down using a transformer. In many ways, a DC-DC converter feeding the load is going through a regulated converter to hold its maximum. Hence, the efficiency of the photovoltaic system is performed.

In order to step up the voltage, the operation consists of switching an IGBT shown in figure 5 at a high commutation frequency, with output voltage control by varying the switching duty cycle (D). When the IGBT is switched on, current flows from the input source through the inductor (L) and the IGBT, then the energy is stored in the inductor. After that there is no current through the Diode (D1), and the load current is supplied by the capacitance hold charge in(C). The IGBT is turned off; L opposes any drop in current by immediately reversing its emf. So, the inductor voltage adds to (i.e., boosts) the source voltage and current due to this boosted voltage now flows from the source through L, D1 and the load, recharging C as well. The output voltage is therefore higher than the input voltage, and it turns out that the voltage step-up ratio is equal to [4]

![Figure 5: Circuit diagram of the Boost converter](image3)

Figure 5 shows the circuit diagram of a boost converter, and a load.

The boost converter is assumed to operate in a continuous conduction mode with two states based on the status of the switch.

\[
V_o = \frac{1}{1-D} V_{in} + R_{pv} \Delta D \tag{9}
\]

Based on the assumption where \( P_{in} = P_{out} \) it can be deduce that

\[
R_{pv} = (1-D)^2 R_{out} \tag{10}
\]

Where \( R_{pv} \) is the equivalent resistance connected to the PV panel and 1-D is actually the proportion of the switching cycle that the IGBT is off, rather than on.

3 MPPT CONTROLLERS

3.1 P&O ALGORITHM

Due to its simplicity, P&O algorithm presented in figure 6 is the most popular [10]. The principle of this controller is to provoke perturbation by acting (decrease or increase) on the PWM duty cycle command and observe the output PV power reaction. If the actual power \( P(k) \) is greater than the previous computed one \( P(k-1) \), then the perturbation direction is maintained otherwise it is reversed [3].

The \( \Delta D \) crisp value is chosen by trial and tests in simulation. The P&O diagram is:

If the crisp value \( \Delta D \) is very big or very small then we may lose information. Despite the P&O algorithm is easy to implement it has mainly the following problems

- The PV system will always operates in an oscillating mode.
- The PV system may fail to track the maximum power point and as result operate in current or voltage zones.
3.2 SLIDING MODE CONTROL

The method of control is divided into two steps the first is determine the voltage value at which the system operates with its maximum of power, and then the second is to operate the system with this voltage value that gives the maximum power.

**Step 1**

In this part of the work, the main objective is to construct a MPP voltage-reference generator that meets the MPP. Specifically, this generator is expected to compute on-line the optimal voltage value $V_{\text{MPP}}$ so that, if the voltage $V_p$ is made equal to $V_{\text{MPP}}$ then, maximal power is captured. In fact this method does not require irradiation measurement.

![Figure 6: P&O Algorithm global structure](image)

**Figure 6: P&O Algorithm global structure**

This function is created using Matlab Fitting Curve Toolbox. In this work several test has been done using different type of function such as, Fourier, gaussian, rational, and the polynomial function like the work of Abderrahim, [10]. Finely we deduce that the power function fits more the Atersa model.

The constructed function is denoted as :

$$F(x) = ax^b + c$$

Where the $a$, $b$, $c$ coefficient as numerical values specific for the used PV panel. With: $a=-8.638$; $b=-0.1697$; $c=19.74$;

**Step 2**

After determined the $V_{\text{ref}}$ the implemented (SMC) algorithm calculate the difference between the acquired PV voltage and the $V_{\text{ref}}$ and then, via the boost converter force the PVG to operate at the reference voltage value ($V_{\text{ref}}$) and therefore at the maximum power zone.

$$S = e = V_p - V_{\text{ref}}$$

$$u = \frac{1}{2} \left(1 + \text{Sign}(S) \right)$$

$$u = \begin{cases} 
1 & S > 0 \\
0 & S < 0 
\end{cases}$$

**Stability demonstration:**

The stability can be analyzed using the Lyapunov stability method. A positive definite function $V$ is defined as:

$$V = \frac{1}{2} S^2 > 0$$

Whose time derivative is:

$$\dot{V} = \frac{dS}{dt} S \dot{S}$$

Considering

$$\dot{S} = \dot{e} = \dot{V}_p$$

**When $S>0$**

The switch will be open, this imply that the duty cycle will increase. From the boost converter model
equation (10) we have, $R_{pv} = (1 - D)^2 R_{\text{out}}$ and using this equation, we can observe that if the duty cycle D increases, then $R_{pv} = (1 - D)^2 R_{\text{out}}$ decreases so based on the PV dynamic given by the I-V characteristic shown in figure 8, the $I_p$ will increase and $V_{p}$ will decrease equivalently from eq (8), it can be deduced that, when the voltage ($V_{p}$) increase/decreases the current ($I_{p}$) decrease/increases, so, if the resistance connected to the PV panel increases and ($V_{p}$) decreases.

So as a consequence in this case, this imply that

$$
\dot{V}_{p} < 0 \quad \text{and} \quad \dot{S} < 0
$$

and finally

$$
SS < 0
$$

When $S < 0$, using the same method

The switch will be close, this imply that the duty cycle will decrease. If the duty cycle D decreases, then $R_{pv} = (1 - D)^2 R_{\text{out}}$ increases so based on the PV dynamic given by the I-V characteristic shown in figure 8, the $I_p$ will decrease and $V_{p}$ increase equivalently from eq (8), it can be deduced that, when the voltage ($V_{p}$) increase/increases the current ($I_{p}$) increase/decrease, so if the resistance connected to the PV panel increase then ($V_{p}$) increases and ($I_{p}$) decreases, and this imply that:

$$
\dot{V}_{p} > 0 \quad \text{and} \quad \dot{S} > 0
$$

and then

$$
SS < 0
$$

Finally, using the Lyapunov stability theory it can be concluded that $S$ reaches the state $S = 0$ means that the system reaches the desired voltage value $V_{\text{ref}}$ and hence the convergence to the point of maximum power.

4 SIMULATION RESULTS

In this section, the PV system global control shown in figures 1 is implemented. The sliding-mode MPPT, with optimal voltage reference, is compared to P&O algorithm. The robustness of both controllers is tested over internal and external variation. The system is tested over a sudden step load variation and irradiation change.

Figure 9 present the I-V and P-V characteristic at fixed temperature and different irradiation values (500 and 1000W/m²).

Figures 10, 11 show respectively the irradiation and load variation.

Figure 12 (a) shows the controllers output. The SMC build directly a PWM output signal toward the converter IGBT gate, however the P&O algorithm generate a duty cycle signal that will be used with a reference saw signal (MLI) to generate a PWM IGBT drive signal. Figure 12(b) in a zoom of figure 12 (a) and shows the impact of the irradiation variation on the SMC frequency.

Figures 13, 14, 15 show the PVG current, voltage and power respectively. These figures show that in spite of the load change: the operation point of the PV remains constant in the MPP due to the robustness of controllers. When the irradiation changes, the MPP also changes its position, so the controller act in order to track the new MPP.

Figure 16 and 17 show the load voltage and current.
The obtained simulation results show that both systems using different controller present a good maximum power tracking, however the SMC controller present less oscillations and fast tracking in the response.

5 CONCLUSION
In this work, a complete study of PV systems integrating an MPPT controller was studied. The proposed PV system is composed of a PV generator, a boost converter and a resistive load. In order to bring up the system efficiency a designed SMC MPPT controller was presented. This controller guarantees high dynamic system performances. Simulation results are given to highlight the obtained performances. This study is the foundation of a practical implementation follow-up this research work.

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APPENDIX A

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$G$, $G_{ref}$</td>
<td>Global, Reference insulation (W/m²).</td>
</tr>
<tr>
<td>$I_p$, $V_p$</td>
<td>Cell output current and voltage.</td>
</tr>
<tr>
<td>$R_p$, $R_s$</td>
<td>Cell parallel and series resistance (Ω).</td>
</tr>
<tr>
<td>$n$</td>
<td>Solar ideal factor</td>
</tr>
<tr>
<td>$E_g$</td>
<td>Band gap energy (eV)</td>
</tr>
<tr>
<td>$I_{rs}$</td>
<td>Reverse diode saturation current (A)</td>
</tr>
<tr>
<td>$K_{SCT}$</td>
<td>Short circuit current temperature (A/K).</td>
</tr>
<tr>
<td>$T_c$, $T_{c_{ref}}$</td>
<td>Cell junction and Reference temperature (°C).</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Boltzmann constant (1. 38e-23)</td>
</tr>
<tr>
<td>$D$</td>
<td>Duty cycle</td>
</tr>
<tr>
<td>$N_s$, $N_p$</td>
<td>Number of series and parallel modules.</td>
</tr>
<tr>
<td>$ns$</td>
<td>Number of series cells</td>
</tr>
</tbody>
</table>
Referencias


