Development of a Sliding Control Maximum Power Point Tracker for Photovoltaic

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Abstract: - This paper proposes a control strategy of a Maximum Power Point Tracking (MPPT) impedance adapter coupling a photovoltaic generator to a battery. The proposed strategy is based on the sliding mode control theory of continue systems permitting a direct control of power converter. The PV generator price is even relatively high, so the user is interested to the optimal coupling of PV generator to electromechanical loads. In fact, this system used optimal coupling in order to have maximum power during the whole operating period. This paper, consisting of a Boost type dc/dc converter, which micro-processor, PIC16F877A, is used to implement the sliding mode controller. Comparing with other techniques used in the past, the use of the proposed MPPT control improves the PV system performance. The results of simulation and experiment are present.

Key-Words: - MPPT, Battery charger, Sliding control, Lyapunov function

1 Introduction

Due to depletion of fossil energy and environmental contamination, a renewable energy application such as photovoltaic (PV) system has been widely used for a few decades. The PV energy is free, abundant and distributed through the earth. Among the PV energy applications, they can be divided into two categories: one is stand-alone system and the other is grid-connected system. Stand-alone system requires the battery bank to store the PV energy which is suitable for low-power system. On the other hands, grid-connected system does not require the battery bank and has become the primary PV application for high power applications. The main purpose of the grid-connected system is to transfer maximum solar array energy into grid with a unity power factor.

The output power of PV cell is changed by environmental factors, such as illumination and temperature. Since the characteristic curve of a solar cell exhibits a nonlinear voltage-current characteristic, a controller named maximum power point tracker (MPPT) is required to match the solar cell power to the environmental changes. Many algorithms have been developed for tracking maximum power point of a solar cell. In recent years, the research of the PV MPPT control methods has been paid extensive attention by many specialist and obtained some fruits such as: P&O and fuzzy control etc. because the output energy of the PV arrays changes frequently by the surroundings, improving the speed of tracking the PV power system could obviously improve the system performance.

The existing tracking control methods for the MPPT can be classified into five categories: (i.) hill-climbing [1] /perturb and observe (P&O) [2]-[4]. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. Hill-climbing can fail under rapidly changing atmospheric conditions. (ii.) incremental conductance [5] [6]; (iii.) open-circuit voltage and short-circuit current [7]-[9]; (iv.) fuzzy logic control [10]; and (v) neural network control [11]. X. Li et al. introduced the fuzzy tracking control approaches [10] in 2002. But it is very difficult to formulate the fuzzy rules, which are usually obtained from the trial-and-error procedure. In 2006, the computational expensive neural network was adopted by Tariq et al. [11]. The algorithm requires on-line learning in order to make the robot perform properly.

In this paper, we come up with sliding mode control strategy [12]-[15] to solve the problem of MPPT under the condition of all kinds of radiation levels. This paper is organized as follows. The
system analysis and mathematical modeling are presented in Section 2, and Section 3 aims at the controller design. Section 4, simulation and experimental results are presented. In Section 5 concludes this paper.

2 The System Analysis and Mathematical Modeling

The output energy of the PV arrays is influenced by the surrounding, such as the surrounding temperature, the solar radiation and the terminal voltage of PV arrays etc, the PV arrays characteristic curve is shown as Fig.1. Mathematical model of the solar array can be expresses as equation (1)

\[ I = I_{g} - I_{sat} \left[ \exp \left( \frac{q}{AKT} V \right) - 1 \right] \]  

Fig.1 The PV arrays characteristic

where \( I_{g} \) denotes a current of a solar array, \( V \) denotes an output voltage of a solar array, \( q \) denotes an electron charge (C), \( I_{sat} \) denotes a cell reverse saturation current (A), \( K \) is the Boltzman’s constant (J/K), \( T \) is a cell temperature (K), \( A \) denotes the ideality factor.

In order to charger the battery, the PV MPPT system adopt step up type DC-DC converter topology system. Fig. 2 presents its system structure.

Fig. 2 The circuit diagram of PV DC-DC converter system

Fig. 2 shows the Boost Converter to transfer power to load from solar array. In the fig.2, \( D \) represents the switch function of the power switch device to control the output energy of the solar array. When \( D = 0 \), power will be switched to open. When \( D = 1 \), power will be switched to close. From Fig.2, we can draw the system dynamic model as follows.

\[
\begin{align*}
V_i &= L \frac{di_i}{dt} + (1-D)V_o \\
i_L &= i_i - C_1 \frac{dV_i}{dt} \\
i_0 &= (1-D)i_L - C_2 \frac{dV_0}{dt} \\
V_i &= (i_i - i_L)/C_1 \\
i_L &= -\frac{1}{L} (1-D)V_0 + \frac{1}{L} V_i \\
V_0 &= \frac{1}{C_2} (1-D)i_L - \frac{1}{C_2} i_0
\end{align*}
\]

\[
\dot{x} = \begin{bmatrix} \dot{V}_i \\ \dot{i}_L \\ \dot{V}_0 \end{bmatrix}
\]

\[
f(x) = \begin{bmatrix} (i_i - i_L)/C_1 \\ 1/L (V_i - V_o) \\ 1/C_2 (i_L - i_0) \end{bmatrix}
\]

\[
g(x) = \begin{bmatrix} 0 \\ V_o/L \\ -i_L/C_2 \end{bmatrix}
\]

\[
\dot{x} = f(x) + g(x)D
\]

3 The Controller Design

Based on the solar array characteristic curve shown in fig.1, when the solar array is operating in its maximum output power state, we can get

\[
\frac{\partial P}{\partial V_i} = 0
\]

Where (6) represents maximum power achieved.

\[
\frac{\partial P}{\partial V_i} = \frac{\partial (V_i i)}{\partial V_i} = \frac{\partial i}{\partial V_i} V_i + i = 0
\]

From (7), the switch function can be selected,
\[ S(x) = \frac{\partial P}{\partial V_i} = \left( \frac{\partial i}{\partial V_i} V_i + i_i \right) \] (8)

Based on the two states of PV arrays in fig 1 and the system circuit diagram shown as Fig.2, the switch control signal can be selected as

\[
D = \begin{cases} 
0 & S \geq 0 \\
1 & S < 0 
\end{cases} \] (9)

Let

\[
\dot{S} = \frac{\partial S}{\partial x} x = \frac{\partial S}{\partial x} f(x) + \frac{\partial S}{\partial x} g(x)D_{eq} = 0 \] (10)

Therefore, the equivalent control variable is shown below.

\[
D_{eq} = \frac{i_b}{i_L} \] (11)

Theorem: For the system shown in (5) and the switch function (8), if the expression (9) is adopted, they could make the system eventually stabilize at the status that switch function is equal to zero from any initial state.

Proof:
Let Lyapunov function as

\[
V = \frac{1}{2} S^2 > 0 \] (12)

\[
\dot{V} = S \frac{dS}{dt} = \frac{dP}{dD_{eq}} \frac{d}{dt} (\frac{dP}{dD_{eq}}) \]

Substituting equation (1) into (8), then

\[
S = \frac{\partial P}{\partial V_i} = \left( \frac{\partial i}{\partial V_i} V_i + i_i \right) = I_g - I_{sat} \left[ \exp \left( \frac{qV_i}{AKT} \right) - 1 \right] - \frac{qI_{sat} V_i}{AKT} \exp \left( \frac{qV_i}{AKT} \right) \]

\[
= I_g + I_{sat} - I_{sat} \left[ \exp \left( \frac{qV_i}{AKT} \right) - 1 \right] \exp \left( \frac{qV_i}{AKT} \right) \]

\[
= \left( I_g + I_{sat} \right) - I_{sat} \left( 1 + \frac{qV_i}{AKT} \right) \exp \left( \frac{qV_i}{AKT} \right) \] (13)

3.1 When S > 0
Base on (8) (9) and fig. 1, the system is operating in left, the switch function D = 0, and V_i is increase.

\[
\frac{dV_i}{dt} > 0 \] (14)

\[
\frac{dS}{dt} = - \frac{qI_{sat}}{AKT} \left[ \exp \left( \frac{qV_i}{AKT} \right) \right] \frac{dV_i}{dt}
- I_{sat} (1 + \frac{qV_i}{AKT}) \left[ \exp \left( \frac{qV_i}{AKT} \right) \right] \frac{q}{AKT} \frac{dV_i}{dt} \] (15)

Bring (14) into (15), then \( \frac{dS}{dt} < 0 \), so

\[
S \frac{dS}{dt} < 0 \] (16)

3.2 When S < 0
The system is operating in right, the switch function D = 1, V_i is decreasing, so

\[
\frac{dV_i}{dt} < 0 \] (17)

Finally, substituting equation (17) into (15), then \( \frac{dS}{dt} > 0 \) and \( S \frac{dS}{dt} > 0 \).

Obviously, the system could reach global stability and the switch function is tending to zero whether the system is operating in left or in right.

3.3 Control algorithm
The system control rules can be present as follows.

\[
D = \begin{cases} 
0 & S \geq 0 \\
1 & S < 0 
\end{cases} \] (18)

And the switch functions as:

\[
S(x) = \frac{\partial P}{\partial V_i} = \left( \frac{\partial i}{\partial V_i} V_i + i_i \right) \] (19)

4 Simulation and Experiment Results
4.1 Simulation
This paper used Matlab/Simulink to simulate P&O, fuzzy and sliding mode control. Fig. 3 shows comparison of the tracking maximum power which reveals the sliding mode controller only needs 0.06s, fuzzy controller needs 0.24s and P&O controller needs 1.74s. Therefore, the proposed sliding mode controller is improved its performance of MPPT.

![Fig.3 The system output power (1 kW/m², 25 °C)](image)
Fig. 4 shows the tracking condition of the sliding mode controller as the illumination changes. As the time changes from 1 second to 1.2 second and the isolation changes from 0.6 kW/m² to 1 kW/m². Hence, the MPPT changes from 14 W to 24.5 W.

Fig. 5 shows the tracking condition of the controller as the temperature changes. As the time changes from 2 second to 2.2 second and the temperature changes from 25 °C to 50 °C. Hence, the MPPT changes from 25 W to 23 W.

4.2 Experiment

Fig. 7 shows the control architecture, the control system comprises Microcontroller PIC16F877A, MOSFET, L etc.

Fig. 8 shows the photovoltaic system. DC/DC is the charge tracking the maximum power. The storage battery is as the load.
Fig. 9 shows the photovoltaic system of MPPT. $T_{P&O} = 85.9 \text{sec}$, $T_{Fuzzy} = 16.3 \text{sec}$, $T_{sliding} = 8.2 \text{sec}$

5 Conclusions

This paper presents the sliding mode controller from VSC that controls Booster type converter of solar array and battery charger to compete the tracking of MPP. After using Matlab/Simulink to simulate P&O control, fuzzy control and sliding control, compare its response time. According to the fig.3, the PV maximum power point tracking (MPPT) speed is faster apparently comparing the P&O and fuzzy control method. Seen from the simulating result, figure 4, 5 and 6, it is obvious that the efficiency of the PV MPPT is greatly improved the system shown implements the sliding control algorithm. In order to prove the feasibility of the sliding control method; a system of PV arrays was designed as fig.7 and 8. In the control system comprises Micro-controller, IC16F877A, IGBT, L etc. Experimental results show the response time of the proposed sliding control is better than P&O and fuzzy control.

References:


