Photovoltaic MPPT Algorithm Based on Hybrid Boost Converter and Variable Step Size Incremental Conductance

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Abstract. Aiming at the problem of low voltage gain of traditional boost converter and the incompatibility of tracking speed and tracking accuracy with the traditional incremental conductance algorithm (INC), this paper uses the hybrid boost converter as the DC/DC converter of photovoltaic system, and designs the variable step size INC algorithm control strategy to achieve Maximum power point tracking (MPPT) of photovoltaic. Simulink simulation model verifies the feasibility of the proposed algorithm, which effectively improves the output voltage and power generation efficiency of the photovoltaic system.

1 Introduction

With the widespread application of new energy power generation technologies such as photovoltaic cells, the market has put forward higher requirements on the output voltage and power generation efficiency of new energy power generation devices. Therefore, DC/DC converters and maximum power tracking technologies are needed to increase power generation output voltage and power generation efficiency [1-2]. The traditional boost converter is the most commonly used DC/DC converter in photovoltaic, but its output voltage can reach a larger value only when the duty cycle is close to 1, so the output voltage is particularly limited. Literature [3] used cascaded boost converters to achieve high voltage gain, but each stage has a power switch tube, which increases the difficulty of control and the cost is higher. The quadratic boost converter used only one switch tube, and the boost ratio is doubled compared to the traditional boost converter. However, its boost capability still has a certain amount of room for improvement [4]. Literature [5] proposed a hybrid boost converter with the switch-inductor structure based on the quadratic boost converter, which not only improves the boosting capability, but also improves the efficiency of photovoltaic. Due to the non-linear characteristics of the photovoltaic cells [6], it is necessary to track the MPP through MPPT to improve the power generation efficiency of photovoltaic cells. The INC algorithm is widely used because of its simple structure and easy implementation [7-8]. But its step size is fixed, it is easy to cause misjudgement when the light intensity changes suddenly, and the tracking speed and tracking accuracy are not coordinated [9]. The existing research literatures usually only solves the problem of low output voltage or MPPT of photovoltaic, without comprehensively considering the output

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voltage and power generation efficiency of photovoltaic. Therefore, in this paper, the hybrid boost converter is used as the DC/DC converter of photovoltaic, and variable step size INC algorithm is used to track the maximum power of photovoltaic cells, which can effectively improve the output voltage and power generation efficiency of photovoltaic system.

2 The hybrid boost converter

2.1 Topology structure of hybrid boost converter

The topological structure of the hybrid boost converter is shown in Figure 1. It is composed of 1 switch inductor, 2 capacitors C_1, C_2 , 1 power switch tube S , 3 diodes D_3, D_4, D_5 and an inductor L_3 . Among them, the switch inductor is composed of 2 inductors L_1, L_2 and 3 diodes D_1, D_2, D_{12} , which is to replace the input inductor in the traditional boost converter. The boost of the hybrid boost converter is $(1+Dt)$ times higher than that of the quadratic boost converter, and its boost ratio is:

$$\frac{U_{out}}{E} = \frac{1+Dt}{(1-Dt)^2} \quad (1)$$

Where Dt is the duty cycle.

Fig. 1. Topology structure of hybrid boost converter

2.2 Analysis of working modes

The size of the inductance L_1, L_2 will affect the working mode of the hybrid boost converter, but its boost ratio remains unchanged, both are $U_{out}/E = (1 + Dt)/(1 - Dt)^2$ [4]. Therefore, the hybrid boost converter in this paper takes inductance $L_1 = L_2$. The working mode of the hybrid boost converter is analysed below.

In different periods of time, the power switch S can be divided into two states: on and off. The inductance and capacitance in the circuit are charged and discharged alternately. Working mode 1 ($t_0 \leq t \leq t_0 + DT$), the power switch S is turned on, D_1, D_2, D_4 are turned on, and D_3, D_5, D_{12} are turned off; at this time, the power supply E charges the inductor L_1 and L_2 , the capacitor C_1 charges the inductor L_3 , and the capacitor C_2 provides energy for the load. The equivalent circuit is shown in Figure 2. Working mode 2 ($t_0 + DT \leq t \leq t_0 + T$), the power switch S is cut off, D_1, D_2, D_4 are turned off, and D_3, D_5, D_{12} are on; the power

supply E and the inductor L_1, L_2 release energy to the capacitor C_1 and the inductor L_3 , while the inductor L_3 supplies energy to the load and charges the capacitor C_2 . The equivalent circuit is shown in Figure 3. According to the on-off conditions of the switch S in different modes and the volt-second balance characteristics of the inductance element, we can get:

$$\begin{cases} U_{C1}Dt + (U_{C1} - U_{C2})(1 - Dt) = 0 \\ EDt + (E - U_{C1})\frac{L_1}{L_1 + L_2}(1 - Dt) = 0 \\ EDt + (E - U_{C1})\frac{L_2}{L_1 + L_2}(1 - Dt) = 0 \\ U_{C2} = U_{out} \end{cases} \quad (2)$$

Where U_{C1} and U_{C2} are the terminal voltages of capacitors C_1 and C_2 , and E is the DC power supply. When $L_1 = L_2$, the boost ratio of the hybrid boost converter in continuous working mode is:

$$\frac{U_{out}}{E} = \frac{1 + D}{(1 - D)^2} \quad (3)$$

Fig. 2. Working mode 1

Fig. 3. Working mode 2

2.3 Characteristic analysis

Figure 4 shows the output voltage curves of the three boost converters when the DC input voltages are all 10V and the duty cycle $Dt=0.5$.

Fig. 4. The output voltage curves of the three boost converter

Figure.3 shows that when the input voltage $U_{in} = 10V$, $Dt = 0.5$, the traditional boost converter $U_{out} = 20V$, which meets its boost ratio $\frac{U_{out}}{U_{in}} = \frac{1}{1-Dt}$; the quadratic boost converter $U_{out} = 40V$, which also satisfies its boost ratio $\frac{U_{out}}{U_{in}} = \frac{1}{(1-Dt)^2}$; the hybrid boost converter $U_{out} = 60V$ also satisfies its boost ratio $\frac{U_{out}}{U_{in}} = \frac{1+Dt}{(1-Dt)^2}$. Therefore, the hybrid boost converter has obvious advantages in boost ratio compared with the other two boost converter, which can meet the demand of high boost ratio of the PV system.

3 Variable step size incremental conductance algorithm

In this paper, the variable step size INC is used to track the MPP of the PV system. Compared with the traditional INC algorithm, this method takes into account the relationship between tracking speed and tracking accuracy.

The step length of the variable step size INC algorithm is to automatically change the size of the step length according to whether the operating point is near the MPP, so as to minimize the oscillation when the power is in a steady state. When the operating point is far away from the maximum power point, a larger step size is used to ensure the maximum tracking speed; when the operating point is close to MPPT, the step size is reduced to reduce oscillation and realize the maximize tracking accuracy. The step modification equation is:

$$\begin{cases} \left| \frac{dP}{dU} \right| = \left| \frac{P(m) - P(m-1)}{V(m) - V(m-1)} \right| \\ step = M \times \left| \frac{dP}{dU} \right| \\ Dt(m) = Dt(m-1) \pm step \end{cases} \quad (4)$$

Where M is the tracking coefficient.

The variable step size INC algorithm control flow chart is shown as in Figure 5.

Fig. 5.The variable step size INC algorithm control flow chart

4 Simulation verification and result analysis

In this paper, a photovoltaic system MPPT algorithm simulation model based on a hybrid boost converter and variable step size INC algorithm is built on the Simulink, as shown in Figure 6.

Fig. 6. Simulation model of photovoltaic MPPT algorithm based on hybrid boost converter and variable step size INC

In order to study the tracking of the MPP when the light intensity changes suddenly, it is divided into two situations: a sudden increase in light intensity and a sudden decrease in light intensity:

- i. Sudden increase in light intensity, the light intensity changes from 1000W/m² to 500W/m²;
- ii. Sudden decrease in light intensity, the light intensity changes from 500W/m² to 800W/m²;

Figures 7 and 8 show the MPPT output curve based on the traditional INC algorithm and the variable step size INC algorithm when the light intensity suddenly increases.

Fig. 7. Output power curve of traditional INC algorithm

Fig. 8. Output power curve of variable step size INC algorithm

Figures 9 and 10 show the MPPT output curve based on the traditional INC algorithm and the variable step size INC algorithm when the light intensity suddenly decreases.

Fig. 9. Output power curve of traditional INC algorithm

Fig. 10. Output power curve of variable step size INC algorithm

From Figure 7, Figure 8, Figure 9 and Figure 10, we can see that when the light intensity suddenly increases or decreases, the variable step-size INC algorithm has smaller fluctuations than the traditional INC algorithm, and it can quickly track the MPP. The traditional INC algorithm has large steady-state oscillation amplitude, causing energy loss. The variable step size INC algorithm has small steady-state oscillation amplitude, which shows that the tracking speed and tracking accuracy of the variable-step size INC algorithm are better than the traditional INC algorithm. At the same time, the hybrid Boost circuit achieves a boost ratio of more than 2.5 times when the duty cycle is less than 0.3. Therefore, it is of great help to increase the output voltage of the photovoltaic system.

To sum up, when the external conditions suddenly change, the photovoltaic system algorithm based on the hybrid boost converter and variable step size INC can quickly track the MPP, and the steady-state power oscillation is small and the boost ratio is high, which meets the design requirements.

5 Conclusion

In this paper, the hybrid Boost converter and the variable step size INC algorithm are used to the photovoltaic, and the Simulink simulation model verifies the feasibility of the method. The results indicates that the hybrid Boost converter can effectively increase the output voltage of the photovoltaic under the condition of low duty cycle; and the variable-step size INC algorithm realizes the maximum power point tracking of the photovoltaic cell. The contradiction between tracking speed and tracking accuracy in the tracking process is solved, and the combination of the two effectively improves the output voltage and power generation efficiency of the photovoltaic system.

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