

Research and simulation of two-level grid-connected photovoltaic inverter system

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Abstract: The photovoltaic cell can achieve the optimal state, and the solar energy is converted into electrical energy sufficiently in the two-level PV power system by using the method of MPPT which is based on the front stage Boost converter. The back stage network side inverter adopts the method of deadbeat control and the grid power factor turns to be 1. The maximum power point tracking is realized, and the grid current has the same frequency and phase with the grid voltage through simulation. Therefore, efficiency of the solar module is improved and the sine AC wave of the inverter control circuit is high-quality. Each converter can achieve relatively independent function in the two-level PV power system by the method of Matlab/Simulink software simulation. The simulation shows that it is very conducive to the modular design and integration of the system.

Key words: photovoltaic; MPPT; deadbeat control; simulation

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Solar energy is a kind of clean and renewable energy nowadays, so it has aroused more and more concern. The PV power generation system can be divided into two kinds of the PV off-grid power system and PV grid power system^[1]. The PV off-grid power system is used for rural electrification, communications and industrial applications. The PV grid power system is mainly used for combining buildings in a city, as well as used for large desert PV power plants. Such applications have become the mainstream of the PV market^[2].

The front stage Boost converter with the method of improved CVT start which is in combination with the variable step size disturbance observer method can realize the simulation of MPPT. The advantages of the method are that it can quickly track the maximum power point and reduce the disturbance near the maximum power point. Further, the method can also save energy.

The back stage network side inverter generally adopts the method of double loop to control the voltage and current. It is a relatively mature classical control method and easy to implement. However, it has slow dynamic response speed and needs long adjustment time. The output current waveform quality is weak when rapid changes occur in the light condition. In this paper, the method of the deadbeat control is adopted. Deadbeat control method has the advantages of fixed switching frequency, good dynamic response and low harmonic content. In addition, it can output high-quality grid current.

1 Control principle of two-level grid-connected photovoltaic system

Fig.1 shows the two-level PV power system circuit. The controller 1 is able to realize the maximum power point tracking which means that it achieves MPPT control of the front stage Boost converter^[3]. Controller 2 achieves control of the unity power factor and control of DC side voltage, which realizes that frequency and phase of the grid current are the same as the grid voltage^[4].

1.1 MPPT control based on front stage DC/DC converter

The output voltage of the Boost converter is controlled by the network side inverter, so adjusting the Boost converter switching duty cycle is equal to adjusting the input current of the Boost converter. In this way, output voltage of the photovoltaic cells is regulated. According to the output voltage and output current of the photovoltaic cells which are detected, the Boost converter can regulate operating point of the photovoltaic cell voltage command U_{ref} by MPPT control algorithm. Then the sampled value of the output voltage of the photovoltaic cells U_{PV} is subtracted from U_{ref} , and the input voltage closed-loop control of the Boost converter is realized by a PI regulator. So the MPPT control of photovoltaic cells is implemented.

In this paper, the maximum power point tracking

is achieved by using method of the improved CVT start which is in combination with the variable step size disturbance observer. Larger step of voltage disturbance can be able to improve the tracking

speed and reduce the time of photovoltaic cells in the area away from MPP. The tracking accuracy is certified by using smaller step of voltage disturbance in area near the MPP region.

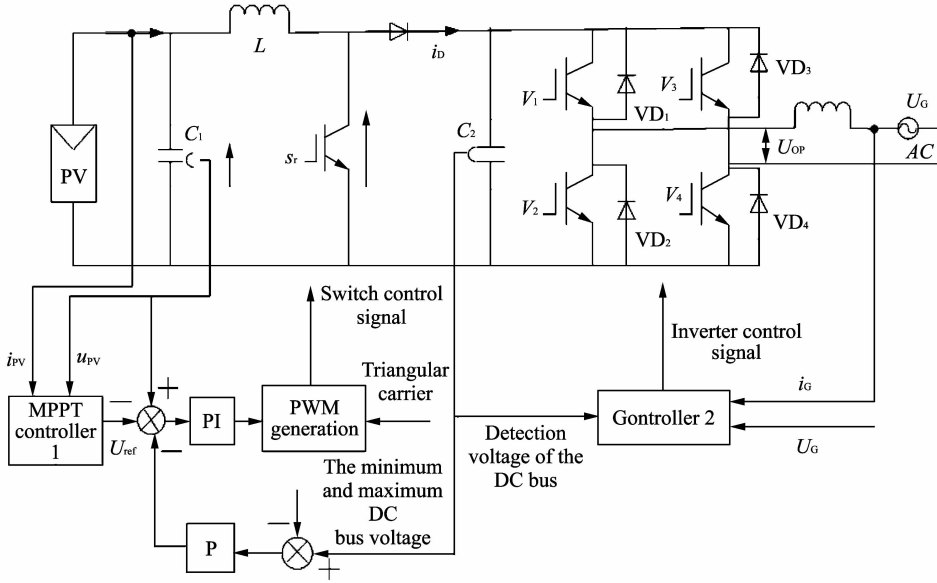


Fig. 1 Two-level PV power system circuit

1.2 PV grid-connected inverter control

Deadbeat control principle is described as follows. Firstly, the next switching cycle of PWM pulse width is calculated by the state equation of the inverter and output feedback signal^[4]. Secondly, the tube's turn-on and turn-off of the power inverter bridge is controlled according to the pulse width^[5]. Ultimately, output waveform of the inverter is displayed. The deadbeat control can adapt to the PV grid-connected inverter control because it has advantages of good dynamic performance, undistorted output waveform, short transient response time and so on^[6-9].

The deadbeat control scheme is adopted by the back stage network side inverter. Eq.(1) can be obtained from Fig. 1. That is

$$U_{op} = U_G + j\omega L i_G, \quad (1)$$

where U_{op} is output voltage of the grid inverter; U_G is grid voltage; i_G is grid current; L is inductance of the boost circuit.

The time domain circuit equation Eq.(2) is obtained by Eq. (1).

$$U_{op} = U_G + L \frac{di_L}{dt} + Ri_L, \quad (2)$$

where i_L is output reference current of the inverter.

Eq. (3) is discrete process of Eq. (2). We have

$$i_{L[n+1]} = i_{L[n]} + \frac{T_s}{L} \{ U_{op[n]} - U_{G[n]} - Ri_{L[n]} \}, \quad (3)$$

where T_s is sampling period; $i_{L[n]}$ is the current

value which is sampled at the n -th times about inductance L ; $U_{op[n]}$ is the arithmetic mean of U_{op} at the n -th sampling period; $U_{grid[n]}$ is the arithmetic mean of U_{grid} during the n -th sampling period; $i_{L[n]}$ is the arithmetic mean of i_L during the n -th sampling period.

In fact, $U_{op[n]}$ is the pulse voltage, and its pulse width $D_{[n]}$ is as follows

$$D_{[n]} = \frac{U_{op[n]}}{U_{dc}}. \quad (4)$$

Output voltage of the inverter can be obtained by controlling the sampled pulse width, so controlling $U_{op[n]}$ means to control the output voltage of the inverter.

Eq. (5) is calculated by Eq. (3).

$$U_{op[n]} = \frac{L}{T_s} \{ i_{L[n+1]} - i_{L[n]} \} + U_{G[n]} + Ri_{L[n]}, \quad (5)$$

$i_{p[n+1]}$ can be used instead of $i_{L[n+1]}$ in Eq.(5) if the inductor current is able to track the reference current at the sampling time of $(n+1)$. As a result, Eq. (6) is obtained

$$U_{op[n]} = \frac{L}{T_s} \{ i_{p[n+1]} - i_{L[n]} \} + U_{G[n]} + Ri_{L[n]}. \quad (6)$$

Eq. (7) is calculated when Eq. (4) is put into Eq. (6).

$$D_{[n]} = \frac{\frac{L}{T_s} \{i_{p[n+1]} - i_{L[n]}\} + U_{G[n]} + i_{L[n]}}{U_{dc}}. \quad (7)$$

In analysis of the deadbeat control principle presented here, the inverter reference current signal at the next cycle is the premise of obtaining the inverter pulse width at the next sampling cycle, and the next PWM cycle time is calculated by the above formula. Fig.2 shows the schematic of reference current obtained by the grid side inverter.

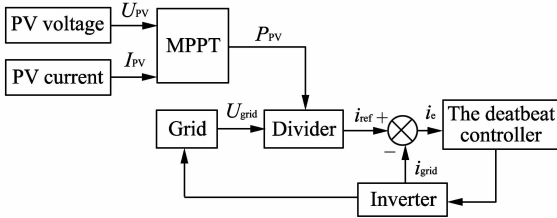


Fig. 2 Schematic of reference current obtained by inverter

1.3 Algorithm two-level grid-connected photovoltaic system

Fig.3 shows algorithm flow chart of the two-level grid-connected photovoltaic system. Disturbance step is adjusted adaptively when the difference is not 0 but between V_k and V_{k-1} . The end of the return will be completed if V_k is equal to V_{k-1} . Firstly, the open voltage of PV system is sampled, and the initial voltage of CVT is set. So the output voltage of PV cell is controlled, moving from the open voltage to the maximum power point voltage. Secondly, the variable step disturbance observer method is adopted when the output voltage reaches the needed point. Then, output power P can be obtained by the MPPT control strategy, and valid value of the reference current is calculated when power P is divided by the grid voltage. Then, reference current signal of the

inverter which is at the next cycle is determined according to the phase of the grid voltage. Finally, the inverter pulse width is able to control tube's turn-on and turn-off of the power inverter bridge.

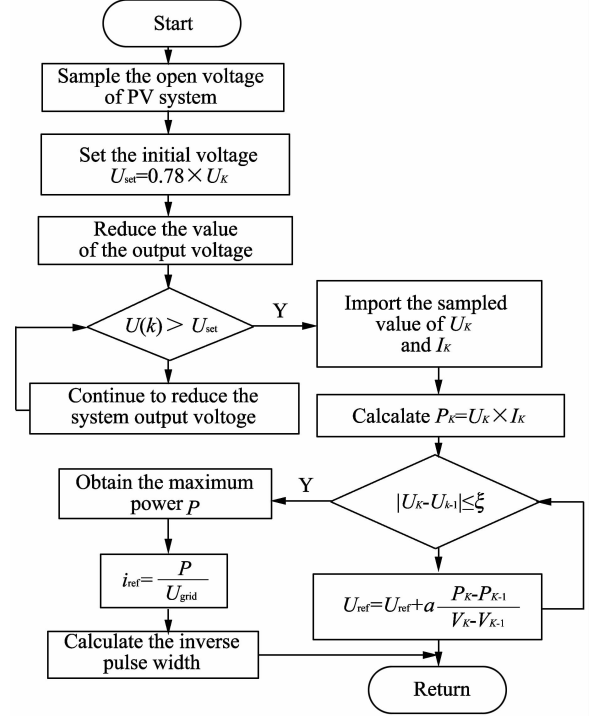


Fig. 3 Algorithm flow chart of the two-level grid-connected photovoltaic system

2 Simulation and analysis

The simulation about the Boost circuit parameters are as follows. The switching frequency f is 10 kHz; inductance L is 6 mH; DC capacitor C is 1 500 μ F. The two-level photovoltaic power generation system simulation model is set up based on the above parameters, as shown in Fig.4.

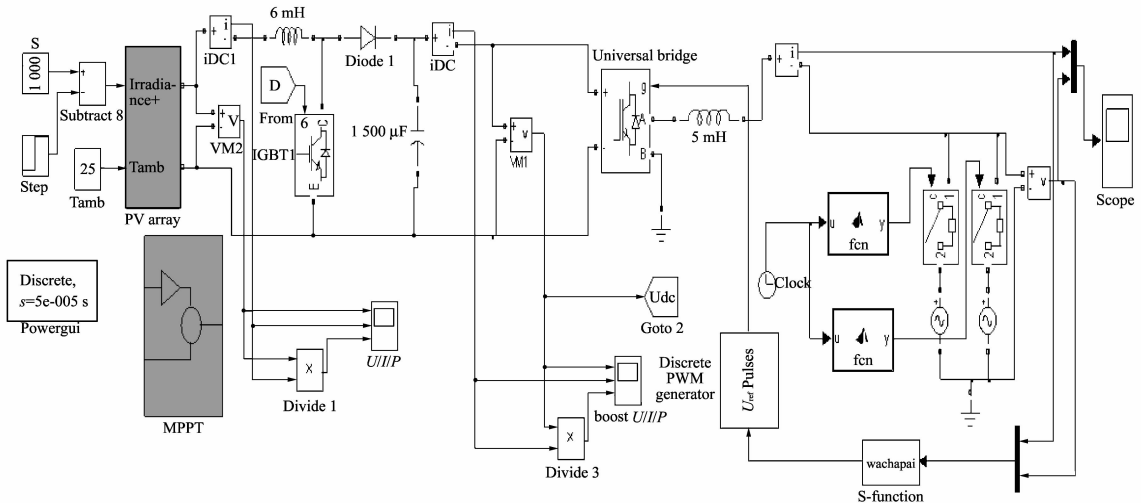


Fig. 4 Two-level photovoltaic power generation system simulation model

Simulation diagram is shown in the MPPT control model based on the front stage DC/DC converter in Fig. 5. The optimal state is realized when a is 0.01 in Eq. (8), compared with various step curves which concludes different colors. In other words, the tracking speed is the fastest and the volatility is the minimum, so MPPT tracking is better realized.

$$V_{\text{ref}} = V_{\text{ref}} + a \frac{P_k - P_{k-1}}{V_k - V_{k-1}}. \quad (8)$$

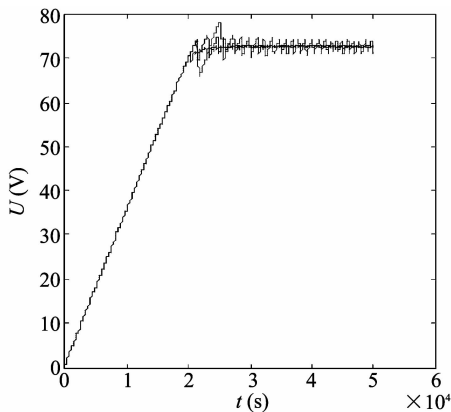


Fig. 5 Voltage tracking diagram of MPPT control

Simulation results of the double loop which controls voltage and current are shown in Fig. 6. The current can be able to track the voltage well, but the output current waveform is distorted and the waveform quality is not high.

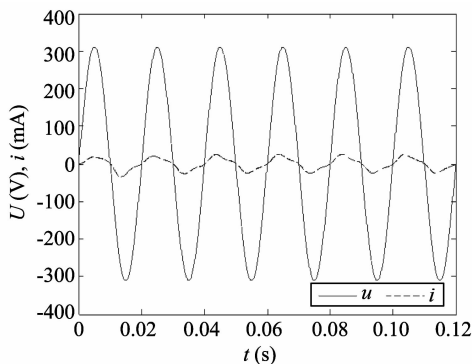


Fig. 6 The simulation of double loop

Fig. 7 shows the waveforms that the current can track the grid voltage in the deadbeat control model of the network side inverter. The grid current can track voltage quickly to achieve! the same frequency and phase of the grid current and grid voltage. The grid current waveform will be able to maintain stability after 0.01 s when frequency of the grid voltage is from 50 Hz to 60 Hz at 0.08 s. So the grid current can track the grid voltage precisely. The waveform in Fig. 7 proves that there is short transient time and good steady-state performance in the deadbeat control.

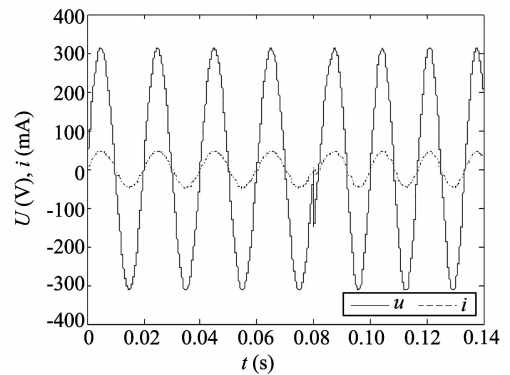


Fig. 7 Waveform that current tracks the grid voltage

3 Conclusion

Simulation model of the two-level PV power system is put forward in this paper. The simulation module is realized in the simulation environment. The front stage Boost converter uses the method of improved CVT start which is in combination with the variable step size disturbance observer method realizes the simulation of MPPT. The back stage network side inverter uses the method of the dead-beat control to control the grid inverter current. Current and voltage of the grid have the same frequency and phase. The maximum power point tracking and grid inverter control are relatively independent in the simulation model. The entire system is not only conducive to the modular design but also more flexible and reliable.

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两级式光伏并网发电系统的研究与仿真

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摘 要: 在两级式光伏发电系统中, 采用基于前级 Boost 变换器的 MPPT 方法, 可以使光伏电池达到最优状态, 即最大限度的将太阳能转化为电能。后级网侧逆变器采用无差拍控制, 使电网功率因数为 1。通过两级式并网发电系统的仿真, 可以实现最大功率点的跟踪, 而且使并网电流与电网电压达到同频同相。因此, 光伏模块的效率能够得到提高, 逆变控制器的电流呈现高质量的正弦交流波形。通过 Matlab/Simulink 软件进行仿真, 前后级都能实现相对独立的功能。仿真结果表明: 此方案更有利于系统的模块化设计和集成。

关键词: 光伏; MPPT; 无差拍控制; 仿真

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