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Research Article

A Two-Stage Wind Grid Inverter with Boost Converter

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At present, the conversion efficiency of commercial small wind grid inverter is low, and, in case of low wind speed, the wind energy cannot be used efficiently. In order to resolve this problem, it is necessary to improve the topological structure and control strategy, and design a new small wind grid inverter. In this paper, we apply a two-voltage stage topology with boost converter. The boost circuit is to achieve the maximum power output of the wind energy by the segmented regulation, while the improved inverter topology realizes the overall system function with the former stage circuit. The experimental results show that the new wind grid inverter has superior performance in the low wind speed, and has the high quality energy output. This research has an important practical significance to improve the utilization of renewable energy.

1. Introduction

As a kind of renewable clean energy, wind energy is getting more and more attention of researchers [1]. At present, the utilization of wind energy is usually in the way of the large- or medium-scaled grid-connected mode. The operation of wind power generation requires support from a strong power grid and thus limits its application [2]. Small scale wind power generating system generally adopts the direct drive permanent magnet synchronous generator and does not need the transmission device. It may operate efficiently in the high wind speed range with greatly improved power efficiency and reduced operation and maintenance costs. The small wind power generation has become an important development direction in new energy power generation, characterized by being more economical, convenient, and practical [3, 4].

At present, the research on the grid-connected inverter of wind power generation system mainly concentrates on how to control the output side, while paying little attention to how to control the input side, that is, DC part. The resulting consequences are the fact that the commercial small wind power generation system does not operate perfectly under low wind speed environment. In our area, the wind speed is always low all the year, so the traditional commercial grid-connected inverter cannot realize grid generation. Our research aims to improve the performance of small wind power under low wind speed range and to increase the energy utilization ratio [5].

We have done some research on the topology structure and control strategy of the small wind grid-connected inverter. The grid-connected inverter used the two-stage circuit topology with isolation transformer [6]. The former stage of the main circuit converts the variable output from the rectifier to the DC power that can satisfy the requirements of the inverter, and the second stage is the single-phase bridge inverter circuit. The main purpose of the isolation transformer is to reduce the output voltage of the inverter, to reduce the voltage of the bus section, to increase the input voltage range of the DC, and to improve the utilization rate of the wind energy. On the control strategy, we use the segmented control for the front stage of the inverter; that is, when the DC input voltage of the inverter is low, the strategy is the boost control method, and while the DC input voltage is high, the strategy is the MPPT control method, which outputs the maximum wind energy power. The second stage of the inverter adopts triangle wave compare control to achieve the current tracking [7]. Through the improvement of inverter topology and control strategy, we can improve the performance of small wind power generation system at low speed, improve the energy utilization, and promote the development and utilization of wind power generation.

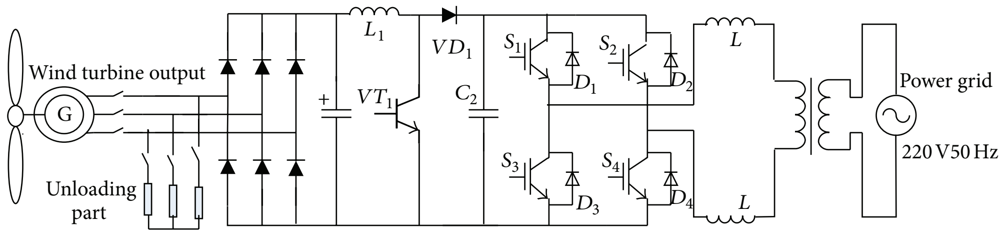


Figure 1: The topology structure of the small wind power generation system.

2. The Main Circuit Topology of the Single-Phase Grid-Connected Inverter

This system adopts the two-stage isolation circuit topology with the isolation transformer, as shown in Figure 1. It consists of wind turbine, generator, unloading control protection device, rectifier, boost circuit, and inverter. The three-phase AC output of the wind power generator is rectified to DC power by the uncontrolled rectifier unit and then obtains the maximum power output through DC/DC circuit. The single-phase full bridge inverter outputs the AC power and connects to grid after the filter inductance and transformer [8].

The mathematical equations for the permanent magnet synchronous generator in the dq0 coordinate are

$$u_{sd} = p\psi_{sd} - \omega_r \psi_{sq} - r_s i_{sd}$$
$$u_{sq} = p\psi_{sq} + \omega_r \psi_{sd} - r_s i_{sq} \tag{1}$$

$$\psi_{sd} = -L_d i_{sd} + \psi_r$$
$$\psi_{sq} = -L_q i_{sq} \tag{2}$$

$$T_e = i_{sq}\psi_{sq} - i_{sd}\psi_{sq}. \tag{3}$$

The purpose of the boost circuit is to boost the input DC voltage and provide the stable bus voltage U_{dc} to the inverter device.

When VT_1 is on,

$$\Delta iLf\,(t) = \frac{U_i}{Lf} T_{on} \tag{4}$$

and when VT_1 is off,

$$\Delta iLf\,(t) = \frac{U_o - U_i}{Lf} T_{off}. \tag{5}$$

When the circuit is working in steady state, the inductive energy is stored and released in a switch cycle in theory. Consider

$$\Delta iLf\,(t) = \frac{U_i}{Lf} T_{on} = \frac{U_o - U_i}{Lf} T_{off}. \tag{6}$$

So the output of the boost circuit is

$$U_o = \frac{1}{1-D} U_i, \tag{7}$$

where D is the duty ratio.

The inverter adopts a single-phase bridge inverter circuit. At present, the output side of the traditional commercial grid-connected inverter is mainly the nonisolated grid-connected structure, with the output voltage being 220 V and the bus voltage being 400 V. Considering the continuity of the output current, the duty ratio of the DC/DC circuit is limited from 0.2 to 0.9, the DC input voltage that can be grid-connected must be higher than 40 V, and the starting voltage is usually 50~70 V. While the wind energy output voltage of Tianjin area is mostly from 30 to 50 V, the traditional commercial grid-connected inverter cannot utilize the wind energy and the performance of the low wind speed is not ideal enough. In this paper, the designed output side of the grid-connected inverter is the isolation transformers using the ratio of 1 : 2, the inverter output voltage is 110 V, and the designed bus voltage is 300 V. According to the design requirements, as long as the DC input voltage is greater than 30 V, the inverter would work at grid-connected mode. The designed starting voltage in this system is 40 V. Therefore, the main circuit topology structure can effectively utilize the low wind speed in this paper.

3. The MPPT Control of the Former Stage

The output voltage range of the small wind power generation system in this paper is 30~150 V. In order to ensure the reliable operation of the inverter, it is needed to boost and stable the DC input voltage to meet the requirements of bus voltage. The output voltage of small wind power generation system is low in low wind speed all the year in Tianjin. When the DC input voltage is low, the inverter uses the boost control to stable the bus voltage level, which can ensure that the inverter is working in grid-connected mode. When the DC input voltage is high, the inverter uses the MPPT control to achieve the maximum power output of the wind energy. The design of the DC/DC control strategy can not only use the low speed wind energy effectively but also realize the efficient utilization of the high speed wind energy; thus it greatly improves the energy efficiency of the small wind power generation system.

The control flow diagram for the above-mentioned DC/DC converter is shown in Figure 2, where the reference values are subjected to $U_{ref1} < U_{ref2} < U_{ref}$, and can be set as required. In the following examples, we set $U_{ref1} = 40$ V, $U_{ref2} = 80$ V, and $U_{ref} = 150$ V.

There are many control algorithms to achieve the maximum power point tracking, such as the perturbation-observation method and the incremental conductance method.

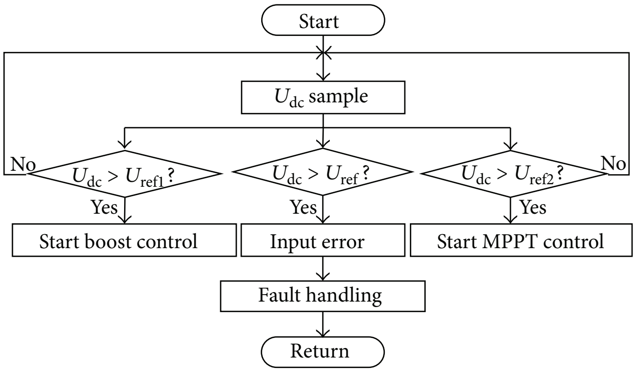


Figure 2: The DC/DC control flow chart.

In the incremental conductance method, the voltage and current of the input energy are sampled, and then the wind incremental conductance is compared with the instantaneous conductance to change the control signal. The incremental conductance method has many advantages, for example, the high precision control and fast response speed, and is also applicable to the atmospheric fast-changing conditions. Hence we adopt the incremental conductance method to achieve the maximum power point tracking control.

4. The Grid-Connected Inverter Control

According to whether there is a current feedback control loop or not, the current control can be divided into indirect current control and direct current control. These two control methods have their advantages and disadvantages. This paper adopts the direct current control method. The open-loop transfer function of grid system is

$$G_L(s) = K_{pwm} \cdot \frac{K_p s + K_i}{s} \cdot \frac{1}{L_s + R_L}, \tag{8}$$

where K_{pwm} is the inverter gain.

As shown in Figure 3, this paper adopts double closed loop control, namely, voltage outer loop and current inner loop. The main function of voltage outer loop is to stabilize the DC voltage and to give the current instruction value IL∗ at the same time. The current inner loop controls the amplitude and phase of the grid-connected current to track the grid-connected given current IL∗. The design of the inner current loop is the key of the whole control system [9, 10].

The generation of the sine of instruction current includes generation of phase-lock loop and SPWM waveform and output instruction current which has the same frequency and phase with the grid voltage. There are two methods to realize the phase-locking, analog and digital method. The analog method is not suitable for high power, high precision equipment due to the complex circuit and low precision, while the digital method is based on DSP chip, owning higher intelligent degree, and can achieve the online control algorithm changes without changing the hardware circuit. Therefore, we used the digital method to let the grid-connected current and grid voltage have the same frequency and phase strictly in this paper. The triangular wave comparison method is used to track the real-time current. The triangular wave comparison control is different with the SPWM control; it can be seen as the optimal combination of SPWM method and instantaneous hysteresis comparison method.

5. The System Control Flow Chart

The system software consists of the main program and interrupt program. The program is written in the main program or interrupt program according to the real-time requirement, so as to ensure the real-time feature and efficiency of the grid-connected control.

The flow chart of the main program is shown in Figure 4. The main program completes the register initialization, detects the system state, and then comes into dead circulation. When the peripheral interrupt source generates an interrupt, the interrupt program begins execution. The interrupt service program includes the T1 period interrupt subroutine, the T1 underflow interrupt subroutine, and the capture interrupt subroutine. The T1 cycle interrupt subroutine mainly completes the sampling pulse width calculation and the assignment of comparison register; the capture interrupt subroutine makes the reference current signal track the grid voltage frequency and phase.

6. The Experiment Results Analysis

In order to study the rationality and validity of the system, this paper made a comparative test analysis. Based on the realization of the design requirements of the system, this paper also studied the traditional control strategy of the single-phase grid-connected inverter, in which control mode the DC started voltage is greater than 50 V.

To compare the wind power inverter's performance in the low speed section of the traditional control strategy and the new control strategy, considering the system to be reliable and stable at the same time, the DC input voltage in the traditional control strategy is 60 V in this paper. As the input DC voltage requirement of this system is lower than the traditional control strategy, the start voltage in this system is 40 V. Figure 5 shows the output waveform under two kinds of control strategy.

Experimental results show that the output current can track the grid voltage well and the current waveform is also smooth. As shown in Figure 5, when the DC input voltage reaches the start voltage, the grid-connected inverter starts working and the grid-connected current is output stable.

Figure 5(a) is the output results with the input voltage of 60 V in the traditional control strategy, and Figure 5(b) is the one with 40 V in the innovative control strategy. Although the DC input voltages required are different, there is no significant difference in their output performance. Traditionally, the value of 40 V is less than the start voltage, and the grid-connected inverter is unable to work. Namely, the wind energy under low speed has to be discarded. On the contrary, they are utilized with our innovative control strategy. Thus,

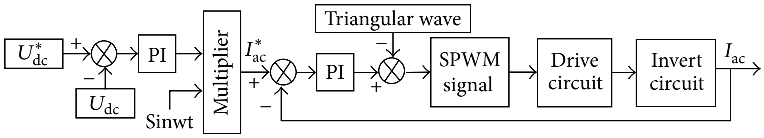


Figure 3: Double closed loop control block.

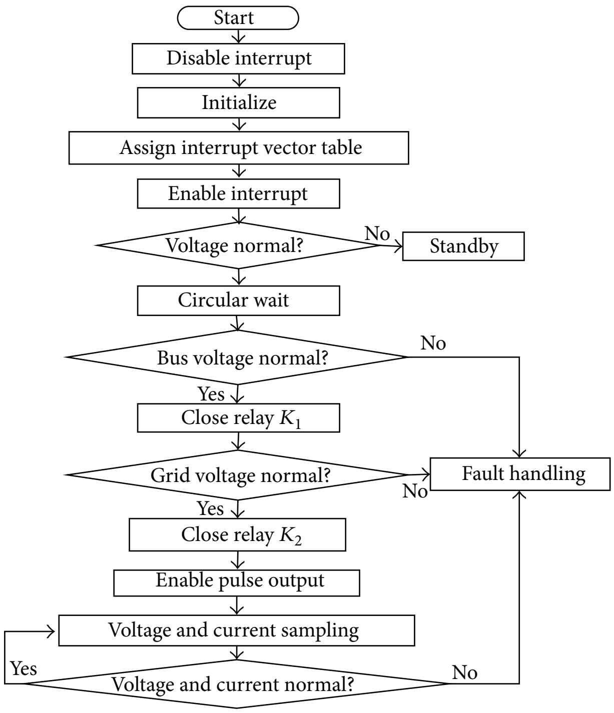
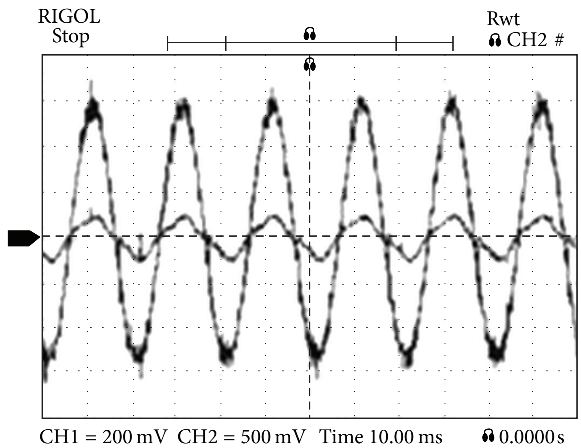
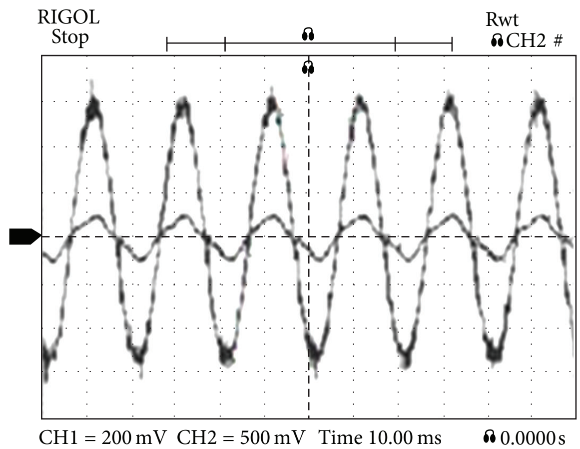


Figure 4: The main program flow chart.



(a) Traditional control strategy (U_{dc} = 60 V)



(b) Innovative control strategy (U_{dc} = 40 V)

Figure 5: Output results under different control mode.

we take full advantage of the resources, further improved the performance of the output current, and achieved the design requirements of the system.

7. Conclusion

In this paper, we improved the topology and control strategy on the basis of the traditional commercial grid-connected inverter, designed a new small wind single-phase grid-connected inverter based on DSP, and carried out relevant experiment. The experimental results show that the designed topology structure improves the performance of the small wind power generation system under low wind speed with the new control strategy and is reasonable and effective, which meets the design requirements of grid-connected inverter.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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