ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

GRID-CONNECTED CONVERTER CONTROL STRATEGY BASED ON RELATIONSHIP BETWEEN MAGNITUDE AND PHASE OF SYSTEM VOLTAGE

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ABSTRACT

Grid-connected converter is an important power interface between the DC bus of renewable energy power system and public grid. By virtue of vector relation of grid voltage, converter voltage and line impedance voltage, real-time control of active current and reactive current injected into the grid is realized. The simulation results show that grid-connected converter based on relationship between magnitude and phase of system voltage can flexibly regulate active power and reactive power system, and meet the requirement of grid connection of renewable energy power system.

KEYWORDS: grid-connected converter, power adjustment, renewable energy power system, control strategy

INTRODUCTION

As new clean energy, solar power, wind power and other renewable power systems are flexible, environmentally friendly and renewable. In recent years, especially in china, it is developing rapidly. Grid-connected converter is important interface between renewable energy power generation system and the public grid for adjusting active and reactive power injected into the grid, which determines the overall operating performance of renewable power generation system [1].

Grid-connected converter control should meet two basic requirements: (1) DC bus voltage is stable to guarantee input-output balance of renewable energy power generation system. (2) Current injected into the grid is sinusoidal and its phase is consistent with grid voltage phase to ensure the converting efficiency avoid high harmonic pollution on the grid.
The core function of grid-connected converter is to control AC current inflowing into the grid. Currently, most grid-connected converter mainly adopts direct current control strategy [2~4]. Direct current control can achieve rapid speed for AC current adjustment, having good dynamic characteristics, but it requires high-precision current sensor to increase converter cost. In addition, traditional current hysteresis control has variable switching frequency. As result, converter filter design difficulty will be increased [5~8].

Grid-connected converter control system based on relationship between magnitude and phase of system voltage is one effective PWM converter control method, which relies on the vector relationship of grid voltage, converter voltage and line impedance voltage. This control strategy can dynamically regulate the current injected into utility grid power in real-time. The principle of the control strategy is clear, simple and easy to implement. More importantly, it does not need the current sensor, which decreases system cost.

VOLTAGE VECTOR RELATIONSHIP OF GRID-CONNECTED CONVERTER SYSTEM

Grid-connected converter includes a three-phase bridge converter circuit and a LC low-pass filter circuit, connected by an isolating step-up transformer with the public grid. Without affecting the accuracy of the system modeling, grid-connected converter is simplified as follows [9~10]:
(1)Three-phase grid voltage is symmetrical and s sinusoidal;
(2) Grid-side filter inductor is linear, and it has no saturation;
(3) T_1-T_6 are ideal switches;
(4) The switching frequency is much higher than grid voltage frequency;
(5) Filter capacitance value is very small and its phase shift is ignored;

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(6) The transformer is regarded as one part of the grid.

Without considering the transformer transformation ratio, grid-connected converter system is shown as Fig.1, in which, v_{dc} is DC bus voltage; L is filter inductor; R is loop equivalent resistance; i_a 、 i_b 、 i_c is inductor current; e_a 、 e_b 、 e_c is the grid voltage.

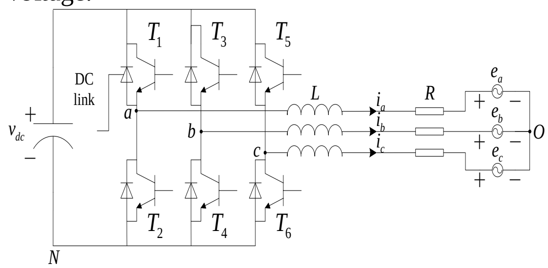

Fig.1Circuit of Converter connected to the grid

Under the control of the sinusoidal pulse width modulation (SPWM) method, AC voltage of the converter is SPWM pulse u_{CN} whose main component is the fundamental sinusoidal voltage. Ignoring the impact of higher harmonics, we can consider u_{CN} is three-phase AC voltage with the frequency same as that of the grid, whereby, the connection relation between the converter and the grid can be simplified to an equivalent circuit shown by Fig. 2. In Fig. 2, L_N is as grid-coupled inductor; R_N is line resistance; u_{CN} is grid voltage; $\dot{i}_{SN}$ is the current injected into the grid and $N = a,b,c$.

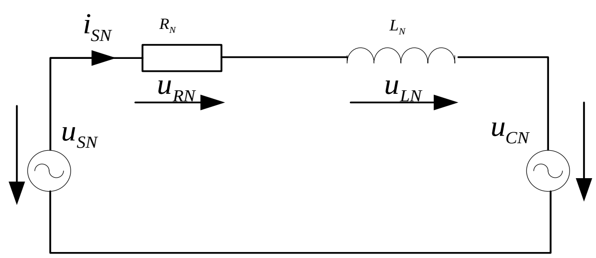

Fig.2 Equivalent circuit of grid-connected converter system

According to equivalent circuit, the relationship of grid voltage, converter voltage and loop impedance voltage is

$$u_{SN} = u_{CN} + u_{RN} + u_{LN} \qquad (1)$$

Vector relation of voltage and current in the circuit mentioned above is:

$$\dot{I}_{SN} = \frac{\dot{U}_{SN} - \dot{U}_{CN}}{Z_N}$$

$$Z_N = \sqrt{R_N{}^2 + (\omega L_N)^2} \qquad (2)$$

Grid-connected converter powers absorbed are:

$$P_S = 3U_S \cdot I_S \cos\varphi = 3U_S \cdot I_{SP}$$

$$Q_S = 3U_S \cdot I_S \sin\varphi = 3U_S \cdot I_{SQ} \qquad (3)$$

Among them, U_s is grid voltage; I_s is grid current; I_{SP} is the active component of the current; I_{SQ} is reactive component of the current.

From Eq. (3), it can be seen that in normal conditions, active and reactive power absorbed by converter depend only on the amplitude and the phase of I_s.

Suppose active and reactive power absorbed by the grid-connected converter are respectively P_S^* and Q_S^*. According to (3), it is easy to gain the expected values of active current and reactive current components of converter current and they are:

$$I_{SP}^* = \frac{p_S{}^*}{3U_S}$$

$$I_{SQ}^* = \frac{Q_S^*}{3U_S} \qquad (4)$$

Therefore, the effective value of expected AC current absorbed by grid-connected converter:

$$I_S^* = \sqrt{I_{SP}^{*\,2} + I_{SQ}^{*\,2}} \qquad (5)$$

And the phase of converter current is:

$$\varphi^* = \arctan\frac{I_{SQ}^*}{I_{SP}^*} = \arctan\frac{Q_S^*}{P_S^*} \qquad (6)$$

So the complete expected converter current is:

$$i_{SN}^* = \sqrt{2} I_S^* \sin(\omega t + \varphi^*) \qquad (7)$$

Where ωt is the phase of the grid voltage in real time.

At this point, the voltage drops of circuit resistance and inductance respectively should be:

$$u_{RN}^* = R_N \cdot i_{SN}^* = \sqrt{2} R \cdot I_S^* \sin(\omega t + \varphi^*) \qquad (8)$$

$$u_{LN}^* = j\omega L_N \cdot i_{SN}^* = \sqrt{2}\omega L_N \cdot I_S^* \cos(\omega t + \varphi^*) \qquad (9)$$

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According to Fig.2, expected output voltage of grid-connected converter should be:

$$u_{CN}^{*} = u_{SN} - u_{RN}^{*} - u_{LN}^{*} \qquad (10)$$

According to power adjustment process, as long as grid-connected converter voltage is controlled, active and reactive power absorbed by converter can be regulated. This is the theoretical principle of grid-connected converter control strategy based on relationship between magnitude and phase of system voltage.

CONTROL STRATEGY BASED ON SYSTEM VOLTAGE RELATIONSHIP

Grid-connected converter is essentially an adjustable voltage source. The expected values of active power and reactive power must be converted to the expected output voltage of grid-connected converter that is the voltage command. By virtue of the voltage command and classic sinusoidal pulse width modulation method (SPWM), grid-connected converter can absorb corresponding active and reactive power. **Therefore, the generation of voltage command value is the core of converter control strategy.**

With expected value of active power and reactive power, based on Eq. (1)~(10), grid-connected converter voltage command can be gained:

$$\begin{aligned} u_{CN}^{*} &= \sqrt{2}U_S \sin \omega t \\ &- \sqrt{2}R \cdot \sqrt{\left(\frac{P_S^{*}}{3U_S}\right)^2 + \left(\frac{Q_S^{*}}{3U_S}\right)^2} \cdot \sin\left(\omega t + \arctan \frac{Q_S^{*}}{P_S^{*}}\right) \\ &- \sqrt{2}\omega L_N \cdot \sqrt{\left(\frac{P_S^{*}}{3U_S}\right)^2 + \left(\frac{Q_S^{*}}{3U_S}\right)^2} \cdot \cos\left(\omega t + \arctan \frac{Q_S^{*}}{P_S^{*}}\right) \end{aligned} \qquad (11)$$

Eq. (11) shows that converter control strategy based on system voltage relationship does not need current information and dynamic modeling, but requires prior accurately circuit impedance parameters. In addition, same as other control strategy, it is also necessary to track the phase of the grid voltage.

In summary, control strategy based on system voltage vector relationship of renewable energy generation systems is shown as Fig. 3.

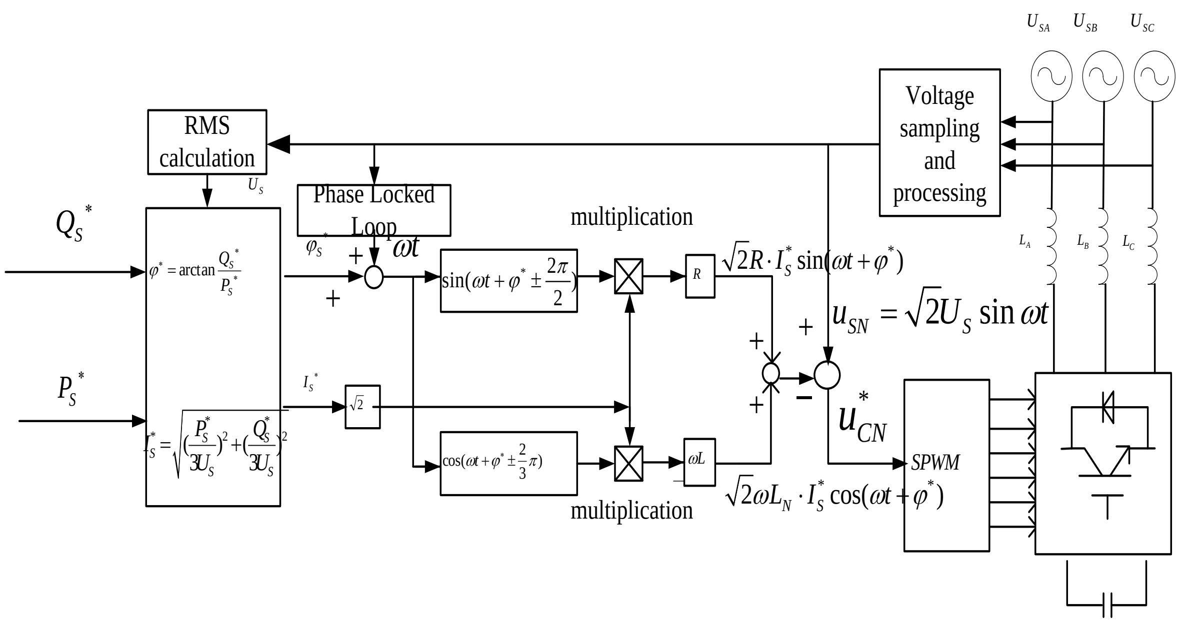

Fig 3 Control strategy for grid-connected converter

SIMULATION TEST

To verify the validity of the converter control strategy mentioned above, a grid-connected converter controlled by this strategy is simulated by Matlab/Simulink software that is shown in Fig. 3.

Simulation conditions are as follows: DC voltage is 800V; single-phase grid voltage is 220V; AC circuit resistance is0.5Ω; AC circuit inductance is 2.5mF; switching frequency is 6 kHz.

Due to symmetry of three-phase system, output voltages of 3 phases are similar, so the simulation result is shown by the voltage and current of one single-phase. Fig. 4 shows two-way active current absorbed by the grid-connected converter; Fig.5 shows two-way active current together with

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Scientific Journal Impact Factor: 3.449
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reactive current absorbed by the grid-connected converter.

Simulation results indicate that grid-connected converter can quickly and efficiently track the active power and reactive power commands.

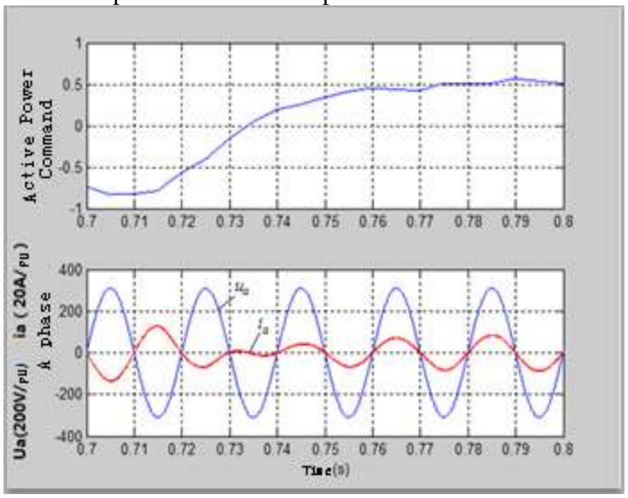

Fig.4 Two-way active power

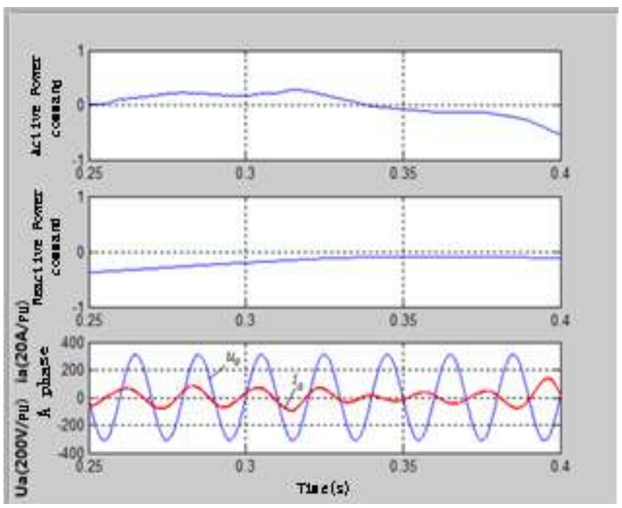

Fig.5 Active power together with reactive power

CONCLUSION

The paper analyzes vector relation of grid voltage, converter voltage and line impedance voltage and researches control strategy based on this voltage relationship. The simulation results show that the control strategy can dynamically adjust bidirectional active and reactive power.

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