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The Application of Stationary VOC-PR with PLL for Grid side Converter-based Wind Power Generation System

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Abstract—Voltage oriented control PR is combined with space vector modulation and phase locked loop to control the grid side converter in wind power generation system in this paper. First the mathematical models of grid side converter and LCL filter as well as grid are given. Then the control strategy of grid side converter-based wind power generation system is given in detail. Finally the simulation model consisting of the grid side converter wind power generation system is set up. The simulation results have verified that the control strategy is feasible to be used for control of grid currents, active power, reactive power and DC-link voltage in wind power generation system. It has laid a good basis for the real system development.

Keywords—Grid side converter; proportional resonant converter; space vector modulation; voltage oriented control; phase locked loop

I. INTRODUCTION

Wind power generation is researched and developed very well by many countries in the world as a valuable sustainable energy resource. And people have gotten lots of achievements with their great efforts^[1-9, 11]. It is well known that the wind power generation system with back to back converter is very complex. Therefore the grid side converter-based wind power generation system is only studied in this paper. Its simplified structure is shown in Fig. 1. Where the ‘VOC’ is voltage oriented control, PR is proportional and resonant regulator, PLL is the three-phase locked loop, V_d , V_d^* are the measured and reference values of DC-link voltage respectively, P^* , Q^* is reference values of active and reactive power respectively, i_A , i_B and i_C are three-phase grid currents respectively, similarly v_A , v_B and v_C are three-phase grid voltages respectively, S_A , S_B and S_C are the switching signals of three upper bridges of grid side converter respectively, the three ones of three lower bridges are compensated for on or off in each bridge. The following first describes the mathematical models of each part shown in Fig. 1. Then simulation model of the total system is set up based on the simulation models of various parts and gives corresponding analyses.

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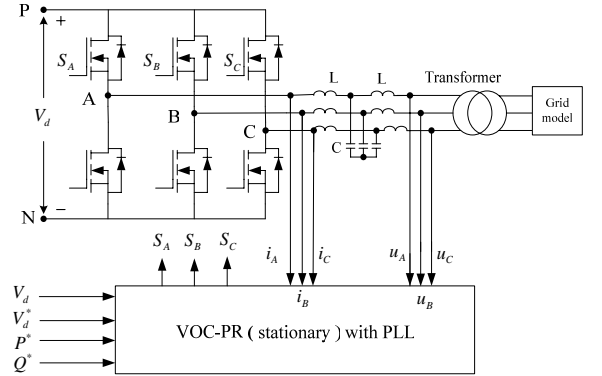


Fig. 1 The simplified diagram of the VOC-PR with PLL

II. THREE-PHASE GRID MODEL

Suppose the grid is a symmetrical three-phase power supply. So its current model can be defined as follows:

$$\begin{cases} i_a = I_m \cdot \sin(\omega t) \\ i_b = I_m \cdot \sin\left(\omega t - \frac{2\pi}{3}\right) \\ i_c = I_m \cdot \sin\left(\omega t - \frac{4\pi}{3}\right) \end{cases} \quad (1)$$

Similarly, its voltage model is defined as follows:

$$\begin{cases} u_a = U_m \cdot \sin(\omega t) \\ u_b = U_m \cdot \sin\left(\omega t - \frac{2\pi}{3}\right) \\ u_c = U_m \cdot \sin\left(\omega t - \frac{4\pi}{3}\right) \end{cases} \quad (2)$$

III. MODEL OF THE LCL FILTER

The three-phase LCL filter is used to reduce the high order harmonics at the grid side. Because of its symmetry and convenience of analysis, an equivalent single phase LCL filter is selected shown as Fig. 2^[5, 8]. Its equivalent impedance, Z_e is:

$$Z_e = \frac{Z_I Z_C}{Z_I + Z_C} + Z_G \quad (3)$$

Where $Z_I = sL_I$, $Z_C = 1/(sC_F) + R_D$, $Z_G = sL_G$.

Then

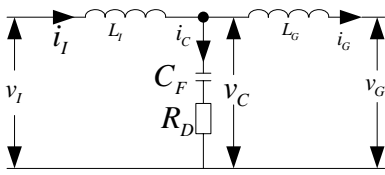
$$Z_e = \frac{s^3 L_l L_g C_F + s^2 R_D C_F (L_g + L_l) + s(L_l + L_g)}{s^2 L_l C_F + s R_D C_F} \quad (4)$$


Fig.2 The topology of LCL filter

Thus its transfer function is obtained:

$$\frac{i(s)}{v(s)} \Big|_{v_l=0} = \frac{1}{Z_e} \quad (5)$$

Substituting (4) into (5) yields

$$\frac{i(s)}{v(s)} \Big|_{v_l=0} = \frac{s^2 L_l C_F + s R_D C_F}{s^3 L_l L_g C_F + s^2 R_D C_F (L_g + L_l) + s(L_l + L_g)} \quad (6)$$

According to KVL and KCL law, the model is not difficult to be obtained as shown in Fig. 3.

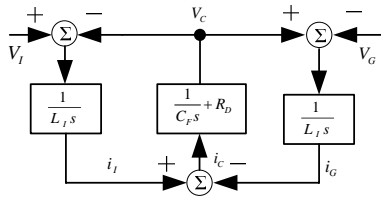


Fig. 3 The model of single phase filter

IV. MODEL OF GRID SIDE CONVERTER

The topology of grid side converter is shown in Fig.4. It has three active legs. This is the reason why one has to use three switching functions (a, b, c) to describe the control of each leg.

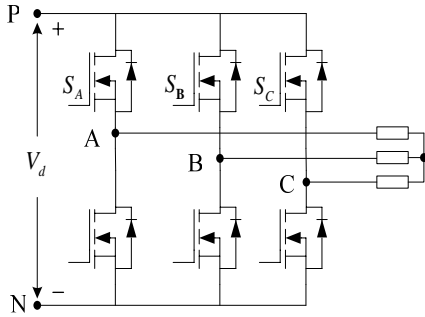


Fig. 4 The simplified topology of grid side converter

Each switching function is associated with one corresponding leg of three ones. We can show the line to neutral voltage in form of matrix equations:

$$\begin{bmatrix} v_{ao} \\ v_{bo} \\ v_{co} \end{bmatrix} = \frac{U_{DC}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_A \\ S_B \\ S_C \end{bmatrix} \quad (7)$$

Similarly, the line to line voltages are obtained:

$$\begin{bmatrix} v_{ab} \\ v_{bc} \\ v_{ca} \end{bmatrix} = U_{DC} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} S_A \\ S_B \\ S_C \end{bmatrix} \quad (8)$$

V. THE CONTROL STRATEGY OF GRID SIDE CONVERTER

Because the generator side converter is a two-level inverter it has only 8 switching states. Therefore it is simple and practical. The space vector modulation (SVM) is used for its modulation strategy so as to improve its modulation performance compared with SPWM. Here SVM is one of the preferred real time modulation techniques and is widely used for digital control of voltage source inverters. This section presents the brief principle and implementation of SVM for the two-level inverter, which is well known to people. The active and zero switching states can be represented by active and zero space vectors, respectively. A typical space vector diagram for the two-level inverter is shown in Fig.

All six active vectors can be derived as follows^[10]:

$$\vec{V}_k = \frac{2}{3} V_d e^{j(k-1)\frac{\pi}{3}}, k=1, 2, \dots, 6 \quad (9)$$

They are stationary which form a regular hexagon with 6 equal sectors in Fig 5. But the required reference vector \vec{V}_{ref} rotates in space at an angular velocity $\omega = 2\pi f_1$, where f_1 is the fundamental frequency of the output voltage. The angular displacement between \vec{V}_{ref} and the α -axis of the $\alpha - \beta$ plane can be obtained with an integral component.

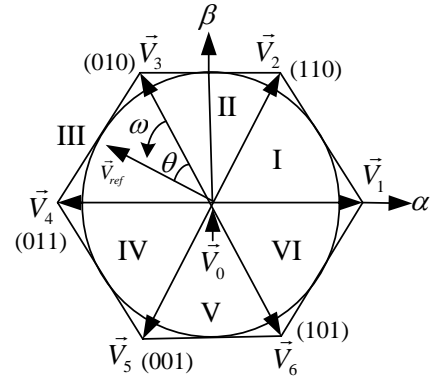


Fig. 5 The space vector diagram of 2-level inverter

According to 'volt-second balancing principle, that is, the product of the reference voltage \vec{V}_{ref} and sampling period T_s is equal to the sum of the voltage multiplied by the time interval of chosen space vectors, we can calculate the duty cycle time of corresponding vectors.

VI. GRID SYNCHRONIZATION METHOD

The output voltage phase angle of the three phase system has to follow their respective grid voltage phase angle and, as a consequence, the reference currents will be in phase to their corresponding voltages. The independent synchronization can be implemented with a PLL shown in Fig. 6^[1-2, 6-7].

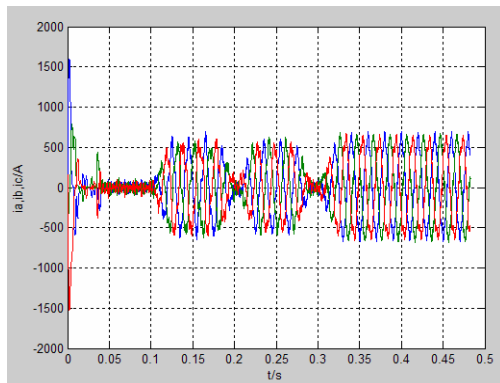


Fig. 10 Three-phase grid currents of the system

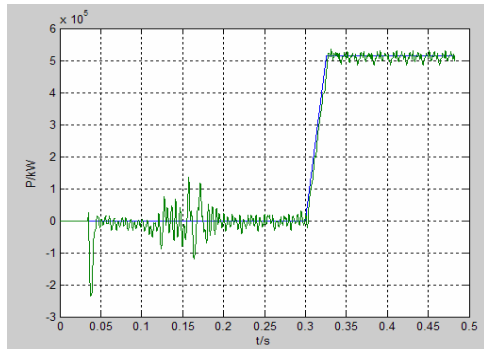


Fig.11 The reference and measure values of grid active power

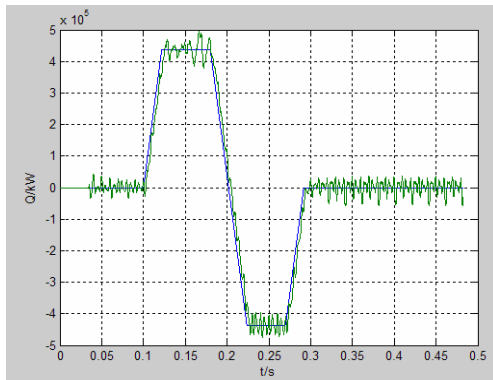


Fig.12 The reference and measure values of grid reactive power

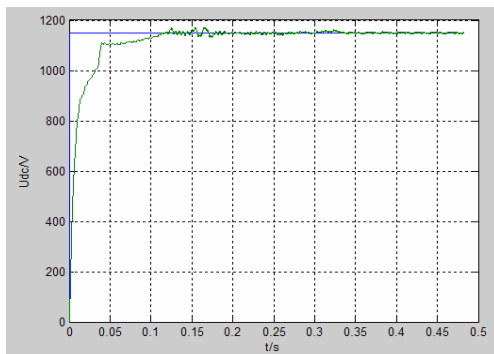


Fig.13 The reference and measure values of DC-link voltage

IX. CONCLUSION

The simulation models set up in this paper are feasible. They can control the grid currents, active power, reactive power, DC-link voltage of the wind power generation system well. It has some useful values for the further development of the wind power generation system.

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