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

Guo, Yougui; Zeng, Ping; Li, Lijuan ; Deng, Wenlang; Blaabjerg, Frede

Published in:
Proceedings of the 3rd International Conference on Power Electronics and Intelligent Transportation System, PEITS 2010

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Guo, Y., Zeng, P., Li, L., Deng, W., & Blaabjerg, F. (2010). The Application of Stationary VOC-PR with PLL for Grid side Converter-based Wind Power Generation System. In *Proceedings of the 3rd International Conference on Power Electronics and Intelligent Transportation System, PEITS 2010* IEEE Press.

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

Yougui Guo, Ping Zeng，Lijuan Li，Wenlang Deng
College of Information and Engineering
Xiangtan University
Xiangtan, China
guoygxtu@gmail.com

Frede Blaabjerg
Institute of Energy Technology
Aalborg University
Aalborg, Denmark

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 gird 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-Gride 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 word 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 gird 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.

湘潭大学项目资助（09XZX22）

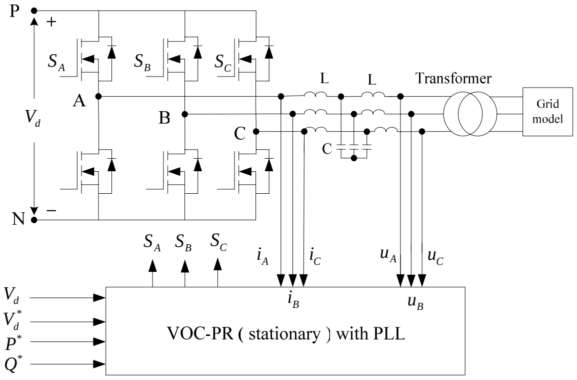

Fig .1 The simplified diagram of the VOC-PR with PLL

II. THREE-PHASE GRID MODEL

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

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

Similarly, its voltage model is defined as follows:

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

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:

$$Z_e = \frac{Z_I Z_C}{Z_I + Z_C} + Z_G \tag{3}$$

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

Then

$$Z_e = \frac{s^3 L_I L_G C_F + s^2 R_D C_F \left(L_G + L_I\right) + s\left(L_I + L_G\right)}{s^2 L_I C_F + s R_D C_F} \tag{4}$$

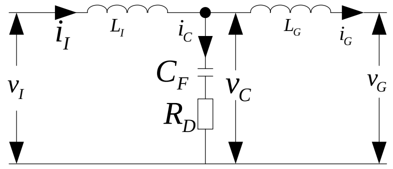

Fig.2 The topology of LCL filter

Thus its transfer function is obtained:

$$\left.\frac{i(s)}{v(s)}\right|_{v_I=0} = \frac{1}{Z_e} \tag{5}$$

Substituting (4) into (5) yields

$$\left.\frac{i(s)}{v(s)}\right|_{v_I=0} = \frac{s^2 L_I C_F + s R_D C_F}{s^3 L_I L_G C_F + s^2 R_D C_F \left(L_G + L_I\right) + s\left(L_I + L_G\right)} \tag{6}$$

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

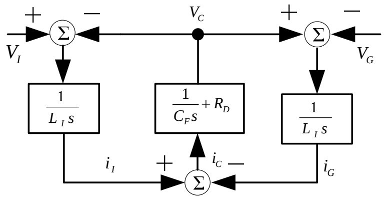

Fig. 3 The model of single phase filter

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.

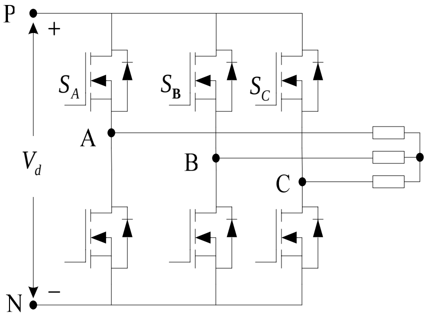

Fig. 4 The simplified topology of grid side converter

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:

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

Similarly, the line to line voltages are obtained:

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

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]:

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

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.

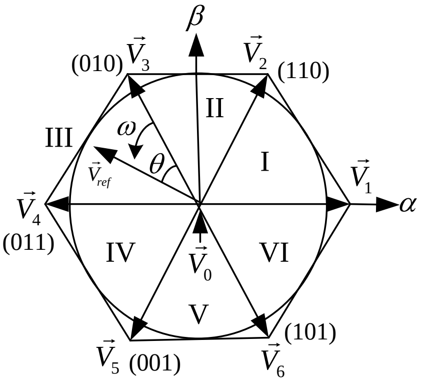

Fig. 5 The space vector diagraph of 2-level inverter

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].

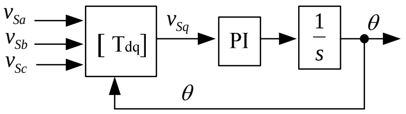

Fig. 6 The configuration of three phase PLL

Where

$$[T_{dq}] = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{4\pi}{3}\right) \end{bmatrix}$$

, $\theta = \omega t$, the same as that in (1).

VII. THE CONTROL STRATEGY OF THE TOTAL SYSTEM

The control strategy of the total system can be implemented by voltage oriented control(VOC) with proportional resonant controller and current with phase locked loop(PLL) in the stationary frame[11]. It can be obtained by following three steps. The current is oriented along the active voltage which is so-called voltage oriented control. The PLL is used to detect the line to neutral voltage angle, θ which is required for transformations of high performance vector control for induction machine. The currents and voltages are transformed from three-phase stationary frame (abc) to two-phase stationary frame ($\alpha\beta$) and their α -axis and β -axis current components are controlled with PR regulators. The standard PI controller is used to control the active power and reactive power, α -axis and β -axis voltage components, and the DC voltage of the input terminal in the grid side converter.

(1) Work out the angle of grid voltage. The three-phase grid voltages are first transformed into α -axis and β -axis voltage components, then they are calculated to obtain the angle, angle frequency and amplitude of grid voltage with PLL as shown in Fig.7.

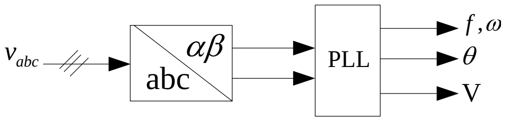

Fig.7 Calculation of gird voltage angle, frequency and amplitude

(2) Calculate the references of grid currents i_α^* and i_β^*.

Step 1, three-phase grid currents and voltages are measured by LEM current and voltage sensors respectively. Then they are transformed to fit for ADC of DSP board by the suitable interface circuit. Finally the active power and reactive power are calculated.

Step 2, the active power and reactive power are compared with their references. Then they are controlled by PI respectively. And the synchronous frame component of current reference, i_q^*.

Step 3, the DC link voltage is compared with its reference. Then the error is controlled by PI. Its output is compared with the output of PI of active power error to obtain the synchronous frame component of current reference, i_d^*.

Step 4, i_d^* and i_q^* are transformed by rotational coordinates to obtain the stationary frame components of i_α^* and i_β^*. The complete process is shown in Fig.8.

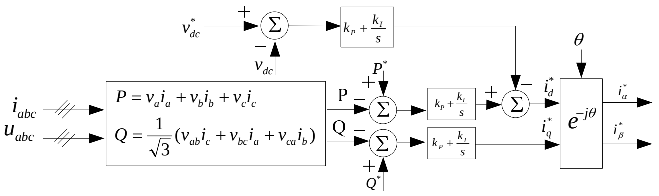

Fig.8 The calculation of current references in stationary frame

(3) Decide the switching control signals

Step 1, three-phase gird currents are transformed into two current components of stationary frame, i_α, i_β.

Step 2, i_α, i_β are compared with their references to obtain their errors respectively, then the errors are controlled by PR to obtain voltage references, v_α^*, v_β^* of two-phase stationary frame.

Step 3, v_α^*, v_β^* are used for input signals of SVM to generate upper bridge switching control signals, S_A, S_B, S_C.

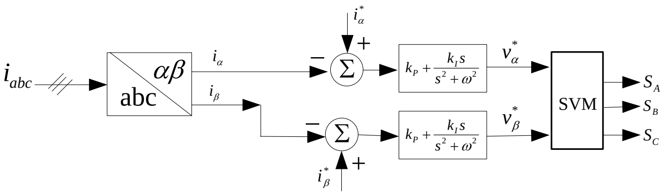

Fig. 9 The generation of control signals of grid side converter

VIII. SIMULATION ANALYSIS

Here main parameters used: Nominal grid frequency, 50Hz. Rated converter module output current, 515A. Rated grid voltage, 690V. Nominal DC-link voltage, 1050V. Grid filter capacitances, 167uF. Grid filter inductance, 0.4mH. And R_D is 2.1ohm. Switching frequency, 2.5kHz. Control frequency, 5kHz. DC-link capacitance, 18 capacitors in 6 parallel groups, each with 3 in series. Each capacitor is 450 V, 5.6 mF, equivalent total capacitance 11.2 mF.

On the basis of above discussion of several parts, simulation models are set up and measured respectively till right. Then they are connected step by step to consist of the total system. After a series of parameters are set the simulation test begins and the corresponding results are obtained shown in Fig.10-13 respectively.

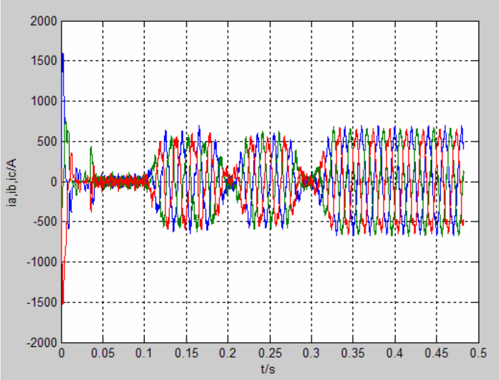

Fig. 10 Three-phase gird currents of the system

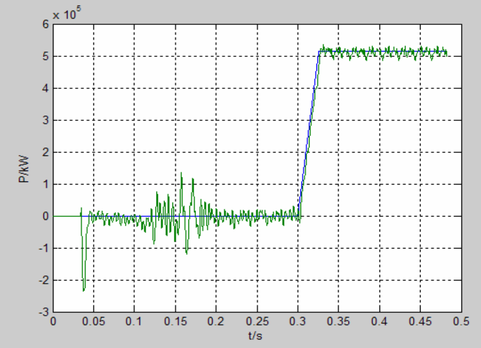

Fig.11 The reference and measure values of grid active power

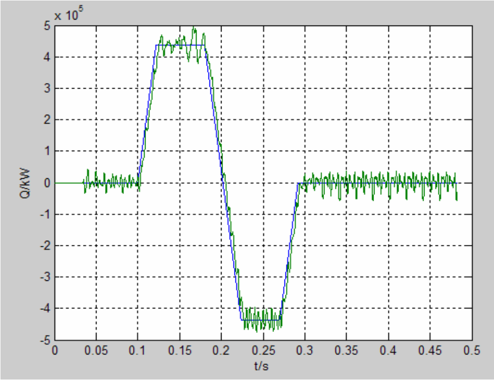

Fig.12 The reference and measure values of grid reactive power

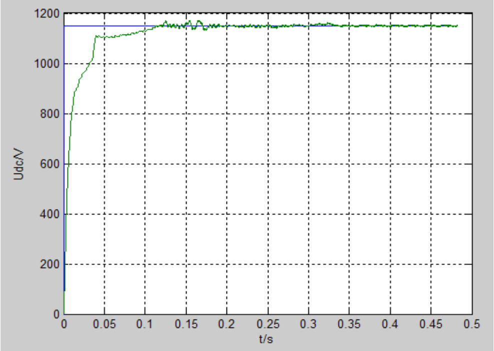

Fig.13 The reference and measure values of DC-link voltage

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.

ACKNOWLEDGMENT

I am very grateful to my contact person, professor Frede Blaabherg giving me many good opportunities and conditions while my staying in institute of energy technology, Aalborg university for one and half years.

REFERENCES

[1] Frede Blaabjerg, Remus Teodorescu, Marco Liserre, Adrian V. Timbus. Overview of Control and Grid Synchronization for Distributed Power Generation Systems. IEEE Transactions on Industrial electronics, 2006, Vol.53 No.5: 1398-1409

[2] Teodorescu, R.; Blaabjerg, F.; Liserre, M.; Rodriguez, P. PLL Algorithm for Power Generation Systems Robust to Grid Voltage Faults. Power Electronics Specialists Conference, PESC '06. 37th IEEE 18-22 June 2006 pp: 1 - 7

[3] Li W., Joos, G., Belanger J. Real-time simulation of a wind turbine generator coupled with a battery super-capacitor energy storage system. IEEE Transactions on Industrial Electronics, 2010, vol. 57, no. 4, pp. 1137-1145

[4] Bimal K.Bose, "An adaptive Hysteresis-Band Current Control Technique of a Voltage-Fed PWM Inverter For Machine Drive System", IEEE Transactions on Industrial Electronics, vol. 37, no. 5, Oct. 1990 pp. 402 - 408

[5] Liserre, M., Blaabjerg, F., Teodorescu, R. Grid Impedance Estimation via Excitation of LCL-Filter Resonance, IEEE Transactions on Industry Applications, vol. 43, no. 5, 2007 , pp. 1401 - 1407

[6] Ciobotaru, M., Teodorescu, R., Blaabjerg, F. Improved PLL structures for single-phase grid inverters. International Conference on Power Electronics and Intelligent Control for Energy Conservation, Proceedings of PELINCEC, October 2005, pp. 16-19

[7] Silva, S.M., Lopes, B.M., Filho, B.J.C., Campana, R.P., Bosventura, W.C. Performance evaluation of PLL algorithms for single phase grid-connected systems. Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE, vol. 4, Oct. 2004 pp. 2259 - 2263

[8] Erika Twining; Holmes, D.G. Grid current regulation of a three-phase voltage source inverter with an LCL input filter. IEEE Transactions on Power Electronics, vol. 18, no. 3, May 2003, pp. 888 - 895

[9] Teodorescu, R.; Blaabjerg, F. Flexible control of small wind turbines with grid failure detection operating in stand-alone and grid-connected mode. IEEE Transactions on Power Electronics, vol. 19, no. 5, Sept. 2004, pp. 1323 - 1332

[10] Bin Wu. High-Power Converters and AC Drives, IEEE press, 2006

[11] Teodorescu,R., Blaabjerg,F., Liserre.M.- Proportional-Resonant Controllers. A New Breed of Controllers Suitable for Grid-Connected Voltage-Source Converters, Proceedings of OPTIM'04, 20-21 may 2004, Brasov, vol. III pp 9-14