THE PROPORTION OF RESONANT DOUBLY-FED WIND-ENERGY GENERATION DUAL PWM CONVERTER

DUAN Yu-bo, SHEN Hong-yu, YUAN Ying-zi, XU Jian-jun, WANG Jian-ren
Northeast Petroleum University
Daqing, 163318, P.R.China
Email yuanyingzi0122@163.com

ABSTRACT
Double PWM converter is the control core of doubly-fed wind power system. The traditional control mode is at most combined with PI controller. Under the unbalanced condition of the power grid, PI control method is very difficult to guarantee control requirements. This paper used the PR (proportion resonance) control method, while the controller can guarantee the system without the static sent output and rotor side active power and reactive power decoupling control, it also saves coupling term and a feed-forward compensation, reduces the number of coordinate transformation, still can effectively reduce the power grid frequency offset influence the inductance current of the inverter output, so as to improve the control precision of the algorithm and the grid power quality. Through the simulation test and the results analysis, it verifies the feasibility and accuracy of the theory.

KEY WORDS
Doubly-fed machine; Double PWM converter; PR controller; Power decoupling

1. Introduction
VSCF wind generators have been gradually recognized for the high utilization of wind energy, its core dual-PWM converter control strategy is particularly important. The dual PWM converter can accomplish AC-DC-AC converter process in structure; and two-way flow of energy in the point of function. The traditional control method is the grid-side converter using PI double-loop control, and the rotor side converter using PI-based vector control. PI-based control methods can achieve the basic requirements of the dual-PWM converter, but in the case of grid imbalance, it is difficult to ensure the stable operation of the system. Feeblish harmonic suppression capabilities, and a series of rotating coordinate transformation control algorithm to achieve the degree of difficulty, which reduce the control precision [1-2]. In order to meet the requirement of better control, this article design the control system of grid-side and rotor-side converter through a combination of PR controller, thereby increasing the robustness of the system and the unit output power quality.

2. Optimization of the PR Controller
PR controller (the proportion of resonant controller) is constituted of proportional integral aspects, the transfer function is:

\[ G_{PR}(s) = K_p + 2K_i \frac{s}{s^2 + \omega^2} \]  \hspace{1cm} (1)

There are some problems in the practical application: the accuracy of the data and analog components in the circuit is likely limited, and the operand of control algorithm is huge, which is impossible to achieve real-time control; It can not suppress harmonics effectively when the grid frequency fluctuations occur [3]. Therefore, under the condition that it can ensure the advantages of PR control, optimizations of the PR control are put forward, the transfer function is:

\[ G(s) = K_p + 2K_i \frac{\omega s}{s^2 + 2\omega s + \omega^2} \]  \hspace{1cm} (2)

At the present time, the power of interconnected systems are getting bigger and bigger in wind power generation system, the higher the demand on the grid and wind turbine power quality. Large system disturbance mainly 3,5,7,11 inferior low-harmonic, low harmonics can cause heating of the system, the impact of unit noise and the motor torque ripple. Change the resonant frequency \( \omega \) in (2) to \( h \cdot \omega \) ( \( h = 3,5,7 \) ), we get harmonic compensation function is:

\[ G_h(s) = \frac{K_h s}{s^2 + (h \cdot \omega)^2} \]  \hspace{1cm} (3)

Harmonic responses occur near \( h \cdot \omega \), so the PR controller optimized harmonic compensation been superimposed low harmonic compensation on this basis, and when the grid voltage disturbances, positive and negative sequence harmonic compensation [4].

3. Grid-side of the PR Control System
3.1 Establishment of Mathematical Model
In order to reduce the harmonics of the circuit, the power devices uses controllable switch the IGBT. Treat rotor side converter part as a load, as a consequence, the grid
Circuit characteristics of voltage-type PWM rectifier (VSR), the DC side of the use of capacitive energy storage, so that the DC side presents a low impedance voltage source characteristic. The three-phase bridge circuit of the rectifier is more suitable for the balanced three-phase grid systems. Constitute a three-phase AC power from a three-way AC power by adjusting the parameters to achieve the desired results [5-8]. Suppose the grid EMF is three-phase symmetrical linear; the grid- side of the filter inductor is not saturated and linear. In order to represent the power switch logical values more accurately, assuming S= 1, the upper bridge arm is turned on, the lower bridge arm is turned off; when S=0, the upper bridge arm is shutdown, the lower bridge arm opening.

According to Kirchhoff’s voltage law we can get [6]:
\[
L \frac{di_a}{dt} + R i_a = u_a - (u_{dc} S_a + u_{xc})
\]

In (5), \(u_a\), \(u_b\), \(u_c\) are three-phase voltage sources; \(i_a\), \(i_b\), \(i_c\) are three-phase input current; \(i_L\) is load current; \(u_{dc}\) is output voltage of DC side; in three-phase neutral system, the summation of three-phase current is zero, and the three-phase grid voltage is nearly balance, so:
\[
\begin{align*}
  i_a + i_b + i_c &= 0 \\
  u_a + u_b + u_c &= 0
\end{align*}
\]

3.2 Control Strategy
In the dual PWM converter control system, the grid-side converter control strategy is to maintain a smooth DC voltage output and to ensure that the input power factor closes to 1 in order to get better input characteristics. Traditional control systems are mostly using PI control, the control structure shown in Figure 2.
It could be found from Figure 3, the grid-side of the three-phase alternating current flowing through coordinate transformation can get the current two-phase stationary coordinates. By comparing the feedback voltage with a
given voltage, get the reference current, then the coordinate transformation of the reference current in the two-phase stationary coordinates is obtained, after the comparison the current as the input of PR control, PR controller’s output as the input voltage of the SVPWM modulation of SVPWM after the switching signal to the converter main circuit, in order to achieve the grid-side converter control strategy.

Compared with the PI control strategy, PR control method eliminates the need for current and voltage control instructions of the coordinate transformation, also eliminates the need for coupling and feed forward compensation term, thereby reducing the impact of the external environment and line parameters on the system, and because of the PR controller's own advantage, the control accuracy of the system is higher, at the same time the harmonic suppression effect is more prominent, and more stable.

4. PR control system of the rotor side

4.1 The Basic Structure and Function of the Rotor Side Converter

The rotor side converter is the hub of the grid-side converter and the doubly-fed induction motor, the entire wind power system control is achieved through the rotor side converter. Wind energy utilization and energy conversion of the doubly-fed induction motor can be controlled by controlling the rotor side PWM converter, the inverter circuit is similar, but the result is the two-way flow of energy, the topology is shown in Figure 4.

\[
\begin{bmatrix}
& \Psi_{d} \\
\Psi_{q} \\
\end{bmatrix} = \begin{bmatrix}
-\rho & \rho & 0 & 0 & 0 & 0 \\
\rho & -\rho & 0 & 0 & 0 & 0 \\
0 & 0 & -\rho & 0 & 0 & 0 \\
0 & 0 & 0 & -\rho & 0 & 0 \\
0 & 0 & 0 & 0 & -\rho & 0 \\
0 & 0 & 0 & 0 & 0 & -\rho \\
\end{bmatrix}
\begin{bmatrix}
I_{d} \\
I_{B} \\
I_{C} \\
I_{a} \\
I_{b} \\
I_{c} \\
\end{bmatrix} + \begin{bmatrix}
\Psi_{d} \\
\Psi_{B} \\
\Psi_{C} \\
\Psi_{a} \\
\Psi_{b} \\
\Psi_{c} \\
\end{bmatrix}
\]

(7)

(2) Winding flux could be divided into self-inductance flux and mutual inductance flux, the flux equation can be expressed as:
4.3 Control Strategy

The control idea is: the frequency of the excitation current given slip frequency by controlling the excitation voltage, active and reactive power of the rotor current to be adjusted independently. The wind velocity is the randomness and uncertainty, making the rotor current frequency constantly change, which produces the slip frequency. PR controller could adjust AC signal without static error adjustment, which does not only make the resonant frequency and slip frequency of equal size, but also achieve the adaptive adjustment of rotor current. Figure 5 is a control block diagram of the PR control strategy of rotor side converter.

PR control block diagram shows that the PR control strategy eliminates the need of feed forward compensation under the PI control and two coordinate transformation.

When the fluctuation of the grid voltage occurs, PR control could optimize the shortcomings of stator flux oriented vector usefully. PR control solves the problem of low rotor side control precision; the effect of low harmonic suppression has also been improved, which enhances the robustness of the system.

5. Experimental results and analysis

5.1 The Grid-side Converter Analysis

In order to verify the correctness and feasibility of the grid-side of the control strategy, according to the analysis of the mathematics model of the grid-side converter we established the system under Simulink blocks of the simulation model. The system simulation parameters: the grid voltage is 380V; the grid frequency is 50HZ; capacitance of grid-side is 0.2; inductance of grid-side is 5mH; load resistance is 50; DC bus capacitor is 1.1mF, DC bus back EMF is 600V; scale factor of voltage regulator is 0.14; integral coefficient of voltage regulator is 7.5; scale factor of current regulator is 8.1; integral coefficient of current regulator is 0.7845.

Figure 6 shows the waveform of grid-side converter power grid voltage and current in the PR control strategy when the generator is running in the synchronous state and over synchronous state. It can be seen, grid-side converter working in rectifying state when generator works in the synchronization condition; while, in the...
synchronization condition, converter working in inverter state, which realizes the functions of almost undistorted sinusoidal current.

(a) Generator sub-synchronous operation

(b) Generator super-synchronous operation

Figure 6. PR control the net side of the grid voltage and input current waveform

Figure 7. PI control strategy under the DC bus voltage

Figure 8. PR control strategy under the DC bus voltage

Through the contrast of figure 7 and figure 8 we can obtain that a given current have step change, DC bus voltage did not produce big changes and be more stable in 0.02 seconds. DC bus voltage fluctuate smaller than in a PI control and play a harmonic control function in figure 8, which realize DC characteristics very well.

5.2 The Rotor-side Converter Analysis

Rotor-side PWM converter simulation data: the wind turbine is rated at 2.3kW, wind turbine radius is 2.5m, the gear ratio is 8.2, the wind maximum utilization factor is 0.44; double-fed motor star-delta connection, the number of pole pairs is 2, stator rated voltage is 220V, the resistance of the stator side is 0.445 $\Omega$, the inductance of the stator is 2mH; rotor side resistance 0.824 $\Omega$, rotor inductance 2mH; mutual inductance is 69.42mH.

(a) Stator three-phase current waveform

(b) Rotor speed waveform

(c) Stator active power waveforms

(d) Stator reactive power waveforms

Figure 9. The rotor side of the PR control system simulation results

In figure 9, after the rotor PWM converter side simulation stably operates, the stator current amplitude is about 1.2A, the speed in 1400r/min, stator active power of 1070W and the reactive power of 300W. The wind speed changes at
the time of 0.1 second, the motor speed by 1400 RPM increases to 1600r/min, the stator current amplitude also increases to 3A, active power mutates and continues to increase to 1550w for stable, the reactive power is stable. The results after the motor disturbance indicate that the motor can get the maximum wind and adjust the speed. The amplitude of the stator current has a corresponding change, but the stator is in frequency 50 Hz and the output wave form is stable, realizing the variable speed constant frequency. When perturbed, the active power of stator current responses quickly, and the reactive power is stable, so that the system operation well.

6. Conclusion

In order to improve the function of PI controller in the double PWM converter, the paper brings into the proportion resonance controller. Through the analysis and simulation we prove that the control strategy of the PR double PWM converter is correct, and realizes that the unit power factor operates and stably output. In the rotor side, it achieves the state output, the maximum wind power of capture, active power and reactive power independent regulation. At the same time, it reduces the double PWM converter harmonic content, which improves the precision of system control and the quality of grid power.

References