Control Strategy of Total Output Power Ripple Cancellation for DFIG in MV Wind Power Systems under Unbalanced Grid Conditions

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ABSTRACT

This paper proposes a control strategy of total output power ripple cancellation for both of Machine-Side Converter (MSC) and Grid-Side Converter (GSC) in a DFIG under unbalanced grid conditions. The proposed control strategy for the MSC is the zero torque ripple control algorithm with an enhanced LVRT capability. The control algorithm for the MSC exhibits reduced torque pulsation in steady-state unbalanced grid conditions. In addition, this control algorithm also minimizes a peak value of rotor current in transient unbalanced grid conditions. The total output power ripple cancellation control algorithm is adopted in the GSC. The total output power ripple cancellation is achieved by nullifying the oscillating component of the total output active and reactive power at the summing point of stator and rotor of DFIG. The proposed control strategy for the GSC reduces the output power oscillation leading to the improved quality of wind farms output.

1. Introduction

Wind power installation has been increasing both in number and size of individual wind turbine unit. Doubly Fed Induction Generator (DFIG) is widely used as wind generator due to its economic requirement of power converter in rotor side. The structure of DFIG wind power system with a back-to-back three-level NPC voltage source converter is described in Fig. 1. Because of the direct connection between the stator and grid, the unbalanced grid voltage causes unbalanced stator currents. The unbalanced currents generate unequal heating of the stator windings and oscillations of torque resulting in a mechanical stress on the drive train as well as adverse acoustic noise [1]. Asymmetrical voltage sag of grid, which can also be regarded as an unbalanced input, often gives a rise to transient overshoot of rotor currents leading to the degraded capability of low voltage ride-through (LVRT).

Control of the Machine Side Converter (MSC) in DFIG wind power system with a back-to-back converter to reduce torque pulsation by compensating the rotor current under unbalanced grid voltage has been studied in past few years. Control method to reduce torque pulsation and rotor current harmonics by compensating negative sequence components utilizing either GSC or MSC was developed in [2]. In [3], control methods to eliminate pulsations of torque using MSC and to compensate oscillation of active and reactive power of stator were presented.

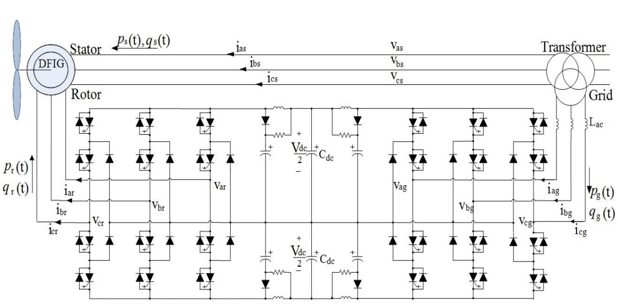

Fig 1 Overall scheme of DFIG wind turbine with a back-to-back three-level NPC voltage-source converter

The control methods of the Grid Side Converter (GSC) under unbalanced input supply have been also investigated in past few years. In [4], Suh and Lipo have proposed a method to directly control the instantaneous active power at the poles of the rectifier. The control method to set the zero negative-sequence current of GSC has been studied in [5]. In [6], control methods to compensate oscillation of active and reactive power of GSC output were presented. However, the coordinate control of both MSC and GSC to achieve more stable operation of DFIG has not been paid attention. Very little works dealing with the control strategy by using both of MSC and GSC in a DFIG to achieve more stable operation can be found in previous literatures.

In this paper, a grid unbalanced compensating control strategy for both of MSC and GSC is proposed for the medium-voltage DFIG wind power system of MW range equipped with a back-to-back three-level neutral-point clamped voltage-source converter. The problems generated by unbalanced grid conditions such as over current of rotor and total active and reactive power ripples are evaluated. Using the control targets addressed in [4], the performance factors of Low Voltage Ride-Through (LVRT) capability and instantaneous active power pulsation are investigated. The coordinate control of both MSC and GSC to achieve the total output power ripple cancellation for DFIG is implemented and its performance is verified through simulation.

2. Control strategy for the MSC

The control algorithm for the MSC to be considered in this paper is zero torque ripple control algorithm with an enhanced LVRT capability. The control algorithm is based on two control algorithms, the zero torque ripple control algorithm and the zero negative-sequence rotor current control algorithm.

The output torque (T_{em}) is obtained from the electromagnetic output power, P_{em}. P_{em} is directly calculated from the energy conversion term of total output power (p_e).

$$p_e(t) = -\frac{3}{2} Re\{V_{dq}^{s} I_{dqs}^{s*}\} - \frac{3}{2} Re\{V_{dq}^{s} I_{dqr}^{s*}\} \tag{1}$$

The zero torque ripple control algorithm is designed to minimize the ripple of torque at the shaft of wind turbine as shown in (2). The positive and negative sequential components of rotor current can be calculated from four control targets based on (3).

$$P_{ems2} = 0, \; P_{emc2} = 0 \tag{2}$$

$$\begin{bmatrix} P_{em0} \\ \hat{Q}_{so} \\ P_{ems2} \\ P_{emc2} \end{bmatrix} = \frac{3L_m\omega_r}{2L_s\omega} \begin{bmatrix} V_d^p & V_q^p & -V_d^n & -V_q^n \\ \frac{\omega}{\omega_r}V_q^p & -\frac{\omega}{\omega_r}V_d^p & -\frac{\omega}{\omega_r}V_q^n & \frac{\omega}{\omega_r}V_d^n \\ -V_q^n & V_d^n & -V_q^p & V_d^p \\ -V_d^n & -V_q^n & V_d^p & V_q^p \end{bmatrix} \begin{bmatrix} I_{dr}^p \\ I_{qr}^p \\ I_{dr}^n \\ I_{qr}^n \end{bmatrix} \tag{3}$$

The zero negative-sequence rotor current control algorithm is designed to the zero magnitude of negative-sequence rotor current. The positive and negative sequential components of rotor current can be calculated from four control targets based on (4).

$$I_{dr}^{n} = 0, \; I_{qr}^{n} = 0 \tag{4}$$

$$\begin{bmatrix} P_{em0} \\ \hat{Q}_{so} \end{bmatrix} = \frac{3L_m\omega_r}{2L_s\omega} \begin{bmatrix} V_d^p & V_q^p \\ \frac{\omega}{\omega_r}V_q^p - \frac{\omega}{\omega_r}V_d^p \end{bmatrix} \begin{bmatrix} I_{dr}^p \\ I_{qr}^p \end{bmatrix} \quad (5)$$

The proposed control strategy is considered in the zero torque ripple control algorithm with an enhanced LVRT capability for the MSC. Under the relatively shallow grid unbalance condition, i.e. below 10% voltage drop condition, the zero torque ripple control algorithm is adopted in order to minimize torque ripple and current harmonics in a longer time span. As the grid unbalance condition becomes severe, i.e. upper 10% voltage drop condition, the zero negative-sequence current control algorithm is chosen due to its superior performance regarding LVRT capability.

3. Control strategy for the GSC

The instantaneous total output active power is obtained by taking the real part of the complex power [4].

$$p_t(t) = Re\{S_t\} = (P_{so}+P_{go}) + (P_{ss2}+P_{gs2})sin(2\omega t) + (P_{sc2}+P_{gc2})cos\,(2\omega t) \quad (6)$$

The instantaneous total output reactive power can be developed based on a set of voltages lagging the input voltages by 90˚ [4]. A complex quantity, T_t referred as a quadrature complex power is defined and given in (7). The instantaneous output reactive power $q_t(t)$ is equivalent to the real part of T_t [4].

$$T_t = \frac{3}{2}V_{dq}^{s\,'}I_{dq}^{s*} = -\frac{3}{2}(-je^{j\omega t}V_{dq}^{p} + je^{-j\omega t}V_{dq}^{n})\{e^{j\omega t}(I_{dqs}^{p} + I_{dqg}^{p}) + e^{-j\omega t}(I_{dqs}^{p} + I_{dqg}^{p})\}^* \quad (7)$$

$$q_t(t) = Re\{T_t\} = (Q_{so}+Q_{go}) + (Q_{ss2}+Q_{gs2})sin(2\omega t) + (Q_{sc2}+Q_{gc2})cos(2\omega t) \quad (8)$$

In this paper, the total output power cancellation control algorithm is achieved by nullifying oscillating components of the instantaneous total output active power as shown in (9).

$$P_{ts2} = 0,\; P_{tc2} = 0 \quad (9)$$

The four reference current values are calculated by using in (10).

$$\begin{bmatrix} P_{to} \\ Q_{to} \\ P_{ts2} \\ P_{tc2} \end{bmatrix} = \frac{3}{2} \begin{bmatrix} V_d^p & V_q^p & V_d^n & V_q^n \\ V_q^p & -V_d^p & -V_q^n & V_d^n \\ V_q^n & -V_d^n & -V_q^p & V_d^p \\ V_d^n & V_q^n & V_d^p & V_q^p \end{bmatrix} \begin{bmatrix} I_{ds}^p + I_{dg}^p \\ I_{qs}^p + I_{qg}^p \\ I_{ds}^n + I_{dg}^n \\ I_{qs}^n + I_{qg}^n \end{bmatrix} \quad (10)$$

4. Comparison of Control Strategy

In order to investigate the performance of the proposed control strategy, simulation is made based on the operating condition specified in Table I. The transient rotor currents for the case of the zero torque ripple control algorithm and the zero torque ripple control algorithm with an enhanced LVRT capability in the MSC are illustrated in Fig. 2, respectively. The proposed algorithm of the zero torque ripple control algorithm with an enhanced LVRT capability generates the less peak value (2540 A) of rotor current as compared to the case of the zero torque ripple control algorithm (2712 A).

TABLE I
Parameters of DFIG Wind Power System

Parameter	Value	Parameter	Value
Rated power(MW)	1 5	Stator resistance(mΩ)	1 4
Rated voltage(line)(V)	575	Rotor resistance(mΩ)	0 992
Frequency(Hz)	60	Stator leakage inductance(μH)	89 98
Inertia(kg m^2)	25	Rotor leakage inductance(μH)	82 09
Pole pairs	2	Magnetizing inductance(mH)	1 53
Rated wind speed(m/s)	12	DC link capacitance(mF)	76

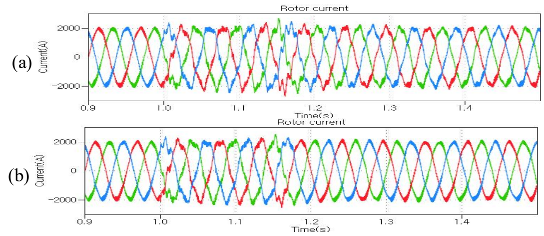

Fig 2 Transient rotor current (IF 1 7% to 20% at t=1 0s and 20% to 1 7% at t=1 15s) (a) Zero torque ripple control algorithm (b) Zero torque ripple control algorithm with an enhanced LVRT capability

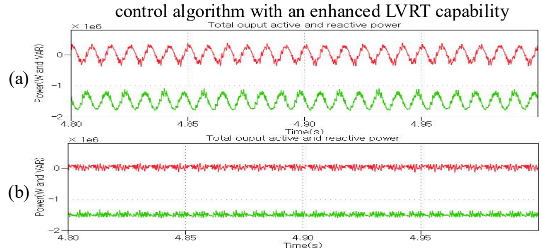

Fig 3 Active and reactive instantaneous power of total output (IF=11%) (a) Ripple-free grid-side power control algorithm (b) Total output power ripple cancellation control algorithm

Also, for the performance of the GSC control algorithm, the ripple-free grid-side power control algorithm is adopted. The instantaneous total output active and reactive power of the two control algorithms are illustrated in Fig. 3, respectively. The proposed algorithm of output power ripple cancellation control algorithm generates the less value (10 kW) as compared to the case of ripple-free grid-side power control algorithm (264 kW).

5. Conclusion

This paper investigates imbalance compensating control strategy for a doubly fed induction wind generator employing a back-to-back three-level NPC voltage-source converter. The zero torque ripple control algorithm with an enhanced LVRT capability exhibits the reduced transient peak of rotor current, i.e. peak of rotor current is reduced by 6% as compared to the conventional techniques. The proposed control strategy for the MSC can also reduce mechanical vibration with a minimized transient rotor current. The coordinate control strategy for both MSC and GSC adopts the total output power ripple cancellation control algorithm. The total output power ripple cancellation control algorithm surpasses the conventional ripple-free grid-side power control algorithm regarding total active power pulsation. The proposed control strategy for the GSC can reduce the output power oscillation to improve quality of wind farms output.

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government (MSIP) (No 2010-0028509) & (No 2014R1A2A1A11053678)

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