A Comparison of Control Algorithms for a Doubly Fed Induction Generator in Medium-voltage Wind Power System under Unbalanced Conditions

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Abstract

This paper investigates control algorithms for a doubly fed induction generator (DFIG) with back-to-back converter in medium-voltage wind power system under unbalanced grid conditions. Operation of DFIG under unbalanced grid conditions causes several problems such as overcurrent, unbalanced currents, active power pulsation and torque pulsation. Three different control algorithms to compensate for the unbalanced conditions have been investigated with respect to four performance factors; fault ride-through capability, efficiency, harmonic distortions and torque pulsation. The control algorithm having zero amplitude of negative sequence current shows the most cost-effective performance concerning fault ride-through capability and efficiency. The control algorithm for nullifying the oscillating component of the instantaneous active power generates least harmonic distortions. Combination of these two control algorithms depending on the operating requirements presents most optimized performance factors under the generalized unbalanced operating conditions.

1. Introduction

Most wind farms employ a doubly fed induction generator with variable wind speed turbines. The structure of DFIG wind power is described in Figure 1. Due to 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 and output power. These pulsations can produce a mechanical stress on the drive train and gearbox as well as a source of acoustic noise [1].

Previous literatures on the control method of the DFIG wind power system with back-to-back converter have been investigated to eliminate the oscillations generated as unbalanced grid conditions in past few years. In [2], Suh and Lipo have proposed a method to directly control the instantaneous active power at the poles of the grid side converter. Control of the machine side converter (MSC) to reduce torque pulsation by compensating the rotor current under unbalanced supply grid voltage was investigated in [3]. In [4-6], control method to eliminate pulsations of torque with MSC and to compensate oscillation of active power at stator into grid by grid side converter (GSC) was presented.

In this paper, three different unbalance compensating control algorithms are compared for the medium-voltage wind power system using DFIG having a three-level neutral-point clamped voltage source converter. Using the control laws addressed in [2] and [7], the key performance factors of fault ride-through capability, efficiency, harmonic distortions and torque pulsation are investigated with respect to each control algorithm. The harmonic distortion of stator currents is studied under the condition of relatively low switching frequency. The cost-effective and most-optimized control algorithm suitable for DFIG in medium-voltage wind power system is proposed.

2. Dynamic model and control algorithms of converter under unbalanced conditions

2.1 Active and reactive power

The active and reactive power of stator can be controlled by regulated rotor current represented by q and d axis components respectively.

$$P_s = -\frac{3}{2}\left(\frac{L_m}{L_{ls}+L_m}\right)v_{qs}^e\ i_{qr}^e \tag{1}$$

$$Q_s = \frac{3}{2}\left(\frac{(v_{qs}^e)^2}{\omega_e(L_{ls}+L_m)}\right) - \frac{3}{2}\left(\frac{L_m}{L_{ls}+L_m}\right)v_{qs}^e\ i_{dr}^e \tag{2}$$

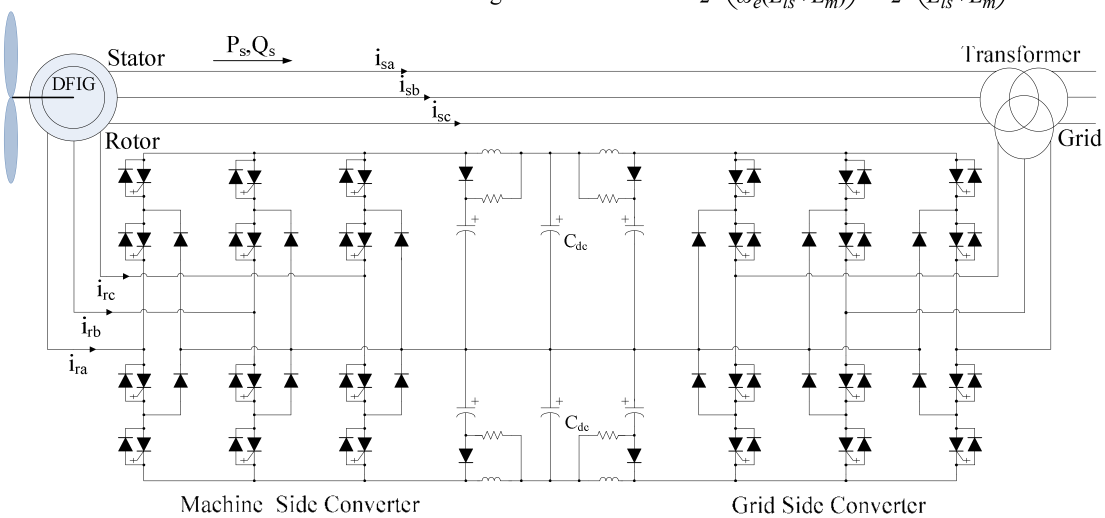

Fig. 1 Overall scheme of DFIG wind power systems with three-level neutral-point clamped voltage source converter

The instantaneous output active power of stator is obtained by taking the real part of the complex power [7].

$$P_s = P_{so} + P_{sc2} cos(2\omega_e t) + P_{ss2} sin(2\omega_e t) \qquad (3)$$

The instantaneous output reactive power, T_s, can be developed based on a set of voltages lagging the pole voltages by 90° [4] and [10]. The instantaneous output reactive power $q_s(t)$ is equivalent to the real part of quadrature complex power T_s.

$$q_s(t) = Real\{T_s\} = \text{Real}\{\frac{3}{2} v_{dqs}^{s\,\prime} i_{dqs}^{s*}\}$$
$$= Q_{so} + Q_{sc2} cos(2\omega_e t) + Q_{ss2} sin(2\omega_e t) \qquad (4)$$

2.2 Machine side converter control

To reduce oscillations of stator active power, the MSC is controlled by applying the three different control algorithms in [8].

Ripple-free control algorithm (control algorithm 1) is achieved by setting both of P_{sc2} and P_{ss2} to zero thereby nullifying the oscillating components of the instantaneous output active power of stator as shown in the followings.

$$P_{sc2} = 0 \;\Rightarrow\; f_1(i_{dr}^p,\ i_{qr}^p,\ i_{dr}^n,\ i_{qr}^n) = 0 \qquad (5)$$

$$P_{ss2} = 0 \;\Rightarrow\; f_2(i_{dr}^p,\ i_{qr}^p,\ i_{dr}^n,\ i_{qr}^n) = 0 \qquad (6)$$

Zero negative sequence of output current algorithm (control algorithm 2) is similar to the control algorithm 1 except that the negative sequence components of output current(i_{dr}^n and i_{qr}^n) are set to zero values as shown in (7).

$$i_{dr}^n = 0,\ i_{qr}^n = 0 \qquad (7)$$

In the single-frame control algorithm (control algorithm 3), the three-phase switching modulation functions of converter (s_a, s_b and s_c) are set to be balanced in a single-frame controller as $v_{dr}^n = 0$, $v_{qr}^n = 0$. This means that the negative sequence components of output current (i_{dr}^n and i_{qr}^n) cannot be regulated thereby resulting in uncontrolled values.

2.3 Grid side converter control

The control objective of the GSC is to keep dc link voltage and terminal voltage constant. The proposed method is control algorithm 1 that outperforms the other two regarding harmonic distortion factor [8].

3. Comparison of three control algorithms

Three different control algorithms compensating for output active and reactive power of stator and torque pulsation under unbalanced conditions are compared in four aspects. The simulation is made based on the operating condition specified in Table I.

TABLE I
PARAMETERS OF DFIG WIND POWER SYSTEM

Parameter	Values	Parameter	Values
Rated power (MW)	1.5	Stator resistance (mΩ)	14
Frequency (Hz)	50	Rotor resistance (mΩ)	0.992
Rated voltage(V)	575	Stator leakage inductance (μH)	89.98
Rotor leakage inductance (μH)	82.09	Magnetizing inductance (mH)	1.53
Rated wind speed(m/s)	12	DC link capacitance (mF)	76
Stator/Rotor turn ratio	1	Inertia (kg.m)	5

Figure 2 summarizes the variation of peak maximum rotor current depending on the depth of grid unbalance. It is noted that the control algorithm 2 is favored as having the smallest amplitude of peak rotor current flowing into machine side converter. This is because the negative sequence component of rotor current is regulated to be zero in control algorithm 2. The major loss components of voltage source converter are the losses in IGCTs and fast diodes in Figure 1. Control algorithm 2 also outperforms the other two methods in the graph. The simulation result regarding the harmonic distortion presents the fact that control algorithm 1 generates the least amount of harmonic distortions in both rotor current and dc link voltage.

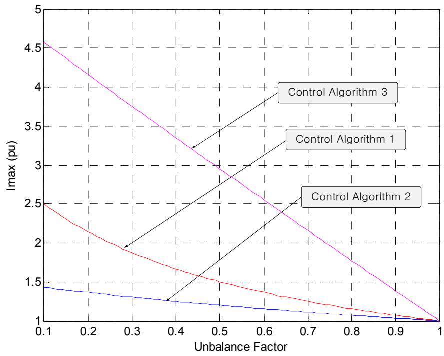

Fig. 2 Comparison of maximum amplitude of ac rotor current

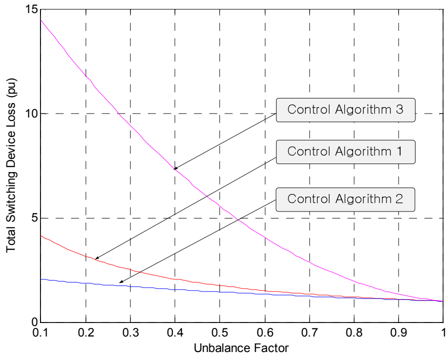

Fig. 3 Comparison of total switch & diode loss

4. Conclusion

In this paper, three control algorithms that reduce the oscillations generated under unbalanced conditions have been investigated with respect to fault-ride through capability, efficiency, harmonic distortions and torque pulsation in medium-voltage wind power system. In simulation results, control algorithm 2 shows the most optimized and cost-effective performance regarding fault ride-through capability and efficiency aspects. The control algorithm 1 outperforms the other two regarding harmonic distortion factor. By combining control algorithm 1 and 2, four factors such as fault ride-through capability, efficiency, harmonic distortion and torque pulsation can be improved under the generalized unbalanced operating conditions.

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