Implementation of Grid Connection of DFIG for Wind Power Generation System

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Abstract - This paper presents an overall control algorithm for a grid-connected wind-power generation system using a DFIG(doubly-fed induction generator) fed by back-to-back PWM converters. The control of DFIG is based on a stator-flux oriented vector control. The system enables not only fast and smooth synchronization but also high performance regulation of active and reactive power. Experimental results shows the feasibility of the control algorithm.

1. Introduction

In recent years there has been a widespread growth in wind energy conversion systems connected to the utility grid in various parts of the world, and as the ratings of these systems are getting higher, some problems with constant speed wind turbine concepts may occur, which might make other alternatives, as the variable speed wind generating systems with adjustable speed generators more attractive [1]. The configurations of variable speed generation that employ a doubly fed induction generator with a four quadrant ac-to-ac converter connected to the rotor windings, present noticeable advantages such as the decoupled control of active and reactive power of the generator, the improvement of system efficiency and the fact that the rotor power converter only needs to handle a fraction (25-30%) of the total power to achieve full control of the generator [2]. The DFIG can be operated with a comparatively large slip range, which allows better use of the available wind energy.

This paper deals with the implementation of a variable speed DFIG system using back-to-back PWM converters for wind turbine, which includes the stator-flux oriented vector control of DFIG, maximum power point tracking control(MPPT) and control strategy for active and reactive stator power. Also, a novel algorithm for soft synchronizing DFIG to the grid. has been proposed. Experimental studies were carried out using a 3kW DFIG system. The results under various operating conditions are presented.

2. DFIG System Control

A schematic diagram of the overall system is shown in Fig. 1. Back-to-back PWM converters are connected between the DFIG rotor and the grid utility.

The DFIG is controlled in a rotating d-q reference frame, with d-axis oriented along the stator-flux vector direction as shown in Fig. 2. For the stable control of the active and reactive power, it is necessary to control them independently. The stator active and reactive power of DFIG are controlled by regulating the current of the rotor windings. Therefore the rotor current needs to be divided into components related to the stator active and reactive power.

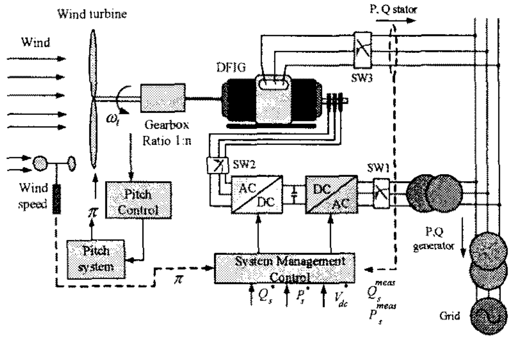

Fig. 1 Basic configuration of DFIG wind turbine system

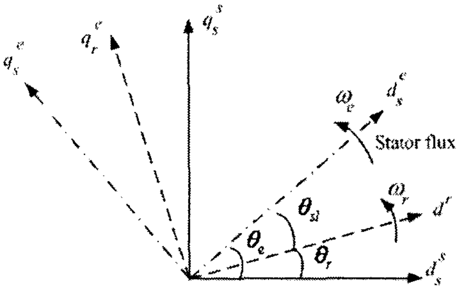

Fig. 2 Vector diagram for stator flux-oriented control

The flux linkages of the stator and rotor in case of vector control are expressed as [3], [4]:

$$\lambda_{ds} = L_m i_{ms} = L_s i_{ds} + L_m i_{dr} \tag{1}$$

$$\lambda_{qs} = 0 \tag{2}$$

$$\lambda_{dr} = \frac{L_m^2}{L_s} i_{ms} + \sigma L_r i_{dr} \tag{3}$$

$$\lambda_{qr} = \sigma L_r i_{qr} \tag{4}$$

where $\sigma = 1 - \frac{L_m^2}{L_r L_s}$

L_m: magnetizing inductance;
L_s, L_r: stator and rotor self-inductances;
λ_{ds}, λ_{qs}: stator d-q flux linkage;
λ_{dr}, λ_{qr}: rotor d -q flux linkage;

i_{ms}, i_{ds}, i_{dr}: magnetizing, stator and rotor d-axis currents.

The stator flux angle θ_s is calculated from

$$\theta_s = \tan^{-1}\left(\frac{\lambda_{qs}^s}{\lambda_{ds}^s}\right) \tag{5}$$

where

$$\lambda_{ds}^s = \int (v_{ds}^s - R_s i_{ds}^s)dt \tag{6}$$

$$\lambda_{qs}^s = \int (v_{qs}^s - R_s i_{qs}^s)dt \tag{7}$$

From (1)-(4), a relationship between the rotor and stator currents can be expressed as

$$i_{qs} = -\frac{L_s}{L_m} i_{qr} \tag{8}$$

$$i_{ds} = \frac{\lambda_{ds}}{L_s} - \frac{L_m}{L_s} i_{dr} \tag{9}$$

Then, stator active and reactive power are calculated as

$$P_s = \frac{3}{2}(v_{qs}i_{qs} + v_{ds}i_{ds}) = -\frac{3}{2}\frac{L_m}{L_s} v_{qs} i_{qr} \tag{10}$$

$$Q_s = \frac{3}{2}(v_{qs}i_{ds} + v_{ds}i_{qs}) = \frac{3}{2}\frac{L_m}{L_s} v_{qs}(i_{ms} - i_{dr}) \tag{11}$$

It is noticeable that the stator active and reactive power components are proportional to the i_{qr} and i_{dr}, respectively. For independent control of active and reactive power, each reference value is set to the optimum operating values. Then the reference currents of i_{qr}^* and i_{dr}^* can be calculated from (10) and (11) respectively.

Fig. 3 shows the configuration of the DFIG wind turbine system and its simplified control block diagram.

The function of the grid-side converter is to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power [4]. If a vector-control method is applied, with a reference frame oriented along the grid voltage vector position, an independent control of the active and reactive power for the grid-side is possible.

3. Synchronization of DFIG to Utility Grid

The synchronization control process can be accomplished by controlling the turbine pitch angle and the generator d-q axis currents. By controlling the rotor d-axis current, the magnitude of the stator EMF can be adjusted equal to the grid voltage. The rotor q-axis reference current is set to zero since the generator is at no-load. In the synchronization control block in Fig. 3, the stator q-axis voltage is compared with the grid voltage and the error value is controlled using PI controllers until the two values become equal. To compensate for any phase difference between the stator EMF and grid voltage, the compensation component $\delta\theta_{sl}$ is added to the calculated slip angle [5].

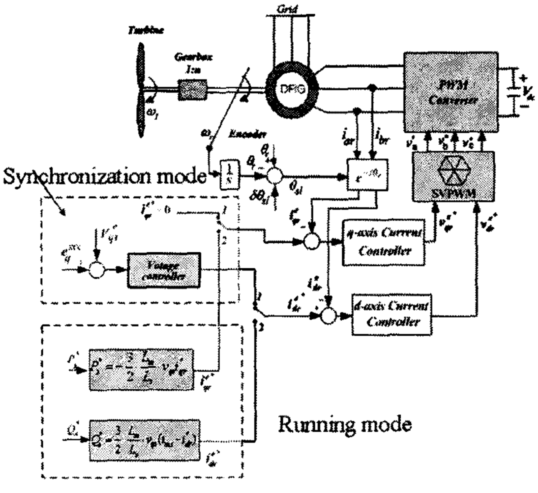

Fig. 3 Control block diagram of DFIG system

The $\delta\theta_{sl}$ is calculated by controlling the stator d-axis voltage to be zero, equally to the grid d-axis voltage.

When the two voltages become the same, the stator of the DFIG is then connected to the utility grid. The back-to-back PWM converters provide a bidirectional power-flow control thereby enabling the DFIG to operate either in subsynchronous $(\omega_s < \omega_e)$ or in supersynchronous modes $(\omega_e < \omega_s)$. In both modes the stator active power is generated from the DFIG and delivered to the grid. On the other hand, the rotor active power is either supplied to the machine in the subsynchronous mode or delivered to the grid in the supersynchronous mode. The stator active power is controlled in optimal tip-speed ratio method [6].

4. Experimental Results

To verify the effectiveness of the proposed control algorithm, a 3kW prototype system was implemented in the laboratory. In Fig. 1, the inverter-side contactor is closed and then the dc-link voltage is controlled to the reference value. Speed, torque, rotor and stator currents are all zero because the rotor and stator are open-circuited. Next, the rotor-side contactor is closed and the synchronization process starts, the d-axis current is controlled to increase the stator EMF until the stator EMF and the grid voltage are equal. Zero phase-difference is obtained by compensating for the phase difference between the two voltages.

As shown in Fig. 4, the stator EMF is zero before starting synchronization procedure. Then, the EMF magnitude, frequency, and phase difference are adjusted with respect to the grid values. It is noticeable that the synchronization process takes almost two cycles, which means that the synchronization control is fast. After satisfying the synchronization conditions, the stator-side contactor is closed and the generator supplies the grid with the power corresponding to the wind speed.

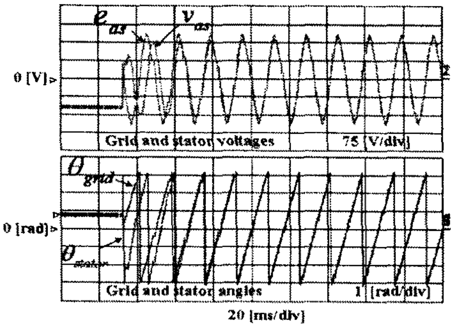

Fig. 4 Generator voltage control at synchronization process

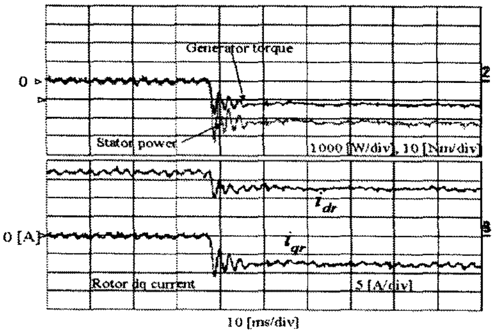

Fig 5 Generator torque and stator power after synchronization.

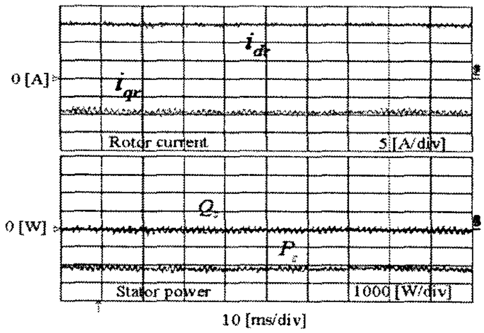

Fig. 6 Rotor currents and stator power

Fig. 5(a) shows the stator active power and generator torque directly after activating the power controller. The rotor d-q current references are adjusted to extract the maximum power and to set the stator reactive power to the desired value as shown in Fig. 5(b). For maximum power and zero reactive power, the rotor d-axis current reference is set to the values shown in Fig. 6(a) and the corresponding active and reactive power are shown in Fig. 6(b). By adjusting the d-axis current of the grid side converter, a unity power factor between the grid voltage and converter current is obtained as shown in Fig. 7(a).

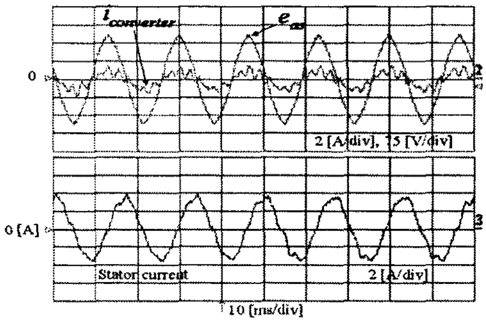

Fig. 7 Unity power factor control and stator current

5. Conclusions

This paper has presented a variable speed generation system with using doubly-fed induction generators. The control system of DFIG has been designed and implemented for grid interactive operation. Stator flux-oriented vector control has been applied to the DFIG control. The operating principle for the MPPT control and stator active and reactive power control were illustrated by the steady-state and transient responses of the power, torque and currents. Experimental results has demonstrated that the proposed control algorithm for synchronization and running modes is feasible and gives a good performance.

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