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Minimization of powers ripple of direct power controlled DFIG by fuzzy controller and improved discrete space vector modulation

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A B S T R A C T

This paper presents a new direct power control (DPC) strategy for a double fed induction generator (DFIG) based wind energy generation system. The strategy of the discrete space vector modulation (DSVM) that is on the basis of the DPC, is implemented. The algorithm to select voltage vector can effectively change the response of the system. So, a new analysis is done and a new switching table is proposed. The proposed switching table is presented to optimize the performance of the voltage vectors by accurately designing the sequence of the voltage vectors. Rearranging the sequence of the voltage space vectors has an influence on active power ripple. To enhance the performance of the closed loop system, fuzzy system is proposed in place of the switching table and hysteresis system. The four variables, rotor speed, errors of the active and reactive powers and stator flux position are exerted to the fuzzy system and the output is the vector that should be implemented to the switching devices. The outperformance of the proposed method is demonstrated by performing simulations in Matlab Software.

1. Introduction

The most important advantages of variable speed wind turbines versus a conventional constant speed system are the improved dynamic behavior, resulting in the reduction of the mechanical stress and fluctuation of the electrical power, and also the increase of the power capture [1]. One of the generation systems, commercially available in the wind energy market, is the doubly fed induction generator (DFIG) which its stator winding is directly connected to the grid and its rotor winding is connected to the grid through a frequency converter (Fig. 1). One of the advantages of this system is that the rating of the power converter is one-third of that of the generator, also operation and four quadrant active and reactive powers.

Direct torque control (DTC) of induction machine was developed in the mid-1980s [2,3]. DTC is an active research control schemes which is on the basis of the decoupled control of flux and torque. DTC provides a very fast and precise torque response without a complex field-orientation block and inner current regulation loops. Some DTC based strategies are voltage vector selection using switching table [2], direct self-control [3], space vector modulation [4], discrete space vector modulation [5] and fuzzy logic [6]. As an intelligent method, fuzzy control does not need the accurate mathematic model of the process. Fuzzy logic controllers were used in direct torque control systems in the past few years. Wei et al. [7] combined DSVM and Fuzzy and gained a good response.

Base on the principles of DTC strategy, direct power control (DPC) was developed for three-phase pulse width modulation (PWM) rectifier. DPC directly controls the stator active and reactive powers. It is possible to control the amplitude of the rotor flux space vector and its relative distance from the stator flux space vector, i.e., a necessary condition for the control of the DFIG.

Several researchers focused on the progress of the DPC techniques that operate at a variable switching frequency [8,9]. Expensive and complicated AC harmonic filters and power converters are the consequence of using the variable switching frequency. DPC at a constant switching frequency was recently developed for the DFIG by [10,11]. But the practical implementations of these methods are more complicated and expensive than conventional DPC. Verij kazemi et al. [12] presented a new DPC on the basis of the DSVM technique. Number of voltage vector generated by this method is more than conventional DPC method. The increase of the number of voltage vectors allows designing more accurate switching tables. The DSVM-DPC achieves a sensible reduction of power ripples and constant switching frequency without increasing the complexity of the conventional DPC.

In this paper, power ripples in DSVM-DPC are analyzed and the optimized switching tables are defined. Then, a new DPC control strategy for DFIG on the basis of fuzzy logic is presented and the performance of the proposed fuzzy system is compared with switching table. Mamdani's min-max method [15,16] is used to compute the inference strategy in the fuzzy system. The rules of the fuzzy

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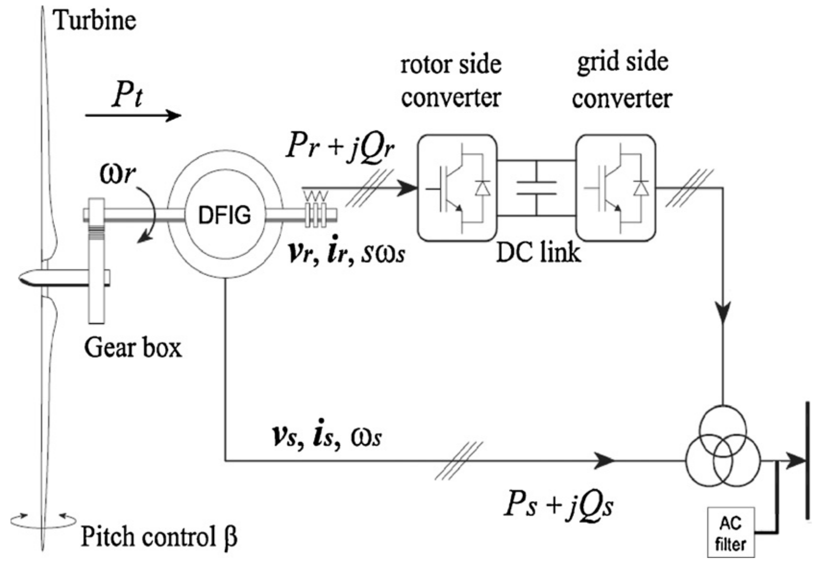

Fig. 1. Schematic diagram of DFIG-based wind generation systems.

system are defined base on a new proposed table. Four variables, error of the reactive and active powers, speed of rotor and the instant position of the flux are used as the fuzzy inputs. Simulation results of a 2 MW DFIG system demonstrate the effectiveness and robustness of the proposed control strategy during variations of active and reactive powers, machine parameters, and wind speed. These are significantly improved while no more expense for designing or application is needed because the new control system does not need a new device. Also, instead of using switching table and hysteresis system, the fuzzy system is employed. Fuzzy logic is able to use human reasoning in terms of fuzzy sets. These terms are quite flexible with respect to the definition and values. So, the variations of vectors exerted to system are smoother. Omitting the hysteresis block in the proposed method, not only we can decrease the costs but also the fuzzy system is robust against noise that results a better performance.

2. Principles of direct active and reactive power control

The dynamic behavior of a DFIG is described by the following equations written in the term of space vectors in a rotor reference frame:

$$V_s = R_s I_s + \frac{d\psi_s}{dt} + j\omega_r \psi_s \tag{1}$$

$$V_r = R_r I_r + \frac{d\psi_r}{dt} \tag{2}$$

$$\psi_s = L_s I_s + L_m I_r \tag{3}$$

$$\psi_r = L_r I_r + L_m I_s \tag{4}$$

where $\psi_r, \psi_s, V_r, V_s, I_r, I_s, R_r,$ and R_s are the fluxes, voltages, currents and resistances of the rotor and stator, respectively. Referring to Ref. [9], the stator active and reactive power inputs from the network can be calculated as

$$P_s = -\frac{3}{2}\frac{L_m}{(\sigma L_s L_r)}\omega_s|\psi_s||\psi_r|\sin\theta \tag{5}$$

$$Q_s = \frac{3}{2}\frac{L_m}{(\sigma L_s L_r)}\omega_s|\psi_s|\left(|\psi_r|\cos\theta - \frac{L_r}{L_m}|\psi_s|\right) \tag{6}$$

where $\sigma = (L_s L_r - L_m^2)/L_s L_r$, ω_s and θ are the synchronous angular frequency and angle between the rotor and stator flux linkage vectors.

The fact that the stator is directly connected to the grid provides a stator flux vector with a constant amplitude and a constant $\omega_s - \omega_r$ in the rotor reference frame.

Derivation along (5) and (6) results in the following equations:

$$\frac{dP_s}{dt} = -\frac{3}{2}\frac{L_m}{(\sigma L_s L_r)}\omega_s|\psi_s|\frac{d(|\theta_r|\sin\theta)}{dt} \tag{7}$$

$$\frac{dQ_s}{dt} = \frac{3}{2}\frac{L_m}{(\sigma L_s L_r)}\omega_s|\psi_s|\frac{d(|\psi_r|\cos\theta)}{dt} \tag{8}$$

Neglecting the rotor resistance in Eq. (2), the rotor flux variations in the rotor reference frame are approximated as:

$$\frac{d\psi_r}{dt} \simeq V_r \tag{9}$$

According to (9) the rotor flux moves in the direction of the applied rotor voltage vector and its speed is proportional to the amplitude of the voltage vector.

For a three-phase two level converter, eight switching combinations can be selected; two of them determine zero voltage vectors and the remains generate six space voltage vectors that have the same magnitude. The α_r–β_r plane is divided into six regions as shown in Fig. 2.

Based on the effects of the voltage vector on the variations of the powers, the diagram of the control system in Fig. 3 was proposed by [9]. In this method, in the first step, stator flux, active and reactive powers are calculated. Then sector position of the stator flux is calculated. Hysteresis block is applied to compare the active and reactive powers with their reference values. Finally, the hysteresis outputs and sector of stator flux are used to choose the appropriate voltage vector from switching table. The selected voltage vector is applied to the rotor.

3. DSVM-DPC principle

As pointed out in Section 2, a three-phase two-level voltage source inverter can only generate 8 possible voltage vectors. At each sampling period, the capability to compensate the power errors strongly depends on the number of available voltage vectors. Although SVM technique can synthesize any voltage vector [10], it is too complicated. DSVM technique uses a standard VSI and synthesizes a higher number of voltage vectors than those used in conventional DPC. The implementation of the DSVM technique requires only a small increase of the computational time.