Implementation of Fuzzy Controller for Rotor Side Converter of DFIG

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Abstract

Implementation of fuzzy controller for the rotor side converter of a utility-connected double-fed induction generator (DFIG) for wind power generation systems (WPGS) described in this paper. In the control schemes, real and reactive powers (PQ) at the stator side of DFIG are strictly controlled to supply the power to the grid. A TMS320VC33 DSP is selected as the controller of this system.

1. Introduction

In recent years, there has been growing interest in utilizing DFIG as a wind power generator. A PACAD simulation and laboratory test with 2 hp wound rotor induction machine driven by dc motor reported that the back-to-back PWM converter of DFIG regulates the real and reactive powers independently [1]. In previous studies, the conventional PID control was adopted as the controller of the system [2], which has been known to have difficulty dealing with dynamic speed tracking, parameter variations and load disturbance. In the previous works, the authors has investigated the possibility of utilizing fuzzy control with easy linguistic implementation as one of the alternatives to overcome the difficulties of the conventional PID control in DFIG system [3]. Study has also been done on comparative study between fuzzy and PI usage as controller [4]. This paper will further describe the research result by describing successful implementation of the control scheme in real prototype system. A DSP (TMS320VC33) was selected to be used as the controller of this system.

2. Wind power generation system with double-fed induction generator

Figure 1 shows the configuration of WPGS with a DFIG as a generator and a back-to-back converter. There are 2 converter controllers used: the grid converter controller and the rotor converter controller. The grid converter controller regulates the magnitude of DC link voltage V_{DC} and the reactive power Q_G at the grid side. The rotor converter controller controls the real power P_s and the reactive power Q_s at the stator side. The control strategies of the grid converter controller are omitted in this paper. Figure 2 shows that 3 axis are used in this stator flux oriented control model: DQ axis for the stationary reference frame, $\alpha\beta$ axis for the rotor reference frame and the xy axis for the stator flux-oriented reference frame. From the vector analysis of DFIG [1], the real power P_s and reactive power Q_s at the stator side of DFIG are

$$P_s = \frac{3}{2}\left|\vec{v}_s\right|\frac{L_m}{L_s} i_{ry} \qquad (1)$$

$$Q_s = \frac{3}{2}\left|\vec{v}_s\right|\frac{L_m}{L_s}\left(\left|i_{ms}\right| - i_{rx}\right) \qquad (2)$$

where v_s is the stator voltage connected to the power line, i_{ms} is stator magnetizing current, and i_{rx} and i_{ry} are rotor currents in stator flux-oriented reference frame.

3. Fuzzy control of DFIG

In this controller, a single fuzzy controller is used to control the whole rotor side converter. In this scheme, the controller will be controlling the power directly through the voltage vector output. The fuzzy logic control design is realized by the operator understanding the converter's characteristics and linguistic rules of the type: "IF the error of the output is positive, then reduce the duty cycle slightly." [5]. For the fuzzy inference to regulate the output powers (P_s and Q_s), the fuzzy control will use 2 input variables, the error, *e(t)* and the change in error, *ce(t)* of the stator power output of DFIG, which for the active power is defined as:

$$e_p(t) = P_{ref} - P_s \qquad (3)$$

$$ce_p(t) = e(nT_s) - e((n-1)T_s) \qquad (4)$$

The output power error and the change of the error have nine fuzzy subsets and the triangle membership function [5]. The parameters of the fuzzy membership functions for $e_p(t)$ and $ce_p(t)$ are [*NVB,NB, NM, NS, ZE, PS, PM, PB, PVB]*=[-3.999, -1.99, -0.6, -0. 254, 0.0, 0. 254, 0.6, 1.99, 3.999] and [*NVB, NB, NM, NS, ZE, PS, PM, PB, PVB*]=[- 0.6, -0.3, -0.02, -0.01, 0, 0.01, 0.02, 0.3, 0.6], respectively. The constants for the output of the Sugeno fuzzy rule base *u(t)* are [-100, -12.5, -3.2, -1.6, 0.8,-0.4,-0.1, 0.0, 0.1, 0.4, 0.8, 1.6, 3.2, 12.5, 100]. The new output of the fuzzy has nine fuzzy subsets defined as the singleton-type membership function [5].

The full fuzzy rule table can be seen in table II. *du(pu)* is the output selection of the fuzzy. In order to defuzzify the fuzzy output to the crisp output, *dz*, the fuzzy inference process uses the simple and effective Sugeno zero-order reasoning method [5]. The new voltage commands, v_{rx} and v_{ry} based on the fuzzy inference can be written as

$$v(nT) = v\left((n-1)T_s\right) + dv\left(nT_s\right) \qquad (5)$$

which are rotor voltages in stator flux-oriented reference frame. Figure 6 shows the overall control block for the fuzzy control.

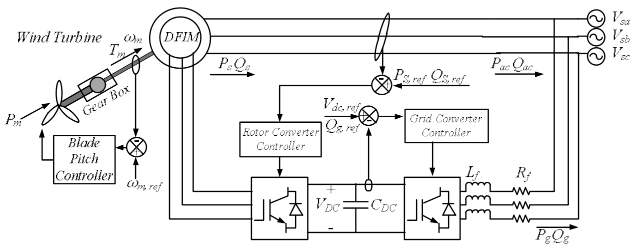

Figure 1. Wind power generation system with double-fed induction generator.

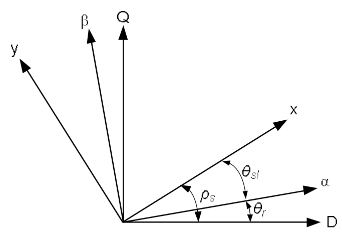

Figure 2. Reference frames for double-fed induction generator.

4. System Design and Experiment

In this section, experiments of the system is described. The experiment employs a permanent magnet synchronous motor to work as a wind turbine. In the experiment setup, we use DSPs (TMS320VC33) to perform the control of the system. The system parameters are described on table II.

TABLE I. FUZZY RULE TABLE

du(pu) — ce(pu) \ e(pu)	NVB	NB	NM	NS	Z	PS	PM	PB	PVB
NVB	NXB	NVB	NVB	NB	NM	NS	NVS	NXS	Z
NB	NVB	NVB	NB	NM	NS	NVS	NXS	Z	PXS
NM	NVB	NB	NM	NS	NVS	NXS	Z	PXS	PVS
NS	NB	NM	NS	NVS	NXS	Z	PXS	PVS	PS
Z	NM	NS	NVS	NXS	Z	PXS	PVS	PS	PM
PS	NS	NVS	NXS	Z	PXS	PVS	PS	PM	PB
PM	NVS	NXS	Z	PXS	PVS	PS	PM	PB	PVB
PB	NXS	Z	PXS	PVS	PS	PM	PB	PVB	PVB
PVB	Z	PXS	PVS	PS	PM	PB	PVB	PVB	PXB

TABLE II. PARAMETERS OF THE WPGS WITH DFIG

Parameters	Value	Unit
Reactive power at stator, Q_s	0	kVar
Peak value of line voltage, V_{AC}	180	V
Stator resistance of DFIG, R_s	4.55	Ω
Rotor resistance of DFIG, R_r	5.32	Ω
Stator leakage inductance of DFIG, L_{ls}	42	mH
Rotor leakage inductance of DFIG, L_{lr}	42	mH
Mutual inductance of DFIG, L_m	297	mH
No. of poles of DFIG, p	4	
DC link voltage, V_{dc}	380	V
Reactive power at grid converter, Q_{ac}	0	kVar
DC link capacitor, C_{dc}	3300	μF
AC resistance at grid converter, R_{ac}	0.1	Ω
Switching frequency, f_s	2.5	kHz

Figure 4 shows the experimental results for the active and reactive powers and phase A voltage and current. Figure 4(a) shows the active and reactive powers. The active power is uncontrolled firstly, then controlled to be zero for 3 seconds (started from the negative overshoot), then increased gradually until it becomes 1kW. The reactive power is uncontrolled firstly, then controlled to be zero (started from the negative overshoot). From the result we can see that the powers are strictly controlled to their references. Figure 4(b) shows the voltage and current waveform. The current and voltage are shown to be in one phase because the reactive power is controlled to be zero. From the result, it is shown that even though the grid voltage is not an ideal sinusoidal grid voltage (e.g. it is not a pure sinusoidal), the fuzzy controller is still robust enough to generate satisfactory result.

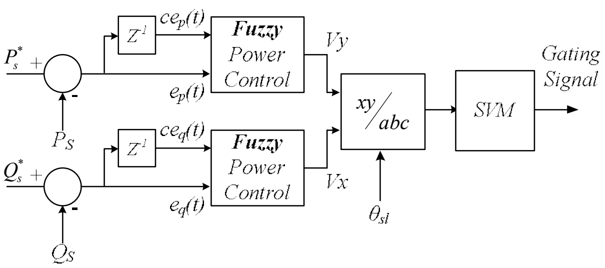

Figure 3. Real and reactive power controller using fuzzy control.

5. Conclusions

In this paper, implementation of fuzzy control algorithm to control the real and reactive powers at the stator of DFIG in WPGS with DFIG independently has been done. Experiment results show that the fuzzy controller work effectively for WPGS with DFIG and a back-to-back SVPWM converter. The powers are strictly regulated and therefore the objectives of the research to design the controllers are met. The fuzzy control is shown to be able to control the dynamic operations of DFIG without knowing the exact mathematical model of the DFIG. The controller can overcome nonlinearities and will be best suited for the nonlinear operation of DFIG for WPGS.

6. References

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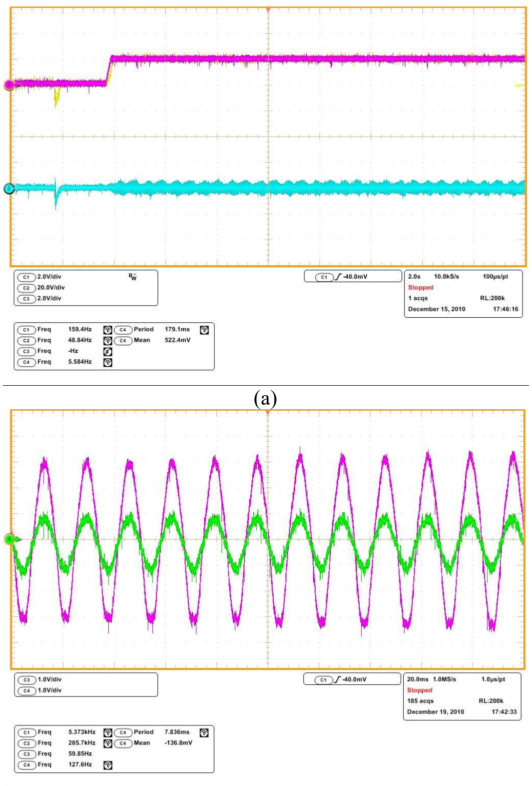

(a)

(b)

Figure 4. Results: (a) Top: active power (real and reference), bottom: reactive power, (b) Purple: stator voltage, green: stator current.