Fuzzy Control for Back to Back Converter in Double-Fed Induction Machine in Wind Power Generation System

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Abstract

This paper describes the control of a utility-connected double-fed induction machine (DFIM) for wind power generation systems (WPGS). Real and reactive powers (PQ) at the stator side of DFIM are strictly controlled to supply the power to the grid without any problems. In this paper the control is realized using Fuzzy PI controller based on the stator-flux orientation control.

Keywords--Wind power generation system, Double-fed induction machine, SPWM converter, Vector control, PQ control, DC voltage control, Fuzzy PI control, PSIM simulation

1. Introduction

Double-fed induction machine (DFIM) is one of electric machines that can be used as wind power generator. A simulation study of the back-to-back converter for DFIM of WPGS was reported to prove independent control of the real and reactive powers at the stator side of the DFIM [1]. In the previous studies accompanying the detailed analysis of the DFIM[2], the conventional PID control was adopted as the error amplifier of the feedback loop. The conventional PID control has been known to have difficulty dealing with dynamic speed tracking, parameter variations and load disturbance. Fuzzy control with easy linguistic implementation is one of the alternatives to overcome the difficulties of the conventional PID control[3]. The simulator is tested in the PSIM simulation program. The results show satisfactory performance of simulator designed without the detailed small signal modeling of WPGS.

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

Fig. 1 shows a wind power generation system (WPGS) with a double-fed induction machine (DFIM) as a generator, a back-to-back converter as a power flow controller and a WPGS optimum controller. The WPGS optimum controller calculates the best operating condition of the WPGS from the given wind speed and the power requirement of the power system. It consists of 3 sub controllers: The grid converter controller, the rotor converter controller, and the blade pitch controller. The grid converter controller regulates the magnitude of DC link voltage *Vd* and the reactive power *QG* at the grid side. The rotor converter controller controls the real power *Ps* and the reactive power *Qs* at the stator side. The control strategies of the grid converter and the blade pitch controller are omitted in this paper.

3. Power control of DFIM in the stator flux-oriented reference frame

3 axis are used in this model: DQ axis is for the stationary reference frame, *αβ* axis is for the rotor reference frame and the

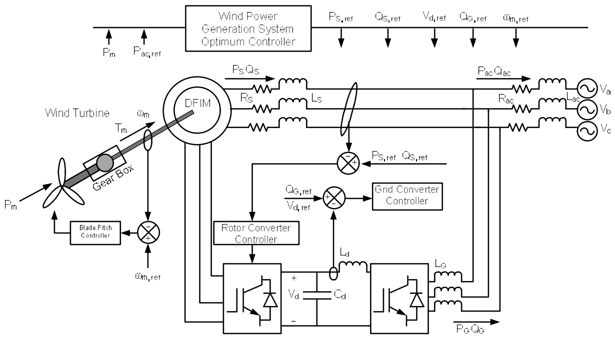

Fig. 1. Wind power generation system with double-fed induction machine as a generator

xy axis is for the stator flux-oriented reference. The *ρs* is the stator flux angle and the *θr* is the rotor angle. In this control, both stator and rotor quantities are transformed to a special reference frame that rotates at an angular frequency identical to the stator flux linkage space phasor. From the vector analysis of DFIM[4], the real power *Ps* and reactive power *Qs* at the stator side of DFIM are represented as

$$P_S = \frac{3}{2}\left|V_S\right|\frac{L_m}{L_s} i_{ry} \tag{1}$$

$$Q_S = \frac{3}{2}\left|V_S\right|\frac{L_m}{L_s} (\left|i_{ms}\right| - i_{rx}) \tag{2}$$

where *Vs* is the stator voltage connected to the power line, *ims* is stator magnetizing current, and *irx* and *iry* are rotor currents in stator flux-oriented reference frame. From (1) and (2), it can be seen that the real power *Ps* and reactive power *Qs* at the stator side of DFIM can be independently controlled with the rotor current vector control. Due to the nonlinear characteristics, precise mathematical modeling of the WPGS including back-to-back converter for calculating the conventional PI feedback control gains has been a difficult task. Fuzzy logic control can be used to control the output powers at the stator side of DFIM without precise mathematical modeling of the WPGS.

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 PI inference to regulate the output powers (*Ps* and *Qs*), there are 2 input variables (the output power error, *e(t)*, and the change in error, *ce(t)*. The output error has the nine fuzzy subsets and the triangle membership function[5]. The change of the error has seven fuzzy subsets and the triangle membership function[5]. The new output of the fuzzy PI has nine fuzzy subsets which are defined as the singleton-type membership function[5]. The fuzzy rule table for the output voltage regulation has 63 rules of the following type:

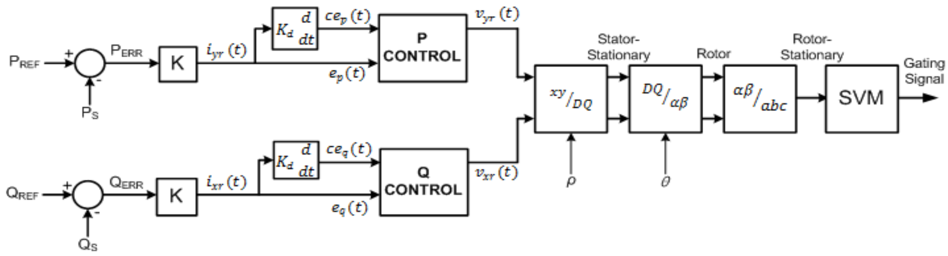

Fig. 2 Real and reactive power controller for wind power generation system with double-fed induction machine as a generator

Rule i : IF (the voltage error $e(t)$ is NS (negative small))
AND the change of the error $ce(t)$ is PS (positive small),
THEN the change of the command is ZE (zero),
where $i = 1, \ldots, 63$.

In order to defuzzify the fuzzy output to the crisp output, dz, fuzzy inference process uses simple and effective Sugeno zero-order reasoning method[5]. Output of the control generates irx of (1) and iry of (2), which are rotor currents in stator flux-oriented reference frame. Overall control block can be seen in Fig. 2.

4. Design example and PSIM simulation

In this section, we present simulations of the fuzzy controlled WPGS which has DFIM to convert the mechanical power of wind turbine to electric power. Rotor side SVPWM converter controls real and reactive powers at the stator side of DFIM. For this time being the Wind Turbine is modeled by a Mechanical-Electrical Interfaces block in PSIM. Simulation results carried out with PSIM for the designed fuzzy PI controller are shown in Fig. 3, 4.

The operating conditions to verify the performance of the fuzzy PI controller for DFIM in WPGS are changed in time as the following:

1) Wind turbine starts to work with speed control at 700 [rpm] as the simulation starts and changes from 700 to 1000 at 1[ms].
2) Fuzzy PI controller begins to work at 1[ms].
3) Stator reference changes 1[kw] at 1[ms], 1.5[kw] at 1.5[ms].

Figure 3 shows that the DFIM generates the real power, 1.0[kW] from 1[s], 1.5[kW] at 1.5[s] with the back-to-back inverter control algorithm of the rotor side proposed in this paper. Figure 4 shows that the DFIM regulates the reactive power, 0[kVAR] from 1[s]. From simulation results, one can see that fuzzy PI controller regulates the output powers even though the operating conditions of WPGS continue to change abruptly.

5. Conclusions

In this paper, fuzzy PI control algorithm is applied to control the real and reactive powers at the stator of DFIM in WPGS with DFIM independently. To test the proposed control algorithm, PSIM simulation studies are performed. The simulation results show that the fuzzy PI controller works efficiently for WPGS with DFIM and a back-to-back SPWM converter.

The proposed fuzzy controller can control power flows in WPGS with DFIG. The fuzzy PI controller in this paper is a kind of PI controller elaborated with linguistic rules and can be designed without knowing the exact system parameters required in a conventional PI design method. Therefore, this design method will be required when WPGS will operate in more complicated and high-level control strategies. Further investigations yet to be done include the hardware experiments of DFIM in WPGS to verify the proposed approach.

References

[1] D. Panda, E. Bennedict, G. Venkataramanan, T. Lipo, “A Novel Control Strategy for the Rotor Side Control of a Double-Fed Induction Machine", *Proc. of IEEE IAS Annual Meeting,* Vol. 3, pp. 1695-1702, 2001.

[2] Osama S. Ebrahim, Praveen K. Jain, Goel Nishith, "Indirect Stator Flux-Oriented Output Feedback Control of Doubly Fed Induction Machine", *Journal of Power Electronics,* Vol.8 No.1, pp. 10-22, Jan. 2008.

[3] G. B. Chung, J. Choi, “Application of Fuzzy PI Control Algorithm as Stator Power Controller of a Double-Fed Induction Machine in Wind Power Generation Systems”, *Journal of Power Electronics*, Vol. 9, pp. 109-116, January, 2009

[4] B. H. Chowdhury, S. Chellapilla, "Double-fed Induction Generator Control for Variable Speed Wind Power Generation", *Electric Power Qstems Research,* Vol. 76, pp. 786-800, June, 2006.

[5] Bimal K. Bose, "Modern Power Electronics and AC Drives", Prentice Hall PTR, Upper-Saddle River, NJ, 2002.

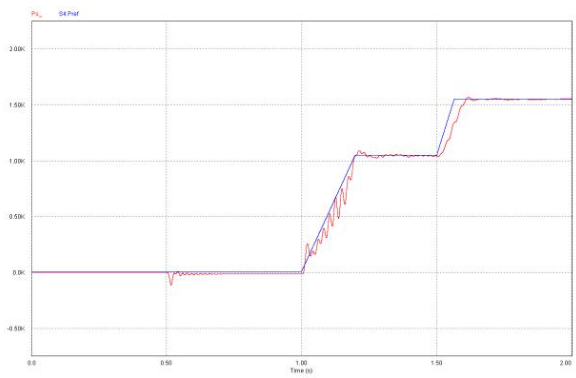

Fig. 3 Real Power at Stator

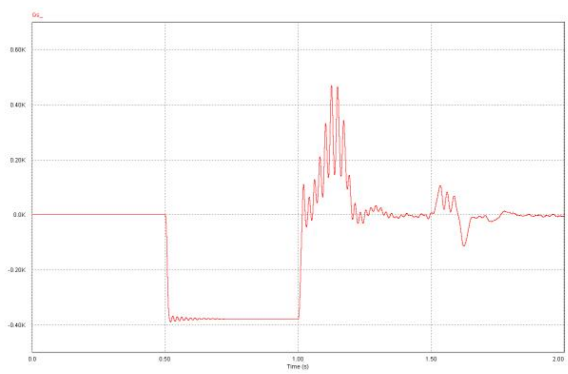

Fig. 4 Reactive Power at Stator