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Research on Fuzzy Control Based on Directional Power Conversion of Wind Generator

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Abstract. For general control of wind power systems, control systems of structure is more complexed, control systems operation precision is not high problem. This article provides a wind directional fuzzy control method for power conversion, the mathematical model of directional control of generator power is established, generator power conversion control system was designed. Then the control system was conducted by using the tool of simulation. The simulation result showed that the system will respond quickly, good stability, high operating reliability, and strong practical value. The control system has a strong ability to control, control system can easily make wind power fuzzy control for future analysis of the class wind directional power of motor and its control strategy research suggests new ways, wind power has a strong significance on the study of the control system.

1. Introduction

The mathematical model of controlled object of CNC servo control system is generally unknown. Aiming at multi axis CNC servo control system, Lanzhou Industry and Equipment Co. Ltd, Lanzhou University of technology researchers [1-24] proposed an NURBS algorithms which based on real-time interpolation and compensating error. When using modern control theory and intelligent control to control, it is necessary to know the mathematical model of the system accurately. CNC servo control system are used to make wind power equipment.

At present, the rapid economic development has caused the consumption of primary energy such as coal to increase rapidly. The energy crisis has become more and more serious. Many countries have begun to turn their attention to the development and utilization of wind energy. Wind energy is a kind of renewable energy that is convenient and effective, taking into account energy enhancement and environmental protection requirements, and has potential for development. In recent years, wind power generation technology has received extensive attention and attention from scholars in various countries. The wind farm is the control center for wind power generation [25, 26] The wind power control method is the key issue of the current wind power generation technology [27], the more commonly used wind power control method has a strong robust control method [28], neural network fuzzy control [29], the best search for superior control method and so on. A fuzzy control method [27, 30] based on the safety margin of backpressure protection for direct air-cooled units is presented. A new type of fuzzy controller is designed, and self-adjusting factor is introduced to adjust the fuzzy controller to suit the complex and changeable control system. A neural network fuzzy control method is given, and the neural network is used to correct the characteristic curve. However, in actual operation, the wind speed changes rapidly, the neural network training is difficult to obtain accurate results, and it will increase the complexity of the system [25, 29].In general, the problems of wind turbine control system include: it is difficult to obtain accurate mathematical models of control objects, complex control structures, and low accuracy.

For wind power generation, a control system that contains uncertainty and non-linear, parameter changes, and it is difficult to describe with an accurate mathematical model.

This paper obtains the power conversion characteristic equation of wind power generator based on the wind power generator model and establishes a generator power directional control system. The fuzzy control method is adopted to control it.

2. Wind turbine model

The fan unit is mainly composed of wind turbine and asynchronous wind turbine. According to the mechanical characteristics of wind turbine, the output power of wind turbine is related to the wind speed [27], namely

$$P_{\mathrm{m}} = \frac{1}{2} C_{\mathrm{p}} \rho \pi R^2 v^3 \tag{1}$$

In the formula:

Cp is the fan power coefficient;

ρ is the air density, kg/m^3;

R is the radius of the fan impeller, m;

v is the wind speed, m/s.

The fan power coefficient reflects the wind energy efficiency of the fan, which is related to wind speed, blade speed and pitch angle. The fan power coefficient C_{p} is related to the tip of the leaf λ, and its functional relationship is shown in Figure 1. Leaf tip speed ratio is the ratio of leaf tip speed to wind speed

$$\lambda = \frac{\omega_{\mathrm{r}} R}{v} = \frac{2\pi R n}{60 v} \tag{2}$$

In the formula: ω_{r} is the wind engine angular speed, rad/s; n is the speed of the wind turbine, r/min.

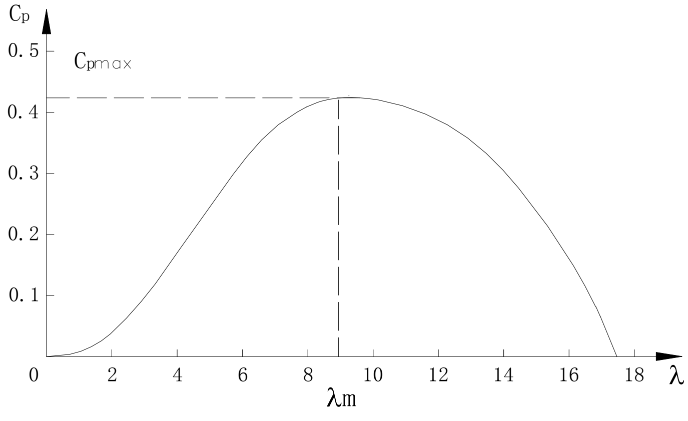

Figure 1. $C_{\mathrm{P}} = f(\lambda)$ Curve Diagram.

It can be seen from Figure 1: C_P changes with λ, and when λ changes from 0 to λ_m, C_p also changes from 0 to C_{Pmax}; When $\lambda = \lambda_m$, $C_p = C_{Pmax}$, C_{Pmax} is the largest wind energy utilization coefficient.

3. Model for directional power conversion of wind turbines

Large wind turbines usually use asynchronous wind turbines. Asynchronous power generation, while absorbing wind energy, provides mechanical work and emits useful power. Its equivalent circuit diagram is shown in Figure 2.

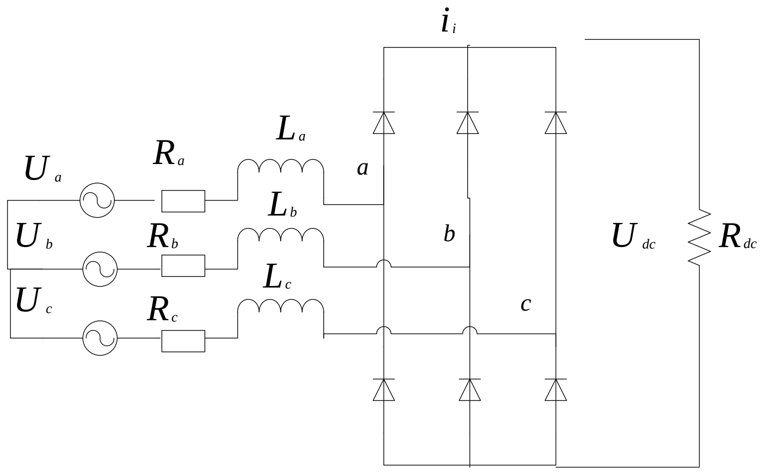

Figure 2. Schematic diagram of the wind generator equivalent circuit.

The following relationship is obtained from the model shown in Figure 2:

$$\begin{cases} i_a + i_b + i_c = 0 \\ U_a + U_b + U_c = 0 \\ C\dfrac{di}{dt} = \sum\limits_{i=a,b,c} S_i i_i \end{cases} \tag{3}$$

In the formula: i_a, i_b, i_c are the three-phase currents provided by the grid, U_a, U_b, U_c are the three-phase voltage provided on both sides of the grid, and C is the capacitance value; Assuming that the circuit control switch is ideal, a logic switch variable function S_i is introduced. When $i=0$, the logic is turned off. When $i=1$, the logic switch is turned on; i_i is the current of the DC segment on the grid side, and the value of $i=a,b,c$ is taken, corresponding to i_a, i_b, i_c, respectively.

$$U_{si} = U_{dc} S_i + \omega_e L i_i - (R i_i + L\frac{di_i}{dt}) \tag{4}$$

In the formula: U_{si} is the three-phase voltage provided on both sides of the grid, U_{dc} is the DC busbar side capacitance voltage on the grid side, and ω_e is the angular frequency of the power supply voltage of the grid.

In the three-phase synchronous rotation coordinate system, the mathematical model of the three-phase voltage width modulation (PWM) rectifier of wind motor is established [23].

$$\mathrm{D}\begin{bmatrix} i_a \\ i_a \\ i_a \\ U_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & \omega_e & \frac{S_a}{L} \\ -\omega_e & -\frac{R}{L} & 0 & \frac{S_b}{L} \\ -\omega_e & 0 & -\frac{R}{L} & \frac{S_c}{L} \\ \frac{S_a}{C} & \frac{S_b}{C} & \frac{S_c}{C} & 0 \end{bmatrix} \begin{bmatrix} i_a \\ i_a \\ i_a \\ U_{dc} \end{bmatrix} + \begin{bmatrix} \frac{U_a}{L} \\ \frac{U_b}{L} \\ \frac{U_c}{L} \\ \frac{-I_{dc}}{C} \end{bmatrix} \quad (5)$$

In the formula: D is the differential operator, R, L represents the resistance and inductance, respectively; I_{dc} is the dc segment current value S_a, S_b, S_c is the equivalent switch function in the three-phase synchronous rotation coordinate system.

The power of the wind generator is

$$P = U_a i_a + U_b i_b + U_c i_c \quad (6)$$

According to formula (3) ~ (6), the overall structure of the generator power directional control system is designed, as shown in Figure 3.

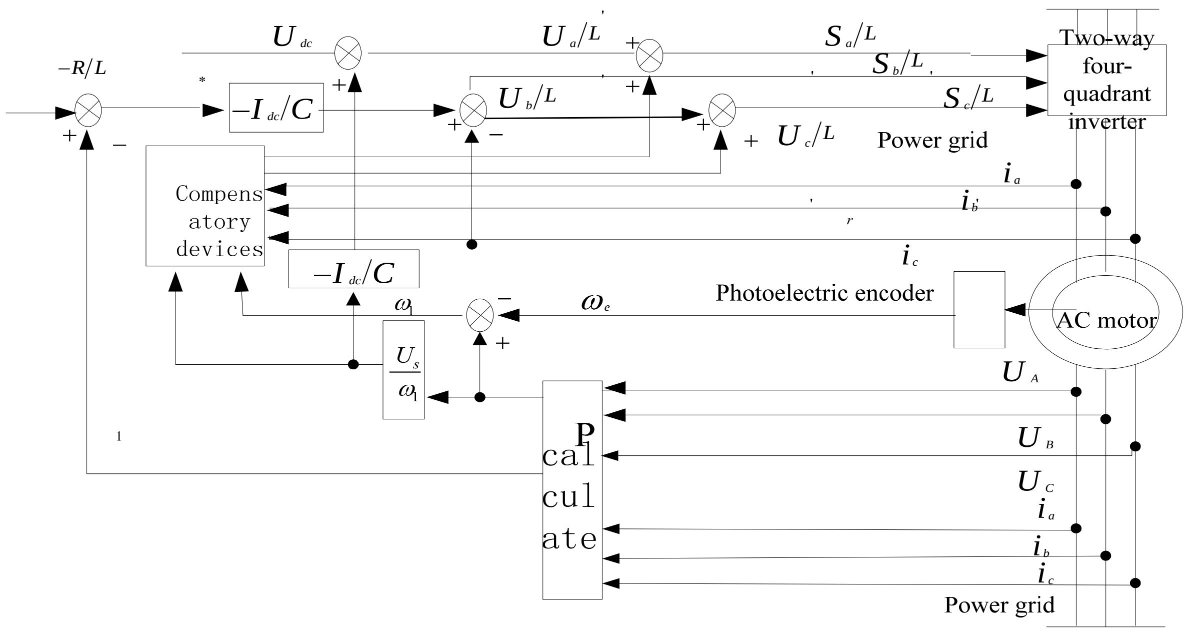

Figure 3. Whole structure of wind turbine power directional control system.

The control between generator power and generator's three-phase current, voltage and angular speed can be realized.

From the above analysis, it can be seen that the control structure of the model has an angular velocity signal ω_e (nonlinear quantity) and an electric current signal i_a, i_b, i_c (inexact quantity) to control the wind generator. The control structure is shown in Figure 4.

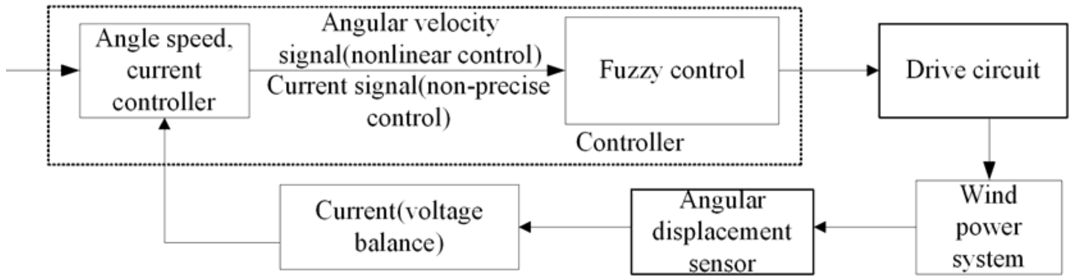

Figure 4. Figure control of wind power generation system.

4. Design of Fuzzy Control

4.1. Design of Fuzzy Control

According to the theory of fuzzy control [27], establish a wind turbine power generation fuzzy control model as shown in Figure 5.

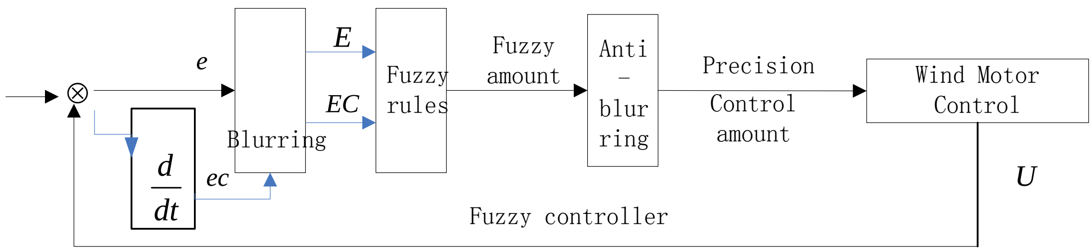

Figure 5. Block diagram of fuzzy control.

4.2. Selection domain

The fuzzy fields of input deviation E, variation rate EC and output control U are all taken as

E = {NB, NM, NS, NO, PO, PS, PM, PB};

EC = {NB, NM, NS, PS, PM, PB};

U = {NB, NM, NS, PS, PM, PB}.

Among them, NB, NM, NS, NO, PO, PS, PM, PB represent negative, negative, small, negative, positive, zero, positive, small, middle, positive and other vague concepts. The fuzzy set domains E, EC, and U are represented by a discrete set of numbers as follows:

E = {-6, -5, -4, -3, -2, -1, -0, +0,+1, +2, +3, +4, +5, +6};

EC = {-6, -5, -4, -3, -2, -1, +1, +2,+3, +4, +5, +6};

U = {-6, -5, -4, -3, -2, -1, +1, +2,+3, +4, +5, +6}.

4.3. Identification of quantitative and proportional factors

The basic domains of assumed deviation, variation rate and output control are $\left[-x_{e_{\max}}, x_{e_{\max}}\right]$, $\left[-x_{ec_{\max}}, x_{ec_{\max}}\right]$, $\left[-y_{u_{\max}}, y_{u_{\max}}\right]$. Let the domain of the fuzzy domain subset taken by the error, change quantity, and control quantity be $[-l, -l+1, \cdots, l-1, l]$; The quantization factor of error, the quantization factor of error change, and the proportional factor of the control amount are determined by the following formula.

$$\begin{cases} k_e = \dfrac{l}{x_{e_{\max}}} \\ k_{ec} = \dfrac{l}{x_{ec_{\max}}} \\ k_u = \dfrac{y_{u_{\max}}}{l} \end{cases} \tag{7}$$

$$k_e = k_{e0} + k_1 \left| |e| - \frac{E_{\max}}{2} \right| \tag{8}$$

$$k_{ec} = k_{ec0}, \text{ when} 0 < |e| < \frac{E_{\max}}{2} \tag{9}$$

$$k_{ec} = k_{ec0} - k_2 |e| \quad \text{when} |e| > \frac{E_{\max}}{2} \tag{10}$$

$$k_u = k_{u0} + k_3 |e| \tag{11}$$

The fuzzy and fuzzy formula is

$$\begin{cases} E = \operatorname{int}(e k_e) \\ EC = \operatorname{int}(ec k_{ec} + \dfrac{1}{2}) \\ u = U k_u \end{cases} \tag{12}$$

In the formula, k_{e0}, k_{ec0}, k_{u0} is the value of k_e, k_{ec}, k_u with zero deviation; $E_{\max}$ maximum error, k_1, k_2, k_3 is the fuzzy coefficient of k_e, k_{ec}, k_u.

The calculation and analysis of k_e, k_{ec}, k_u can be referred to the literature

4.4. Establishment of a membership function

According to the characteristics of the off-wind power generation system, the shape of the triangle is chosen as the membership function. The closer the curve is to the origin, the steeper the curve is, and the smaller the error, the higher the resolution; the farther the curve is from the origin, the slower the curve is, and the greater the error, the lower the resolution. The input deviation E, the variation rate EC and the output U are shown in Figures 6, 7 and 8, respectively.

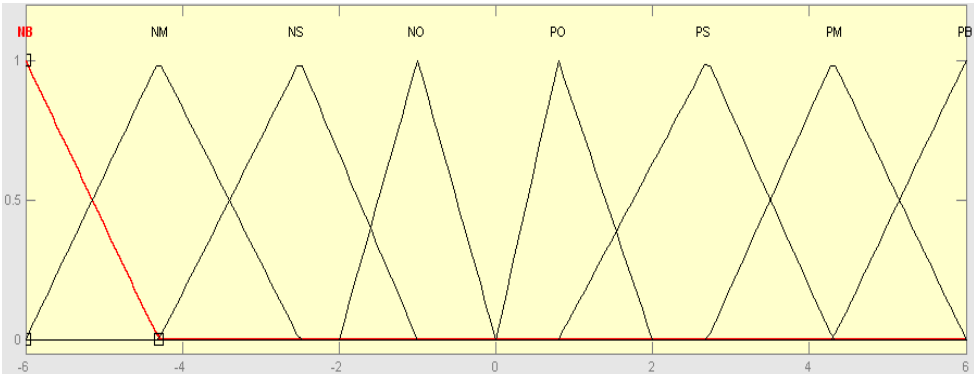

Figure 6. Subjection E function of fuzzy control diagram.

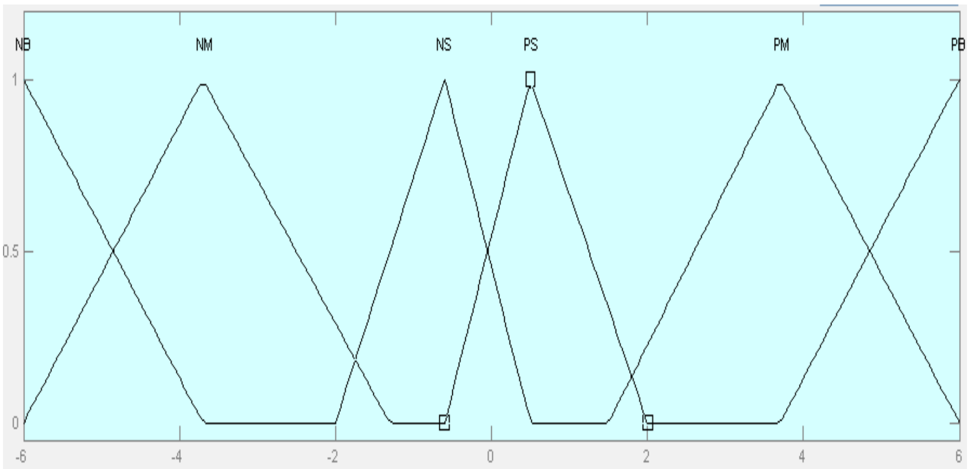

Figure 7. Subjection EC function of fuzzy control diagram.

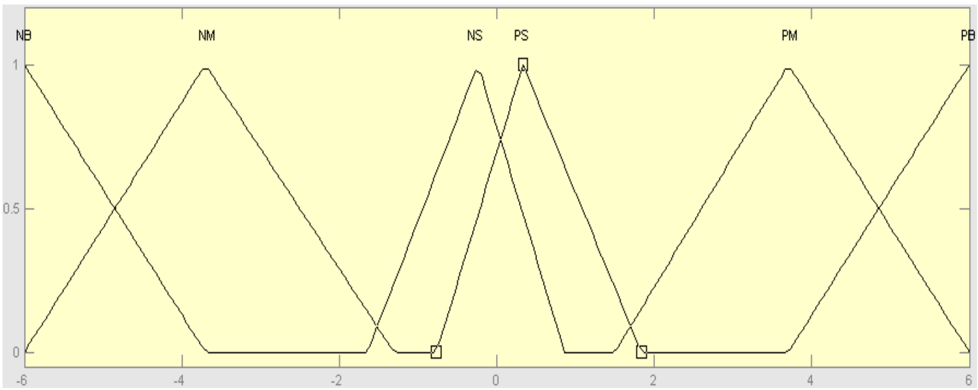

Figure 8. Subjection U function of fuzzy control diagram.

4.5. Fuzzy control rules

The control rules of the fuzzy controller can be written as the following conditional statements:
If $E = A_i$ and $EC = B_j$, then $U = C_{ij}$, $i = 1,2,3,\cdots,m$, $j = 1,2,3,\cdots,n$

Among them: A_i, B_j, C_{ij} is the fuzzy set on the domain of defining error, error change rate, and control quantity respectively. The control rules are shown in table 1.

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Table 1. Regulation Table of fuzzy control.

Control level U		Input variable deviation change rate EC							
		NB	NM	NS	NO	PO	PS	PM	PB
Input variable deviation E	NB	PB	PB	PS	PB	NS	PM	NM	NB
	NM	PB	PB	PS	PB	NS	PM	NM	NM
	NS	PM	PM	PS	PM	NS	NS	NS	NS
	PS	PS	PS	ZS	NM	PS	NM	NM	NM
	PM	NM	NM	NS	NB	PS	NB	NB	NB
	PB	NB	NM	NS	NS	PS	NB	NB	PB

5. Experiment simulation and analysis

According to the mathematical model of the power direction control of the wind motor, a fuzzy control system for the power direction control of the wind motor is established. Experimental platform, as is shown in Figure 9. Matlab is used to perform conventional control and fuzzy control response curve control simulation of the control system. Simulation model diagram, as is shown in Figure 10.The experimental parameters (wind turbine model parameters) are shown in table 2. The simulation results are shown in Figures 11 and 13.

Figure 9. Experimental platform.

Table 2. Motor simulation parameters.

Simulation parameters	Parameter value	unit
Pole logarithm	8	
Moment of inertia	0.0015	$kg{\cdot}m^2$
Rated speed	820	r/min
Friction coefficient	0	
Permeability factor	0.175	Wb
Equivalent resistance	0.085	Ω
Electricity	0.00389	H
Wind speed	8	m/s

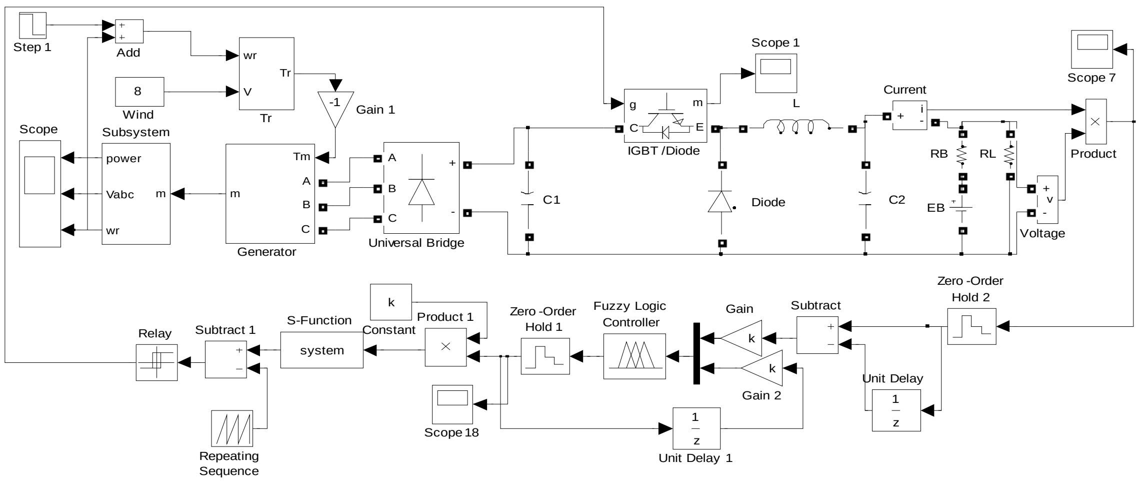

Figure 10. Simulation model diagram.

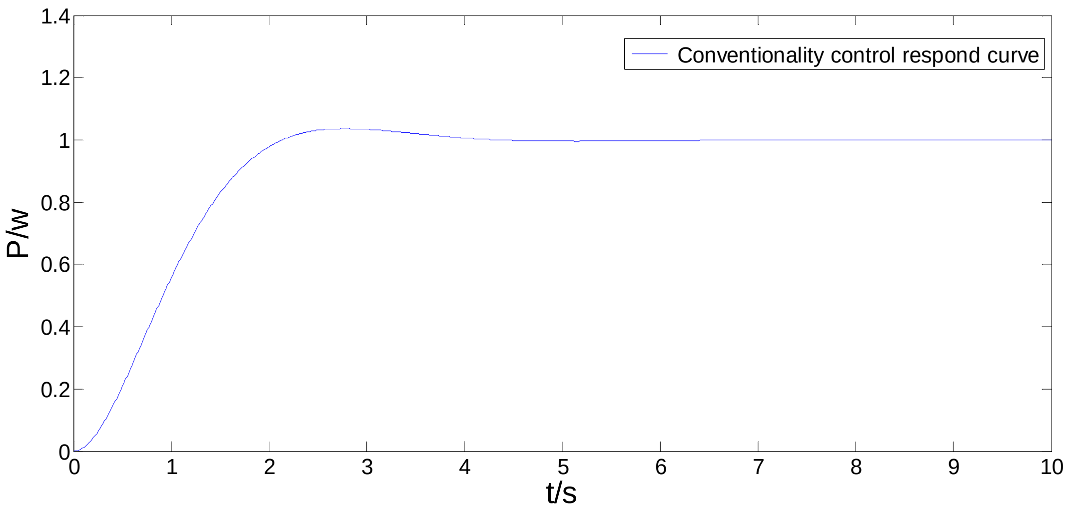

Figure 11. Conventionality control respond curve for imitate diagram.

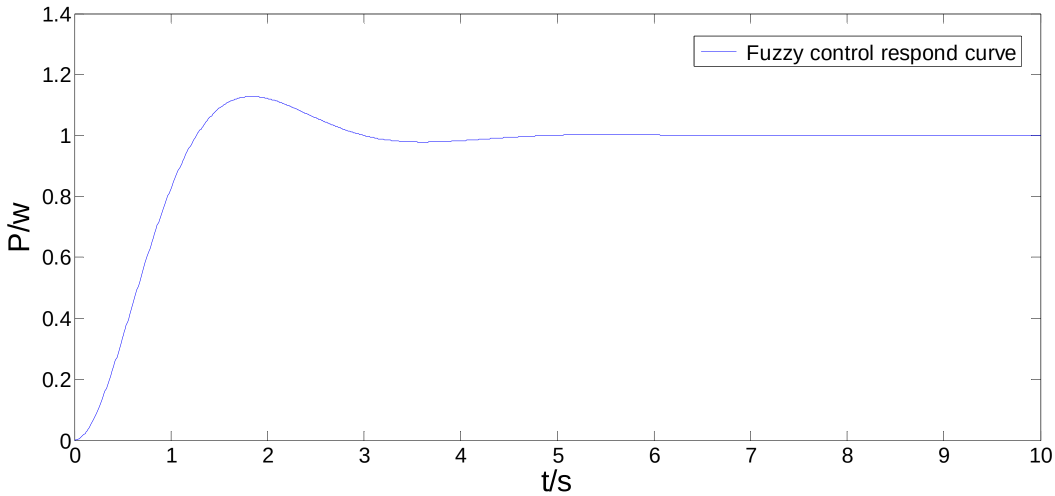

Figure 12. Fuzzy control respond curve for imitate diagram.

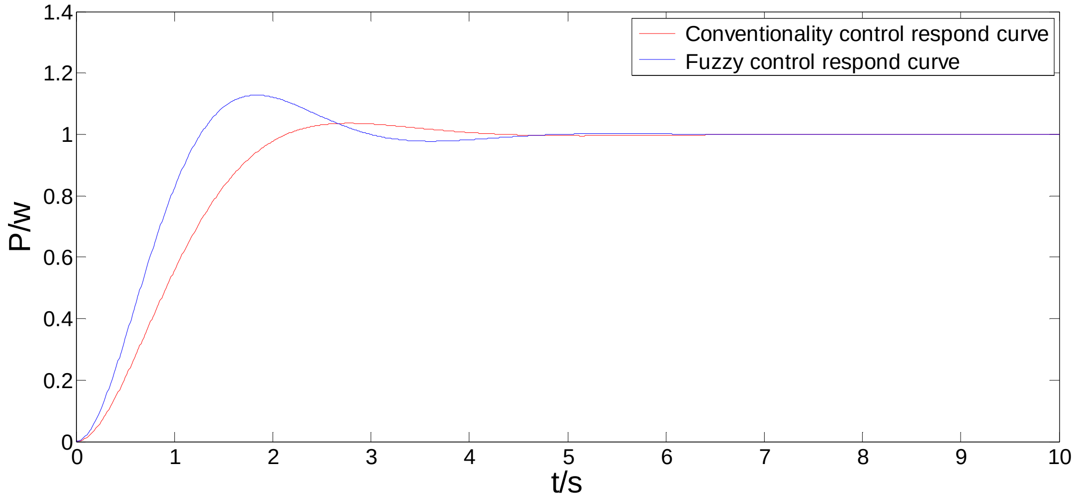

Figure 13. Control respond curve for imitate diagram.

The results show that the control curve rises smoothly and does not oscillate. Meanwhile, the control requirements of zero overregulation, fast response speed and good stability are realized.

6. Summary

(1). Taking the purpose of solving the directional power conversion of wind turbines, taking the establishment of the directional power conversion model of wind

Turbines as a breakthrough, and constructing the control frame diagram of the directional power conversion of wind turbines as a carrier, the control system is controlled by fuzzy control method. It meets the requirement of the directional power conversion control of wind turbine.

(2). Using Matlab / Simulink to perform conventional control and fuzzy control response curve simulation on the control system of the directional power conversion of the wind turbine, the simulation results show that the curve rises smoothly and does not oscillate before the system reaches stability. The control requirement of zero overregulation, fast response speed and good stability of the system is realized. At the same time, the power of the generator is well adjusted, and the control method is proved to be feasible and effective, which is helpful to the normal operation of the wind turbine.

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