The Fuzzy Control and Simulation of Wind Turbine's Variable-pitch

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Abstract—**Based on the analysis of variable-pitch control theory and process, a fuzzy variable-pitch controller has been designed through fuzzy theory. The simulation model of fuzzy variable-pitch controller is built in MATLAB, and its validity and advantages are tested through ideal signal and a simulation example formed by a classical wind power plant, which lay a basis for the following application into actual wind turbine control model.**

Keywords- fuzzy control; wind turbine; variable-pitch;

I. INTRODUCTION

Wind turbine system is a typically multivariable, nonlinear and indeterminate system. The relationship between wind energy and speed is cubic function. When the wind speed has a quick change, output power will also change quickly. Therefore, the control system of wind turbine system must regulate in a quick way so as to guarantee the system's stable operation. The control modes of output power of wind turbine are fixed-pitch control and variable-pitch control [1]. With the uprising development of wind turbine scale, the drawbacks of fixed-pitch control appear gradually. Therefore, variable-pitch control technology has been one of key technologies of wind power generation.

When wind speed changes continuously, variable-pitch wind turbine can retain the angle of attack of vanes at the best angle, which can keep wind turbine having the best conversion rate under different wind speeds. The rapid and reliable variable-pitch control strategy is so important to the wind turbine system's safe, efficient and stable operation. The traditional PID controlling method relies on exact linearization math model, which is difficult to adapt to the multivariable and nonlinear wind turbine system. For instance, when the wind speed changes quickly, PID regulation will show the hysteresis phenomenon in time. However, the intelligent control method needs no exact math model of the controlled object, but it still can achieve a good control effect based on the definite knowledge rule and study reasoning to remedy the drawback of traditional method applied in such nonlinear system as wind turbine [2]. This Paper adopts the fuzzy control of intelligent control method to realize the control of pitch.

II. VARIABLE-PITCH CONTROL MODEL OF WIND TURBINE SYSTEM

Set the power got from wind by wind turbine is P, the utilization factor of wind power is C_p. C_p is an important parameter of measuring wind turbine's efficiency, which is used to represent the energy's amount and its acquiring speed from wind. There is (1) and (2) based on Bates Theory[3]:

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)^{\frac{-21}{\lambda_i}} + 0.0068\lambda \qquad (1)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad , \quad \lambda = \frac{\omega_r}{V_\omega} R \qquad (2)$$

Among which β is pitch angle, the included angle of vane chord length and plane of rotation; λ is the ratio of wind speed and linear speed of vane tip, i.e. tip speed ratio; ω_r represents the angular speed of vane; R is wind wheel's radius.

According to the (1) and (2), the relation curve of C_p and λ in different pitch angle with MATLAB is shown in Fig. 1.

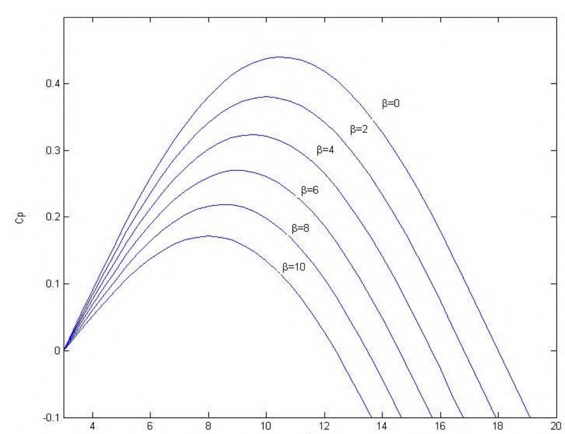

Figure 1. rotor power coefficient in different wind speed

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The following two conclusions are got from the analysis of Fig. 1:

a) to each pitch angle β, there will be a correspondingly largest utilization efficiency of wind energy C_p ;

b) to a random λ, the rotor power coefficient of wind turbine C_p will get the largest value when the pitch angle of vane is zero, and C_p will decrease when β increases.

Therefore, the theoretical basis of pitch angle control can be concluded: when the output power is under rated power, the controller will regulate the pitch angle from β to about 0°, and the relatively largest wind energy can be got at this time. Further, the speed regulation system can regulate the rotor speed that can regulate λ and change C_P, so the largest wind energy can be got in each corresponding wind speed. When the output power exceeds rated power, variable pitch control system will increase β to limit the output power within rated power. The controlling procedure of variable-pitch is shown in Fig. 2.

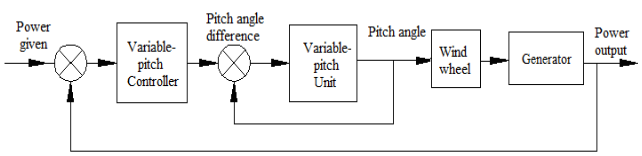

Figure 2. Variable-pitch control process

From Fig. 2, we can see that the variable-pitch control is a reaction control system in closed loop, which is constituted by variable-pitch controller and its motor-driven sets. Set the generator speed or real output power and reference value as input signal, and operating sets regulate the pitch angle on the basis of pitch angle's reference value that can control the output power of wind generator system, so that the unit can get the largest wind energy at the low wind speed and maintain rated power in high speed [4].

III. DESIGN OF FUZZY VARIABLE-PITCH CONTROL SYSTEM

A. The general design of fuzzy controller

The basic idea of fuzzy control is to take samples to acquire the exact value of controlled source and compared with index value to get error signal e. Generally, the error signal e and error rate of change △e as the input of fuzzy controller, and fuzzify e and △e to get fuzzy quantity E and △E and the subset of their fuzzy language. Then the fuzzy decision is made through fuzzy subset and fuzzy control rule (fuzzy relation) according to the combination rule of fuzzy reasoning and defuzzify the fuzzy controlled quantity to get the exact controlled value and control the controlled object through operating units. It is thus clear that the main functional module of fuzzy controller is to fuzzify the exact quantity input by controller and does fuzzy reasoning through related fuzzy rules and defuzzification [5]. See Fig.3 for the basic structure of fuzzy control system based on fuzzy controller.

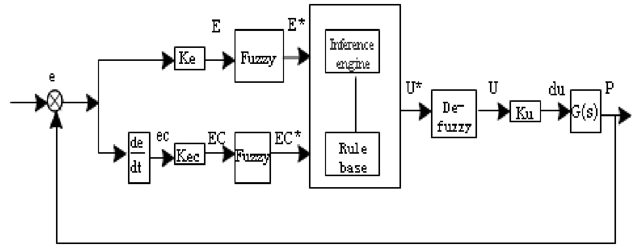

Figure 3. The basic structure of fuzzy control system

This paper adopts the planar fuzzy controller as feather system controller which is widely used at present. The inputs are pitch angle error and its change △e, output is pitch angle control command β_{cmd}. When the wind speed is higher than the rated speed, the pitch angle of paddle will be regulated according to the change of wind speed, by which the output power can also be regulated. The schematic diagram of system feather controller which adopts fuzzy controller can be seen in Fig. 4.

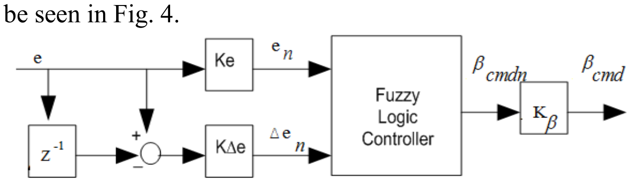

Figure 4. The function diagram of fuzzy variable-pitch controller

B. Fuzzification and fuzzy adjudication

Select the fuzzy sets of pitch error e, error change △e and pitch angle control command β_{cmd} as {NB (negative big), NS (negative small), ZO (zero), PS (positive small), PB (positive big)}. Fuzzification made through triangle membership function, select the fuzzy domain of input variable e and △e as [-0.2, 0.2], the fuzzy domain of output variable as [-0.35, 0.35], and select the scale factor as constant, and confirm that K_e, $K_{\Delta e}$ and K_β respectively are 1.0, 1000 and 100 through trail.

Adopt the control rule and fuzzy inference of Mamdani model and choose IF-THEN way when fuzzily mapping the input variable into output variable, as follow:

IF< e verges to NB> and < △ e verges to NB> THEN< β_{cmdn} verges to NB >;

IF< e verges to O> and < △e verges to O > THEN < β_{cmdn} verges to O >;

IF< e verges to PB> and < △e verges to PB > THEN < β_{cmdn} verges to PB >

The general fuzzy control rule can be expressed as the fuzzy conditional statement in table 1. There are 25 rules can be acquired the expected pitch angle β_{cmdn} .

TABLE I. RULE LIST OF FUZZIFICATION

β_{cmdn}		△e				
		NB	NS	ZO	PS	PB
e	NB	NB	NB	NS	NS	ZO
	NS	NB	NS	NS	ZO	PS
	ZO	NS	NS	ZO	PS	PS
	PS	NS	ZO	PS	PS	PB
	PB	ZO	PS	PS	PB	PB

Set an example, if e is NB and △e is PB, β_{cmdn} is ZO. When input error is PB, input error change is NB, which means the controlled quantity is much smaller than index value. However, the error is being reduced in a relatively large speed that the chosen proportionality coefficient is appropriate, and keeps the current proportionality coefficient invariant that ZO can be fuzzy reasoned.

The output of fuzzy controller is a fuzzy subset, but the controlled object only accepts exact controlled variable, so the question is to transform the fuzzy variable to exact variable. Fuzzy adjudication through membership weighted average decision method to get β_{cmdn} [5], as formula (3) shown:

$$\beta_{cmdn} = \sum_{i=1}^{N} \mu_i C_i / \sum_{i=1}^{N} \mu_i \qquad (3)$$

In the (3), N represents the sum of rules; μ_i represents the membership of I times regular; C_i represents the random point of membership function and coordinate point of output variable [$C_i \in$ {-0.35,-0.5, 0.0, 0.3, 0.5}]. The pitch angle after real regulation β_{cmd} can be got through the product of Scaling factor.

IV. MATLAB MODELING AND SIMULATION

Through the above design of fuzzy logic controller and confirmation of each part parameter, the simulation model of pitch controller based on fuzzy logic can be built. The whole controller simulation model is shown in Fig. 5 [6]-[8].

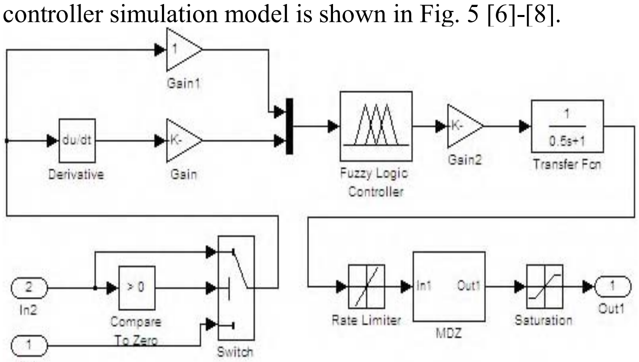

Figure 5. The simulation model of fuzzy pitch controller

The input signal of the controller is d-value of wind turbine output power (or generator revolving speed) and reference power. When the output power (or generator revolving speed) is lower than the rated value, i.e. the input signal is negative, the output oft controller should be 0; when the output power (or generator revolving speed) is higher than the rated value, i.e. the input signal is positive, the output result of controller should be a positive value, and increase as input value enlarges.

To test the correctness of the controller, we choose the amplitude of sinusoidal signal 0.2 as ideal input signal test. In the former half of the cycle, because the sinusoidal signal is positive which is corresponding to the positive d-value of output power of wind turbine (or generator revolving speed) and reference value, the output should be positive and roughly be parabolic shape; in the later half of the cycle, the sinusoidal signal is negative which is corresponding to the negative d-value of output power of wind turbine (or generator revolving speed) and reference value, the output should be 0. Fig. 6 is the actual response of the controller in sinusoidal signal, which basically coincides with the theory, and tests the correctness of the controller and its simulation model design.

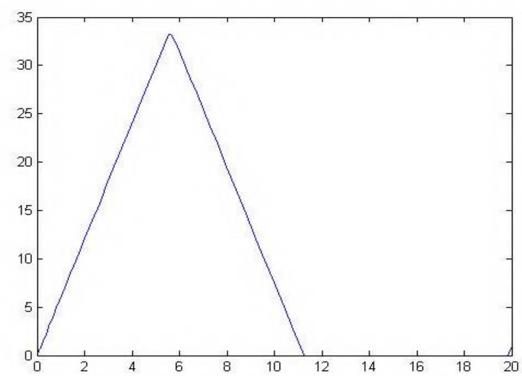

Figure 6. The response of the controller in the ideal sinusoidal signal

In order to further test and verify the effects of fuzzy control strategy, a simulation example formed by a classical wind power plant inserted into power distribution network is established in Matlab. Fuzzy control and traditional PI control are also adopted respectively. Parameters of the wind driven generator are as follows: radius of rotation of the wind wheel is 40m. Swept area of the fan is 5026 m^2 . P_{mN} is 1.5×2MW; S_N is 1.5×2/0.9MV.A. Stator impedance [R,L] is [0.004843, 0.1248]p.u.. Rotor impedance [R,L] is [0.004377, 0.1791]p.u.. Excitation reactance is 6.78 p.u.. Number of pole-pairs is 3. Calculating with the wind speed in Fig. 7(a), output powers of these two kinds of control mode are demonstrated respectively in Fig. 7(b) and Fig. 7(c).

Seeing from Fig. 7, we could find visually that the wind turbine generator with the fuzzy variable pitch control enjoys a smaller fluctuation when the wind speed changes greatly. By calculation, the mean square error of the output power fluctuation under the traditional PI control is 0.0436 and that under fuzzy control is 0.0358. As a result, this new kind of control mode is more flexible and enjoys a better control effect.

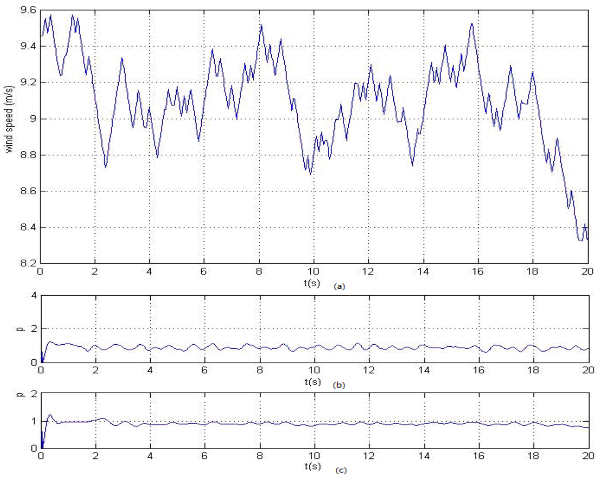

Figure 7. The wind speed and output powers of PI and fuzzy controller

V. CONCLUSIONS

Seeing from the simulation result, we can know when the wind speed is higher than rated speed, the system adopts the variable-pitch control strategy, and regulates the angle of the paddle pitch and input energy of wind unit to make the output power of wind turbine stable around the rated power. By using variable-pitch controller with fuzzy control, the wind turbine system has good dynamic property and steady-state performance, which tests the correctness of the model, and lays a foundation for the application of fuzzy variable-pitch controller into the actual wind turbine model.

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