Wind turbine fuzzy logic individual pitch control based on chaotic optimization

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Abstract. Fuzzy-logic-based algorithms applied in the individual pitch control make the effect of the controlled system imperfect. Thus, an adjustable factor algorithm of adaptive fuzzy PID controller based on chaos theory was proposed. To achieve good control effects, the chaos algorithm was applied in designing the fuzzy PID control system to optimize the parameters of the membership functions of controller under the control of the fuzzy PID. Simulation based on matlab/simulink was made to analyze and to compare fuzzy PID individual pitch control system with and without the chaos algorithm respectively. Simulation results show that, the fuzzy PID individual pitch control system based on chaos algorithm was much more smooth and steady and response faster than the system without chaos algorithm within the rated wind speed.

1. Introduction

Individual pitch control system is an important component of the large wind turbines. It has good effect in the improvement of stability and dynamic stability of wind turbine power output[1-2].The combination of fuzzy control and traditional PID control has been applied in pitch control, due to complex nonlinear system of wind turbines[3]-[8].However, the rules of fuzzy controller and parameter setting have the nature of subjectivity and uncertainty. The control effect has been made imperfect because of the long-term accumulation of experience [9]. With the gradual improvement of the complexity of the controlled object and the continuous improvement of the control effect, the parameters of fuzzy controller are particularly important to be set and optimized.

Chaos motion has characteristics of randomness and ergodicity and inherent regularity [10-11]. Chaos motion can get approximate optimal parameters of fuzzy controller according to self regular pattern. In this paper, fuzzy-logic-individual pitch control based on chaos optimization is proposed. Parameters of fuzzy PID controller are optimized using chaos optimization algorithms.

2. Wind turbine individual pitch control strategy

The main strategies of individual pitch control can be divided into two types, which include the one based on blade acceleration signals weight coefficient and the one based on blade azimuth angle weight coefficient [12]. With the consideration of the first strategy being hardly achieved, in this paper, the second strategy will be adopted. The weight coefficient can be determined by the differences of azimuth angle during the wind turbines blades rotate.

Wind turbines operate constantly during the normal working condition. The blade can be located during azimuth angle θ [13]. The force of each blade in different position makes difference, by which weight coefficient can be confirmed [14]. Each weight coefficient K of individual pitch control system can be calculated by equation (1).

$$K_i = \frac{3\left(1+\dfrac{1}{2}\dfrac{R}{L}\sin\theta_i\right)^2}{\displaystyle\sum_{i=1}^{3}\left(1+\dfrac{1}{2}\dfrac{R}{L}\sin\theta_i\right)^2} \tag{1}$$

Where i shows the number of blade, and θ_i shows the angle of azimuth. θ_i can be gotten by using equation $\theta_i = \omega t + (i-1)\frac{2}{3}\pi$. R (m) is radius of blade, and L(m) is the height of blade shaft relative to ground. $\omega(\text{rad/s})$ shows the angular velocity of wind turbine rotation. Each variation of blade can be totally known with the calculation of equation (2).

$$\begin{cases} \Delta\beta_1 = K_1 * \Delta\beta \\ \Delta\beta_2 = K_2 * \Delta\beta \\ \Delta\beta_3 = K_3 * \Delta\beta \end{cases} \tag{2}$$

Where $\Delta\beta$ is the variation of pitch angle. The weight coefficient K_i of each pitch angle distributes the variation of each blade $\Delta\beta_i$, to achieve individual pitch control, which is shown in Figure 1.
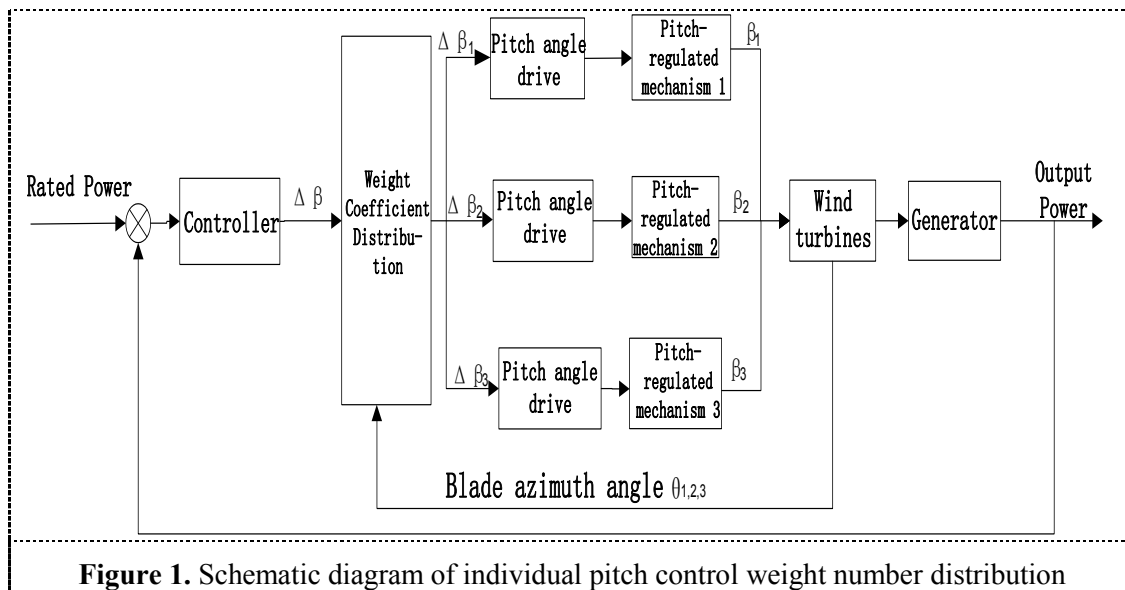

Figure 1. Schematic diagram of individual pitch control weight number distribution

The final control effect is affected by the distribution of K_i and the output of pitch angel $\Delta\beta$. The output of $\Delta\beta$ is usually dominated by the combination of fuzzy control and traditional PID control. By using the relative rules of fuzzy control, the parameters including Kp, Ki, Kd of PID will be adjusted online. The output of systems achieved by the PID algorithms is shown in Figure 2.

The output power of wind turbines is kept around the rated power. Two-dimensional fuzzy controller with dual input and three output is used to obtain the control effect. Where *E* is the power difference and *EC* is the change rate. The parameters *Kp*, *Ki*, and *Kd*. are the output of PID controller. To simplify the algorithm, trigonometric function was adopted to be Double-Input membership function, and Gaussian function was used to be three-output membership function. The final control effect can be achieved by fuzzy inference and defuzzification. The effect of final control will be

influenced by the of controller parameters adjustment. In this paper, individual pitch control is improved by optimizing parameters of the fuzzy controller.

3. Fuzzy controller based on chaos optimization

In spite of good robustness and simple application, the final control effect of fuzzy control can be affected by many other factors. The final effect will be influenced by quantification factor, scale factor, membership function and fuzzy control rules[15]. Chaos optimization with chaotic variable search can be an effective method to optimize the membership function of fuzzy controller[10].In this paper, chaos optimization algorithm with randomness and ergodicity is proposed, the fundamental principles of which is shown in Figure 2.
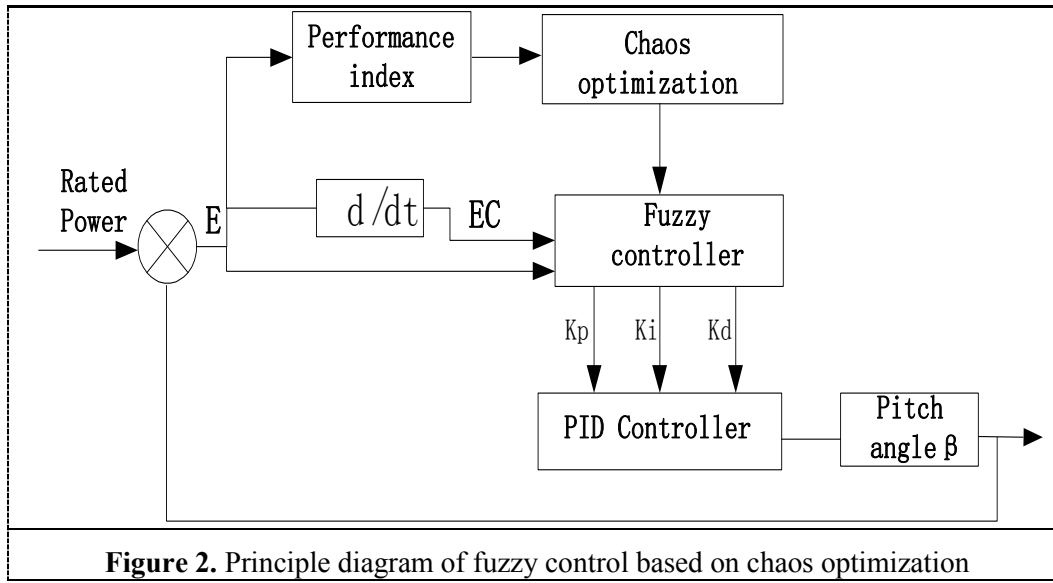

Figure 2. Principle diagram of fuzzy control based on chaos optimization

The membership functions of parameters E and EC in individual pitch controller are adopted in trigonometric function. The eigenvalue can be gotten by the following equation.

$$\{a,b,c\} = CH\left[\sup(x)\right]$$

(3)

Where a,b,c is the left, right, and vertex of a triangle respectively.

The membership functions after regularization are shown in equation (4).

$$\mu(x_i) = \begin{cases} (x_i - a_i^l)/(c_i^l - a_i^l), x_i \in \left[a_i^l, c_i^l\right], \\ (c_i^l - x_i)/(b_i^l - c_i^l), x_i \in \left[c_i^l, b_i^l\right], \\ 0, \\ \qquad\qquad\qquad \text{Others} \end{cases}$$

(4)

Where i takes values in 1-2, *and* x_1 is input of E *and* x_2 is input of EC. Evaluation function of control results can be shown in equation (5) [16].

$$J = \omega_1 \int_0^1 t \left|e(t)\right| dt / \max(e(t)) + \omega_2 \sigma$$

(5)

Where σ can be considered to be the overshoot of centesimal system, besides, $\omega_1 + \omega_2 = 1$.

The chaotic variable can be obtained by means of the Logistic map, as shown in equation (6).

$$X_{n+1} = \mu X_n^*\left(1 - X_n\right), \quad 0 < X_0 < 1$$

(6)

Where n is frequency of Chaos optimization, and can take values in 1 to N. The parameters are in the chaotic states when μ takes the value of 4, where X_n is completely ergodic within 0 to 1. Variables to be optimized will be converted into chaotic variables and the global optimum can be found by searching through chaotic variables.

Parameter optimization steps are as follows:

Step.1: x can be considered to be in the state of chaos when μ take the value of 4. The state of chaos will be extremely sensitively affected by the initial value. Three different initial values are taken value within 0 to 1 and plugged into Logistic map separately, where 3 chaotic variables can be obtained.

Step.2: The parameters to be optimized can update according to equation(7):

$$\hat{x}_{i,n}^{*} = x_i^{*} + z(t)\,x_n$$

(7)

Where i takes value of 1, 2, 3 and $z(t)$ is time-varying parameter. x_i^{*} is a set of parameters in the optimal performance index at present, and $\hat{x}_{i,n}^{*}$ is a new set of parameters.

Step.3: Chaotic rough search is made according to the performance index. The value of performance index is compared with the performance index in limited optimization times. The value of best performance index can be chosen as sub-optimal value.

Step.4: The optimal value can be found from minimum performance index during iteration.

4. Chaos optimization fuzzy PID Independent variable pitch simulation

Part of relevant parameters of individual pitch fuzzy PID controller can be obtained from table 1. The random wind speed near rated speed has been simulated shown in Figure.3. The control effect of the independent variable pitch fuzzy controller based on chaos optimization has been simulated and analyzed, according to chaos optimization method in this paper.

Table 1. The main parameters of WTGS.

Wind turbine and generator parameters	Value
Rated power	1500 kw
Rated wind speed	11 m/s
Impeller radius	38.5 m
Wind rotary inertia	$1\times10^4\ kg\,/\,m^2$
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Generator pole number	2
Generator rotor inertia	70 kg/m^2
Generator voltage	690 V

Figure 3. Diagram of random wind speed signal

Figure 4. Output power of fuzzy controller based on chaos optimization and without chaos optimization
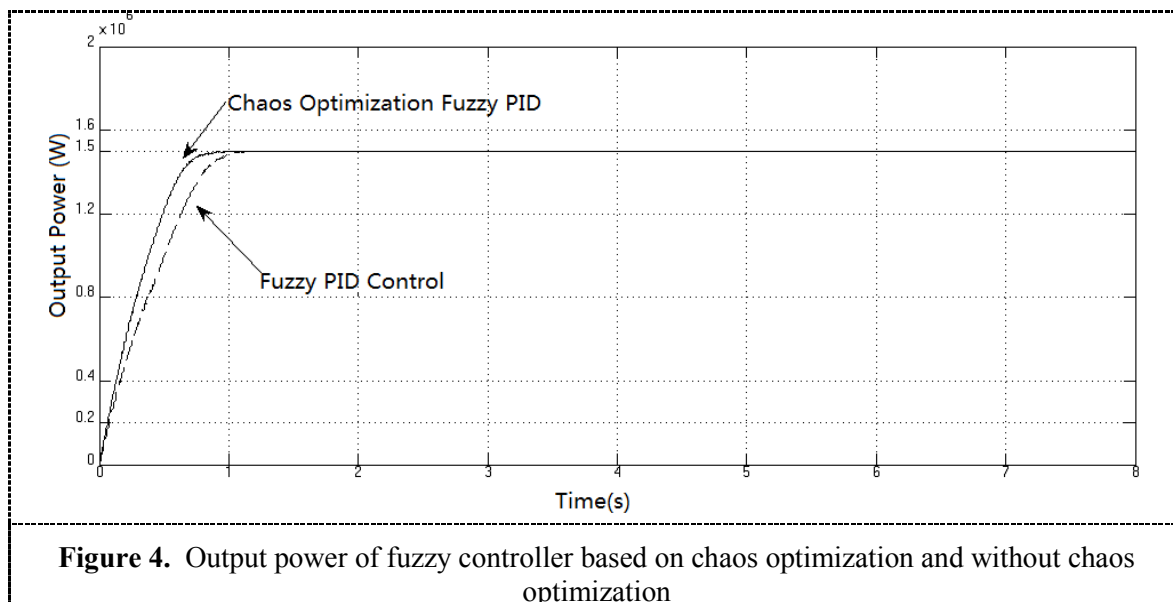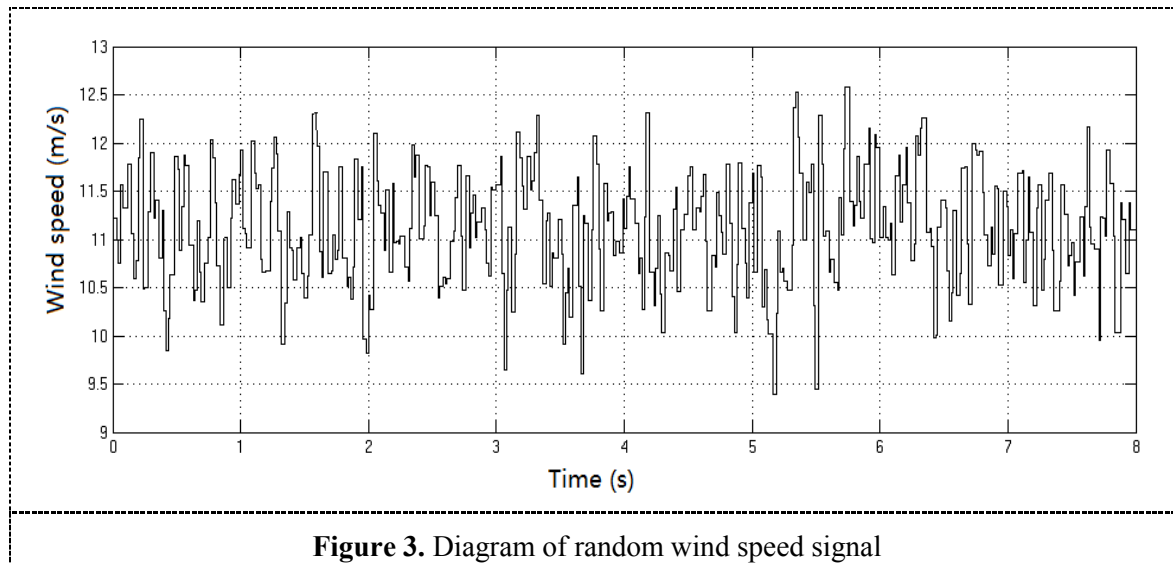
Figure.4 shows the output power simulation of fuzzy PID control which has been Chaos optimized and not optimized. The simulation results show that under the same conditions, the fuzzy PID controller optimized by chaos algorithm controls better and faster than the one without optimized.

5. Conclusion

The final control effect is affected by the uncertainty of the parameters in the independent pitch fuzzy controller. In this paper, a chaos optimization method for individual pitch fuzzy PID control is proposed, and the control effect of the independent pitch fuzzy controller has been meliorated. Simulation results based on matlab/simulink shows that the independent variable pitch fuzzy controller optimized by chaos algorithm responses faster and controls more accurate than the one without optimized. It can be used as a reference for the improvement of the individual pitch fuzzy controller.

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