Journal of mathematics and computer science 8 (2014), 105-112

Contents list available at JMCS

Journal of Mathematics and Computer Science

Journal Homepage: www.tjmcs.com

Fuzzy Controller Used in Yaw System of Wind Turbine noisy

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Article history:
Received May 2013
Accepted June 2013
Available online June 2013

Abstract

Yaw system plays an important role in wind turbine generator because of the direction and intensity of wind is time-varying. Because the model of yaw system is difficult to be set up and some parameters of controller are uncertain. General PID controller is not suit for all operation scope. This paper presents a fuzzy controller to deal with the control of yaw system with disturbances and uncertain factors. To provide a better tracking effect for system, an approach of fuzzy rule is adopted, which PID parameter is adjusted by fuzzy rule when Wind Turbine Generator is operating. Simulation results show that using the present scheme combining conventional PID with fuzzy control, the yaw system can posses better tracking characteristics than PID controller does. It is found from simulation that the fuzzy controller gives the best performance compared to PID controller.

Keywords: Yaw System, Wind Turbine Generator, Fuzzy PID controller.

1. INTRODUCTION

As a green energy, the application of wind power plays a positive role in solving energy and environmental problems. Therefore wind power generating is developing and popularizing worldwide[1]. Wind direction has a nature of stochastic change. This characteristic has a big influence on the generating efficiency of wind turbine generator. The control of yaw control system becomes very important for the horizontal axis wind-driven generator. Yaw system of wind turbine generator is disturbed by many factors, such as load disturbance and friction which is not able to be eliminated, as well as the influence on wind power generator by the change of wind direction and intensity and etc. All factors make the model of wind measurement and yaw system be difficult[2].

Both modern and classical control theory rely on the model of controlled object. These theories are hard to be put into practice because of the uncertainty of the model. With the development of intelligent control theory and measurement technology, some scholars studied yaw strategy of large-scale wind turbine generator and got some useful results[3-5].Fuzzy control doesn’t need exact model of controlled model and is suitable for strong coupling, time-varying and nonlinear system or control. It was applied in wind direction measurement because of its simple and good robust[6-7]. In contrast, conventional PID is although simple and easy to complement but possesses poor robustness[10-11]. By means of combining the conventional PID with fuzzy control, a new yaw system controller can be made, which is simple and has definite robust characteristics. This controller has important application value to improve the yaw system performance and efficiency of wind turbine generator set[8-10]. The basic concept of the fuzzy PID is that conventional PID control combines with fuzzy control theory. The PID parameter can be adjusted according to the operation condition by the fuzzy rule. This makes fuzzy PID not only has characteristic of flexibility and adaptability of fuzzy control but also possesses a wide range application and high precision of conventional PID.

2. YAW SYSTEM

Yaw system consists of yaw control system and yaw drive system. Yaw control system is peculiar servo system of wind turbine generator, which mainly makes wind wheel track the wind direction and unwind cables automatic when cable is winded a certain amounts rings[12]. When angle between wind wheel and wind direction existed, the control system will adjust the wind wheel to orientation same as wind direction after a time lapse for testing. Its typical control functional block diagram is shown in Fig. 1. to desired attitude in a reasonable length of time after a disturbance of the pitch angle, or make the pitch follow a given command as quickly as possible [11].

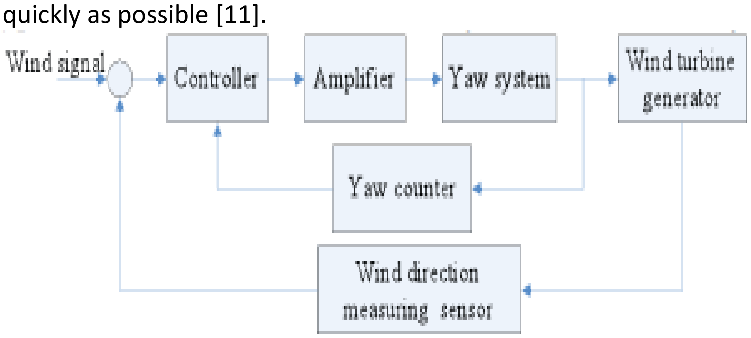

Fig. 1 Typical yaw system functional block diagram [17]

3. FUZZY PID FOR YAW SYSTEM

Fuzzy control is a automatic control. It imitates human thinking to act on controlled object bases on fuzzy control inference, basic theory of fuzzy math, fuzzy language and logic rule inference. It is much suitable for the system whose model is difficult to be built exactly.

3.1. Structure of Fuzzy PID

Compound controller consists of conventional PID and fuzzy controller. Its functional block diagram is shown in Fig. 2 as below:

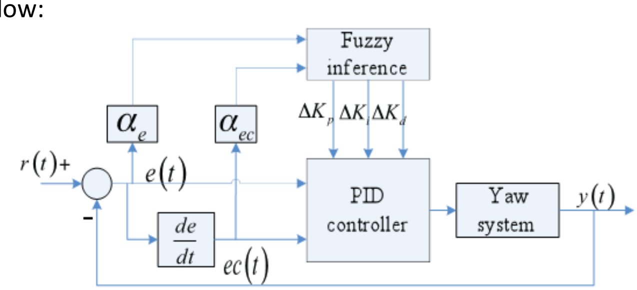

Fig. 2 Structural diagram of fuzzy PID [17]

Fuzzy PID controller is designed as following process:

Firstly, the input and output variables of controller is determined according to the requirement and characteristic of controlled object; Secondly, the domain and membership function of input and output is chosen;

Then the input variables are fuzzified and the fuzzy inference rules is designed; Finally, the output variable is defuzzified. PID parameters are corrected according to equation (1).

$$\begin{cases} K_p(k) = K_{p0} + \Delta k_p(k-1) \\ K_i(k) = K_{i0} + \Delta k_i(k-1) \\ K_i(k) = K_{d0} + \Delta k_d(k-1) \end{cases} \quad (1)$$

Where K_{p0}, K_{i0} , K_{d0} are initial parameter values of PID controller; $K_p(k)$, $K_i(k)$, $K_i(k)$ are PID parameter value on k time, $\Delta k_p(k-1)$, $\Delta k_i(k-1)$, $\Delta k_d(k-1)$ are parameter increment of PID controller on k-1 time.

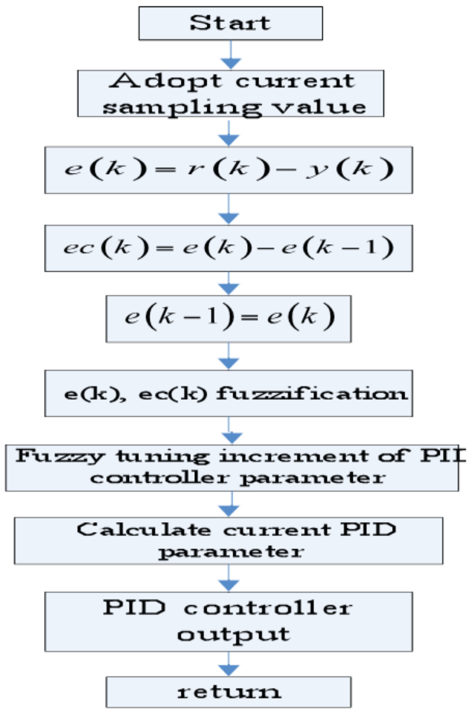

Fig. 3 Workflow of fuzzy PID control[17]

The whole control system flow chart is shown in Fig. 3. Defuzzification of result is acted on motor to track wind direction with yaw motor.

4. DETERMINATION OF FUZZY PID RULE

The input variables of fuzzy PID controller are angle error and error derivative . Fuzzy PID either conquers effectively nonlinearity of system transient process or track target exactly in the linear process through tuning PID parameter according to and . Fuzzy control decision-making table (FDT) is formed when fuzzy rules is in the process of a series of fuzzy operations and inference. During track period of the wind direction, it is just needed to fuzzify the input and . Then the PID coefficient increments are determined by table look up to complete the system of fuzzy control.

Fuzzy rules are shown as following:

- Role of proportional coefficient is to accelerate the system response speed and improve system accuracy. The bigger the , the faster the system respond speed and the higher the regulation accuracy. But system is easily to overshoot and lose instability if is too big.
- The integral coefficient is to eliminate steady-state error. The greater the , the faster the eliminated process of system static error. But if is too big, integral saturation will be generated in the beginning,

which should make large overshoot. Whereas static error is difficult to be eliminated and the system regulation accuracy is deteriorated.

- Differential coefficient can improve the system dynamic characteristics. It reflects the variation trend of error sensitively. Differential control contributes to speed up system response speed, reduce the overshoot and improve system stability. Fuzzy rules table are established as shown in Table11, 2 and 3 based on above principle and experience[13].

5. System modeling

Fig. 4 shows the configuration of the wind energy conversion system (WECS). The squirrel cage induction generator is driven by a horizontal axis wind turbine and is connected to the power network through a line. A bank of capacitors is adjusted at the generator terminals to perform the voltage regulation [18].

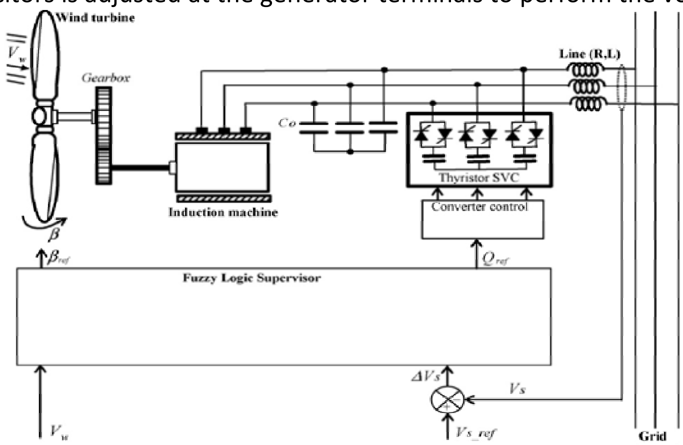

Fig. 4. Wind turbine system configuration[18].

6. THE DESIGN OF FUZZY CONTROLLER

Fuzzy control is based on the artificial experience. Therefore, for those control problem which can't be resolved by traditional methods can often be resolved by the fuzzy control technology. By the fuzzy control technology, it does not know the mathematical model of the plant and easy to control uncertain systems or nonlinear control systems and can restrain the strong disturbance. The basic structure of fuzzy control system shown in Figure 5.

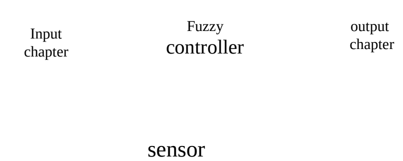

Fig. 5 The basic structure of fuzzy control system [15].

The only difference is to control the device by fuzzy controller to achieve the desired performance. Fuzzy self-tuning PID controller is a conventional PID regulator based on the fuzzy set theory, under the absolute control error and deviation change and the absolute value of the rate, on-line automatically adjusting the proportional coefficient KP, integral coefficient of KI and differential factor KD of the fuzzy controller. Fuzzy controller is a nonlinear control device, using fuzzy reasoning algorithm. The sample data of the controlled process are taken as the clear amount of input to the controller, and then after input quantization factor calculation, are transferred into fuzzy values, so they can be used for fuzzy reasoning by fuzzy language and rules.

To the other part of process, the reasoning results are firstly transferred into clear values by anti-fuzzy inference and thus derive the control output with quantified factor calculation used as the control value for the controlled process. Based on the MATLAB fuzzy logic toolbox, the above control algorithm can be easily implemented [16].

7. DESIGN OF NOMINAL FUZZY CONTROLLER

In order to design the PID parameters based-on fuzzy controller, at first the simplest structure of two-input single output nominal fuzzy controller is given. At any given time instance n with a sampling time Ts, the two input variables of fuzzy controller, error state variable and error change are defined as

$$e(n) = y(n) - r(n) \quad (2)$$

$$\Delta e(n) = e(n) - e(n-1) \quad (3)$$

And its output variable u(n) is the control signal of process.

Without loss the generality, the system is assumed to have r inputs denoted by the r-dimensional vector $U(kT)=[u_1(kT)...u_r(kT)]^T$ and s outputs denoted by the s-dimensional vector $y(kT) =[y_1(kT) - y_s(kT)]^T$. Most often the inputs to the fuzzy controller are generated by some function of the plant output y(Kt)and reference input $y_r(kT)$. The inputs to the fuzzy controller are the error $e(kT)=[e_1(kT)...e_s(kT)]'$ and changes in error $c(kT) =[C_i(kT) ...C_s(kT)]^T$ defined as

$$e(kT) = y_r(kT) - y(kT) \quad (4)$$

$$c(kT) = \frac{yr(kT) - y(kT)}{T} \quad (5)$$

Where $e(kT) = y_r(kT) - y(kT)$ denotes the desired plant output, T is sample period.

For greater flexibility in fuzzy controller implementation, the universes of discourse for each plant input are normalized to the interval $[-1 \;\; 1]$ by means of constant scaling factors. The gains g_e, g_c and g_u were employed to normalize the universe of discourse for the error e(kT) and changes in error c(kT), and controller output u(kT) respectively.

With the plant input is generated from IF-THEN control rules of the form

If $\tilde{e}$ is $\tilde{E}_i$ and $\tilde{c}$ is $\tilde{C}_j$ then $\tilde{u}$ is $\tilde{U}_l$

Where $\tilde{e}$ and $\tilde{c}$ denote the linguistic variables associated with controller inputs e and c respectively. $\tilde{u}$ denotes the linguistic variable associated with the controller output u, $\tilde{E}_i$ and $\tilde{C}_j$ denote the linguistic values respectively and $\tilde{U}_l$ denotes the consequent linguistic value [17] .These are 49 rules that have been utilized as a closed-loop component in designing the FLC for maintaining pitch angle of aircraft system as defined in Table **1** [7].

TABLE 1. FUZZY CONTROL RULES

$e / \Delta e$	NL	NM	NS	ZR	PS	PM	PL
PL	NS	ZR	PS	PM	PL	PL	PL
PS	NM	NS	ZR	PS	PM	PL	PL
ZR	NL	NM	NS	ZR	PS	PM	PL
NS	NL	NL	NM	NS	ZR	PS	PM
NM	NL	NL	NL	NM	NS	ZR	PS
NL	NL	NL	NL	NL	NM	NS	ZR

8. IMPLEMENTATION AND RESULTS

The membership functions for error and Control surface of fuzzy are shown as Figs. 6 and 7 respectivly.

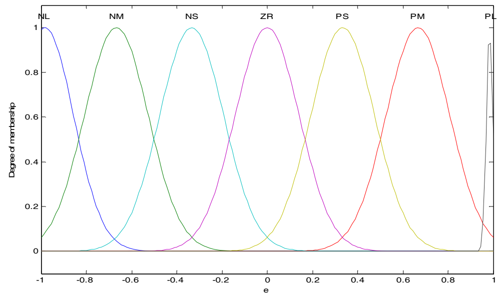

Fig. 6 Membership function of input e and Δe

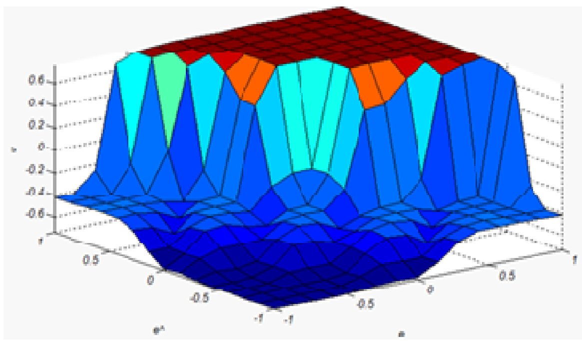

Fig. 7 Control surface of fuzzy logic controller proposed

9. SYSTEM SIMULATION AND ANALYSIS

As the DC motor is a negative feedback closed-loop system, under normal circumstances, its transfer function is:

$$\frac{n(s)}{U(s)} = \frac{-1}{(T_m T_i s + T_m s + 1)} \quad (6)$$

Where: is ratio of transmission of motor under rating magnetic flux; is electromechanical time constant; is load torque; is Laplace transform of motor speed; is Laplace transform of motor voltage. Transfer function of yaw motor is established according to document[14]:

$$G_1(s) = \frac{25}{[(0.007s+1)(0.9s+1)]} \quad (7)$$

Transfer function of speed reducer is:

$$G_2(s) = \frac{30}{s} \quad (8)$$

So the system transfer function is:

$$G(s) = \frac{750}{[s(0.007s+1)(0.9s+1)]} \quad (9)$$

System simulation is carried out in Simulink system. The result of fuzzy PID control is compared with PID. A step signal is adopted as input signal (wind direction signal). The simuation results are shown in figure 8. Fig. 8 is a output response with step signal.

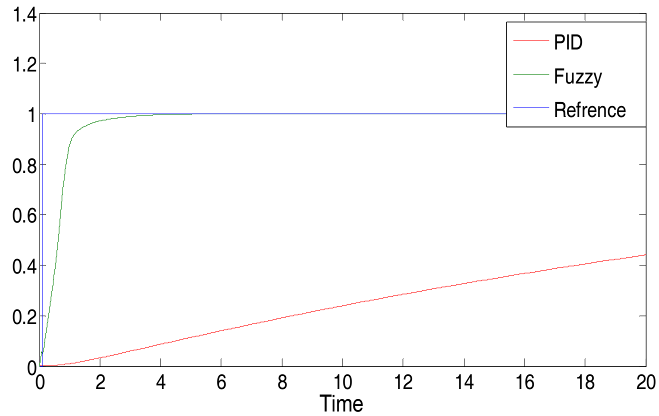

Fig.8. Output response with step input ignal

From the above, it is shown that there are big overshoot, long system response time and poor robustness for disturbance in general PID control. Fuzzy controller improves the system response speed and reduces the regulation time, which makes system have a good tracking characteristic and litter overshoot.

10. CONCLUSTION

In this paper, a novel fuzzy PID controller for yaw control 0f wind turbine generator is presented which combines fuzzy control with conventional PID. This controller not only possesses the simple structure from PID, but also completes with robustness from Fuzzy control. Establishment of fuzzy control rule is to avoid the effect by disturbance and uncertainty, which is in lien with control strategy of actual system better. This control scheme enhances the system response stationarity and control precision to improve the system performance and structure of fuzzy is simple and easy to complement.

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