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Simulation Research of Fuzzy-PID Synthesis Yaw Vector Control System of Wind Turbine

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Abstract:- Enhancing the stability and robust of yawing system effectively, carrying out the simulation research of fuzzy-PID synthesis control. Designing the yawing vector control system with the synthesis controller of fuzzy-PID, modeling the system with Matlab simulation software, and taking simulation test. Comparing the simulation curves with common PID control and fuzzy PID subsection control, the result indicate that the fuzzy-PID synthesis control system has better performances in the stability and robust of yawing system, which increase the safety factor of system.

Key-Words:- Fuzzy-PID synthesis; Stability; Robust; Yawing control; Vector control; Wind turbine.

1 Introduction

Wind energy is the fastest developing green energy. With the consumptions of charcoal and petroleum, fossil energy is drying up, also the pollution of environment becomes more worse, so people bestow favor on clean energies. In many renewable energies, the using of wind energy has made quite great progress[1].

Because of natural reasons, wind possesses randomicity, wind direction changes constantly. To enhance the conversion efficiency of wind power, yawing control system becomes an important part of horizontal axis wind turbine generator system (WTGS). With the change of wind, yawing system starts frequently to facing wind[2]-[3]. The stability and robust is the premises of yawing control. The yawing system often takes yawing control in the work state of wind turbine, in the process of yawing, with the fluctuation of peg-top torque and resistance torque and so on, the load of yawing system becomes fluctuation ,which affect the stability of yawing speed[4-5], and furthermore have a great effect to the vibration of blade and tower, all of these threaten the safety of WTGS. How to enhance the stability and robust of yawing system becomes more and more important[6]-[7]. Also the more and more larger wind turbines request more efficient yawing control to guarantee the stability and robust of yawing recently years, which give a good chance to study the yawing controller[8]-[10].

Asynchronous cage induction-motor, as a executive machine, is in common use because of its characteristic of simple structure, easy maintenance and firm durableness. However, there is serious coupling and nonlinear between of the parameters of motor, which make it difficult to ensure the motor to have upper timing performance and precision with routine control. Vector control realize the dis-coupling of motor’s parameters perfectly, the performance of control can be compared with the control of DC motor. And the fuzzy control system with fuzzy controller has the characteristic of nonlinear and artificial intelligence, don't need precise mathematical model[11]-[13], the robust and adaptability is also better than routine PID control. But the control precise of PID is better than fuzzy control.

In order to enhance the stability, robust and control precise of yawing system to facing wind efficiently, this article have a research at the design of controller based on the merits of vector control, fuzzy control and PID control. This article builds yawing vector system with fuzzy-PID synthesis controller, models the system with Matlab simulation software, and takes simulation test. Comparing the simulation curves with common PID control and fuzzy PID subsection control, the result indicate that the synthesis fuzzy-PID control system has better performances in the stability and robust of yawing system, which increase the safety factor of system. The combining research of vector control and synthesis fuzzy-PID has significance in enhancing the stability and robust of yawing system.

2 Yawing System

Yawing system usually consist of yawing bearing, yawing driven device, yawing braking system, yawing counter, untwist protection etc.. The main function: one is cooperating with the control system of WTGS to make the rotor always face the wind, so that enhancing the converter efficiency of WTGS; the other is to guarantee the safe operation of WTGS. The simple structure fig. of WTGS with the yawing system is showed as fig.3.

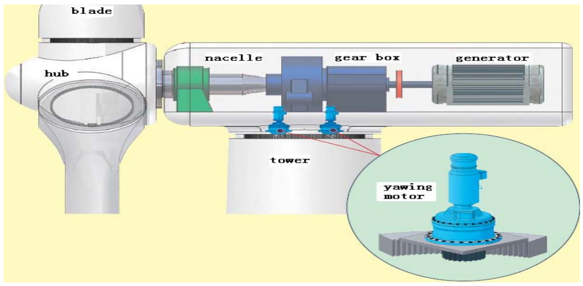


Fig.1. The simple structure fig. of WTGS

2.1 Vector Control System

Vector control realize the independent control of Flux and electromagnetic torque, which not only makes the system have a good static response, but also have a good dynamic response. At the fluctuation of torque load, in order to make the yawing system be faster adjusted to realize the good performance of static and dynamic response of yawing system and enhance the stability and robust of system, this article adapts vector control to control the executive machine of yawing system. The structure sketch map of vector control system is showed as the fig.2.

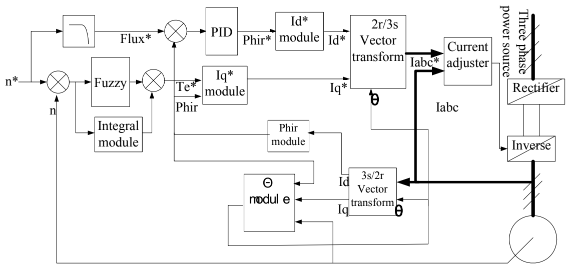


Fig.2. Structure sketch map of Vectors Control

System comprises of speed vector control loop and flux vector control loop. From the sketch map we can know, the fixed value of flux is decided by the speed fixed value and their function relation, and the fixed value Id * is given out through PID modulation and current computation module. The speed error value gives out the Te* after fuzzy-PID synthesis controller, then gives out the value of torque control Iq* through the computation. The fixed values Id*and Iq* become Iabc* through two to three rotation vector transform, then is compared with the measuring value Iabc and gives out the control pulse of main circuit to realize the vector control of yawing system. The structure of two vector control loop of speed and flux enhances the control stability of yawing vector system.

2.2 Simulation Model of yawing system

It is convenient for Simulink to build the simulation model of dynamic system, take a simulation test and analysis the results of simulation. So in order to realize the research, this article adapts the library components of Mtalab Simulink to build the simulation model of yawing vector control system. The fig.3 shows the frame fig. of simulation.

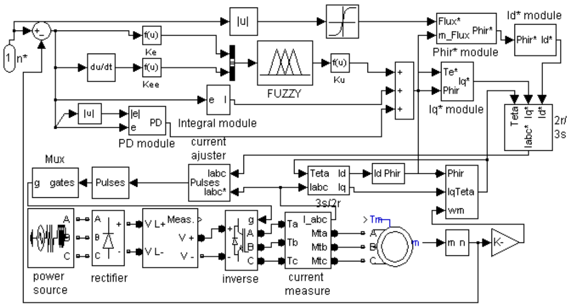


Fig.3. The frame figure of simulation model

In this model, the design of fuzzy-PID is completed by using the fuzzy tool box. From the fig.3 can know, the controller have two input and one output.

3 Fuzzy-PID Synthesis Controller Design

Fuzzy control system is a kind of knowledge control system based on rules, its core is the fuzzy controller with knowledge and intelligence. Fuzzy controller is also named as language controller, its core parts is a set of rules which will give out the output control value after fuzzy inference and fuzzy computation. The performance of fuzzy controller directly decides the performance of fuzzy control system.

3.1 Fuzzy Controller

Fuzzy controller usually comprises of Fuzzy Interface, Data Base, Rule Base, Inference Machine and Defuzzy Interface. Its sketch map is showed as fig.4.

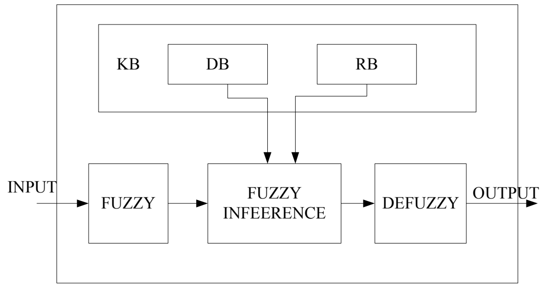


Fig.4. Sketch Map of Fuzzy Controller

3.1.1 Input and Output Variables Transform.

Actual input and output variables need to take scale transform. The former is transformed from actual scale to required domain. The latter is opposite. Two transform can be realized using one expressions as follow:

$$x_0 = (x_{min} + x_{max})/2 + k\left(x_0^* - \frac{x_{max}^* + x_{min}^*}{2}\right)$$
$$k = (x_{max} - x_{min})/(x_{max}^* - x_{min}^*) \qquad (1)$$

Where k is proportion factor; about input variable, x is domain variable, x* is actual variable; about output variable, x is actual variable, x* is domain variable.

3.1.2 Rule Function, Fuzzy Inference and Defuzzy.

Rule function, fuzzy inference and defuzzy are the core of fuzzy controller. Different fuzzy controller can choose different rule function , fuzzy inference and defuzzy methods. This article adapts triangle rule function which has simple expression and higher sensitive. Its expression is showed as follow:

$$\mu_{\tilde{A}} = \begin{cases} \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b < x \le c \\ 0, & x < a \text{ 或 } x > c \end{cases} \qquad (2)$$

Fuzzy inference adapts Mamdani fuzzy inference, its definition expressions is :

$$R = A \times B$$
$$\mu_R(u,v) = (\mu_A(u)) \wedge (\mu_B(v)) \quad (3)$$

In many defuzzy methods, center area method not only have expressions to use, but also is reasonable in theory, this method contains and utilizes all information of fuzzy. Its expression is showed as follow:

$$u = \int x\mu_N(x)dx \Big/ \int \mu_N(x)dx \quad (4)$$

3.2 Design of Fuzzy-PID Synthesis Controller

3.2.1 Fuzzy-PID Synthesis Control System

showed as fig.5, Fuzzy-PID synthesis control system mainly comprises of four parts: Feed-Forward PID; error E and error rate EE fuzzy parts Ke and Kee; fuzzy inference; output control variable proportion part Ku. Feed-Forward PID part is available when error value is in a small scale, which can avoid steady-state error and enhance the sensitive of system at the fluctuation of load.

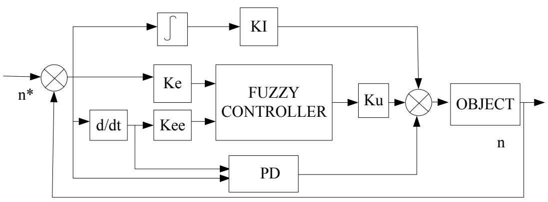
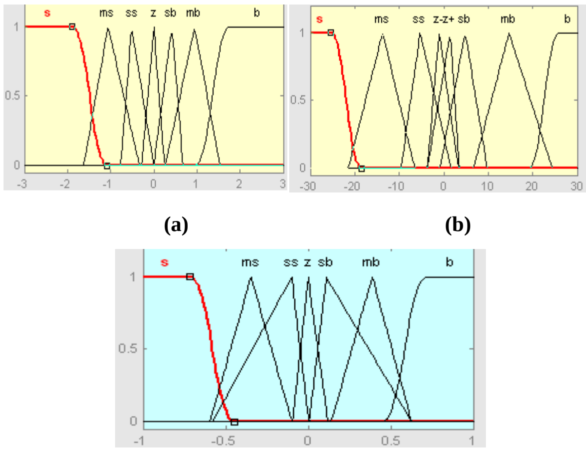


Fig.5. Synthesis Fuzzy-PID Control system

3.2.2 Input, output fuzzy variable and their rule function.

Fuzzy controller have two input and one output. The input variable is speed error e and its rate ee; output variable is u which, adding the feed-forward variable of PID, gives out the fixed value of torque Te*. Transforming e, ee and u to fuzzy variable E, EE and U. E includes {Small, Middle Small, Small Small, Zero-, Zero+, Small Big, Middle Big, Big} eight fuzzy subsets, using language variables, which can be expressed as {S, MS, SS, Z-, Z+, SB, MB, B}, the domain is [-30, 30], and Ke is 1. EE includes {Small, Middle Small, Small Small, Zero, Small Big, Middle Big, Big} seven fuzzy subsets, using language variables, which can be expressed as {S, MS, SS, Z, SB, MB, B}, the domain is [-3, 3], and Kee is $1e^{-5}$. E includes {Small, Middle Small, Small Small, Zero, Small Big, Middle Big, Big} eight fuzzy subsets, using language variables, which can be expressed as {S, MS, SS, Z, SB, MB, B}, the domain is [0, 1], and Ke is 400. Their rule functions are showed as fig.6.



(a) **(b)**

(c)

Fig.6. Membership functions distributing of input E,EE and output U

3.2.3 Fuzzy Control Rules and Fuzzy Decision-making.

Fuzzy control rules comes from the actual control experience. the rules used in this article is:

Ri:if Ei and EEi then Ui (5)

Fuzzy inference adapts Mamdani method; defuzzy is center area method. According to the rules, inference method above and the fuzzy variable of input and output, we obtain the whole table of fuzzy control rules as follow:

Table 1 Rules table of fuzzy control

U \ E EE	S	MS	SS	Z-	Z+	SB	MB	B
S	S	S	MS	MS	Z	SB	MB	B
MS	S	S	MS	SS	Z	MB	MB	B
SS	S	S	MS	SS	SB	MB	B	B
Z	S	S	MS	SS	SB	MB	B	B
SB	S	S	MS	SS	SB	MB	B	B
MB	S	MS	MS	Z	SB	MB	B	B
B	S	MS	SS	Z	MB	MB	B	B

3.3 Feed-forward PID Design

Fuzzy controller has the similar function with PD controller since its input variables are error E and error rate EE. From the linear control theory can know, such controller can make system have good dynamic performance, but can't eliminate the steady-state error. In order to realize no error control, we need to introduce feed-forward integral control in fuzzy control system. Integral control parts will intervene at a small error 'e' to avoid integral saturation, however, the error 'e' can't be too small to integral enough. So the integral domain is [-15,15], and the integral factor is 2000 to quicken the integral process.

When the load fluctuation is near the fixed value, the fuzzy and integral control can't get satisfactory control consequence. So we also introduce PD control in fuzzy control to quicken the modulation at a small error 'e'. The PD domain is [-3, 3], and the PD factor is 30 and $1e^{-4}$ respectively. Thus we introduce PID feed-forward control in fuzzy control system. However the PID domain in this article is different compared with common PID.

4 SIMULATION AND ANALYSIS

The parameters of yawing motor is: P_N = 5kW; U_N = 380V; p = 2; Ls = 74.3mh; Rs = 0.45Ω; Lm = 70.3mh; Rr = 0.85Ω; Lr = 74.3mh; J = 0.11 $Kg\cdot m^2$.

4.1 Load Fluctuation at Fixed Speed Value

The beginning conditions of simulation: fixed speed value n*=700r/min; T_L=30N·m. The speed and torque simulation curves at fluctuate load is showed as fig.7.

(1) When error equals to 15 r/min, the integral of feed-forward PID is available, when error gets to 3 r/min, the proportion of feed-forward PID is available. From the fig.7 we can know PID control and Fuzzy PID subsection control both engender big oscillation, and PID control has steady-state error, Compared with them , Fuzzy-PID Synthesis control has small oscillation and fewer modulating time.

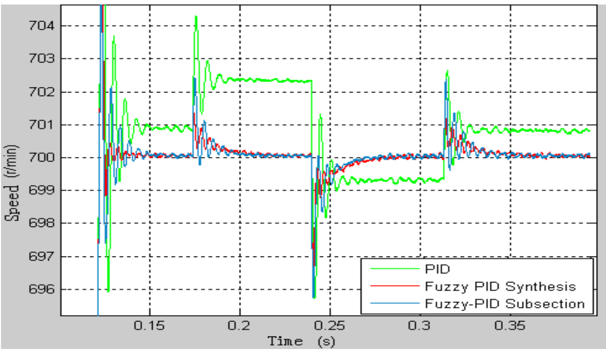
(2) We has done simulation test about different load at 0.18s, 0.24s and 0.32s. At 0.18s, the load T_L changes from 30N·m to zero, the speed of yawing motor begins to rise fast. Fuzzy-PID Synthesis controller responds quickly to make the fixed torque Te* decrease fast to become negative value, thus the acceleration of speed decrease fast until it becomes zero, then Te* rises from negative value to zero, speed also gets back to the fixed value after a little overshooting. Here we can see that PID and Fuzzy PID Subsection control have bigger overshooting and still have bigger speed modulation process with bigger torque modulation. Also the steady-state error of PID becomes bigger.

(3) At 0.24s, load suddenly increase from zero to 60N·m, we can see from fig.7-a that Fuzzy-PID Synthesis control still have better performance behavior. After change, the value between the steady-state error value of PID control becomes big, Fuzzy-PID Synthesis control will not occur this situation.

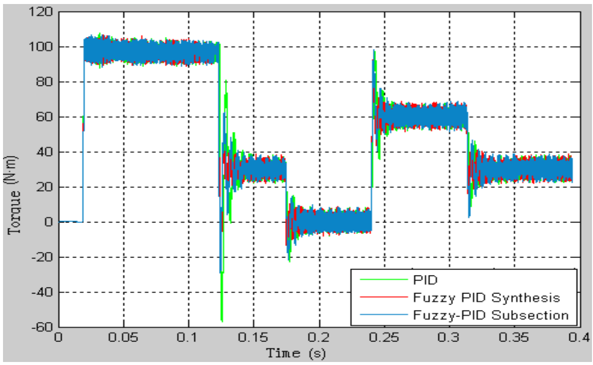
(4) At 0.32s, load changes from 60N·m to 30N·m, the respond and analysis is similar with 0.18s.

Comparing with the speed and torque curves of three controls, we can conclude that Fuzzy-PID

Synthesis control has more better speed and torque curves, which decreases the over-shooting, oscillation and steady-state error of system and make system have more better stability. All of these are significant for the wind turbine to enhance the machine life of yawing motor, reduce the damp friction of yawing brake system and the shimmy the blade[14]-[16], and increase the safety factor of yawing system and even wind turbine.



(a) Speed simulation curves at load torque fluctuating



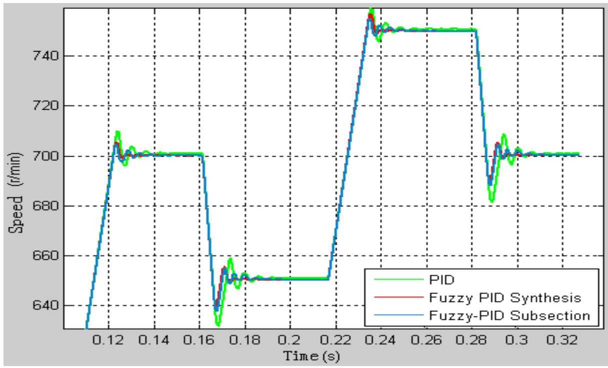
(b) Torque simulation curves at load torque fluctuating

Fig.7. Simulation curves of speed and torque

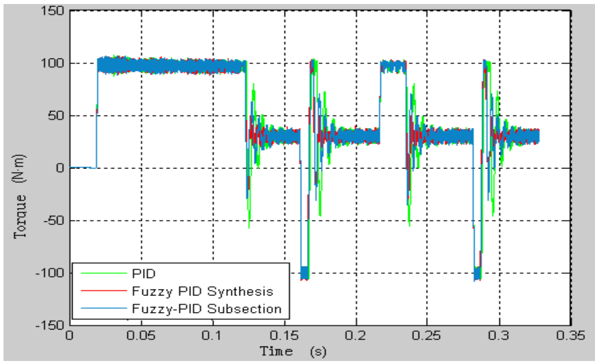
4.2 Speed fluctuation at fixed torque value

When wind speed greatly exceeds the cut-out speed, wind turbine not only needs to brake quickly, but also need to yaw fast in order to reducing the thrust of wind turbine. So both of facing wind control and crosswind control need to decelerate fast to stop machine, decrease over-shooting and oscillation near to the fixed yawing position. In order to see the effect of Fuzzy-PID Synthesis control at the change of wind, we take a simulation research. The simulation curves are showed as fig.8.

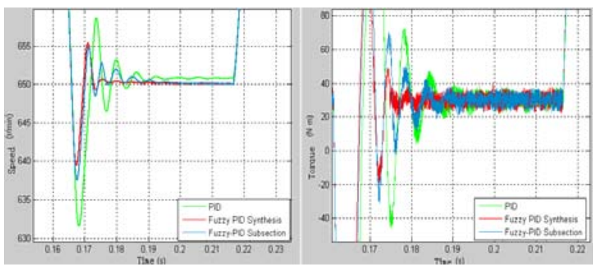
The values of speed we set is 700r/min, 650r/min, 750r/min and 700r/min respectively in order to see the respond of system clearly. The load also change from 30N·m to 60N·m at the same time of the last change of speed. From the fig.8-a,b we can know that PID control and Fuzzy PID Subsection control both have bigger oscillation and modulating time. Compared with them, Fuzzy-PID Synthesis control have more stronger stability and robust. The fig.8-c is the fig. of parts zoom. From the fig. we can see the compared curves more clearly.



a) Speed simulation curves at speed* fluctuating



(b) Torque simulation curves at speed* fluctuating



(c) The figure of parts zoom of speed and torque

Fig.8. Simulation curves of speed and torque

5 CONCLUSION

Stability and robust are the two important performance index of system, especially the stability is the premiss of system to work correctly. In order to enhance the stability and robust of yawing system of wind turbine, we design the Fuzzy-PID Synthesis controller, set up the simulation model of yawing vector control system., and take simulation research. Compared with PID control and Fuzzy-PID Subsection control, the results of simulation indicate that :

(1) whether the change of speed or the change of torque, the yawing vector control system with Fuzzy-PID Synthesis controller have more better stability and robust performance in the aspect of speed control.

(2) about the oscillation and modulation of electromagnetism torque, Fuzzy-PID Synthesis can make system have more smaller ripple, which is significant for the wind turbine to enhance the machine life of yawing motor, reduce the damp friction of yawing brake system and the shimmy the blade, and increase the safety factor of yawing system.

(3) The research has shown an feasible design for yawing controller of wind tuibine. Also the research is resuming, the next step is to realize this controller and apply it in a test yawing system, and more useful arithmetic will be taken into account.

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