
Fuzzy Adaptive Control Design of Induction Motor Speed Sensorless Based on MRAS

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Abstract—In order to solve the real-time parameter adjustment problem of the speed sensorless vector control system for the induction motor, the paper presents a fuzzy self-adaptive method with intelligent gain adjustment. By the means of the sensorless vector control for induction motor, adapt Model reference adaptive system (MRAS) to achieve the rotor position estimation to improve the speed and estimated accuracy, and then design the out-loop controller to achieve high response of speed control. So applying the method of the fuzzy self-adaptive parameter adjustment, track and correct controller parameters in time to achieve high dynamic response. The simulation results confirm the validity and effectiveness of the proposed control strategy.

Keywords —Induction motor; Speed-sensorless; Fuzzy self-adaptive; Model reference adaptive system (MRAS)

1.INTRODUCTION

Because of its simple structure, strong and durable, reliable operation, asynchronous motor can be applied to large capacity, speed adjustment, work and harsh environment, and has been widely used in industrial field. From the constant voltage frequency ratio control mode to vector control mode, to achieve the high performance control of asynchronous motor, which require asynchronous motor speed control system with strong robustness and excellent dynamic and static characteristics. Under the condition of the working condition, the speed sensorless control technology can realize the on-line parameter estimation by eliminating the need of a sensor. This means that the speed sensorless control can improve the volume of the transmission system in the same space structure, in heavy industries such as mining. In conventional induction motor frequency control system, closed-loop speed feedback link is usually through the installation of the speed encoder on the motor to achieve the controlled actual speed sampling. Also even in the speed encoder drive system, speed sensorless control can also be used as a coder emergency measures in case of failure, The key is to adopt this approach not only reduces the entire drive system configuration and maintenance costs, also increased the reliability of the system.

Currently, a lot of Variable-frequency Drive product on the market have the speed sensorless vector control as an optional configuration. With the emergence of digital signal processor with powerful processing capability, high robustness, adaptive parameter estimation and nonlinear state observation are possible, and the new speed sensorless control schemes are constantly being put forward. Siemens, Yaskawa, Toshiba, GE, Rockwell, Mistubishi, Fuji and other famous companies have launched their own SVC control products. Therefore, as an

extended form of induction motor speed control vector control program, speed sensorless vector control has become necessary to develop high-performance drive the focus solutions.

In sensorless vector control system, flux observation and speed estimates are the most critical two technologies, and usually both are interrelated. This is because regardless the field oriented vector control scheme or DTC scheme, the flux observer was originally part of the impact motor control performance. In the system scheme using the speed sensorless vector control system, the performance flux observer is even more important: not only requires the flux observer that cannot measure the actual speed at the situation remains the accuracy of observations, often need to flux observer as a basis for estimate the motor speed. At present, about the speed sensorless vector control, especially on flux observer and speed estimation aspect has made a lot of achievements. Sliding Mode Control[5], Robust Control Adaptive Control[6], the emergence of non-linear control technology, to provide a credible basis for rotor flux obtain accurate information for the induction motor sensorless vector control, Solve nonlinear itself, multivariate and uncertainties brought about by the induction motor limitations.

In this paper, a speed sensorless fuzzy self-adaptive control system based on MRAS for induction motor is proposed. Compared with other control algorithms, the implementation is simple, and the control performance is very good. In this system the rotor flux linkage is calculated by its the voltage equation and current equation, the model reference adaptive method (MRAS) is used to calculate the actual speed, and the fuzzy self-adaptive PID control is used to realize self-tuning speed loop parameters. When the system parameters are seriously unbalanced, this method can still have good robustness and anti-disturbance ability, so an intelligent fuzzy control system is established.

2. SENSORLESS VECTOR CONTROL SYSTEM BASED ON MRAS

According to the control theory of the speed sensorless vector control of induction motor, obtaining the amplitude and angle of the rotor flux is one of the most critical factors affecting the performance of the system control, and the accuracy of speed detection is directly influenced by the accuracy of the magnetic field orientation. AC Speed without speed sensor control strategies, while reducing the equipment, it also avoids the error rate sensor itself may bring. This design uses the design and debugging are relatively simple model reference adaptive system (MRAS), which is simple in design and debugging. The control parameters of the control structure are few, which only has the proportional integral coefficient of the adaptive law. It has a great influence on the research field of speed sensorless control. The literature [1,2,3,4,8] are given on the realization of MRAS, Flux Observer approach and do the relevant simulation and verification, continuous improvement of this method. In view of this, in this paper, the vector control technology of the rotor field orientation (foc) is adopted. The rotor flux observer is built by using the voltage model and current model based on the rotor voltage equation and flux linkage equation of $\alpha\beta$ coordinate system, and using model reference

adaptive system (MRAS) to calculate the speed. In the two-phase stationary coordinate ab voltage equation and flux equations were as type 1 and type 2. The basic relationship shown in

fig. 1: $\psi_{\alpha\gamma}^*$, $\psi_{\beta\gamma}^*$ are in accordance with the voltage model rotor flux obtained; $\hat{\psi}_{\alpha\gamma}$,

$\hat{\psi}_{\beta\gamma}$ are the rotor flux calculated in accordance with the current model.

$$\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \\ u_{r\alpha} \\ u_{r\beta} \end{bmatrix} = \begin{bmatrix} R_s + L_s P & 0 & L_m & 0 \\ 0 & R_s + L_s P & 0 & L_m P \\ L_m P & \omega_r L_m & R_r + L_r P & \omega_r L_r \\ -\omega_r L_m & L_m P & -\omega_r L_r & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} \psi_{s\alpha} \\ \psi_{s\beta} \\ \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix} \quad (2)$$

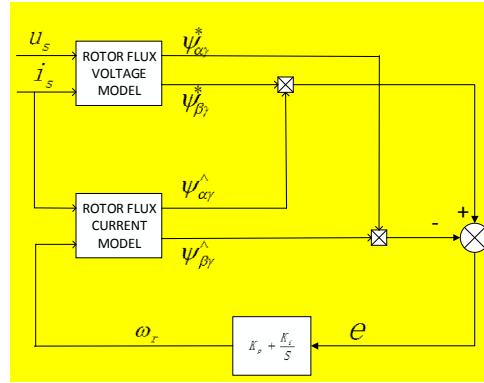


Fig.1 Diagram of the speed signal based on MRAS

According to the formula flux model can be derived as follows (derivation omitted), which estimate the flux including its magnitude and angle.

$$\begin{cases} \psi_r = [L_m / (1 + T_r P)] i_{sd} \\ \omega_s = (L_m i_{sq}) / T_r \psi_r \\ \theta = \int_0^t (\omega_r + \omega_s) dt \end{cases} \quad (1)$$

Where: ψ_r is the rotor flux; ω_s is the slip angular velocity; ω_r is the rotor speed; i_{sd} , i_{sq}

as the stator d, q-axis current; T_r is the rotor time constant, $T_r = L_r / R_r$, L_m is the stator and

rotor mutual inductance, L_r is the rotor inductance; R_r is the rotor resistance ; θ is the flux

angle, $P = du/dt$.

3. FUZZY PI CONTROLLER

When the actual loading motor load, due to actual load torque and load inertia and default parameter settings is not consistent, the speed loop bandwidth narrows, if at this time speed band width to meet the demand, no motor speed crawling or oscillation phenomenon, the proportion of gain and integral time constant of the speed loop of can do not need to be adjusted. If the actual load make the motor work instability, crawling or oscillation occurs or existing velocity loop bandwidth is not ideal, we need to speed loop proportional gain, integration time constant adjustment. The adjustment of these two parameters is a repeated process, which requires accurate knowledge and experience about the load. Gain adjustment can make the motor action closer to instruction, to maximize the mechanical performance. While the speed loop gain parameter self-adjustment reduces the dependence of parameter adjustment of people. In this paper, fuzzy self-adaptive PID control^{[7][9][10]} is used to realize the gain self-adjustment of the speed loop parameters, and the intelligent fuzzy control system is established. When the system parameters has a serious mismatch, this method can still have very good robustness and anti-disturbance ability.

In this paper, fuzzy self-adaptive system mainly by the integral separation k links, error e and error change ec discrete, fuzzy aspects, fuzzy control query table, control output proportional link, and online parameters self-tuning links and other components. Adaptive fuzzy controller error e and error rate of change Δe as input to meet the request for different moments of e and Δe of PID tuning parameters, by means of fuzzy rules to achieve effective correction online PID parameters, which formed a fuzzy self-adaptive PID controller that performance adjustable gain supervised.

The core of the design of fuzzy control is to sum up the technical knowledge and practical experience of engineering design, and to establish a proper fuzzy rule table to obtain the fuzzy control table for Kp, Ki and Kd parameters. The system error and error change rate is defined as the domain of fuzzy sets, $e, ec = \{-3, -2, -1, 0, 1, 2, 3\}$, Its fuzzy subset, $e, ec = \{NB, NM, NS, ZO, PS, PM, PB\}$, where e, ec, Kp, Ki are normally distributed, Whereby each fuzzy subset membership is obtained, And in accordance with the membership table of each fuzzy subset and fuzzy control model of the parameters, using fuzzy synthesis to design fuzzy matrix of PI parameters, which make control system complete PI parameters tuning online by being analysis, looking up and operating the result of fuzzy logic rules. Figure 2 shows the structure diagram of the adaptive fuzzy parameter self-tuning control structure.

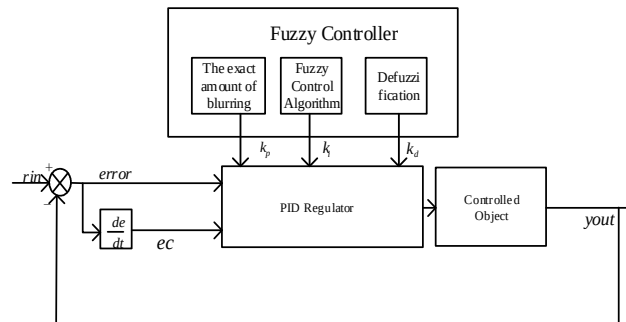


Fig.2 adaptive fuzzy control structure

4. SIMULATION ANALYSIS

To verify asynchronous motors with fuzzy parameters self-tuning controller sensorless control system performance, we use Matlab / Simulink control system for digital simulation, induction motor speed sensorless vector control system shown in Figure3, including a three-phase induction motor module, SVPWM module, PI module, coordinate transformation module, rotor flux estimation module, rotor speed estimation module, inverter module. The system main circuit of SVPWM inverter control circuit, given the speed with estimating the speed through the speed regulator to give torque to the estimated flux value calculated by the current i_{sq} , through the current regulator, and then through the inverse transform PARK two-phase static voltage, through SVPWM modulation control of the inverter output voltage, and thus control three-phase asynchronous motors.

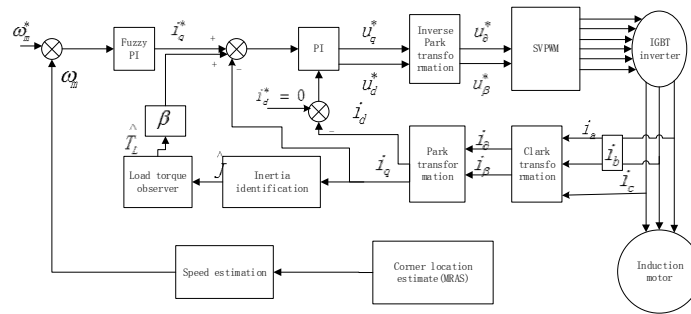


Fig.3 induction motor speed sensorless vector control system

Figure 4 is a speed estimating module, including the coordinate transformation (Clark transform and Park transform), the voltage model and the PI model.

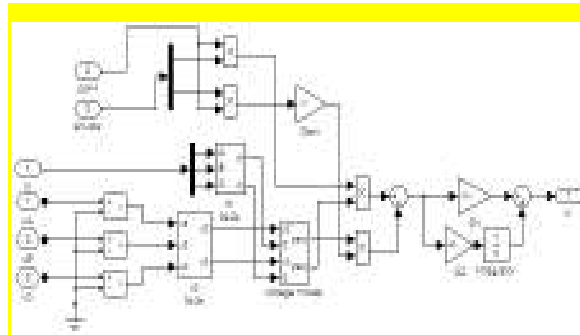


Fig.4 Mode of speed calculation

In this paper to simulate the actual conditions of the asynchronous motor operating environment, the following is the simulation parameters and results. Induction Motors parameters are as follows: 30KW, 380 V, 50 Hz, 4 counter electrode. The initial value is 0 rad/s, Speed is given as 500rpm, Load torque initial value of zero, 0.4 s when loading 60N • m. From Figure 5 it can be seen that, although at the beginning, the estimated speed curve has some fluctuation, but it is very fast to estimate the speed curve and the actual speed curve basically coincide, the convergence time and the precision of speed identification are very high.

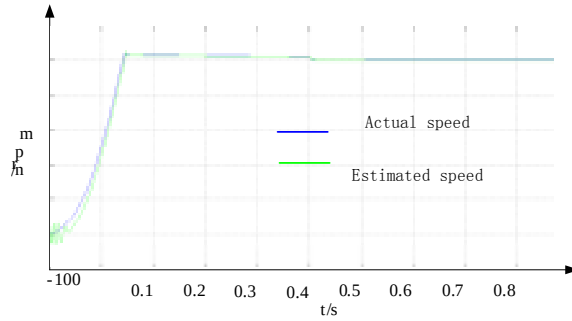


Fig.5 Comparison of actual and calculation speed

From Figure 6 it can be seen that the fuzzy PID controller has a faster response speed than the ordinary PID controller when starting up. At 0.4s, the system suddenly increases $60\text{N} \cdot \text{M}$, and the effect of fuzzy PID controller is much smaller than that of the ordinary PID controller. The robustness of fuzzy PID controller is better. Figure 7 shows the load torque value, which indicates that the identification accuracy is high.

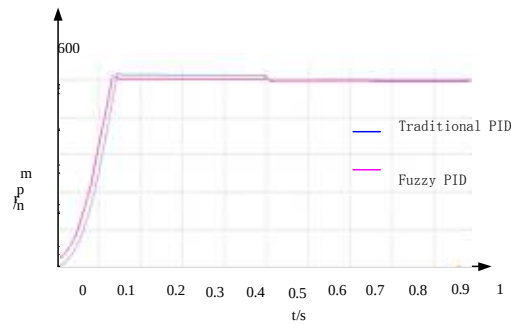


Fig.6 Comparison of Fuzzy self-tuning PID and tradition

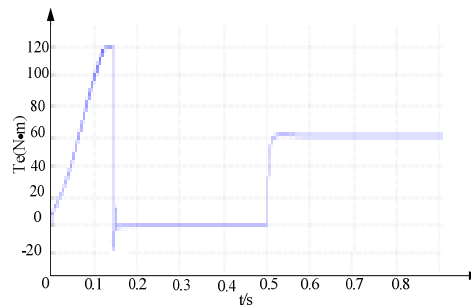


Fig.7 Load torque based on Fuzzy self-adaptive

And in the speed loop the fuzzy PI control scheme was applied to realize the parameter self-tuning, which makes the speed response more close to the actual speed, and the dynamic response and precision of the system is improved, and the robustness of the system is enhanced.

5. CONCLUSION

Asynchronous motor speed sensorless vector control technology, through the advantages of its structure has been more and more widely recognized industry. In addition, the artificial intelligence algorithm is more and more widely used in the engineering practice, the different control method, for different occasions, each has advantages and disadvantages. This article

focuses on its MRAS speed estimation method and fuzzy self-tuning PI two angles simulation analysis and demonstration, simulation results show that the speed estimation method is feasible. At the same time fuzzy control as one of the artificial intelligence control, steady-state performance of induction motor sensorless vector system and the dynamic response will continue to improve, its application will be more extensive.

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