Research on Control of Double Closed Loop Permanent Magnet Synchronous Motor Based on Fuzzy PID

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Abstract

Aiming at the slow response speed, poor tracking accuracy and uncertain external load of traditional PID-controlled permanent magnet synchronous motor (PMSM), a vector control strategy of double closed-loop PMSM based on fuzzy PID is proposed. By describing the mathematical model of permanent magnet synchronous motor (PMSM), a fuzzy-PID control method is developed. According to the principle of fuzzy-PID control, a double closed-loop PMSM model based on fuzzy-PID control is built in Matlab/Simulink and simulated. The simulation results show that the fuzzy PID controller can significantly improve the robustness of the system, overcome the shortcomings of traditional PID regulated by manual experience, meet the requirements of fast response and higher accuracy of permanent magnet synchronous motor, and has good stability.

Keywords

Permanent magnet synchronous motor; fuzzy PID; electric vehicle; MATLAB/Simulink simulation.

1. Introduction

New energy electric vehicles have become the most research potential automotive market research direction in recent years. In the absence of a revolutionary technological breakthrough in electric vehicle battery, the electric drive system has gradually become the research goal of major manufacturers. In the research of various drive motors, among them, permanent magnet synchronous motor (PMSM) has the advantages of heat resistance, high magnetic force, high function, DC to provide AC, and precise control of the motor. The electric vehicle drive has a very high application value, and it is highly valued by the electric vehicle industry at home and abroad. When the car is moving, the electric motor is used to drive the motor to generate power. When the motor is added to its own rotation without external drive (long-term downhill braking and coasting), current will also be generated. If the current generated by the motor rotation in this environment can be fully recovered. Storage, which will be another major breakthrough in energy conservation. Energy recovery requires the motor to operate in a stable output state, producing a stable current. In order to obtain stable output in the MATLAB environment, a fuzzy PID-based control model of the speed and current double-closed-loop permanent magnet synchronous motor system is constructed. Finally, the simulation results are analyzed, and new ideas for future control design and vehicle energy recovery are provided.

2. Mathematical model of permanent magnet synchronous motor

In order to facilitate the study and simplify the analysis process, the mathematical model of the permanent magnet synchronous motor is first assumed to be ideally assumed, as follows :

1. The conductivity of the permanent magnet material is zero;
2. Does not consider the sudden effect of the rotor magnetic field;

3. There is no eddy current, no hysteresis loss, no core saturation;

4. The spatial magnetic potential generated by the stator three-phase current and the magnetic flux distribution of the permanent magnet rotor are sinusoidal;

The mathematical model of the three-phase AC permanent magnet synchronous motor in the two-phase rotating coordinate system is as follows :

Voltage equation:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \frac{d\varphi_d}{dt} \\ \frac{d\varphi_q}{dt} \end{bmatrix} + \begin{bmatrix} -\omega\varphi_q \\ \omega\varphi_d \end{bmatrix} \tag{1}$$

Magnetic chain equation:

$$\begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} = \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \varphi_f \\ 0 \end{bmatrix} \tag{2}$$

Torque equation:

$$T_e = \frac{3}{2} p \left[\varphi_f i_q + \left(L_d - L_q \right) i_d i_q \right] \tag{3}$$

Among them:

ud,uq are the d and q axis components of the stator voltage, unit :V;

i_d,i_q are the d and q axis components of the stator current, unit: A;

φ_d,φ_q are the d, q axis components of the stator flux linkage, unit: Wb

L_d,L_q are the d, q-axis component inductance of the stator winding, unit: H;

R_s is the stator winding resistance, unit: Ω;

φ_f rotor permanent magnet generated magnetic flux, unit: Wb;

T_e is the output electromagnetic torque, unit: N * m

ω is the actual angular velocity of the rotor, unit: rad/s;

t is time, unit: s;

p is the pole logarithm.

3. Fuzzy PID controller tuning strategy

3.1 Fuzzy PID parameter tuning principle

The so-called fuzzy PID control is not a fuzzy control method, nor is it to obtain an approximate control accuracy. Fuzzy PID is actually a gradual refinement control method .

The input of the permanent magnet synchronous motor is a given speed, but there is an error in the output that the output of the permanent magnet synchronous motor does not reach the ideal speed. The error is actually the input of the fuzzy controller.

To perform constant speed control, it is necessary to adjust the speed of the motor according to the current actual speed. For example, if the input speed and the actual speed of the motor are different, then our system must make a negative judgment to offset the positive error.

When the machine is running, an error will inevitably occur, and the rate of error change can be obtained based on the current error and the error at the last moment. Then input the two into the fuzzy controller, you can find the desired output, and the output result is not an accurate value. The fuzzy result obtained from the fuzzy inference needs to be processed to get the accurate value.

In fact, the controlled system will always be affected by various factors or external factors, not linearly. In this case, the PID parameters can be dynamically adjusted by themselves, and correspondingly under different interferences. PID adjustment. The block diagram of the fuzzy PID tuning controller is shown in Figure 1 :

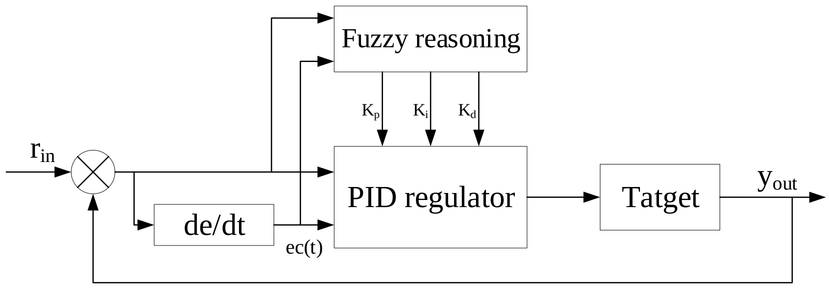

Figure. 1 Fuzzy PID control system structure

In the fuzzy control, the PID parameters can be corrected in real time according to the following formula :

$$k_p = k_p^{'} + (e_i, ec_i)_p \tag{4}$$

$$k_i = k_i^{'} + (e_i, ec_i)_i \tag{5}$$

$$k_d = k_d^{'} + (e_i, ec_i)_d \tag{6}$$

3.2 Fuzzy PID controller design

There are various delays in the closed-loop control system. The effect of the adjustment will always be accompanied by a certain delay and will not be fed back immediately, because the existence of the delay also makes the system adjustment difficult.

The proportional coefficient K_p in the proportional control determines the adjustment speed, and the magnitude of the coefficient K_p affects the response speed of the system. In the adjustment process, the values can be selected in the order of large, small, and large. First, take a larger value to increase the response speed, then take a small value to ensure the response speed, and finally take a larger value to improve the accuracy.

The integral coefficient K_i of the integral control is mainly used to eliminate the steady state error of the system and improve the control precision. Due to the existence of saturation nonlinearity in the system, the integral process may be integrated to cause overshoot in the regulation process. Therefore, in the adjustment process, the integral value K_i can be selected to be smaller in the initial stage, and even zero can be taken to avoid integral saturation; the medium-term integral coefficient K_i is moderately selected in order to obtain better stability; finally, in order to reduce the adjustment static difference , can increase the points in the later stage.

The function of the differential link coefficient is to change the dynamic characteristics of the system, and it has a certain predictive function. It can introduce an effective correction signal in the system according to the change trend of the signal to prevent the signal from deviating greatly. Therefore, the selection of the K_d value is adjusted. The characteristics have a great influence. According to experience, in the initial stage of adjustment, the differential K_d should be increased to avoid overshoot as much as possible; since the change of K_d value is very sensitive to the influence of adjustment characteristics, the value of coefficient K_d should be taken as small as possible and maintained; at the end of adjustment The coefficient K_d value should be reduced, and the adjustment process caused by the initial stage of the compensation is prolonged, thereby accelerating the response and reducing the adjustment time .

The general expression of traditional PID control is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt} \tag{7}$$

According to the expression of the traditional PID and the influence of three parameters on the system operation process, combined with the change of the error e and the error variation ec, the following modulation modes are set for the parameters ΔK_p, ΔK_i, ΔK_d of the PID controller :

When the error e is small, the values of ΔK_p and ΔK_i should be larger to make the system fast and stable. The value of ΔK_d is proportional to the error variation ec. When the value of ec is large, ΔK_d is larger; when the value of ec is smaller, ΔK_d is smaller.

When the value of the error e is in the middle size, in order to reduce the overshoot of the system, the values of ΔK_p and ΔKi cannot be too large or too small, and the value of ΔK_d is small.

When the value of the error e is large, in order to improve the tracking ability of the system and speed up the response speed, the value of ΔK_p should be made larger while preventing the integral saturation.

For a single-input single-output system, if the difference between the input and output is too large, the performance of the controller is not good, and it is necessary to readjust the controller, which is the most common rule in daily life. In order to better explain the problem, the input and output are divided into the following seven levels (PB, PM, PS, ZO, NS, NM, NB). The key of the fuzzy controller is the design of the controller rules. The input of the fuzzy controller is the speed. If constant speed control is needed, the speed of the motor needs to be adjusted according to the current actual speed. For example, the difference between the input speed and the actual speed of the motor is PB, the system must make a NB judgment, in order to offset the error of PB. The difference between the input speed and the actual speed of the motor is NB, and the system will make a PB judgment to offset the impact of the negative. Similarly, in the case where the output difference is NS, the system will make a PS judgment to adjust.

4. Fuzzy PID control system to simulation

4.1 Establish a system structure simulation model

After the fuzzy strategy is determined and the parameters of the fuzzy control are adjusted, the simulation module of the double closed-loop permanent magnet synchronous motor based on fuzzy PID is established in the Matlab/Simulink environment. The simulation model is shown in Figure 2 below:

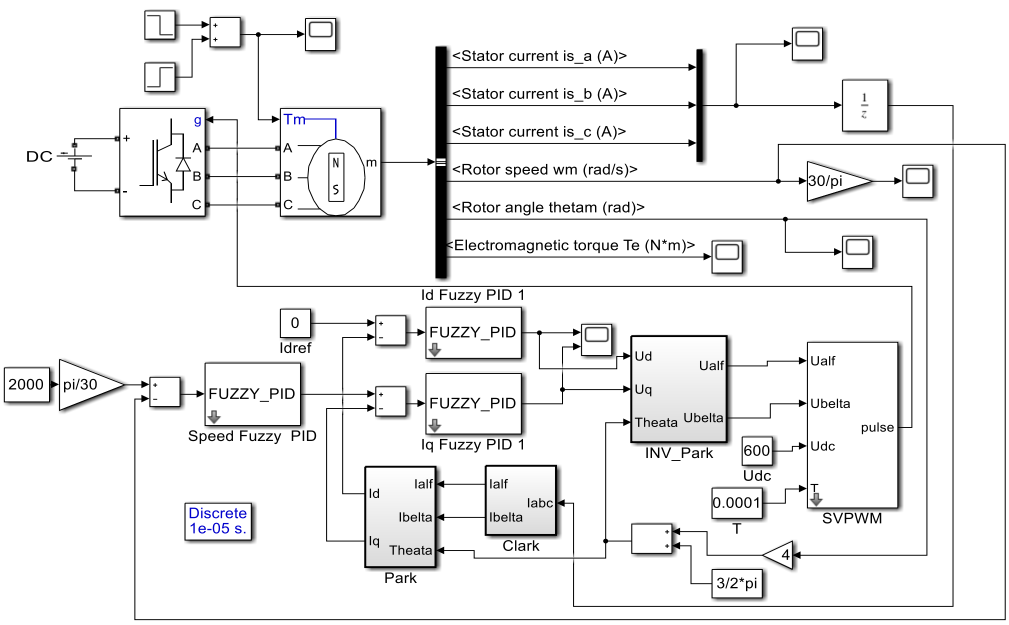

Figure. 2 Simulink simulation model simulation results analysis

4.2 Simulation

After the system simulation model is established, the simulation model is run by adjusting different parameters, and the simulation waveform is observed by the oscilloscope. From the obtained simulation waveform diagram, it is verified whether the simulation model has better control effect.

In the simulation, the given model speed is 2000 rpm, and the load is added midway to interfere, simulating the occasional braking or short climb of the car. The simulation time is 0.3s. The waveforms obtained by the oscilloscope compare the results of the conventional PID and fuzzy PID control.

In this simulation, the parameters of the motor are set as follows: stator resistance Rs=0.05Ω, rotor flux linkage is 0.192Wb, moment of inertia is 0.011kg·m^2, pole logarithm is 4.

First, under the traditional PID control, manually adjust a variety of PID parameters according to personal experience, here list some PID parameters: ①K_p=1,K_i=0.1,K_d=0.01;②K_p=0.5, K_i=0.5, K_d=0.01; ③K_p=0.1,K_i=0.1,K_d=0.01;④K_p=6,K_i=2,K_d=0.01, the waveform of the rotational speed under different parameters is as shown in Fig. 3, and the steady state can be achieved under different parameters. However, it is not possible to determine whether it is or is approaching the optimal adjustment parameter.

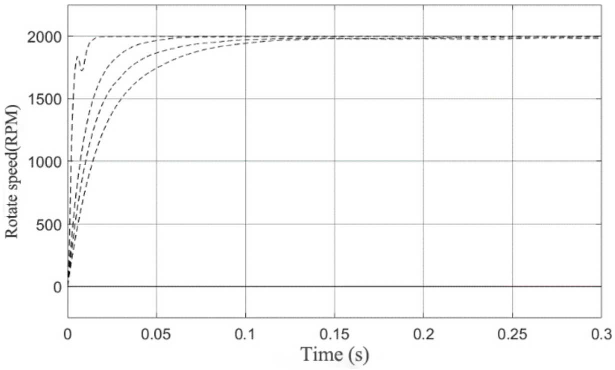

Figure. 3 Adjusting the speed change curve under different parameters of traditional PID

After adding the fuzzy PID, compared with the traditional PID, the performance comparison analysis is as follows:

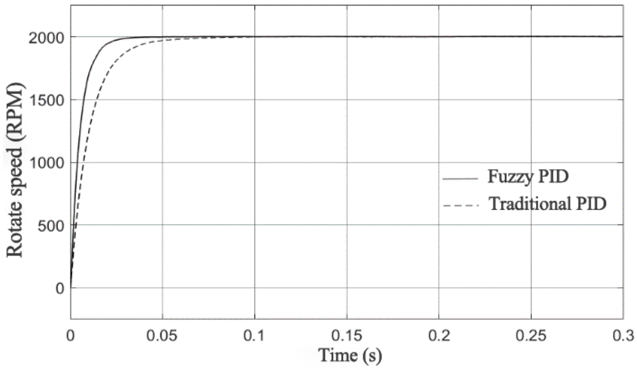

Figure. 4 idling speed curve under two PID controls

Fig. 4 is the curve of the speed change with time under no-load control under two kinds of PID control. Under the fuzzy PID control, the corresponding steady state can reach 2000 rpm at t=0.03s, and t=0.1s under the traditional PID control. When it enters a steady state, it takes a long time and the response speed is relatively slow. It can be seen from the figure that both fuzzy PID control and traditional PID control can achieve good control effects in the idling state.

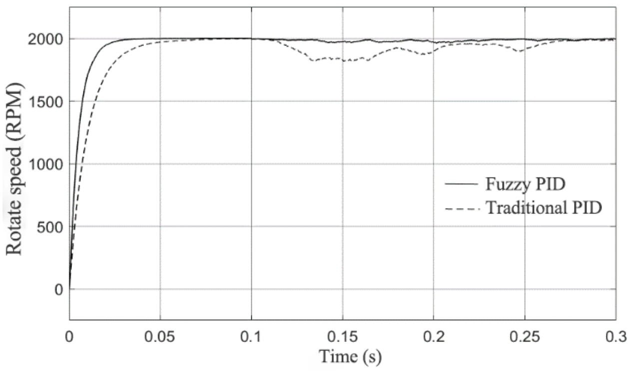

Figure. 5 Speed change with time under load with two PID controls

When t=0.1s, the 50N load is added to the two PID control modes respectively. The control results of the traditional PID and fuzzy PID are shown in Fig. 5. It can be seen from the figure that when t=0.1s suddenly increases the load, the speed of the two will decrease, the fuzzy PID control waveform will drop less, and it can quickly return to the steady state.

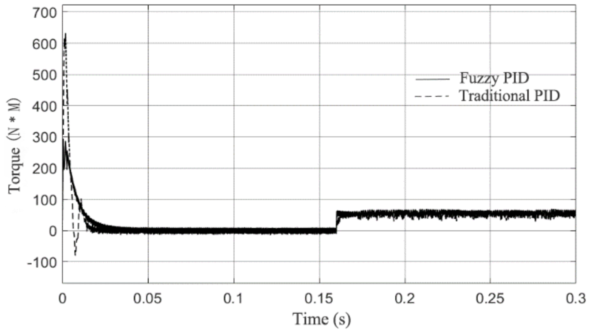

Figure. 6 Torque changes under two PID controls

Figure 6 is a plot of torque versus time for no-load under two PID controls. It can be seen from the figure that under the traditional PID control of the start-up moment, the torque is rapidly reduced after the torque of about 600N·m, and the jitter is brought into a stable state. Under the fuzzy PID control, the torque is stably decreased from 300N·m to a stable state. When t=0.16s, the load is 50N, and both can respond quickly and stabilize. If further comparison, the traditional PID has some jitter and the accuracy of fuzzy PID control is higher.

5. Conclusions

The simulation results show that compared with the traditional PID control, the designed fuzzy PID controller eliminates the dependence of traditional PID control on artificial experience, greatly reduces the error amount and improves the performance of the controller. The start-up is relatively smooth, the overshoot is small, the adjustment time is short, the operation is more stable when the load is suddenly applied, and the fluctuation amplitude is small.

Pure fuzzy PID control can not achieve the desired effect, and the traditional PID control has the advantage that fuzzy control does not have, and can effectively combine the two, which is also a way to improve the performance of permanent magnet synchronous motor. In this control mode, the permanent magnet synchronous motor can perform stable speed output, and the motor is used as power to simultaneously convert into the generator's identity output current for power storage. Realize energy recovery on this basis and solve the problem of electric vehicle life. At the same time, it is also possible to carry out related research on the basis of designing stable speed output, and provide direction for future research on speed control system.

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