Design of permanent magnet synchronous motor speed loop controller based on sliding mode control algorithm

Jiang Qiang¹ and Liao Meng-wei² and Luo Ming-jie³

1 Associate professor, Chongqing University of Technology, Chongqing, China
2 Master degree candidate, Chongqing University of Technology, Chongqing
E-mail: jq61@163.com

Abstract. The control performance of Permanent Magnet Synchronous Motor will be affected by the fluctuation or changes of mechanical parameters when PMSM is applied as driving motor in actual electric vehicle, and external disturbance would influence control robustness. To improve control dynamic quality and robustness of PMSM speed control system, a new second order integral sliding mode control algorithm is introduced into PMSM vector control. The simulation results show that, compared with the traditional PID control, the modified control scheme optimized has better control precision and dynamic response ability and perform better with a stronger robustness facing external disturbance, it can effectively solve the traditional sliding mode variable structure control chattering problems as well.

Keywords: PMSM; SMC; FOC; second order integral

1. Introduction

Permanent magnet synchronous motor (PMSM) has the advantages of simple structure, small volume, high efficiency and reliability, but PMSM is a nonlinear object in nature, the performance of nonlinear control system will be influenced by the variation of motor parameters and external disturbance in the practical application. The sliding mode variable structure control strategy (SMC) can respond fast, be insensitive to parameter change, and has strong anti-interference ability. But in practical systems, chattering exists in SMC.

Employing A novel two order integral type sliding mode control method, based on Schiff and Jarno Lee $L = \frac{1}{2}s^2$, state error of control parameters in finite time convergence would be verified by the function. Results of a simulation based on MATLAB show the designed SMC can improve the
response time of the control system, relieve chattering problem easily which happened in the traditional sliding mode variable structure control system,.Meanwhile, the optimized control system has strong robustness and anti-interference ability.

2. Mathematical model of PMSM and vector control
Three phase permanent magnet synchronous motor (PMSM) is a multivariable, nonlinear and strongly coupled system. In order to facilitate the analysis easily, some assumptions about its conditions are given. The object applied in control algorithm proposed in this paper is the surface permanent magnet synchronous motor , based on the vector control strategy \( i_d = 0 \) and the mathematical model of the motor can be simplified to the type below, the design of algorithm is based on it:

\[
\begin{align*}
    u_q &= -L_p \omega i_q \\
    i_q &= -\frac{R}{L} i_q - \frac{p \psi_f}{L} \omega + \frac{u_q}{L} \\
    \omega &= \frac{3 p \psi_f}{2 J} \frac{B}{J} \omega - \frac{T_y}{J} \\
    \theta &= \omega
\end{align*}
\]

(1)

3. The design of control algorithm
The implementation process of sliding mode variable structure control of the sliding surface is to design the system according to the desired dynamic characteristics of system, making system state move from outside to the sliding surface of sliding surface, once the system reaches the sliding surface, the control effect will guarantee system along the sliding surface at the origin system.

Define the state error equation of the control system:

\[
X = \omega^* - \omega_m
\]

(2)

Where \( \omega^* \) is the reference speed set by the motor and the actual speed of the motor \( \omega_m \).

In this case \( i_d = 0 \) the formula (2) is derived and the formula (1) can be obtained together

\[
\dot{X} = \omega^* - \frac{3 p \psi_f}{2 J} i_q + \frac{B}{J} \omega + \frac{T_y}{J}
\]

(3)

In order to facilitate the design of control rates, Because some of the above formula can be set as a fixed value, let

\[
\alpha = \frac{3 p \psi_f}{2 J}, \quad \beta = \frac{B}{J}, \quad \mu = \frac{T_y}{J}
\]

(4)

So formula (3) can become:

\[
\dot{X} = \omega^* - \alpha i_q + \beta \omega + \mu
\]

(5)
According to the general form of integral sliding surface, the function of the sliding surface is defined as:

$$S = k_1 X + k_2 \int_0^t X dt$$

(6)

Among them, $k_1$ is the proportional gain of controller and $k_2$ is integral gain. Moreover, both as design parameter must be greater than 0.

Derivation of formula (6) below:

$$\dot{S} = k_1 \dot{X} + k_2 X$$

$$= k_1 (\omega - \alpha i_q + \beta \omega + \mu) + k_2 (\omega - \omega_m)$$

(7)

According to the formula (7), in order to ensure the three-phase PMSM speed control system has better dynamic quality, because of $i_d = 0$, the control rate of the target object is designed as follows

Proportion al: $i_{q1} = \frac{1}{k_1 \alpha} (k_2 X + k_1 \beta \omega + k_1 \omega)$

Integral: $i_{q2} = \frac{1}{k_1 \alpha} \left[ \int_0^t \left( x_1 \text{sgn}(S) + x_2 \text{sgn}(S) + (r_1 S + r_2 S) \right) dt \right]$  

$$i_q = i_{q1} + i_{q2}$$

(8)

Where: $x_1, x_2, r_1, r_2$ the undetermined design parameters, and to ensure that the system converges to $0, x_1, x_2, r_1, r_2 > 0$.

As can be seen from the formula (8), because the controller contains integral terms, on the one hand, it can weaken chattering phenomenon, on the other hand, it can also eliminate the steady-state error of the system and improve the quality of the control system.

According to the verification of the Lyapunov function, based on the control rate of speed error system design with sliding mode, according to the sliding mode reaching condition $S \dot{S} < 0$, easy to verify that the system can be converge gradually and tends to 0 in the designed controller.

4. PMSM control system

In order to verify the validity of the sliding mode controller design, based on the $i_d = 0$ vector control strategy, build the overall simulation model of PMSM speed control system, which choose PI control for the current loop control and parameter, build the Simulink model.

According to the PMSM control system above, the control system mainly contains three parts, namely the speed loop, current loop and PWM algorithm, where speed loop has built-in designed two order integral sliding mode algorithm. Through giving specific speed value, the voltage value output is
adjusted by the algorithm, so that the PMSM can realize the speed response more fast.

5. Simulation and analysis
To verify the effect of designed control algorithm, make simulation over PMSM control system, motor parameters are set in the simulation as follows: polar number $p_n = 4$, stator inductance $L_d = L_q = 8.5mH$, stator resistance $R_s = 2.875\Omega$, flux $\psi_f = 0.175Wb$, inertia $J = 0.003kg\cdot m^2$, damping coefficient $B = 0.008N\cdot m\cdot s$.

Settings of simulation condition: DC side voltage $U_{dc} = 311V$, PWM switching frequency $f_{PWM} = 10kHz$, cycle setting as $T_s = 10\mu s$.

Simulation process: set the reference speed $N^* = 1500rad/min$, that is, the dynamic response quality and speed when motor starts to achieve it. In the process of motor running, the initial load torque $T_L = 0N\cdot m$, in $t=0.2$ seconds increase load torque $T_L = 10N\cdot m$, which make changes in the external parameters perturbation effect on motor speed control system, to inspect anti interference ability of designed sliding mode controller. And the simulation experiments are carried out to see the dynamic characteristics of PMSM under PI control, traditional sliding mode control and two order sliding mode control respectively.

The simulation results are shown below

**Figure1(a).** Speed response curve of control system  
**Figure1(b).** Control system error curve

Figure1 shows the system characteristics under three control methods when the desired speed is 1500. Among them, figure1(a) reflects the motor speed tracking characteristics; Figure1(b) reflects the control system error curve. The simulation results show that when the motor starts at the beginning of experiment, although motor speed appeared the overshoot, but still has faster dynamic response than PI control, after reaching the reference speed, system has better control precision. After 0.2 seconds
increasing load torque suddenly, the motor can recover to the set speed value in a short time, which show that the designed speed loop sliding mode variable structure controller has good dynamic performance and anti-interference ability.

6. Conclusions
Aimed at PMSM speed loop control system, introducing the controller design method based on two order integral sliding mode control, by tuning the proportional and integral parameters, effectively improves the dynamic response quality and anti-interference ability of PMSM speed control system. The simulation results show that the controller has obvious advantages over the PI control in speed tracking, and effectively suppresses the chattering phenomenon of the traditional sliding mode control, and enhances the robustness of the control system.

7. Reference
[1] Navaneethan.s.Jerome Jovitha 2015 Speed control of PMSM using power reaching law based sliding mode controller (WSEAS Transactions on systems and control vlo) p270-277
[2] Baik I C and Kim K H and Youn M J 2013 Robust nonlinear speed control of motor using adaptive and sliding mode control techniques ([J].IEEE Proceedings-Electric Power Application) p 145(4):369-376
[3] Andresscu G D and Pitic C I and Blaabjerg F 2008 Combined flux observer with signal injection enhancement for wide speed range sensorless direct torque control of ipmsm drives ([J].IEEE Transaction on Energy Conversion) p 23(2): 393-402
[4] Ran L and Guangzhou Z 2009 Position sensorless control for pmsm using sliding mode observer and phase-locked loop ([C]//Preceedings of the IEEE 6th International Power Electronics and Motion Control Conference) p 1867-1870
[5] Chu J B and Hu Y W and Huang W X 2009 An improved sliding mode observer for position sensorless vector control drive of pmsm ([C]//Preceedings of the IEEE 6th International Power Electronics and Motion Control Conference) p 1898-1902
[6] Lu Tao and Yu Haisheng and Shan Bing and late Jieru 2015 The maximum torque / adaptive sliding mode servo system of permanent magnet synchronous motor current control ([J]. control theory and applications) p 02:251-255
[7] Jiang Hong and Han Junfeng 2014 PMSM. Adaptive fuzzy sliding mode control of servo system ([J]. micro motor) p 05:46-49
[8] Li Zheng and Hu Guangda and Cui Jiarui and Liu Guangyi 2014 Integral sliding mode variable structure control of permanent magnet synchronous motor drive system ([J]. proceedings of the Chinese society of electrical engineering) p 03:431-437