Control of Permanent Magnet Synchronous Motor Using Sliding Mode Reaching Law Method

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Abstract- *Permanent Magnet Synchronous Motor is becoming popular in industrial applications due to high efficiency, high steady state torque density and simple controller of the PM motor drives. In order to optimize the speed-control performance of the permanent-magnet synchronous motor (PMSM) system with different disturbances and uncertainties, a nonlinear speed-control algorithm for the PMSM servo systems using sliding-mode control and disturbance compensation techniques is studied. Sliding-mode control method based on an exponential sliding-mode reaching law (SMRL) is presented in this paper. This SMRL can dynamically adapt to the variations of the controlled system, which allows chattering reduction on control input while maintaining high tracking performance of the controller. Then, an extended sliding-mode disturbance observer is studied in detail to estimate lumped uncertainties directly, to compensate strong disturbances and achieve high servo precisions with chattering free operation. Simulation results show the validity of the proposed control approach.*

Keywords- SMC, Sliding mode reaching law, PMSM, Two level voltage source inverter.

I. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSM) are being widely used in many industrial applications due to their compactness, high efficiency, high power factor and high torque density. The PMSMs are particularly used in high-performance drive systems such as the submarine propulsion, electric vehicle, home appliances, wind generation systems, subway transportation, etc. The permanent magnet synchronous motor eliminates the use of slip rings for field excitation, resulting in low losses in the rotor and low maintenance.

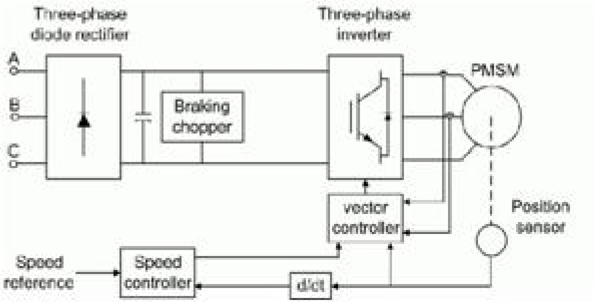


Fig 1.1 Permanent Magnet Synchronous Motor drive

In the permanent magnet synchronous motor control system, the classical proportional integral (PI) control technique is still popular due to its simple implementation. However, in a practical PMSM system, there are large quantities of the disturbances and uncertainties, which may come internally or externally, e.g., non-modeled dynamics, parameter variation, friction force, and load disturbances. It will be very difficult to limit these disturbances rapidly if adopting linear control methods like PI control algorithm.

Non Linear Methods

Many nonlinear control methods have been adopted to improve the control performances in systems with different disturbances and uncertainties, e.g., robust control, sliding-mode control (SMC), adaptive control, back stepping control, predictive control, intelligent control, and so on. In these nonlinear control methods, SMC method is well known for its invariant properties to certain internal parameter variations and external disturbances, which can guarantee perfect tracking performance despite parameters or model uncertainties. It has been successfully applied in many fields.

Proposed Control Strategy

The robustness of SMC can only be guaranteed by the selection of large control gains, while the large gains will lead to the well-known chattering phenomenon, which can excite high-frequency dynamics. Thus, some approaches have been proposed to overcome the chattering, such as continuation control, high-order sliding-mode and complementary sliding-mode method, and reaching law method. The reaching law approach deals directly with the reaching process, since chattering is caused by the non- ideal reaching at the end of the reaching phase. Some reaching laws can restrain chattering by decreasing gain or making the discontinuous gain a function of sliding- mode surface. The discontinuous gain rapidly decreases because of variation of the functions of the sliding surface, thus reducing the robustness of the controller near the sliding surface and also increasing the reaching time.

In order to solve the aforementioned problems, a reaching law, which is based on the choice of an exponential term that adapts to the variations of the sliding-mode surface and system states, is proposed. This reaching law is able to deal with the chattering/reaching time dilemma. Based on this reaching law, a sliding-mode speed controller of PMSM is developed.

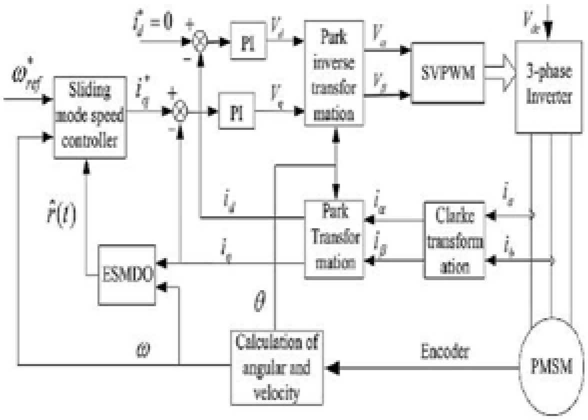
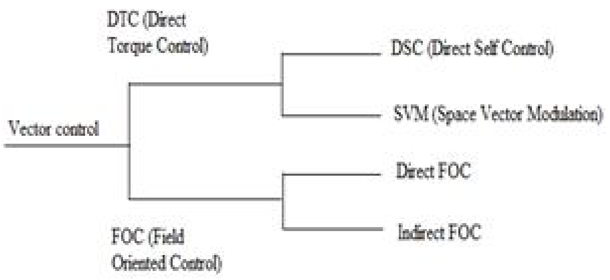


Fig 1.2 Block Diagram of SMC plus ESMDO

Then, to further improve the disturbance rejection performance of SMC method, extended sliding-mode disturbance observer (ESMDO) is proposed, and the estimated system disturbance is considered as the feed forward compensation part to compensate sliding-mode speed controller. Thus, a composite control method combining an SMC part and a feed forward compensation part based on ESMDO, called SMC+ESMDO method, is developed.

II.CONTROL OF PMSM

A Variable Frequency Drive is a type of adjustable speed drive used in electro- mechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.



Vector Control

Field Oriented Control

Field-oriented control (FOC), is a variable-frequency drive (VFD) control method in which the stator currents of a three-phase AC electric motor are identified as two orthogonal components that can be visualized with a vector. One component defines the magnetic flux of the motor, the other the torque. The control system of the drive calculates the corresponding current component references from the flux and torque references given by the drive's speed control. Proportional-integral (PI) controllers are used to keep the measured current components at their reference values.

FOC is used to control AC synchronous and induction motors. It was originally developed for high-performance motor applications that are required to operate smoothly over the full speed range, generate full torque at zero speed, and have high dynamic performance including fast acceleration and deceleration. However, it is becoming increasingly attractive for lower performance applications as well due to FOC's motor size, cost and power consumption reduction superiority.

III. SPEED CONTROLLER DESIGN BASED ON PROPOSED REACHING LAW

Speed-control algorithms should keep the actual speed track of the speed reference ω_{ref} accurately under the occurrence of disturbances. To achieve this control objective, the tracking error is defined as e = $\omega_{ref} - \omega$. Then, according to aforementioned sliding-mode design method, the following sliding-mode surface is chosen:

$$S = e = \omega_{ref} - \omega \quad \text{(linear sliding-mode surface)}$$

Taking the time derivative of the sliding-mode surface yields:

$$\dot{S} = \omega'_{ref} - \dot{\omega}$$

The dynamic equation of the motor can be expressed as follows, $\dot{\omega} = a i_q - b T_l - c\omega$

$$= a_n i_q - b_n T_l - c_n \omega + \Delta a i_q - \Delta b T_l - c\omega$$

$$= a_n i_q - c_n \omega + r(t)$$

Where $a = a_n + \Delta a = 3p^2 \psi_a$

$b = b_n + \Delta b = p/J$

$c = c_n + \Delta c = B/J$

Therefore, the control input is designed as follows: $i_q^* = a_n^{-1}\{\dot{\omega}_{ref} + c_n\omega - r(t) + eq(x_1, S).\operatorname{sgn}(S)\}$

The lumped disturbances r (t) is replaced by the upper bound l, and then the following control input is designed as $i_q^* = a_n^{-1}\{\dot{\omega}_{ref} + c_n\omega + [l + eq(x_1, S).\operatorname{sgn}(S)\}$

It can be found that upper bound l has an important effect on the control performance. However, it is difficult to select upper bound in practical application, because the lumped disturbances are difficult to know the exact value and measure. Though some methods, such as error control and trial, can be used to select upper bound, these approaches are time consuming and cannot provide enough robustness. Therefore, to overcome this drawback, an SMC with the disturbance compensation method is presented.

Speed Controller Design Based On The Proposed Reaching Law And Esmdo

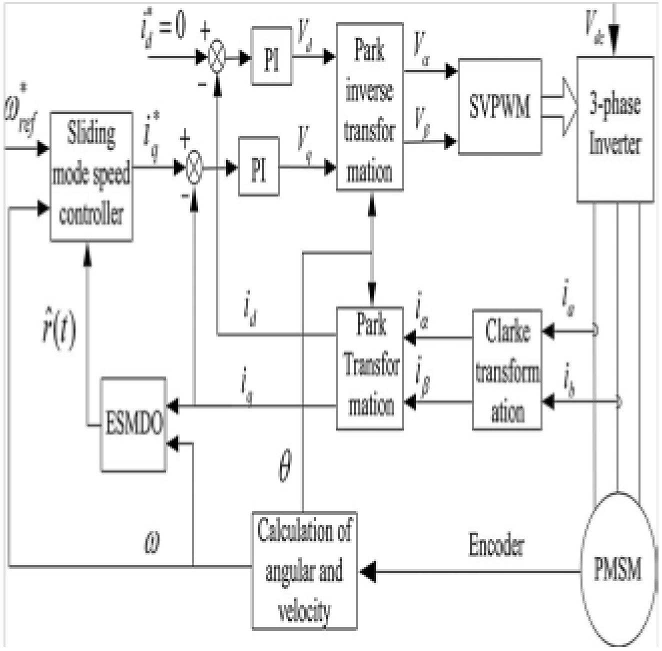


Figure 3.1 SMC+ESMDO control scheme of the PMSM speed-regulation system.

To improve the SMC system performance under disturbances, the ESMDO is adopted to estimate disturbances and the SMC+ESMDO approach is developed. In this approach, estimated lumped disturbances are considered as the feed forward part to compensate disturbances of for mentioned SMC method stated in (6.28). Thus, the control input i_q^* of the SMC+ESMDO approach is designed as

$$i_q^* = a_n^{-1}\{\dot{\omega}_{ref} + c_n\omega - \hat{r}(t) + eq(x_1, S).\operatorname{sgn}(S)\}$$

In this controller, the system disturbances can be estimated and compensated on line, which will improve the regulation ability of SMC system. Next, the Lyapunov function $V = S^2/2$ is chosen,

$$\dot{V} = S.\dot{S} = S(\dot{\omega}_{ref} + c_n\omega - r(t) - a_n i_q)$$
$$= S(-eq(x_1, S).\operatorname{sgn}(S))$$
$$= |S| eq(x_1, S) \leq 0$$

This can guarantee that the designed control system is stable and any tracking error trajectory will converge to zero in a finite time.

IV.SPACE VECTOR PULSE WIDTH MODULATION

Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). It is used for the creation of alternating current (AC) waveforms; most commonly to drive 3 phase AC powered motors at varying speeds from DC using multiple class-D amplifiers. There are variations of SVM that result in different quality and computational requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms.

A three-phase inverter converts a DC supply, via a series of switches, to three output legs which could be connected to a three-phase motor.

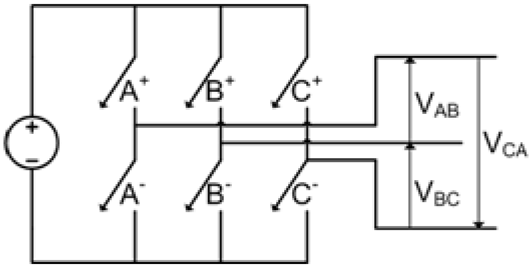


Figure 4.1 Topology of a basic three phase inverter.

The switches must be controlled so that at no time are both switches in the same leg turned on or else the DC supply would be shorted. This requirement may be met by the complementary operation of the switches within a leg. i.e. if A^+ is on then A^- is off and vice versa. This leads to eight possible switching vectors for the inverter, V_0 through V_7 with six active switching vectors and two zero vectors.

To implement space vector modulation, a reference signal V_{ref} is sampled with a frequency f_s ($T_s = 1/f_s$). The reference signal may be generated from three separate phase references using the αβγ transform. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses.

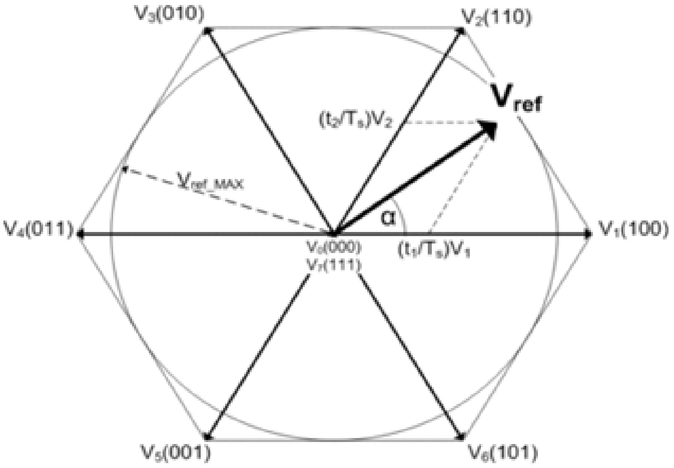


Figure 4.2 All eight possible switching vectors for a three-leg inverter using space vector modulation.

V_{ref} is shown in the first sector.

V_{ref_MAX} is the maximum amplitude of V_{ref} before non-linear over modulation is reached**.**

V. SIMULATION AND RESULT

Space Vector Pulse Width Modulation

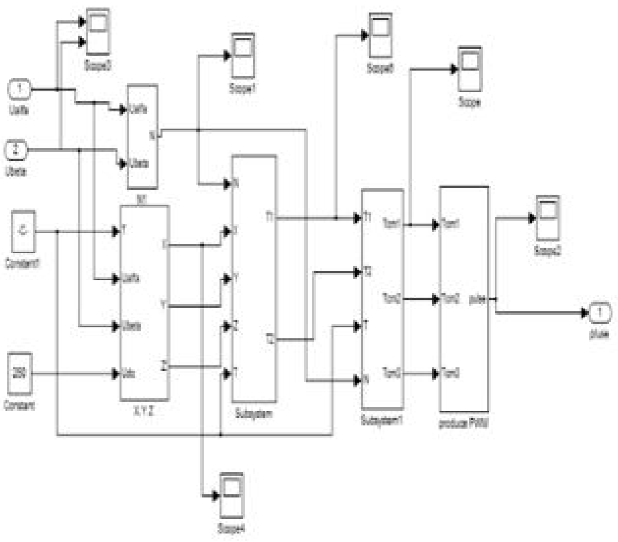


Figure 5.1 Space Vector Pulse Width Modulation

Complete Simulation Diagram

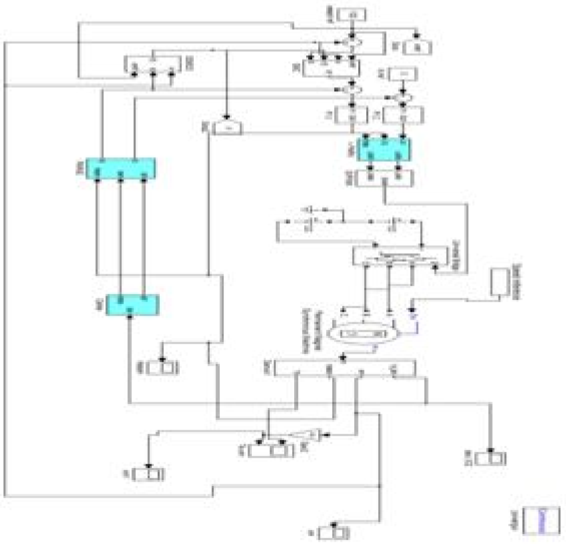


Figure 5.2 Complete simulation diagram

RESULT

Reference speed= 100 RPM

SPEED Vs TIME

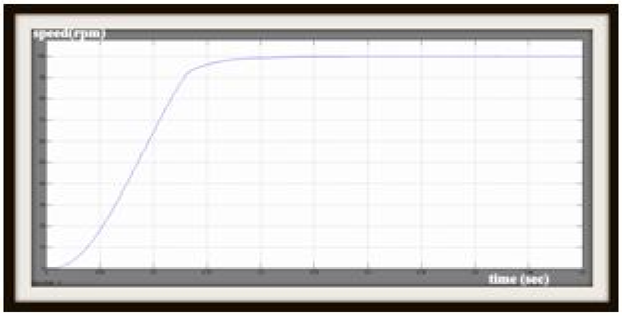


Figure 5.3Speed curve

TORQUE Vs TIME & SPEED Vs TIME

Reference speed = 1000 rpm

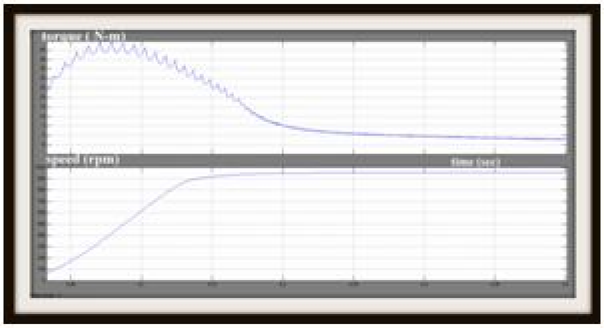


Figure 5.4 Torque curve and Speed curve

The figures show the speed and torque curves with respect to time. The SMC plus ESMDO method provides a smooth response when compared to other methods.

VI. CONCLUSION

It is obvious that the ESMDO can estimate the disturbance exactly and quickly with low chattering, and the SMC+ESMDO method has satisfying disturbance suppression ability. In practical applications, one can implement the proposed algorithm by following steps. First, an SMC speed controller should be constructed according to the proposed reaching law, and then drives the PMSM. Second, the ESMDO can also be constructed using. The effectiveness of the ESMDO when the load is added or removed suddenly. If the disturbance estimate is different from the actual load, one must check whether the parameters of the ESMDO are right. Finally, if the ESMDO can estimate disturbances exactly, estimated disturbances can be considered as the feed forward part to compensate disturbances.

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