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Speed Control of a Fuzzy-Logic-Controller-Based IPMSM Drive

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Abstract— This project presents an online loss-minimization algorithm (LMA) for a fuzzy-logic-controller (FLC)-based interior permanent-magnet synchronous-motor (IPMSM) drive to yield high efficiency and high dynamic performance over a wide speed range. LMA is developed based on the motor model. In order to minimize the controllable electrical losses of the motor and thereby maximize the operating efficiency, the *d*-axis armature current is controlled optimally according to the operating speed and load conditions. For vector-control purpose, FLC is used as a speed controller, which enables the utilization of the reluctance torque to achieve high dynamic performance as well as to operate the motor over a wide speed range.

Keywords—PMSM; MATLAB; Fuzzy; SMC

I. INTRODUCTION

RECENTLY, the permanent magnet synchronous motors (PMSMs), which have advantages such as high efficiency and low inertia, have been extensively utilized in ac motor drive applications along with the rapid development in power electronics and especially digital signal processors (DSPs) that can quickly perform advanced vector control algorithms. To control PMSM, linear control schemes, e.g., proportional-integral (PI) controller and linear-quadratic regulator have been widely applied due to their relatively simple implementation [1]–[4]. Unfortunately, PMSM servo system is a nonlinear system with unavoidable and unmeasured disturbances, as well as parameter variations. Moreover, in practical applications, PMSM systems are always confronted with various disturbances that may be generated internally, e.g., friction force and unmodeled dynamics, or externally, e.g., load torque. As a result, it is very difficult for linear control schemes to achieve high performance.Therefore, nonlinear control methods can become an alternative solution to accurately track the reference trajectory of PMSM. In recent years, various nonlinear control algorithms have been presented, such as adaptive control [5], [6], robust control [7], backstepping control [8], feedback linearization control [9], direct torque control [10]–[12], and intelligent control [13]. In particular, sliding mode control (SMC) [14], [15] is one of the most attractive methods that can precisely regulate PMSM. It is well known that the most salient advantage of this technique is robustness to system uncertainties and disturbances. However, its implementation suffers from a chattering problem which occurs when the control input switches is continuously across the boundary. This is undesirable because it involves high control activity and may excite high-frequency dynamics [16]. To suppress the chattering, various methods such as SMC with boundary layer [16] and SMC with sliding sector [17] have been proposed. The basic idea behind these works is to smooth the control action across the sliding surface while preserving the traditional SMC law. To improve the system response of the traditional SMC, in [18], a two-phase SMC law that incorporates the distance of the system state from the sliding surface into the controller design was presented. The principle of this method is to include an extra distance dependent on variable term that helps reduce the hitting time because the switching control action in SMC is usually not strong enough to attenuate chattering. However, chattering may still occur under certain operating conditions.

II. SYSTEM MODELING

In the dq rotor reference frame, a surface-mounted PMSM can be expressed as the following dynamic model ,where TL is the load torque, . is the electrical rotor angular position, . is the electrical rotor angular speed, iqs is the q-axis current, Vqs is the q-axis voltage, ids is the d-axis current, Vds is the d-axis voltage, d1(t) and d2(t) are the disturbance inputs representing the system nonlinearity or the unmodeled uncertainty, p is the number of poles, motor parameters Rs, Ls, J, B, and .m are the nominal values of the stator resistance, the stator inductance, the rotor inertia, the viscous friction coefficient, and the magnetic flux, respectively, and ki> 0, i =1, ..., 6 are the parameter values depending on Rs, Ls, J, B, and .m. In this paper, the following assumptions will be made to design an observer-based fuzzy sliding mode speed controller.

1) iqs, and ids are measurable.
2) TL is unknown and T.L is equal to zero [6], [19].
3) The desired speed .d is constant and ..d =¨.d =0.
4) di(t), i =1, 2 is unknown but bounded as |di(t)|=di, where di =0 is known.

III. FUZZY SLIDING MODE SPEED CONTROLLER DESIGN

A. Sliding Surface Design

In SMC, the system dynamics is only determined by the dynamics of the sliding surface. In this section, the sliding surface will be designed.

B. Switching Law Design

Let the control inputs Vqs and Vds be decomposed as the following control law

$$Vqs = (Vqf + Vqbf)$$
$$Vds = (Vdf + Vdbf)$$

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where Vqf and Vdf are the nonlinear decoupling control terms to compensate for the nonlinearities of PMSM, and Vqbf and Vdbf are the switching control terms to force the system trajectory to the sliding surface.

Define the nonlinear decoupling control law Vqf and Vdf as

Vqf =k1k4iqs +k1k5. +k1ids. +k2ß

Vdf =-.iqs.

a switching feedback control strategy can straightforwardly be designed such that the system trajectory is driven onto the switching surface s =0 and it is maintained there for all subsequent time.

Let the switching control law Vqbf and Vdbf be defined as

Vqbf =-cß -(k1d1+e1)·sgn(s1)

Vdbf =-(d2+e2)·sgn(s2)

where di is already defined in A4 and ei > 0.

C. Stability of Sliding Mode Controller

Stability analysis of an SMC system is decoupled into two phases. The first is to show the stability of the reduced-order sliding mode dynamics. The second is to verify the reach ability condition.

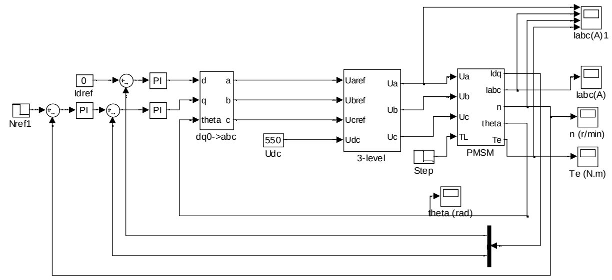
First, from the relationship ß =..e, the sliding surface (4) can be rewritten as

s1=c.e +..e, s2=ids.

By setting s =.s =0and using the equivalent control method [20], it can be shown that the sliding mode dynamics restricted to s =0 is given by

..e =-c.e

which is asymptotically stable if c > 0.



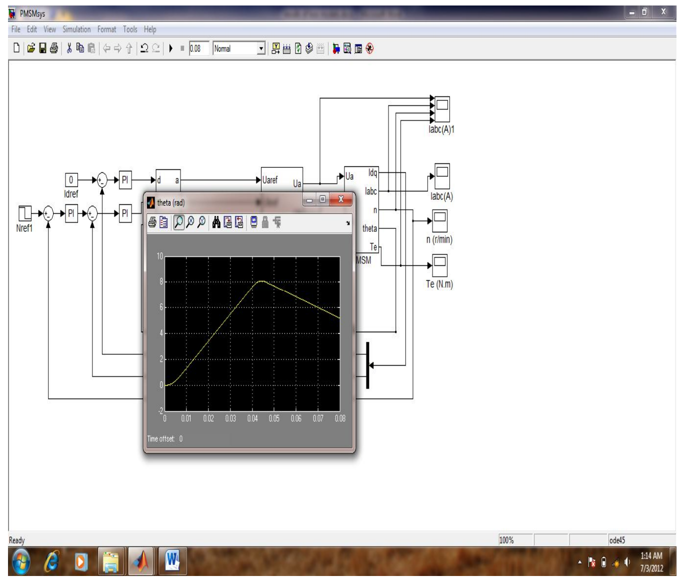


Fig 1:load torque observation design

IV. LOAD TORQUE OBSERVER DESIGN

The proposed fuzzy SMC law requires the knowledge of load torque TL, so the control performance can be seriously degraded in the presence of load torque variations if the term TL is not properly considered. In this section, a simple load torque observer will be designed.

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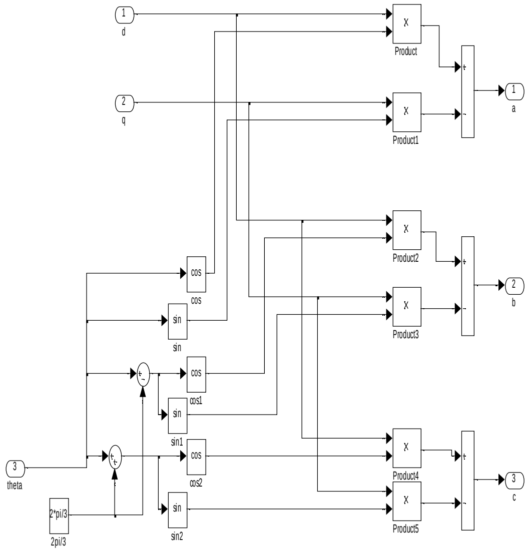
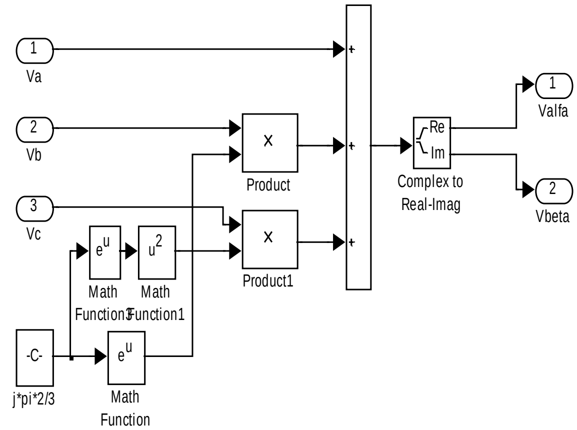


Fig 2:



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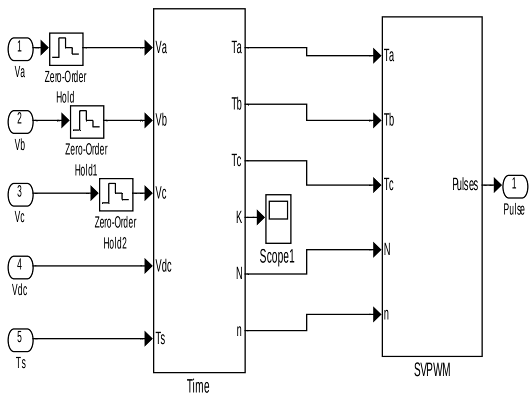

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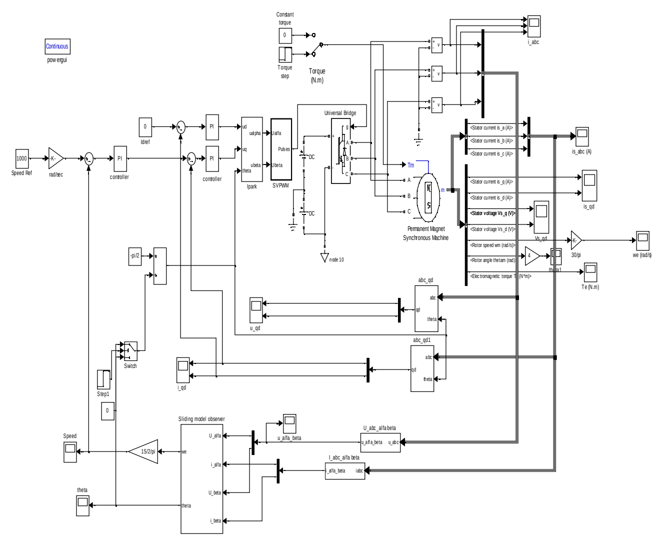

Fig 5:

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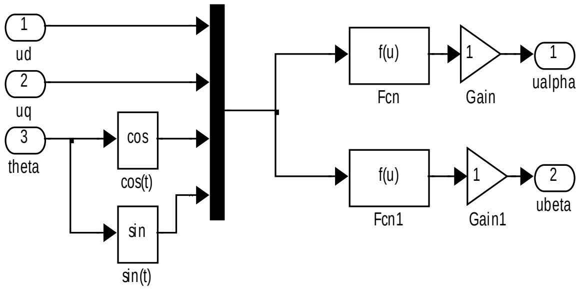

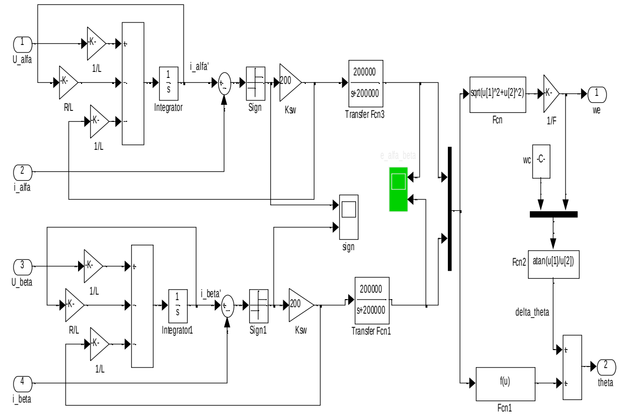

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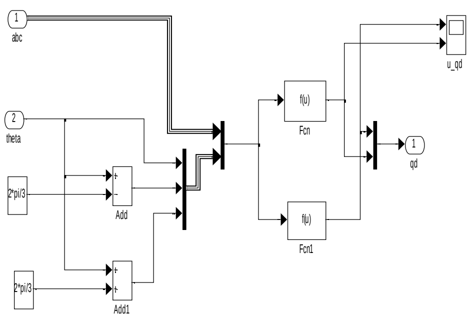

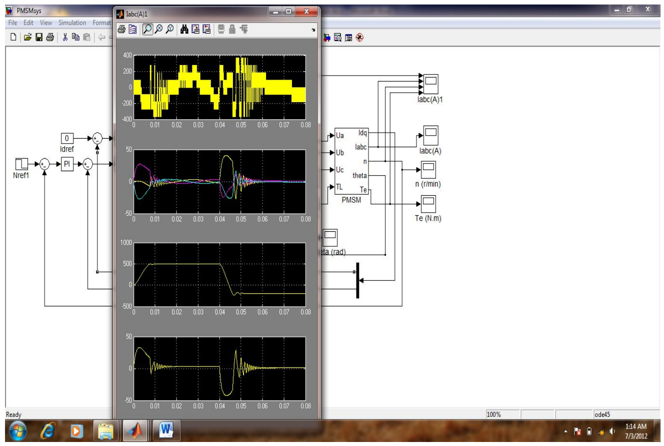

Fig 8:

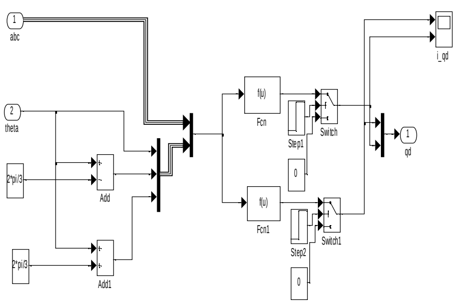

Fig 7:

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V. CONCLUSION

This paper proposed a fuzzy sliding mode speed controller with a third-order load torque observer for a robust speed tracking of a IPMSM. The proposed observer-based fuzzy SMC method took into account the disturbance inputs representing the system nonlinearity or the unmodeled uncertainty to guarantee the robustness under motor parameter and load torque variations. Simulation and experimental results clearly demonstrated that the proposed control system can not only attenuate the chattering to the extent of other control methods (e.g., PI control, fuzzy control, etc.) but can also give a better transient performance in comparison with the non-fuzzy sliding mode controller under the conditions of motor parameter and load torque variations.

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