Performance Study of Sliding Mode Controller based Induction Motor Drive

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Abstract--**Induction motors are popular among all types of electrical machines. Speed control of such motors is challenging due to coupling effect of speed-flux loops. Control is also exigent due to parametric variations, large operating range and external disturbances. A well established sliding mode control(SMC) technique is potential candidate to solve above said problems. Performance of SMC for Induction motor(IM) speed control is investigated for set point tracking, load disturbance and parametric variation. The simulation results show SMC based IM control is superior to conventional Proportional-Integral(PI) approach. The performance of SMC is further enhanced by adding PI control with SMC. It helps to remove offset present with only SMC.**

Index Terms—**Field Oriented Control, Induction motor, Sliding Mode Control**

I. INTRODUCTION

Exceptional reliability, high efficiency, simple construction, low maintenance cost, low weight and ruggedness of Induction motors (IM), make them more attractive over DC motors, which suffer from the major drawback of commutator sparking. However, Induction motors' nonlinear dynamics and coupling of torque-flux loops, make their control a challenging task. A real burst through in IM control was the design of the field-oriented control(FOC), which enables the decoupled control of rotor flux and electromagnetic torque. This has increased the popularity of induction motors in variable speed and variable torque applications [1],[2],[3],[4].

Indirect FOC, is a standard flux position estimation approach, butit's control performance suffersdue to parameter variations and load disturbances. A high performance industrial drive must have fast response, preferably without overshoot, good external disturbance rejection and robustness to parameter variations [4],[5].

This paper presents a performance study of Sliding Mode Control (SMC) for IM drives along with its comparison with Proportional-Integral (PI) and also with SMC-PI combination based IM drive.The simulation results show the efficacy of the SMC-PI algorithm. For SMC, the system given in [6] is used, while for PI, the Simulink Power System power_acdrive model is used. For SMC-PI combination a PI term is added to the SMC output[7] in the system used in [6]. To have standardcomparison, the systems have been brought to a common platform. All the schemes are compared based on various criteria including parameter sensitivity, load torque disturbance and set point tracking.

The paper is organized as follows:The basic concept of Sliding Mode Control is discussed in section II. The simulation study of IM with various algorithms is presented in section II.

II. SLIDINGMODECONTROL

Sliding Mode Control or a Variable Structure Control Strategy is basically a robust control technique. SMC was first proposed and elaborated in early 1950's in the Soviet Union.A detailed survey on development and applications of SMC is presented in [8].SMC is equally useful for linear as well as certain class of nonlinear systems. It is a leading contender for Induction motor drives. It gives order reduction, invariance to torque variation, fast dynamic response and parameter uncertainties[9],[10],[11]. To understand robust properties of SMC, a linear system given in equation (1) is considered.

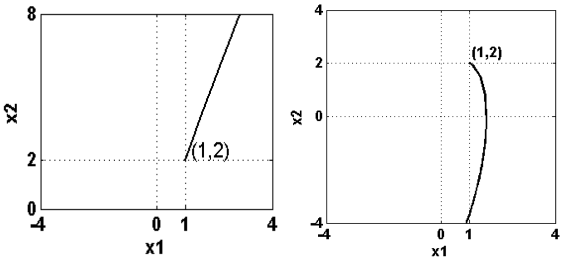
$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = 2x_2 - x_1 + u \quad (1)$$

System matrix for the system in eqn.(1) is

$$A = \begin{bmatrix} 0 & 1 \\ -1 & 2 \end{bmatrix} \quad (2)$$

Thesystem in eqn.(1), when simulatedfor positive andnegative control input with the initial condition $(x_1, x_2) = (1,2)$ gives the phase trajectories as shown in Fig. 1(a) and 1(b) respectively.



(a) (b)

Fig.1 Phase trajectories for (a) $u = + x_1$ and (b) $u = - x_1$

Fig. 1(a) and 1(b) show that the system is unstable for both positive and negative control laws. The same system is controlled by sliding mode control law,

$$u = -\; x_1 sign(\sigma) \quad (3)$$

where,

$$\varphi = - \quad \sigma(x_1,x_2) > 0$$

$$\varphi = - \quad \sigma(x_1,x_2) < 0$$

$\sigma = x_1$ is the switching function formed by the switching lines:

$$s = 0.5x_1 + x_2 \text{ and} \quad (4)$$

$$x_1 = 0 \quad (5)$$

The phase trajectory with SMC is as shown in Fig.2

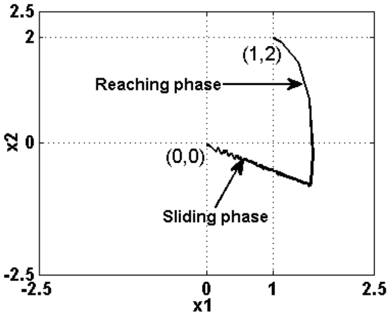
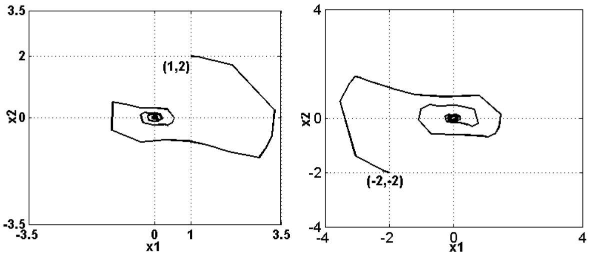


Fig.2 Phase trajectory with SMC

From Fig. 2, it is seen that with SMC, the system is stabilized.To check the robustness property of SMC, change in (a) system matrix A and (b) initial condition have been applied.The results are presented in Fig. 3(a) and 3(b) respectively.



(a)(b)

Fig.3 Phase trajectory with SMC for change in (a) system parameter and (b) initial condition

It is evident from Fig. 3(a) and 3(b), that the SMC demonstrates robust performance against parametric variations and initial conditions. It also guarantees asymptotical convergence. This provides motivation to apply SMC for the control of Induction Motor which suffers from parametric variations and uncertainty in the dynamics.

III. SMC FOR INDUCTION MOTOR DRIVES

Ideal decoupling of Induction motor using vector control is possible only if the motor parameters used in designing a controller remain unchanged. However, in addition torotor parameter variations with temperature, IM drives are subjected to load torque disturbances, error in approximations in the model used in analysis and the design of controller.

This section presents simulation results of comparison between (i) PI based IM drive,(ii) SMC based IM drive and (iii) Combined SMC and PI based IM drive. The models considered for comparison are from SimPower Systems toolbox of MATLAB for PI and model used in [6] for SMC and for the SMC-PI combination.

The PI controller is tuned with $K_p = 50$ and $K_i = 5$ for speed control loop. Torque reference output from the PI controller is then converted to torque producing currentreference (I_{sq}^{*}), while externally fed flux reference is used to generate flux producing current reference (I_{sd}^{*}) the block diagram for the scheme is shown in Fig.4

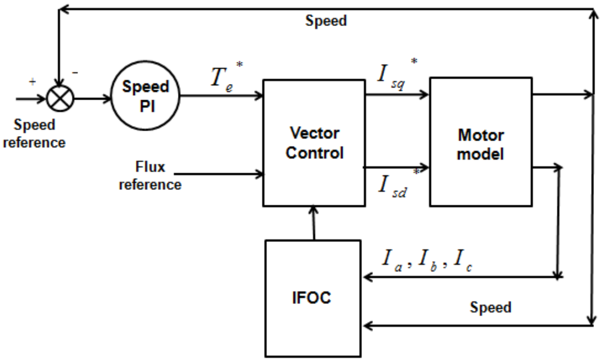


Fig. 4. Block diagram for PI based IM drive

In case of SMC based drive, speed error and flux error are fed to the SMC. The voltage references (U_{sq}^{*}) and (U_{sd}^{*}) generated by the SMC are then fed to the motor model to obtain speed, flux and torque output. Fig. 5 shows the block diagram for SMC based drive.

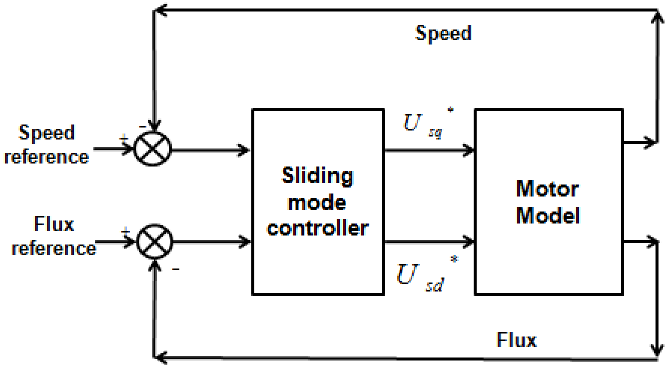


Fig. 5. Block diagram for SMC based IM drive

For the proposed case of combined SMC and PI, a PI term with $K_p = .6$ and $K_i = 4.7625$ is added to the speed control loop SMC output generated in the second case with SMC as shown in Fig.6

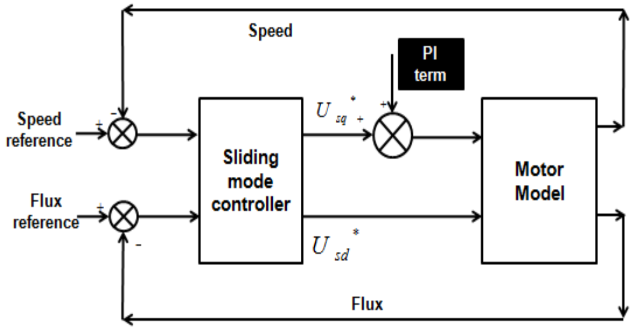


Fig. 6. Block diagram for SMC+PI based IM drive

Different cases under which simulation is carried out are:

a) Step change in reference speed
b) Step change in load torque
c) Change in rotor resistance (R_r)

The comparative study of the results for the three schemes is shown below:

a) Step change in reference speed

The reference speed is changed from 0 rad/s to 120 rad/s at t=0. The speed response is shown in Fig.7 below:

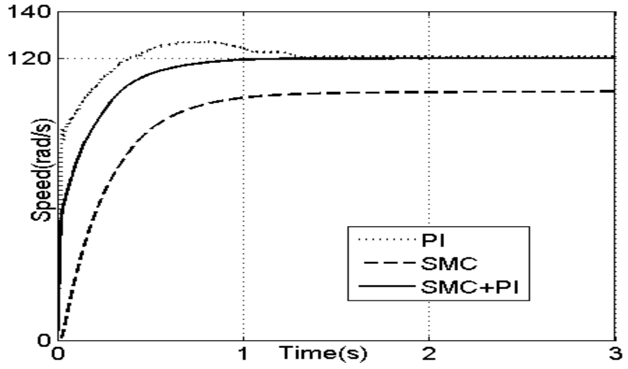
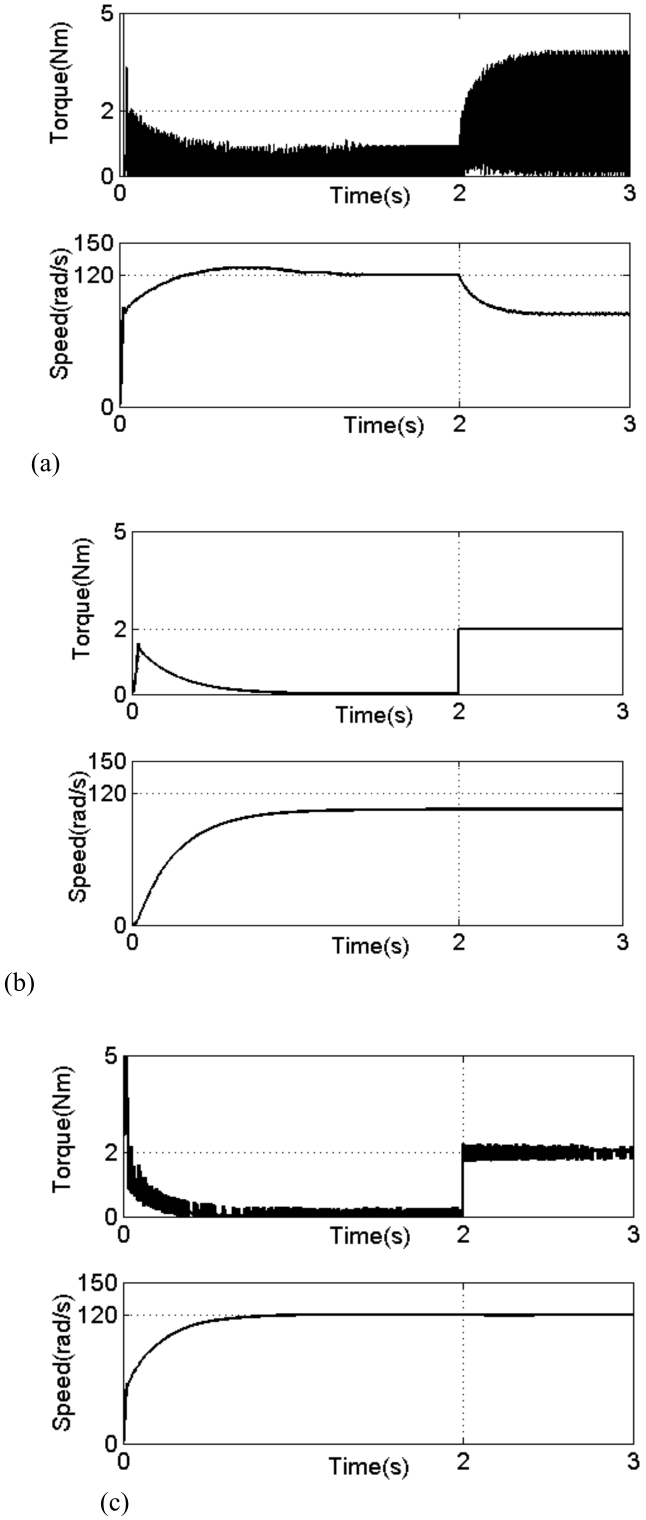


Fig.7Speed response of PI, SMC and SMC+PI

It is observed that speed response with PI gives an overshoot, while with SMC overshoot is removed, but an offset in the speed is observed. Adding a PI term to the SMC output removes the offset as well as response is overshoot free.

b) Step change in load torque

A step increase in load torque of 2 Nm is applied at t=2. Fig. 8(a), 8(b) and 8(c) show the torque and speed response of the controls being compared.



(a)

(b)

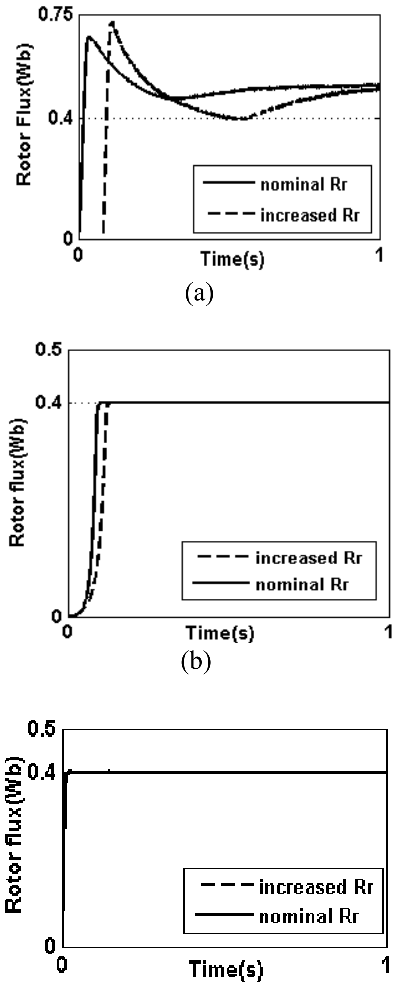
(c)

Fig.8Speed and torque curves for (a) PI , (b) SMCand (c) SMC+PI

From Fig 8(a), a dip in speed is observed when a step increase in load torque is applied for the case of PI based drive, while from Fig.8(b) and 8(c), it is evident that there is almost no effect of load torque change on speed in SMC and SMC+PI based drive. It is also observed that addition of PI to SMC adds undue oscillations in the torque response.

c) Change in rotor resistance (R_r)

As, it is a well known fact that the rotor resistance of an induction motor changes with temperature which in turn affects the rotor flux, rotor flux response curves for an increase in rotor resistance by 100% are shown in Fig.9(a), 9(b) and 9(c) for the three control strategies being discussed.



(a)

(b)

(c)

Fig.9Rotor flux response before and after the increase in rotor resistance for (a) PI , (b) SMC and (c) SMC+PI

From Fig 9(a), a visible deviation in rotor flux is observed in case of PI based drive.Fig.9(b) shows a minimal disparity for SMC while for SMC + PI, almost no deviation between the flux response with nominal and increased rotor resistance is seen in Fig.9(c).

IV. CONCLUSION

Conventional PI speed controller gives an offset-free speed response but displays overshooting and is also sensitive to parameter variations. SMC is found to be fast, insensitive to the parameter variations and robust, except for the disadvantage of exhibiting speed offset. The proposed SMC+PI algorithm, demonstrates excellent dynamic performance, insensitivity to parametric uncertainties and external disturbances along with high accuracy for an IM drive application.

Hardware implementation of SMC+PI algorithm on programmable digital device requires discrete sliding mode control which may be further explored.

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