Position Control of Induction Machine Using New Technique to Reduce Chattering

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***Abstract* - Induction Motors have been used as the workhorse in the industry for a long time due to its easy build, high robustness, and generally satisfactory efficiency. However, they are significantly more difficult to control than DC motors. One of the problems which might cause unsuccessful attempts for designing a proper controller would be the time varying nature of parameters and variables which might be changed while working with the motion systems. One of the best suggested solutions to solve this problem would be the use of sliding mode control (SMC). This paper presents the design of a new controller for a vector control induction motor drive that employs an outer loop speed controller using SMC. Several tests were performed to evaluate the performance of the new controller method, and two other sliding mode controllers. From the comparative simulation results, one can conclude that the new controller provides high performance dynamic characteristics and is robust with regard to plant parameter variations.**

***Index Terms*- Induction motor, Nonlinear control, Sliding mode control, Position control.**

I. Introduction

There is a demand for high performance electric drives capable of accurately executing torque, speed or position demands. This has necessarily led to a growth in the number and sophistication of control methods applied to this problem [1-3]. Particular attention has been devoted to the induction motor (IM) for reason of cost, size, weight, reliability, simplicity, efficiency and ease of manufacture. The application of advanced control schemes for position or speed control of the IM has been made possible by the increasing power and reducing costs of microprocessors and digital signal processors. Over the past decade, field-oriented control (FOC) or vector control (VC) technique has been widely used in industry for high performance IM drive [4-7], where the knowledge of synchronous angular velocity is often necessary in the phase transformation for achieving the favourable decoupling control. Traditionally, two feedback loops are configured to implement a vector controlled IM drive system. The inner loop is a current regulation loop whereas the outer one is a speed or position regulation loop. Conventionally, the proportional plus integral (PI) controller is simple and very easy to design and implement, and a PI controller is used for both inner and outer loops. However, the performance of PI controller for speed or position regulation degrades under external disturbances and machine parameter variations. Furthermore, the PI controller gain has to be carefully selected in order to obtain a desire response. This makes the use of traditional PI controller a poor choice for industrial variable speed drive applications where higher dynamic control performance with little overshoot and high efficiency is required. The parameter variation issues can be solved by advanced control techniques such as self tuning regulators, and SMC [8-10].

SMC as a branch of robust control is a powerful technique to control nonlinear systems with uncertainty. The theory of SMC has been developed firstly in Soviet Union by Emelyanov, introduced after by Utkin [11-13], and more recently studied by several authors [14-18]. The SMC can offer many good properties, such as insensitivity to parameter variations, external disturbance rejection, and fast dynamic response. These advantages of SMC have been employed in the position and speed control of ac servo systems [1-3]. The major shortage of SMC is the chattering phenomenon. Several methods have been described in literature to alleviate the chattering. In general, a sliding motion can be divided into two phases: a reaching phase and a sliding phase. The reaching phase is also called non-sliding phase, in which the trajectory approaches the sliding surface from an arbitrary initial position within a finite time. The sliding phase ensures that the trajectory asymptotically move towards the equilibrium point of the sliding surface. When the system states are on the sliding phase, the system response will only depend on the pre-designed sliding surface parameters and is independent of system dynamics. The insensitivity of the controlled system to uncertainties exists in the sliding mode, but not during the reaching phase. Thus, the system dynamic in the reaching phase is still influenced by uncertainties. Therefore, various methods have been suggested to eliminate or lessen the system sensitivity by minimizing or even removing the reaching phase. In [19], high gain feedback was used to minimize the reaching phase. Unfortunately, this may cause sensitivity to unmodelled dynamics and chattering which is undesirable in a physical system. In [20], a time varying sliding surface was proposed to remove the reaching phase by imposing a constraint that initial errors be zero in tracking control.

In this paper, to reduce chattering and accelerate reaching phase a new and simple corrective control signal is proposed depend on the distance between the state error trajectory and sliding surface. To evaluate the performance of the proposed new SMC technique, we provided a series of simulations and a comparative study between the performances of the new proposed controller strategy and two different types of sliding mode controller laws under three different test conditions, nominal inertia, high inertia, and rotor resistance mismatch. Simulation results show that the new sliding mode controller strategy scheme can achieve better performance rotor position control of a vector controlled induction machine tracking than the two different types of sliding mode controller algorithms in the face of system parameters variation.

II. Sliding Mode Controller Techniques

This section presents the design of new robust sliding mode controller for a vector control IM drive that employs an outer loop position controller using SMC strategy. Also in this section, two of the most popular sliding mode controller methods are studied and their performance compared with the new proposed controller scheme.

A. New Sliding Mode Controller Technique

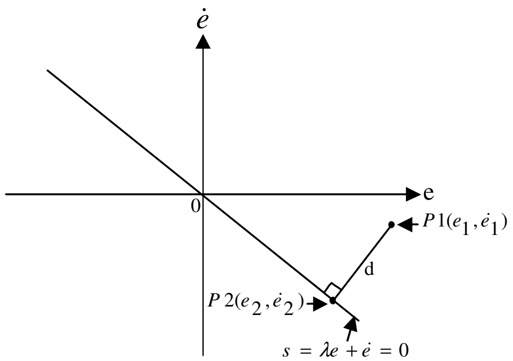

Fig. 1 Derivation of signed distance

From Fig. 1 the distance from P1 to the sliding surface (s) is given by the following equation:

$$d = \left[(e_2 - e_1)^2 + (\dot{e}_2 - \dot{e}_1)^2 \right] = \frac{|\lambda e_1 + \dot{e}_1|}{\sqrt{\lambda^2 + 1}} \quad (1)$$

Without loss of generality (1) can be rewritten as the following equation:

$$d = \frac{|\lambda e + \dot{e}|}{\sqrt{\lambda^2 + 1}} \quad (2)$$

The signed distance (d_s) is defined for an arbitrary point P as follows:

$$d_s = sign(s)\frac{|\lambda e + \dot{e}|}{\sqrt{\lambda^2 + 1}} = \frac{\lambda e + \dot{e}}{\sqrt{\lambda^2 + 1}} = \frac{s}{\sqrt{\lambda^2 + 1}} \quad (3)$$

From above equation seen that if s>0 then d_s>0, and if s<0 then d_s<0. From this relation the absolute magnitude is proportional to the distance from sliding surface (s=0), we can conclude that:

$$u_c = -K_d d_s \quad (4)$$

Where K_d positive constant that is defined as weight of distance to improving the control effect. The corrective control action can be determined by distance between the state error trajectory and sliding surface only. It is know that when the state error trajectory is far from the sliding surface $|d_s|$ is large the corrective control gain should be increased to force the state trajectories to approach the sliding surface rapidly and vice verse. Based on the above discussed heuristics, the following rules are proposed.

* If $|d_s|$ is large then u_c is large.

* If $|d_s|$ is small then u_c is small.

* If $|d_s|$ is zero then u_c is zero.

This approach has significant advantage that by applying the large control input when the state error trajectory far from sliding surface, not only the chattering on sliding surface is reduced but also the rate of reaching phase is accelerated. In order to investigate the effectiveness of the new sliding mode controller method, it was applied to position control of induction machine using computer simulation. The control law is proposed as:

$$u = u_{eq} + u_d + u_c \quad (5)$$

Where u_{eq}, u_d and u_c are control signals for the equivalent, discontinuous, and corrective controls respectively. The u_d is defined as:

$$u_d = -K \ \mathrm{sign}(s) \quad (6)$$

The sliding surface (s) defined as

$$s = \lambda\theta_e + \dot{\theta}_e \quad (7)$$

Where θ_e = tracking error = θ_r (rotor position) -θ_d (desired rotor position), λ is a strictly positive constant that determine the bandwidth of the system, and K is a positive scalar. For real time implementation the sign term needs to be substituted by a saturation function to attenuate chattering.

$$u_d = -K \ \mathrm{sat}\left(\frac{s}{\phi}\right) \quad (8)$$

where ϕ define the width of the boundary layer. Finally the control law is modified to:

$$u = u_{eq} - K \ \mathrm{sat}\left(\frac{s}{\phi}\right) + \frac{-K_d}{\sqrt{\lambda^2 + 1}} s \quad (9)$$

B. Pseudo Technique

This control technique is similar to the signum technique except that it addresses the chattering problem. A smoothing factor is introduced in signum function as follows [21]:

$$u_p = -K_p \frac{s}{|s| + \delta} \quad (10)$$

Where sliding surface (s) has the same definition as (7), K_p is a positive scalar, and δ is a small positive design constant. The signum function effectively becomes a continuous function to avoid the discontinuous effect.

C. Saturation Technique

Slotine proposed a technique to change the dynamics near to the sliding surface in order to avoid a real discontinuity and at the same time to preserve the sliding mode properties [20]. This technique introduces a boundary layer (ϕ) on both sides of the sliding surface in order to avoid the chattering effect in the control signal. This technique, however, does not ensure the convergence of the state trajectory of the system to the sliding surface, and probably results in the existence of the steady state error. This control algorithm is represented by the following equations.

$$u_{sat} = -K_{sat} sat(\frac{s}{\phi}) \tag{11}$$

where sliding surface (s) has the same definition as (7). By choosing the control gain K_{sat} large enough to overcome the effect of external disturbances (usually set to the maximum value of control effort), the phase trajectory will be forced into the boundary layer (BL) when it is outside. Inside the boundary layer, the control law is continuous thereby eliminating the chattering problem. Therefore the only design parameter to choose is the boundary layer width. If too small the saturation control law will resemble the pure discontinuous sliding mode control law approach, if it is too large, the control performance will be influenced.

III. Sliding Mode Position Control

In this section, the three sliding mode controller laws presented previously are compared using the same rotor position reference command. The position control goal is to force the rotor position θ_r to track the desired rotor position referenceθ_d. For the position control system, the mechanical equation of an IM drive can be represented as:

$$\ddot{\theta}_r = \frac{1}{J}(-B\dot{\theta}_r - T_L + T_e) \tag{12}$$

Where J is the moment of inertia, B is the damping coefficient, T_L is the torque of external load disturbance, and Te denotes the electromagnetic torque. With the implementation of field oriented control, the electromagnetic torque can be simplified as:

$$T_e = K_t i_{qse}^* = \frac{3PL_m^2}{2L_r} i_{dse}^* i_{qse}^* \tag{13}$$

Where L_m is the magnetizing inductance per phase, L_r is the rotor inductance per phase referred to stator, P is the number of pole pairs, i_{qse}^* and i_{dse}^* denote the torque and flux current commands. Substituting (13) into (12), the mechanical dynamic of the IM drive system can be represented as:

$$\ddot{\theta}_r = \frac{1}{J}(-B\dot{\theta}_r - T_L + K_t i_{qse}^*) \tag{14}$$

IV. Simulation Results

The new controller's performance was compared with that of the other tow sliding mode controller laws under three different test conditions, nominal inertia, high inertia, and high inertia with rotor resistance mismatch. The different sliding mode controller algorithms are compared using the same rotor position reference command. The design parameters of the three sliding mode controllers are shown in appendix VII. The variable control parameters K, K_{sat} and K_p are set to the maximum value of control effort possible (9A). The Matlab/Simulink software package is used for the comparison.

A. Nominal Condition

In this section the tracking performances of the new proposed sliding mode controller technique and other two different types sliding mode controller schemes are compared under nominal condition. Figs 2-4 show the rotor position tracking, rotor position tracking error, and control effort performance using the three sliding mode controller techniques. The results show that high precision rotor position tracking can be achieved using the three sliding mode controllers. The maximum rotor position errors for the new proposed, pseudo and saturation sliding mode controllers are recorded as ±0.002rad, ±0.005rad, and ±0.027rad, respectively. However, the new sliding mode controller algorithm shows smaller peak rotor position error compared to the pseudo and saturation sliding mode controller laws. This means that the new sliding mode controller strategy can track the rotor position command more accurately than the other two sliding mode controller algorithms. For both saturation and new sliding mode controllers the peak error is below the theoretical tracking precision (ϕ/λ) figure of 0.08 rad. Fig. 4 shows plot of control effort i_{qse}^* versus time for the three sliding mode controllers. In the nominal parameters case, all three sliding mode controllers exhibit broadly similar control output responses.

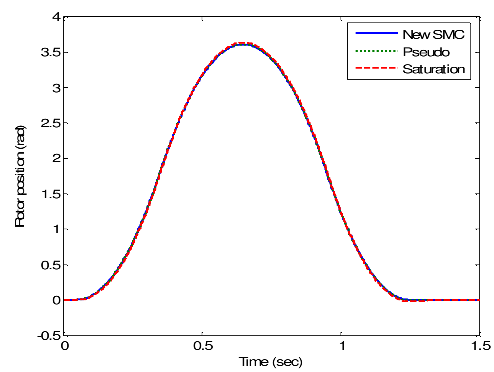

Fig. 2 Rotor position tracking performance

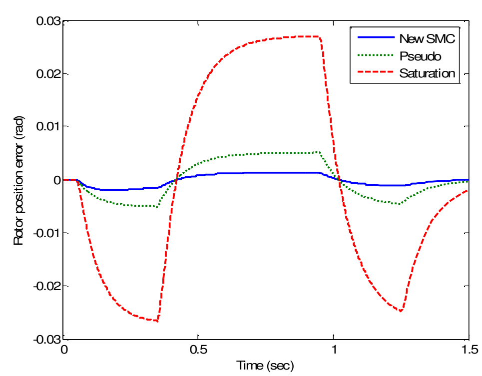

Fig. 3 Rotor position tracking error

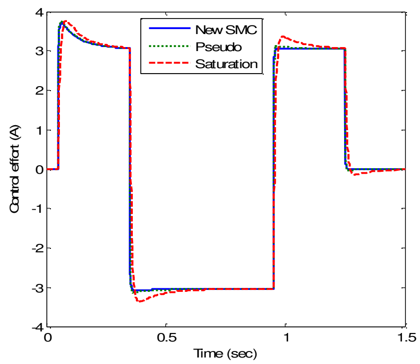

Fig. 4 Control effort

B. Increase the Moment of Inertia

The simulation test conditions are the same as in the previous section, but here the moment of inertia of the motor is doubled. Figs 5-7 show the simulation results for the three controllers. Despite the high moment of inertia in the system, the results show that high precision rotor position tracking still can be achieved using the three controller techniques. However, the simulation results show larger peak rotor position errors when the moment of inertia is increased. Furthermore, the error produced by saturation sliding mode controller is larger than the other controller laws. In fact, the peak rotor position error for the saturation sliding mode controller is almost about three times as great as the peak error of the new controller. In the moment of inertia case, a higher control effort is demanded to counter this change.

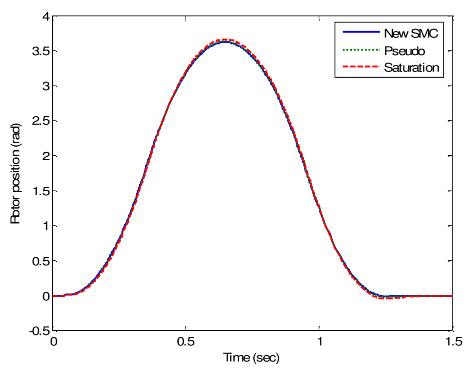

Fig. 5 Rotor position tracking performance

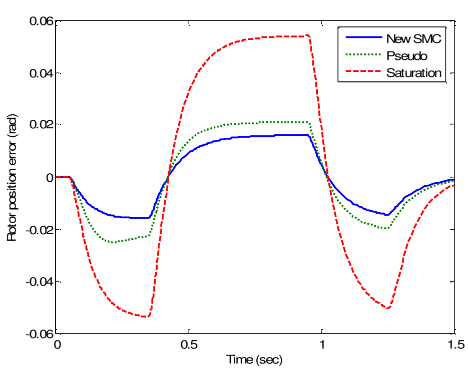

Fig. 6 Rotor position tracking error

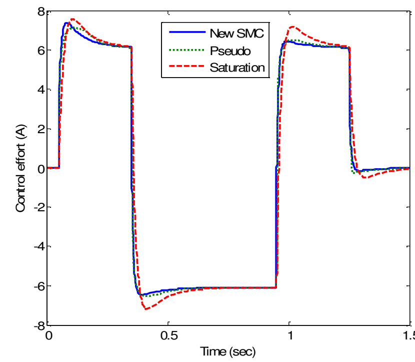

Fig. 7 Control effort

C. Increase the Rotor Resistance

In order to test the robustness of the three sliding mode controller algorithms with rotor resistance mismatch, the rotor resistance is increased to 1.75Ω during the simulation tests. Figs 8-10 show the simulation results for the three sliding mode controller algorithms under consideration. Three controller's exhibit increased tracking rotor position errors for the rotor resistance mismatch. Thus, when the rotor resistance changes, the torque response changes and effects the rotor position. However, the new sliding mode controller is again proven to be more robust against parameter variations with smaller peak rotor position error. Fig. 10 shows plot of control effort versus time for the three controllers. In this case, a higher control effort is demanded to counter this change.

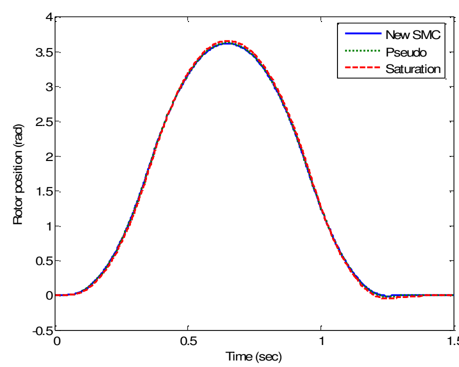

Fig. 8 Rotor position tracking performance

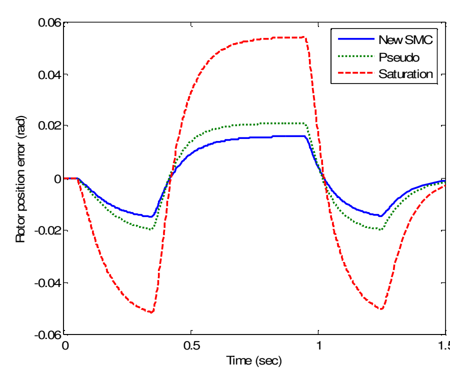

Fig. 9 Rotor position tracking error

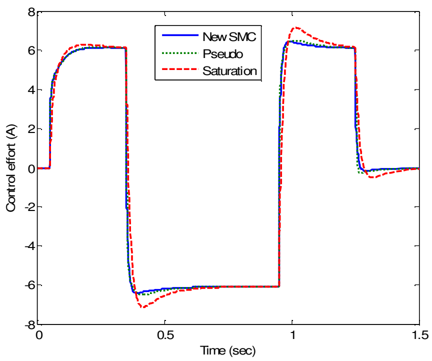

Fig. 10 Control effort

V. Conclusions

In this paper, new technique to reduced chattering for sliding mode control is submitted to design the rotor position control of induction machine. To validate the performances of the new proposed control law, we provided a series of simulations and a comparative study between the performances of the new proposed control strategy and those of the Pseudo and Saturation sliding mode controllers. The sliding mode controller algorithms are capable of high precision position tracking. From the comparative simulation results, one can conclude that the three controller techniques demonstrate nearly the same dynamic behaviour under nominal condition. Also from the simulation results, it can be seen obviously that the control performance of the new sliding mode controller strategy in the rotor position tracking, robustness to parameter variations is superior to that of the other sliding mode controller laws.

VI. Appendix

Table I The design parameters of the three controllers

SMC Techniques	Parameters	Values
Pseudo	K_P	9
	δ	0.1
	λ	10
Saturation	K_{sat}	9
	ϕ	0.8
	λ	10
New SMC	ϕ	0.8
	λ	10
	K_d	200
	K	9

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