Performance Improvement of Sliding Mode Controller based Indirect Vector Controlled Induction Motor Drive

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Abstract— **High performance induction motor drives require a better transient and steady state performances. In this paper, an improved Speed and Torque Performances of vector controlled induction motor drive is incorporated with sliding mode controller to improve the overall performance. This Sliding Mode Controller based approach improves the Speed Performance and also reduces the total harmonic distortion. To validate the proposed method numerical simulations have been carried out and compared with the conventional FOC algorithm. The simulation results show that the overall performance of the proposed algorithm is much better when compared to conventional FOC algorithm under different operating conditions.**

Index Terms— **FOC, VCIMD, SMC, THD**

I. INTRODUCTION

High performance induction motor drives require independent control of torque and flux, which can be achieved by using the FOC strategy. Hence, this control technique is becoming popular in many industrial applications. In 1972 F. Blaschke presented a paper on FOC for induction motor [1]. Though FOC method gives decoupled control, it requires reference frame transformations, which increases the complexity of the system. To improve the performance of FOC strategy, many researchers have published various papers [2-4]. In 1985, Takahashi introduced direct torque control (DTC) scheme [5]. In contrast to FOC, Scalar control method gives inherent coupling effect i.e torque and flux are the functions of voltage or current and frequency, so it gives sluggish response and system is easily subjected to instability. This problem can be solved by vector control method.

Moreover, FOC gives decoupled control of torque and flux. By this method Induction motor can be controlled like a separately excited DC Motor. Conventional FOC based algorithm gives poor speed performance when the sudden load is applied on the Induction Motor drive, and also it gives more amount of total harmonic distortion [6]. This drawback can be overcome by using the Sliding mode controller based vector control Induction Motor drive. Sliding mode controller based vector controlled induction motor drive (VCIMD) gives good speed performance and also reduces the total harmonic distortion [7-10].

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II. CONVENTIONAL FOC ALGORITHM

Though the induction motor has a very simple construction, its mathematical model is complex due to the coupling factor between a large number of variables and the non-linearities. The FOC offers a solution to circumvent the need to solve high order equations and achieve an efficient control with high dynamic. The FOC algorithm controls the components of the motor stator currents, represented by a vector, in a rotating reference frame. In the FOC algorithm, the machine torque and rotor flux linkage are regulated by controlling the stator current vector. The stator current vector is resolved into a torque producing component (i_{qs}^*) and flux producing component (i_{ds}^*) in a rotating reference frame respectively. The flux component is oriented along the rotor flux linkage vector, and the torque component is perpendicular to the flux component. This decouples the torque control from the flux control. The electromagnetic torque expression for an induction motor is given as

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}\right) \quad (1)$$

To achieve decoupling control, the entire rotor flux is aligned along d-axis and hence the q-axis flux component will become zero. With this, the torque expression can be modified as given in (2).

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\psi_{dr} i_{qs}\right) \quad (2)$$

Hence, the total rotor flux can be given as in (3).

$$\psi_r = \psi_{dr} = L_m i_{ds} \quad (3)$$

From (1), it can be observed that the rotor flux is directly proportional to i_{ds}^* and is maintained constant. Hence, the torque linearly depends on i_{qs}^* , and provides a torque response as fast as the i_{qs}^* response. Then, the slip frequency can be evaluated from (4) and added to the rotor speed to generate unit vectors.

$$\omega_{sl} = \frac{L_m R_r}{L_r \Psi_r} i_{qs}^* \quad (4)$$

III. SLIDING MODE CONTROLLER

A sliding mode control (SMC) is basically an adaptive control that gives robust performance of a drive with parameter variation and load torque disturbance. In SMC the drive response is forced to tract sliding along a predefined trajectory or reference model in a phase plane by a switching control algorithm, parameter variation and load disturbance. The design and implementation of sliding mode controller is simpler. SMC is applied to induction motors, servo with dc motors, synchronous motors such as robot drives, machine tool control, etc.

The electromechanical equation of an induction motor is described as

$$J\frac{d\omega_m}{dt} + B\omega_m + T_L = T_e \tag{5}$$

Where *J* and *B* are the inertia constant and the viscous friction coefficient of the induction motor system respectively, T_L is load torque, T_e is the electromagnetic torque of induction motor and ω_m is the rotor mechanical speed in angular frequency, which is related to the rotor electrical speed by

$$\omega_m = \frac{2\omega_r}{P}$$

The electromechanical equation can be modified further as

$$\dot{\omega}_m + a\omega_m + d = bT_e \tag{6}$$

Where $a = \frac{B}{J}$, $b = \frac{1}{J}$ and $d = \frac{T_L}{J}$.

Consider the electromechanical equation (6) with uncertainties as

$$\omega_m = -(a + \Delta a)\omega_m - (d + \Delta_d) + (b + \Delta_b)T_e \tag{7}$$

Δ_a Δ_b and Δ_d represents the uncertainties of the terms *a*, *b* and *d* respectively introduced by system parameters *J* and *B*. Further, consider the tracking speed error as given in (8)

$$e(t) = \omega_m(t) - \omega_m^*(t) \tag{8}$$

Where ω_m^* is the rotor reference speed command in angular frequency. Then, by taking the derivative of (8) with respect to time yields

$$e(t) = \omega_m(t) - \omega_m^*(t) = -ae(t) + f(t) + x(t) \tag{9}$$

Where the following terms have been collected in the signal *f(t)*,

$$f(t) = bT_e(t) - a\omega_m^* - d(t) - \dot{\omega}_m^*(t) \tag{10}$$

and the *x(t)*, lumped uncertainty, defined as

$$x(t) = -\Delta a\omega_m(t) - \Delta d(t) + \Delta bT_e(t) \tag{11}$$

Now, the sliding variable with integral component can be defined as

$$S(t) = e(t) - \int_0^t (h - a)e(\tau)d\tau \tag{12}$$

Where *h* is a constant gain. Also in order to obtain the speed trajectory tracking, the following assumptions are made .

Assumtion-1: The gain *h* must be chosen so that the term (*h-a*) is strictly negative and hence *h<0*.

Then the sliding surface can be defined as given in (13)

$$S(t) = e(t) - \int_0^t (h - a)e(\tau)d\tau = 0 \tag{13}$$

based on the developed switching surface, a switching control that guarantees the existence of sliding mode, a speed controller is defined as

$$f(t) = h\,e(t) - \beta sgn(S(t)) \tag{14}$$

Where β is the switching gain and $sgn(\cdot)$ is the sign function defined as

$$sgn(S(t)) = \begin{cases} +1, & \text{if } S(t) > 0 \\ -1, & \text{if } S(t) < 0 \end{cases} \tag{15}$$

Assumption-2: The gain β must be chosen so that

$\beta \geq |x(t)|$ for all time

Consider the Lyapunov function candidate as given in (16).

$$V(t) = \frac{1}{2}S(t)S(t) \tag{16}$$

Its time derivative is calculated as:

$$V(t) = S(t)S(t) = S.(e - (h - a)e) \tag{17}$$

Using the Lyapunov's direct method, since $V(t)$ is clearly positive definite, $V(t)$ is negative definite and $V(t)$ tends to infinity as $S(t)$ tends to infinity, and then the equilibrium at the origin $S(t) = 0$ is globally asymptotically stable. Therefore $S(t)$ tends to zero as the time *t* tends to infinity. Moreover, all trajectories starting off the sliding surface S=0 must reach it in finite time and then will remain on this surface. This system's behavior on the sliding surface is usually called sliding mode.

When the sliding mode occurs on the sliding surface, then, $S(t) = S(t) = 0$ and the tracking error *e(t)* converges to zero exponentially. Finally, the reference torque command T_e^* can be obtained by substituting (14) in (10) as given in (18)

$$T_e^*(t) = \frac{1}{b}\left[(h.e) - \beta sgn(S) + a\omega_m^* + \omega_m^* + d\right] \tag{18}$$

Therefore, the proposed sliding mode speed control resolves the speed tracking problem for vector controlled induction motor drive, with some uncertainties in load torque.

IV. SLIDING MODE CONTROLLER BASED VECTOR CONTROLLED INDUCTION MOTOR

The block diagram of proposed algorithm is as shown in Fig. 1 As in conventional vector control, the proposed vector control algorithm generates d-axis and q-axis reference stator currents, which are at synchronously rotating reference frame. The generated d - and q - axis current commands are compared with their actual current values obtained from the measured phase currents with sliding mode controller. The current errors are used to produce d- and q-axes flags as inputs to the switching table. Based on the outputs of hysteresis controllers and position of the stator current vector, the optimum switching table will be constructed. This gives the optimum selection of the switching voltage space vectors for all the possible stator current vector positions.

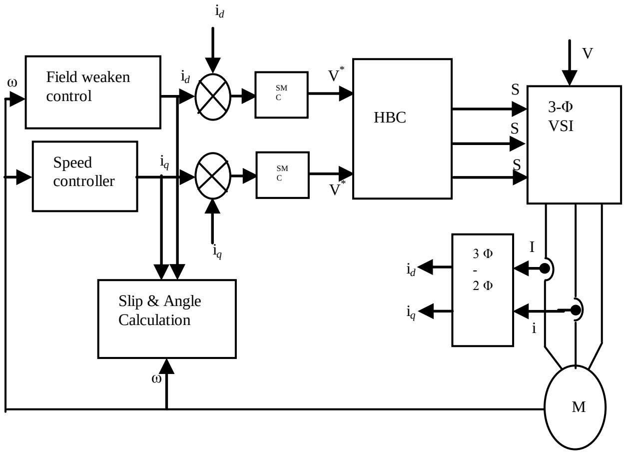

Fig. 1 Block diagram of SMC based vector controlled induction motor drive

V. RESULTS AND DISCUSSIONS

To validate the proposed algorithms, numerical simulation studies have been carried out by using Matlab-Simulink. For the simulation studies the dc link voltage is taken as 540V.The parameters of the induction motor used in this paper are R_s =1.57ohm, R_r=1.21ohm, L_m=0.165H, L_s=0.17H, L_r=0.17H and J=0.089Kg-m^2.

The simulation results are shown from Fig. 2 – Fig. 9.

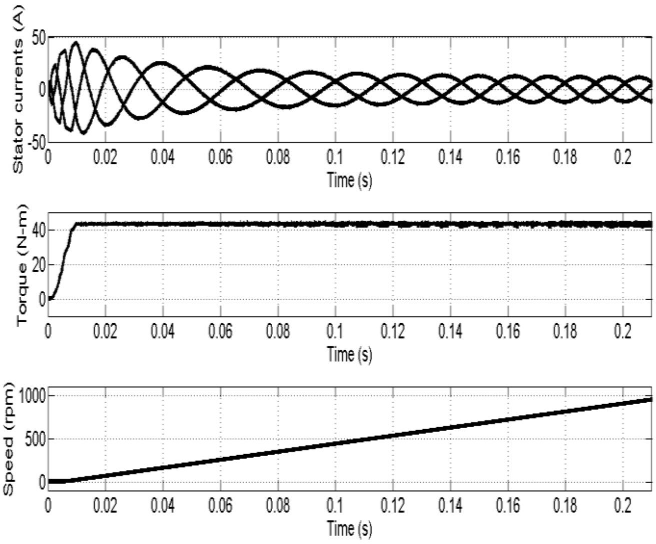

Fig. 2 starting transients with conventional FOC algorithm

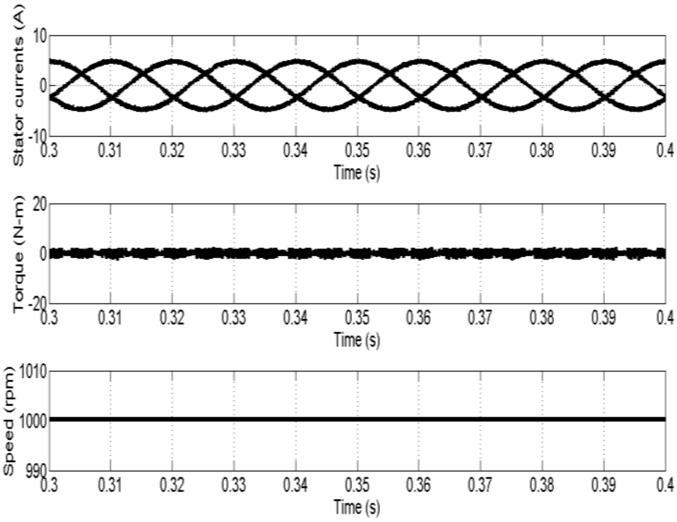

Fig. 3 steady state plots with conventional FOC algorithm

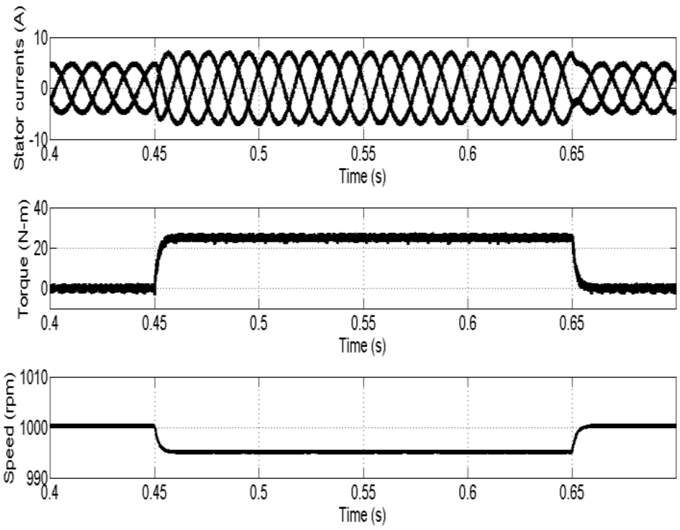

Fig. 4 Transients in speed, torque and currents during step change in load (a load torque of 25 N-m is applied at 0.45 s and removed at 0.65 s) with conventional FOC algorithm.

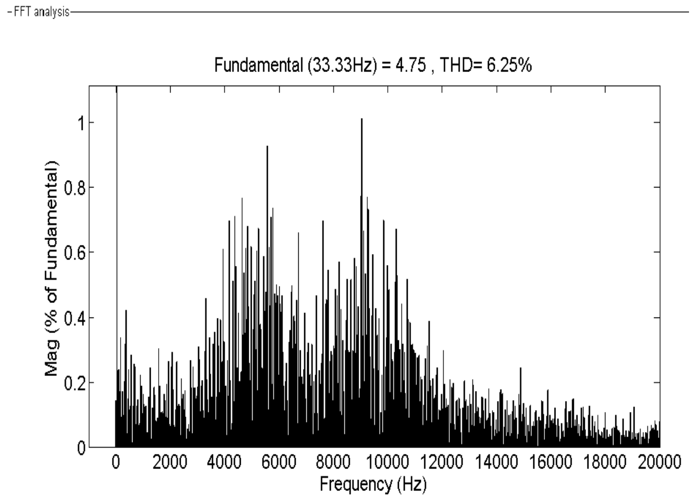

Fig. 5 Harmonic spectra of steady state line current with conventional FOC algorithm

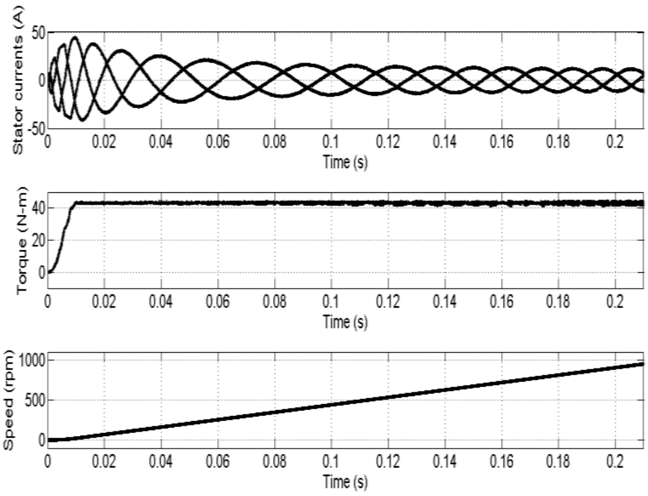

Fig. 6 starting transients with SMC based FOC algorithm

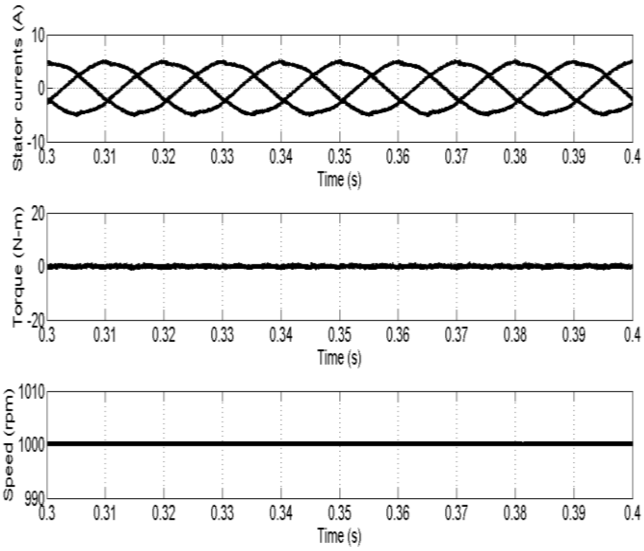

Fig. 7 steady state plots with SMC based FOC algorithm

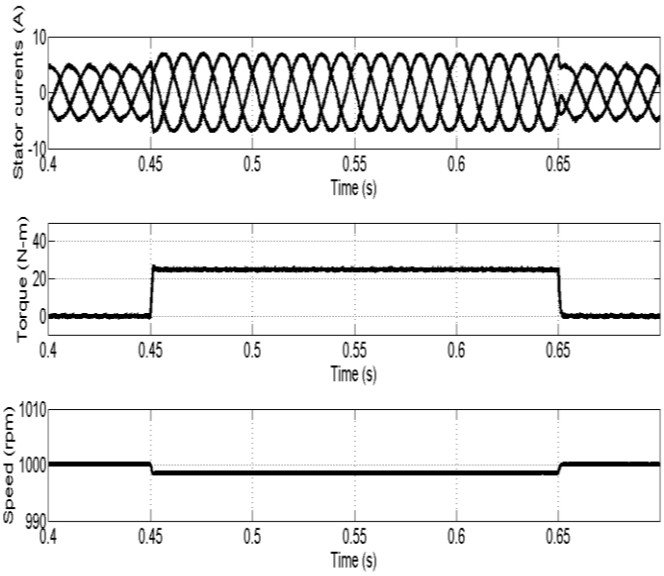

Fig. 8 Transients in speed, torque and currents during step change in load (a load torque of 25 N-m is applied at 0.45 s and removed at 0.65 s) with SMC based FOC algorithm.

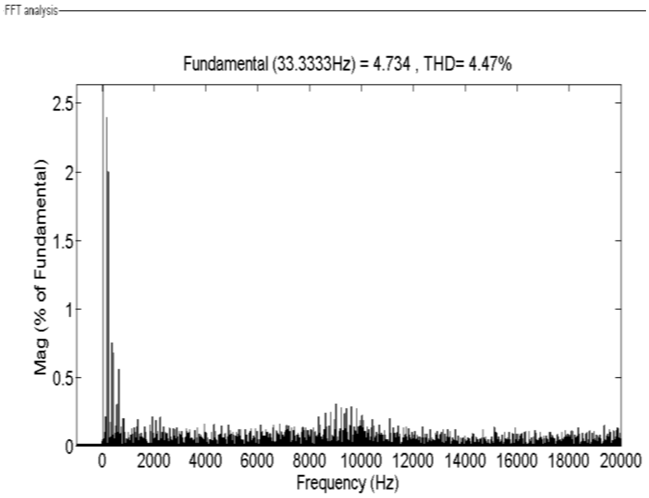

Fig. 9 Harmonic spectra of steady state line current with SMC based FOC algorithm.

VI. CONCLUSION

It is possible to control the induction motor like a separately excited dc motor by using vector control method. conventional vector controlled induction motor drive gives a good steady state and transient responses. In this paper, an improved speed and torque Performances of vector controlled induction motor drive is incorporated with sliding mode controller to improve the overall performance. This sliding mode controller based approach improves the speed performance and also reduces the total harmonic distortion. When there is a step change in the load torque, the momentary decrease in speed with proposed system is less when compared to conventional system. So the overall performance of drive is improved with proposed system under all operating conditions.

REFERENCES

[1] F. Blaschke "The principle of field orientation as applied to the new transvector closed loop control system for rotating-field machines," Siemens Review, 1972, pp 217-220.

[2] W. Leonhard, "30 years of space vectors, 20 years of field orientation, 10 years of digital signal processing with controlled AC-drives, a review (Part 2)". EPE Journal, No. 2, Oct, 1991, pages 89-102.

[3] J. A. Santisteban, and R. M. Stephan, "FOC methods for induction machines: an overview," IEEE Trans. On Education, vol. 44, no. 2, pp. 170-175, May 2001.

[4] Isao Takahashi and Toshihiko Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor," IEEE Trans. Ind. Applicat., vol. IA-22, no.5, Sep/Oct 1986, pp. 820-827.

[5] Domenico Casadei, Francesco Profumo, Giovanni Serra, and Angelo Tani, "FOC and DTC: Two Viable Schemes for Induction Motors Torque Control" IEEE Trans. Power Electron., vol. 17, no.5, Sep, 2002, pp. 779-787.

[6] Marian P. Kaimierkowski, Maciej A. Dzieniakowski, and Waldemar Sulkowski, "Novel Space Vector Based Current Controllers for PWM-Inverters" IEEE Trans. Power Electronics, vol.6, no.1, Jan, 1991, pp. 158-166.

[7] Zhihong, L., Panda, S.K., Zhang, D.Q., Liang, Y.C. "Modified sliding mode speed controller for vector controlled induction motor drive" IEEE Trans. Power Electronics vol.1, no.1, Jan, 1998, pp. 294-299.

[8] Sumit sunil rashinkar, and subhash s. sankeshwari "Sliding mode controller based indirect vector control of Induction Motor" has been published in International Journal of Advances in

Engineering and Technology, Volume 7, Issue No.5, pp.1470-1475, Nov., 2014

[9] A.M. Hava, and Emre Ün, "Performance Analysis of Reduced Common-Mode Voltage PWM Methods and Comparison With Standard PWM Methods for Three-Phase Voltage-Source Inverters" IEEE Trans. Power Electron., vol.24, no.1, pp. 241-252, Jan, 2009.

[10] P.Surekha, Dr.K. Satyanarayana and Dr.A.Kailasa Rao "DTC based FOC strategy of Induction Motor drive for the mitigations of CMV " has been published in International Journal of Advances in Science and Technology, Volume 6, Issue No.4, pp.31-42, April 2013.

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