International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

Efficient Speed Estimation of an Induction Motor Drive Using Sliding Mode Observer Algorithm

G. Venkatesh, [1]
Asst. Professor,
Dept. of EEE,
SVEC, Tirupati,
India

S.VijayaBhaskar, [2]
Asst. Professor,
Dept. of EEE,
SVCET, Chittoor,
India

B. Mohan Reddy, [3]
PG Student,
EEE Branch,
SVCET, Chittoor,
India.

Abstract

In this paper accurate information of the rotor of induction motor is determined for its effective speed control. In decoupled control of induction motor, sensors such as encoders are used to get the rotor information. Use of the sensors results in more cost, complexity and less reliability. In the present work, an identification scheme is developed for the simultaneous estimation of speed and stator resistance of sensor less induction motor over a wide range. This parallel estimation of speed and stator resistance makes the identification scheme parameter insensitive. The developed method of speed estimation is based on Sliding Mode Observer (SMO) by using Popov's hyper stability theory. The performance of the developed SMO and its speed estimation accuracy, with a d-q model of induction motor, are verified by simulation over a wide speed range from zero to high levels beyond the base speed.

Key Words: *Sliding Mode Observer (SMO), d-q model of induction motor, sensor less induction motor, stability.*

1. Introduction

Induction motors have been the working-horses in industry for high-performance variable speed applications in a wide power range that covers from fractional horse power to multi-megawatts. There are different control techniques of induction motor drives, including scalar control, vector control, direct torque and flux control, adaptive control, intelligent control with expert systems, neural network and fuzzy logic control etc control of induction motor drives without any speed sensors is growing rapidly named as "sensor less control of induction motor drives" during the last two decades.

In the present work, speed estimation algorithm based on a sliding-mode current observer (SMO), which combines Variable Structure Control (VSS), Popov's hyper stability theory is developed. Observers require the exact knowledge of stator resistance, while both indirect (observer-less) and direct (observer-based) field oriented controls do not achieve field orientation and speed estimation when stator resistance is not exactly known, so that performance and power efficiency degrade and also a speed estimation algorithm should be insensitive to parameter variations, like stator resistance during low and zero speed operations. So a stator resistance's online identification scheme based on the same theory is developed and used in parallel with the speed estimator. A modified SMO with an online identification scheme of magnetizing inductance is presented to operate in the field-weakening region. Effective modelling and simulation of such systems require a software tool that can handle all these functions in an integrated environment. So MATLAB/SIMULINK software tool is used to simulate and for the study of the proposed system.

This paper addresses that mutual inductance of an induction machine may vary considerably when the flux reference varies. An important and frequent application of a variable flux reference is the operation in the field-weakening region. Standard assumption of constant mutual inductance is no longer valid and it becomes necessary to compensate for the mutual inductance variation. The paper proposes a novel method for online mutual inductance identification in vector controlled induction machines. The method is characterized with very simple structure, ease of implementation, very low parameter sensitivity, and capability to provide an accurate estimate under both transient and steady state operating conditions. Full experimental verification of the proposed scheme is provided and a number of potential applications in a vector controlled induction motor drive are discussed.

2. Problem Formulation

In this paper only stator resistance and magnetizing inductance variations are considered. Accurate knowledge of stator resistance is of utmost importance for correct operation of a sensor less drive in the low speed region. Since stator resistance inevitably varies with operating conditions, stable and accurate operation at near zero speed requires an appropriate online identification algorithm for the stator resistance. In addition to this, in high performance applications, the induction motor is controlled through field orientation techniques that require knowledge of the rotor speed. Since speed sensors decrease the reliability of a drive system (and increase its price), a common trend in motor control is to use an observer/estimator to estimate the speed.

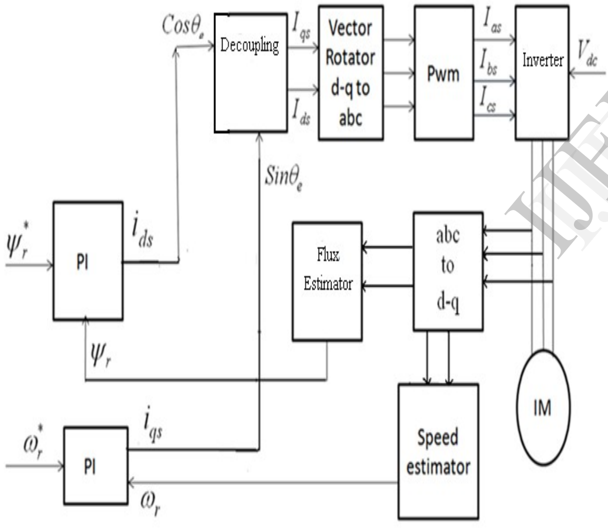

***Fig.1** Block diagram of sensor less control of induction motor*

In this paper a speed estimation algorithm is developed where speed and stator resistance are estimated in parallel by constructing a sliding mode observer (SMO) with Popov's hyper stability theory. The structure of the observer is modified in such a way that the variation of main flux saturation is recognized within the speed estimation algorithm. This requires the online identification algorithm of the magnetizing inductance. To make the proposed SMO parameter insensitive, the magnetizing inductance is also estimated in parallel with stator resistance and rotor speed.

3. Speed and Stator Resistance Estimation Procedure

Construction of SMO

The induction motor can be represented by its dynamic model expressed in the stationary reference frame in terms of stator current and rotor flux as follows:

$$\frac{d}{dt}\begin{bmatrix} i_s^s \\ \lambda_r^s \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{bmatrix} i_s^s \\ \lambda_r^s \end{bmatrix} + \begin{bmatrix} b_1 \\ 0 \end{bmatrix}[v_s^s] = Ax + Bv_s$$

…(3.1)

With reference to the introduced mathematical model and considering the stator currents as the system outputs, the sliding-mode current observer can be constructed as

$$\mathbf{p\hat{i}s}_s = \hat{A}11\hat{i}\,ss + \hat{A}12\hat{\lambda}sr + b1uss + K\,sgn\,(\hat{i}\,ss \;\square\; i\,ss)$$

…(3.2)

$$p\hat{\lambda}sr = \hat{A}21\hat{i}\,ss + \widehat{A}22\widehat{\lambda}sr$$

…(3.3)

Where *K* is the switching gain.

The error equation which takes into account parameter variation can be expressed, by subtracting (3.1) from (3.2), as follows:

$$\frac{de_i}{dt} = A_{11}e_i + A_{12}e_\lambda + \Delta A_{11}\hat{i}_s^s + \Delta A_{12}\hat{\lambda}sr + K\,\mathbf{sgn}\,(\hat{i}\,ss - i_s^s)$$

…(3.4)

Where

$$e_i = \hat{i}_s^s - i_s^s \;;\quad e_\lambda = \hat{\lambda}\mathbf{sr}\text{-}\lambda_r^s$$

$$\mathbf{\Delta}A = \begin{bmatrix} \Delta A_{11} & \Delta A_{12} \\ \Delta A_{21} & \Delta A_{22} \end{bmatrix}$$

The sliding surface S is constructed as

$$S(t) = e_i = \hat{i}_s^s - i_s^s = \mathbf{0}$$

…(3.5)

Whereas the switching function of SMO is defined as

$$\mathbf{sgn}(S) = \begin{cases} \mathbf{1}, & \mathbf{if}\ S \geq \mathbf{0} \\ \mathbf{-1}, & if\ S < \mathbf{0} \end{cases}$$

If rotor speed and stator resistance are considered as variable parameters, assuming no other parameter variations, the matrix Δ*A* is expressed as follows:

$$\Delta A_{11} = \frac{-\Delta I R_s}{\sigma L_s}$$
$$\Delta A_{12} = \frac{-\Delta J \omega_r}{\epsilon}$$
$$\Delta A_{21} = 0$$
$$\Delta A_{22} = \Delta J \omega_r$$

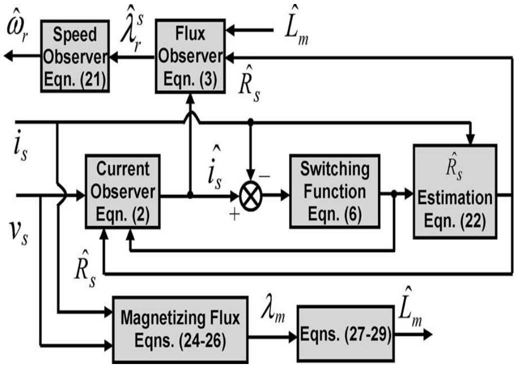

Fig2. *Block diagram of speed, stator resistance, & magnetizing inductance identification schemes.*

An identification system for speed and stator resistance is shown in Figure 3.1, which is constructed from a linear time-invariant forward block and a nonlinear time-varying feedback block. The system is hyper-stable if the forward block is positive real and the input and output of the nonlinear feedback block satisfy Popov's integral inequality. Figure 3.2 shows the block diagram of parallel speed and stator resistance estimation algorithms based on a combination of SMO and Popov's hyper stability theory.

4. Simulation Model

The following assumptions are made to derive the dynamic model of induction machines.

- Uniform air gap.
- Balanced stator and rotor windings, with sinusoidally distributed emf.
- Inductance versus rotor position is sinusoidal.

Saturation and parameter changes are neglected

The mathematical model of any machine is required for their simplicity. Here, using a two-phase motor in direct and quadrature axes derives the dynamic model of the induction motor. The per phase equivalent circuit of the induction motor is only valid in steady state condition. In order to reduce this complexity the transformation of axes from 3-phase to 2-phase is necessary. In this chapter, induction motor d-q modelling is discussed in detail and the MATLAB/SIMULINK models are shown with their relevant equations.

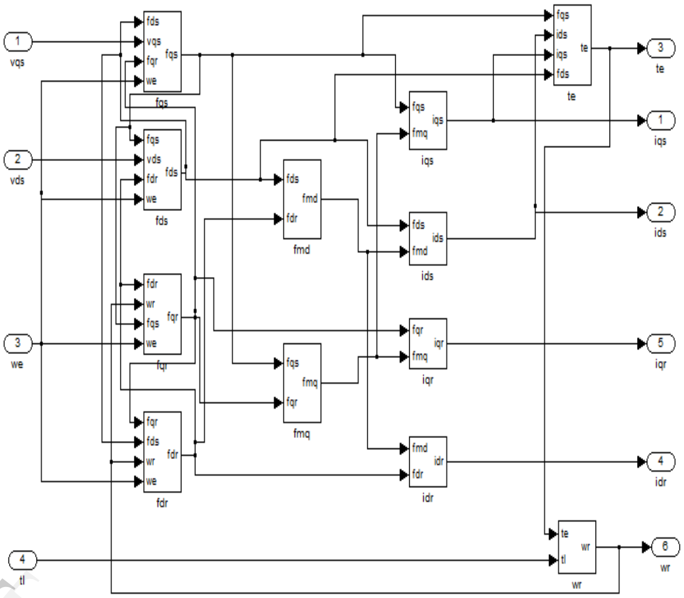

Fig3. *D-Q model of induction motor*

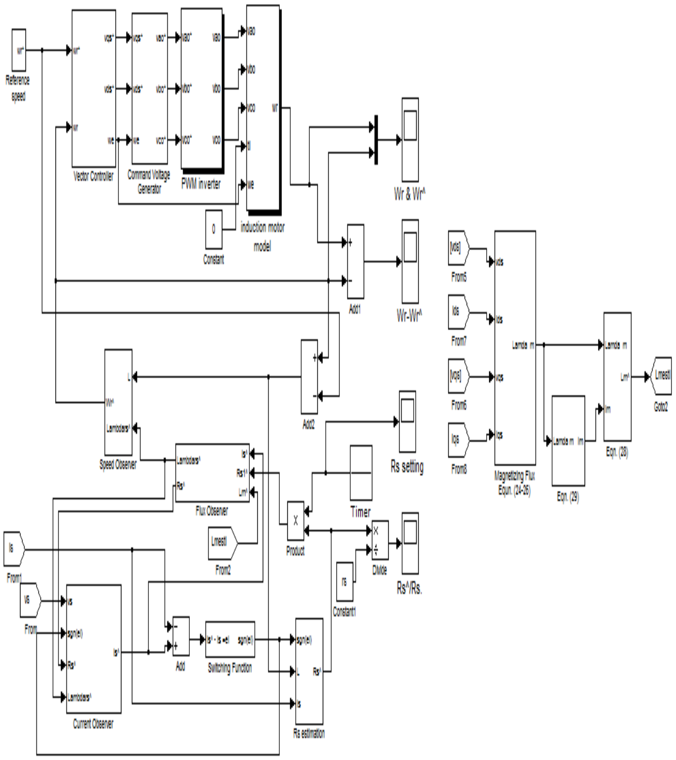

Fig4. *Simulink model of parallel speed and Rs estimation with online Lm identification*

5.Results

This paper presents the analysis of online estimation algorithms of stator resistance, rotor speed and magnetizing inductance of sensorless induction motor by using sliding mode observer (SMO) over a wide range from zero to high levels beyond the base speed.

5.1Simulation results of Speed estimation error at high and low speed operation

Speed estimation error for +20% Rs error in the observer at 150 rad/sec

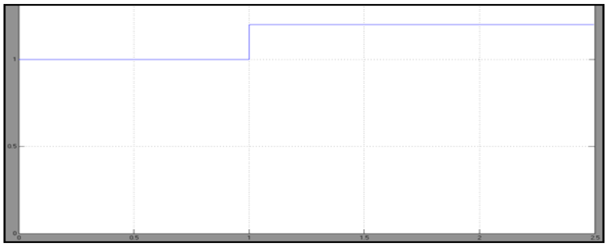

Fig 5.1 *Time [sec] Vs Rs [p.u.]*

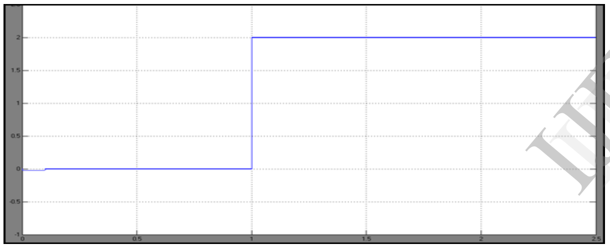

Fig5.2 *Time [sec] Vs Speed error [rad/sec]*

5.2 Simulation results of actual and estimated speeds, and speed estimation error for initial levels of stator resistance during low speed operation

At a speed command of 2 rad/s

$$\tilde{R}_{so} = 1.5R_s$$

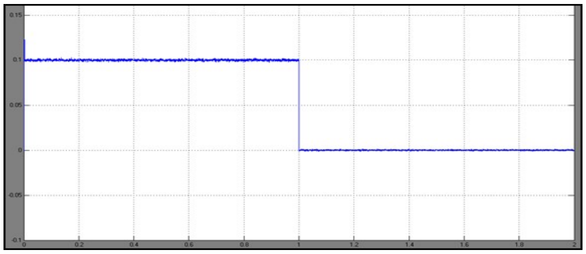

Fig5.3 *Time [sec] Vs Speed error [rad/sec]*

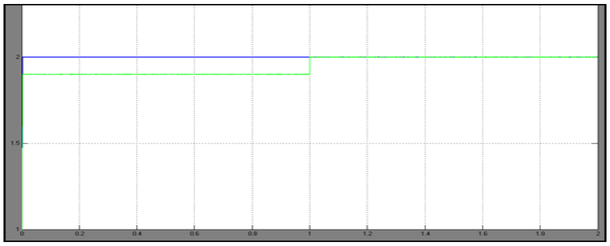

Fig5.4 *Time [sec] Vs Speed [rad/sec]*

5.3 Simulation results of actual and estimated speeds, and speed estimation error for step change of speed command to 250 rad/s

With constant parameter SMO

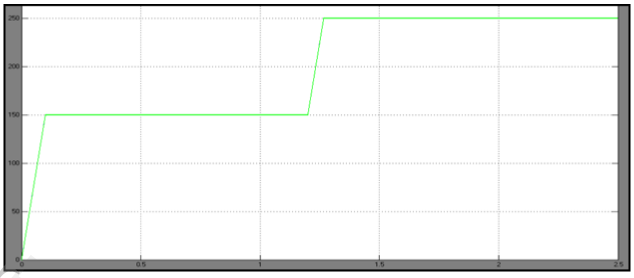

Fig 5.6 *Time [sec] Vs Speed [rad/sec]*

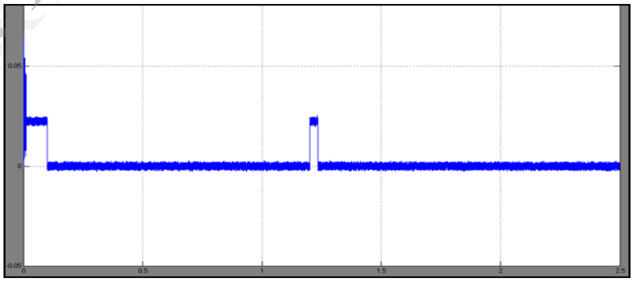

Fig5.7 *Time [sec] Vs Speed error [rad/sec]*

With modified SMO

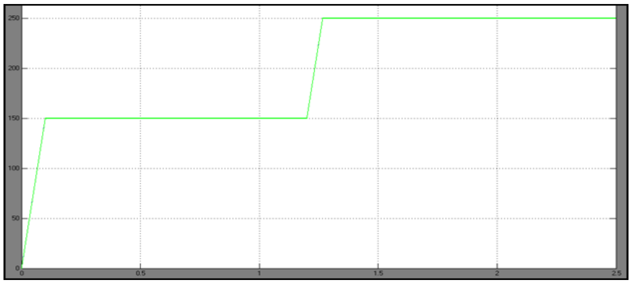

Fig5.8 *Time [sec] Vs Speed [rad/sec]*

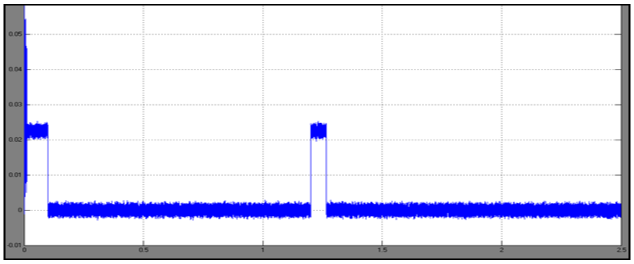

Fig5.9 *Time [sec] Vs Speed error [rad/sec]*

6.Conclusions

In this paper, parallel speed and stator resistance identification schemes of sensor less induction motor drives have been developed to overcome the problem of stator resistance variation, particularly in the low speed region. Estimation algorithms have been obtained based on a sliding mode current observer (SMO) combined with Popov's hyper stability theory. The supremacy of a particular speed estimation method is weighted by its successful operation and accuracy over a wide speed from zero to high values beyond the base speed. For this purpose, a modified SMO for speed estimation in the field-weakening region has been introduced. With an indirect field-oriented controlled induction motor, the superiority of the modified SMO over the constant parameter one for wide-speed-range estimation, from zero to high values beyond the base speed, has been proved by simulation results by using MATLAB/SIMULINK.

References

[1] M. S. Zaky, M. M. Khater, H. Yasin, S. S. Shokralla, and A. El-Sabbe, "Speed-sensor less Control of induction motor drives," *Eng. Res. J.*, vol. 30, no. 4, pp. 433–444, Oct. 2007.

[2] Q. Gao, G. Asher, and M. Sumner, "Sensor less position and speed control of induction motors using high-frequency injection and without offline precommissioning," *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2474– 2481, Oct. 2007.

[3] G. Guidi and H. Umida, "A novel stator resistance estimation method for speed-sensor less induction motor drives," *IEEE Trans. Ind. Appl.*, vol. 36, no. 6, pp. 1619–1627, Nov./Dec. 2000.

[4] A. B. Proca and A. Keyhani, "Sliding-mode flux observer with online rotor parameter estimation for induction motors," *IEEE Trans. Ind. Electron.*, vol. 54, no. 2, pp. 716–723, Apr. 2007.

[5] S. Maiti, C. Chakraborty, Y. Hori, and M. C. Ta, "Model reference adaptive controller-based rotor resistance and speed estimation techniques for vector controlled induction motor drive utilizing reactive power," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 594–601, Feb. 2008.

[6] V. Vasic, S. N. Vukosavic, and E. Levi, "A stator resistance estimation scheme for speed sensor less rotor flux oriented induction motor drives," *IEEE Trans. Energy Convers.*, vol. 18, no. 4, pp. 476–483, Dec. 2003.

[7] M. Barut, S. Bogosyan, and M. Gokasan, "Experimental evaluation of braided EKF for sensorless control of induction motors," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 620–632, Feb. 2008.

[8] M. S. Wang and C. M. Liaw, "Improved field-weakening control for IFO induction motor," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 39, no. 2, pp. 647–658, Apr. 2003.

[9] E. Levi, M. Sokola, and S. N. Vukosavic, "A method for magnetizing curve identification in rotor flux oriented induction machines," *IEEE Trans. Energy Convers.*, vol. 15, no. 2, pp. 157–162, Jun. 2000.

[10] E. Levi and M. Wang, "Online identification of the mutual inductance for vector controlled induction motor drives," *IEEE Trans. Energy Convers.*, vol. 18, no. 2, pp. 299–305, Jun. 2003.

[11] "Modern Power Electronics and AC Drives" by Bimal K Bose, PHI Learning Private Ltd. 2012.

[12] Modern Power Electronics and AC Drives by Bimal K. Bose.