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Performance Analysis of Sensor Less Based DTC of Induction Motor

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ABSTRACT— Direct Torque Control is most widely used in industrial standard for high power induction motor drives. The conventional DTC method uses the hysteresis-based voltage switching method which has some drawbacks of higher torque ripple and speed pulsation. The main aim of the paper is to obtain the enhanced torque control and smooth flux trajectory. The proposed approach uses the sensorless drive which is incorporated in Direct Torque Control to improve the performance. Sensorless drive eliminates the shaft mounted speed encoder which is undesirable in a drive because it increases the cost and reliability problems. Sensorless method is used to estimate the speed signal with the help of machine terminal voltages and currents. The proposed method is simulated with the help of MATLAB and result shows that performances are improved.

KEYWORDS— Direct Torque Control, MRAS, and Induction motor.

I. INTRODUCTION

In recent years the sensorless based direct torque control of induction motor drive has grown significantly due to its reduced hardware complexity, cost effective, elimination of sensor cable, increased reliability and less maintenance requirements [1], [2].

The principle of conventional Direct Torque Control is to controls the torque and flux directly or independently by selecting proper inverter switching states [3] that includes the hysteresis band controller which has some advantage of ease of implementation and simple structure. Hysteresis controller has main drawbacks of higher torque ripple, flux ripple and speed pulsation [4]. To solve the above problems, a direct torque control with space vector modulation schemes is introduced. In this method, closed loop for estimation of torque and flux is implemented as in DTC but the inverter switching states is produced by SVM signal [5], [6].

To obtain better torque and smooth flux control of induction motor drives, various sensorless-based methods have been used for speed estimation and give a good performance in large speed range. The different methods are speed adaptive flux observer [7], [8], model reference adaptive system [9], [10] slip calculation method and extended kalman filter [11], [12]. Among various machine model-based methods, Model Reference Adaptive System (MRAS) appeared to be the best solutions for speed sensorless drives [13], [14].

This paper proposes the Model reference adaptive system which is used to estimate the rotor speed with the help of machine terminal voltages and currents. MRAS observer is widely preferred due to its ease of implementation with high speed of adaptation for wide range of applications, although this approach leads to small variations in low speed region. The Popov's hyper stability criterion is used to estimate the stability of closed loop speed [5], [6]. The proposed control scheme for sensorless based DTC-SVM is elaborately discussed in this paper.

Section 1 describes the mathematical model of Induction Motor drive. Section 2 describes the proposed sensorless drives and DTC-SVM. Section 4 shows the simulation results for DTC, Sensorless DTC and Sensorless based DTC-SVM. Section 5 gives conclusion and future works.

II. SENSORLESS BASED DTC-SVM

A. Machine Equations

The behavior of IM is analyzed with the use of space phase quantities in a stationary reference frame. The voltage balance equations for the d-q axes are as follows.

$$V_{qs} = R_S I_{qs} + P\psi_{qs} - \psi_{qs} P\theta \qquad (1)$$

(2)

$$V_{dr} = R_r I_{dr} + P\psi_{dr} + \psi_{qr} P\beta \qquad (3)$$

$$V_{qr} = R_r I_{qr} + P\psi_{qr} - \psi_{dr} P\beta \qquad (4)$$

The fluxes can be computed as

$$\begin{bmatrix} \psi_{ds} \\ \psi_{dr} \\ \psi_{qs} \\ \psi_{qr} \end{bmatrix} = \begin{bmatrix} L_s & L_M & 0 & 0 \\ L_M & L_R & 0 & 0 \\ 0 & 0 & L_s & L_M \\ 0 & 0 & L_M & L_R \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{dr} \\ i_{qs} \\ i_{qr} \end{bmatrix} \qquad (5)$$

The mechanical equation is given as

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt} \qquad (6)$$

$$T_e = \frac{3}{2}\frac{p}{2}\left(\frac{L_M}{L_S L_r}\right)(\psi_s * \psi_r) \qquad (7)$$

Where,
P- Number of poles

$$\Psi_s = L_s I_s + L_m I_r \qquad (8)$$

$$\Psi_r = L_r I_r + L_m I_s \qquad (9)$$

$$L_s = L_r L_s + L_m{}^2 \qquad (10)$$

Where, V_{ds} , V_{qs} are stator voltage in d and q axis respectively. I_{ds} , I_{qs} are stator current in d and q axis respectively. R_s, R_r are stator and rotor resistance respectively. L_s, L_r, L_M are stator inductance, rotor inductance and mutual inductance.

B. Proposed Model Reference Adaptive System

The proposed structure is a model-reference adaptive system MRAS, it consists of three steps: reference model, adaptive model and an adaptive method. The proposed sensorless drive is presented in Figure 1.

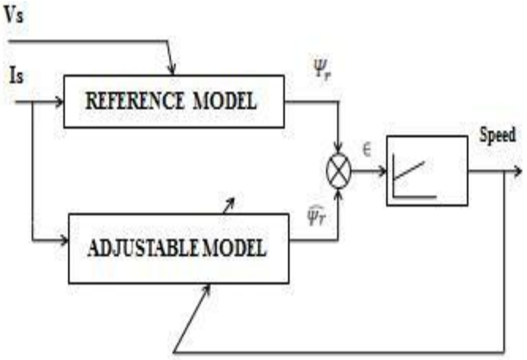


Fig.1 Block Diagram of sensorless drive.

Both models are referred to in the stationary reference frame. The output of a reference model is compared with the output of an adjustable or adaptive model until the errors between the two models vanish to zero.

1) Reference Model: This model receives the machine stator side voltage and current signals and calculates the rotor flux vector signals. The stator and rotor flux linkages in the stator reference frame are defined as

$$\Psi_{dr}^s = \frac{L_r}{L_m}(\Psi_{ds}^s - \sigma L_s i_{ds}^s) \qquad (11)$$

$$\Psi_{qr}^s = \frac{L_r}{L_m}(\Psi_{qs}^s - \sigma L_s i_{qs}^s) \qquad (12)$$

Where $\sigma = 1 - \frac{L_m^2}{L_s L_r}$; Leakage co-efficient.

$$\Psi_{ds}^s = \int (V_{ds}^s - R_s i_{ds}^s)dt \qquad (13)$$

$$\Psi_{qs}^s = \int (V_{qs}^s - R_s i_{qs}^s)dt \qquad (14)$$

2) Adaptive Model: The adjustable or adaptive model equation is simpler and is obtained from the current model of the machine equations in stationary reference frame using stator currents if the speed signal ω_r is known.

$$\Psi_{dr}'^s = -\frac{1}{T_r}\Psi_{dr}^s - \omega_r \Psi_{qr}^s + \frac{L_m}{T_r} i_{ds}^s \qquad (15)$$

$$\Psi_{qr}'^s = -\frac{1}{T_r}\Psi_{qr}^s + \omega_r \Psi_{dr}^s + \frac{L_m}{T_r} i_{qs}^s \qquad (16)$$

Where $T_r = \frac{L_r}{R_r}$; Rotor time constant.

With the correct speed signal, fluxes calculated from reference model matches with the adaptive model.

3) Adaptation Algorithm: An adaptation algorithm with P-I control can be used to tune the speed when the error = 0.In designing the adaptation algorithm, it is important to take account of overall stability of the system. Using Popov's criteria for hyper stability [18] for asymptotically stable system, the speed estimation equation is

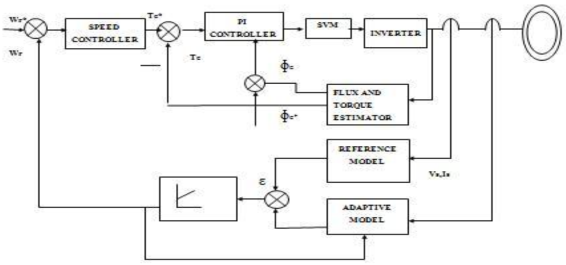
$$\omega_{r\wedge} = \in \left(K_p + \frac{K_I}{s}\right) \qquad (17)$$

$$\in = X - Y = \Psi^{s}_{qr}\, \Psi'^{s}_{dr} \quad \Psi^{s}_{dr}\, \Psi'^{s}_{qr} \qquad (18)$$

Estimation accuracy is good if parameter variation is considered as constant.

C) Direct Torque Control with SVM

In Direct torque control, it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state. To overcome the classical DTC drawbacks like increased torque ripple, SVM based DTC is used here. The block diagram of sensorless based DTC with SVM is shown in fig 2.



Block Diagram of Sensorless based DTC-SVM for Induction Motor.

The proposed topology of the DTC-SVM comprises two PI regulators for flux and torque. The controller receives inputs in the form of torque and stator flux errors and generates the inverter's command signals. The SVM unit produces the inverter control signals. It receives the reference voltage in stator reference frame.SVPWM is a digital modulation technique which treats sinusoidal voltage as a constant vector rotating at constant frequency. This PWM technique approximates the reference voltage V_{REF} by combination of the eight switching patterns (V_0 to V_7). Figure shows space vector representation.

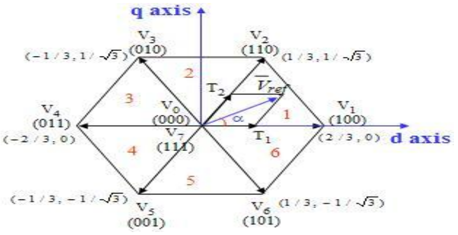


Fig.3 Space Vector Representation.

Steps involved in implementing the space vector PWM is given as

- Calculation of V_q, V_d, V_{REF} and angle(α) .
- Calculation of T_1, T_2, $T_{0.}$
- Calculation of switching time for each switch.

III. SIMULATION RESULTS

To validate the effectiveness of the MRAS based DTC-SVM methods, a two-level sensor less based DTC-SVM motor drive was developed in MATLAB environment and simulation results are presented here in fig 6. The Model Reference Adaptive System based DTC drive is illustrated in Fig. 1.

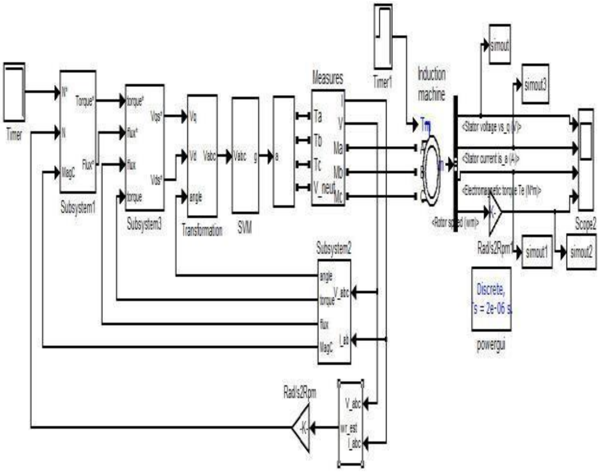


Fig.6 MATLAB modelling of sensorless based DTC of Induction Motor.

Sensorless MRAS technique is employed for closed loop speed estimation. A simulation work has been carried out on an induction motor with the specifications given in appendix. The proposed MRAS scheme is simulated in MATLAB/SIMULINK which is shown in Fig.7. Fig. 8 and Fig. 9 shows stator current for DTC of induction motor and sensorless based DTC of induction motor.

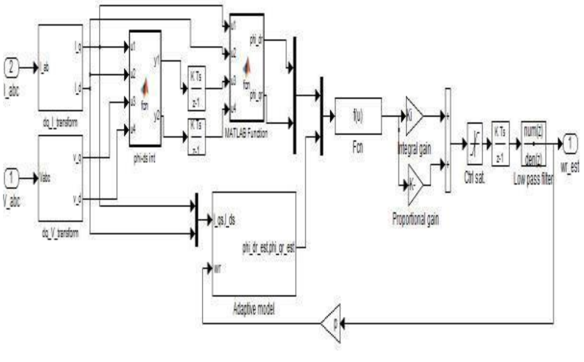


Fig.7 Implementation of MRAS scheme in IM.

When load torque of 500Nm is applied at time t = 0.3s in classical DTC and sensorless based DTC, same magnitude of stator current is flow in induction motor. But current pulsation in sensorless based DTC is comparatively reduced.

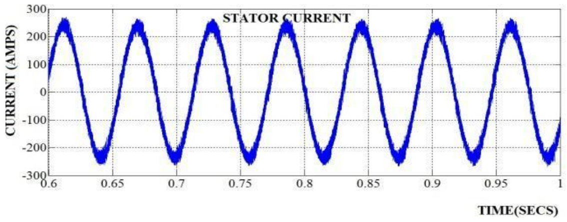


Fig.8 Stator Current for DTC of Induction Motor.

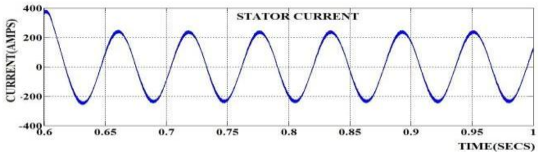


Fig.9 Stator Current for Sensorless based DTC of Induction Motor.

Stator flux of direct torque control and sensorless based direct torque control of induction motor is shown in Fig. 10 and Fig. 11.When compared with DTC, stator flux is more uniform in sensorless based DTC.

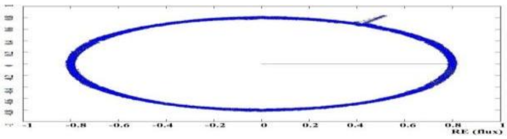


Fig.10 Stator flux trajectory for DTC of induction motor

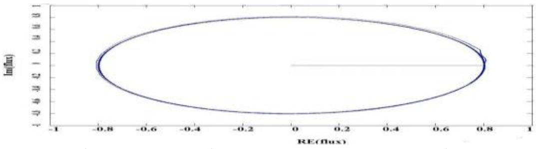


Fig.11 Stator flux trajectory for sensorless based DTC of Induction motor.

Electromagnetic torque response for DTC and sensorless based DTC for induction motor is shown in fig.12 and fig. 14.The Fig. 12 shows the electromagnetic torque for DTC of induction motor. Initially the motor run with a electromagnetic torque of 300 Nm. At t = 0.3 s, the load torque of 500 Nm is applied to the motor shaft while the motor speed is still ramping to its final value. This forces the electromagnetic torque to increase to the maximum value and then to stabilize around 500 Nm once the speed ramping is completed. Speed ramping is completed at t = 0.6s.

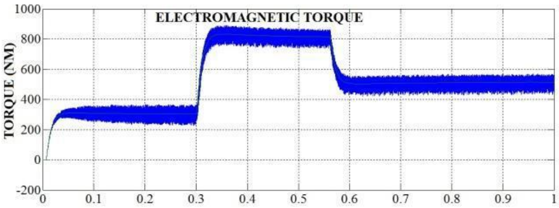


Fig.12 Electromagnetic Torque for DTC of Induction Motor.

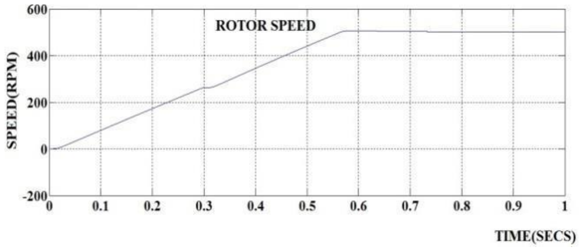


Fig.13 Rotor Speed for DTC of Induction Motor.

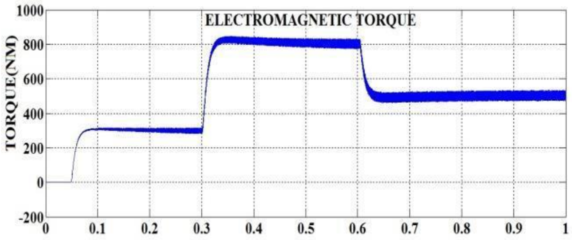


Fig.14 Electromagnetic torque for sensorless based DTC of induction motor.

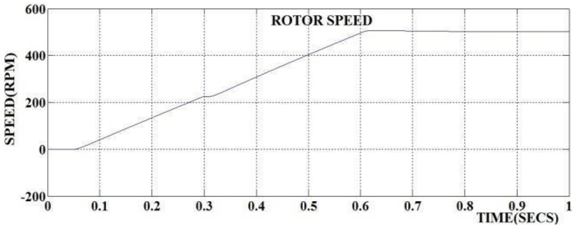


Fig.15 Rotor Speed for sensorless based DTC of Induction Motor.

In sensorless based direct torque control when motor is starts with zero load torque at t=0s, it will oscillates and settles to its steady state with 300Nm initially. When load torque of 500 Nm is applied at 0.3 seconds applied, motor oscillates and then settles at steady state. In steady state the load torque oscillates between maximum and minimum value of 520 Nm to 460 Nm.

TABLE II

TORQUE RIPPLE COMPARISON

Torque Ripples In Induction Motor	
Classical Direct Torque Control	24%
Sensorless Direct Torque Control with SVM	13%

Comparison of torque ripple in DTC and DTC with sensorless is shown in table. Therefore from results in table it is inferred that proposed scheme has less torque ripple, smooth flux response and less current pulsation.

IV CONCLUSION AND FUTURE WORK

In this paper, sensorless based direct torque control technology for induction machine has been proposed. Speed estimation is achieved using model reference adaptive system which eliminates the need speed sensor. Sensorless based DTC improve induction motor performance in terms of flux, torque and current response. Application of Neuro-Fuzzy in error minimization in MRAS will gives more accurate speed estimation which will be future scope. The simulation results verify that the proposed scheme improves the performance of induction motor.

APPENDIX

Motor parameter used in the simulation: Induction Motor Detail

460V, 149.2KW, 4 Poles, 1785 rpm

Stator resistance	14.85e-3 ohm
Stator inductance	0.3027 mH
Moment of inertia	3.1 kg.m2
Friction coefficient	0.08 N.m.s/rad

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