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Model Reference Adaptive System for Speed and Position Sensorless Control of PMSM

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Abstract

The efficient operation of high performing Variable Speed Drives (VSD) requires rotor angle information. Sensorless methods have become very fascinating for industrial users, as these inhibit several advantages over sensor based methods. In this paper, a Model Reference Adaptive System (MRAS) has been implemented for speed estimation of Permanent Magnet Synchronous Motor (PMSM) Drive and the performance has been analyzed for various speed and load torque values. The test results demonstrate that the MRAS based PMSM has a good speed tracking capability, and accuracy of drive.

Keywords: Permanent Magnet Synchronous Motor; Sensorless speed control; vector control; Model Reference Adaptive System;

INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) has added advantages like smaller size, highly efficient, high power density and large torque-current ratio. It has become an attraction for many industrial applications among other available motor options i.e. dc and induction motors especially after advancements in power electronics technology and its control [1-2]. Present framework shows proclivity for VSD's (Variable Speed Drive) in a wide range of power application like aviation industry, power plants and in many automobile applications [3]. The control strategy plays a key role to accomplish the requirements of each application but practical executions of these drive systems have major hurdle like high cost and responsive to temperature variation. Each control strategy has prime task to estimate the rotor position [4-5].

Conventionally sensors were being used to fetch the rotor position information but installation and maintenance of these sensors are difficult, as the drive becomes heavier, more complex, and less reliable with cost on higher side. Therefore, sensorless drives arise and this emerging technology conquers the downsides of the sensors. Various sensorless techniques for vector control scheme are adaptive, non-adaptive, signal injection and artificial intelligence based methods [6-10].

Apart from AC drives, Model Reference Adaptive Control (MRAS) has been used for many applications such as aerospace [11], robotics [12], autopilot and electrical power generation [13], etc. The MRAS is a simple and highly accurate technique but suffers from various motor parameter variations, which needs to be taken care off.

In this paper, the vector control of PMSM by sensorless speed estimation using MRAS method has been proposed. The simulation and performance analysis for variable speed and torque values have been carried out in the MATLAB/Simulink environment. The test results demonstrate the effectiveness of the proposed method.

MODELING OF PMSM

To analyze PMSM, the following assumptions are considered.

- Core losses assumed zero,
- Flux (rotor) is considered constant,
- Saturation in core is neglected,
- Balanced 3 phase supply voltage is considered and
- MMF distribution is considered to be sinusoidal produce by Stator windings

With the assumptions made above, the mathematical modelling of PMSM has been done in a d-q rotating frame as [14]:

$$\frac{d}{dt} i_{dq} = -\frac{R_S}{L_s} i_{dq} + \frac{1}{L_S}\left(u_{dq} - e_{dq}\right) \quad (1)$$

where, $u_{dq} = [u_d u_q]^T$ are stator voltages and $i_{dq} = [i_d i_q]^T$ are the currents in stator winding and $e_{dq} = [e_d e_q]^T$ are the induced back –EMF.

$$e_d = -L_s i_q \omega_r \quad (2)$$

$$e_q = -L_s i_d \omega_r + \lambda_f \omega_r \quad (3)$$

where, R_S and L_s represent the stator resistance and inductance and λ_f is rotor magnetic flux.

Electromagnetic torque produced as

$$T_e = \frac{3}{2} P \lambda_f i_q \quad (4)$$

Mechanical equation can be written as

$$\frac{d}{dt}\omega = \frac{1}{J_m}(T_e - B\omega - T_l) \quad (5)$$

where J_m is the rotor inertia; B is the viscous damping constant and T_l is the load torque.

A. Sensorless Control

In sensorless control, the rotor information are fetched by using algorithms having many merits like better efficiency, reliable, quick response and lower cost. In spite of this, the sensorless controls have some demerits like sophisticated design (e.g. Kalman filter), complexity in designing of switching law (e.g. sliding mode control). Few of the sensorless methods become inefficient at standstill or low speeds, and also can be uneconomical for low cost applications.

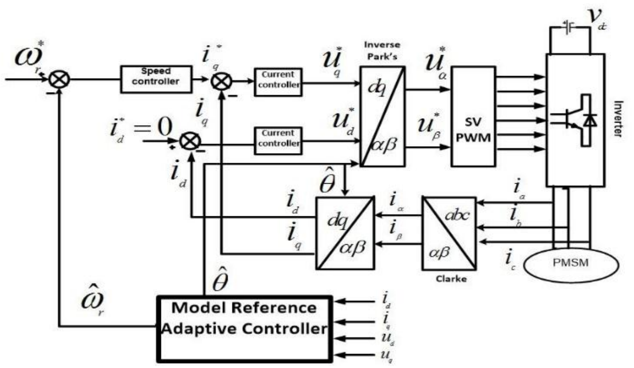

Figure 1. Schematic Block of sensorless vector control

A connection diagram of MRAS based sensorless PMSM drive has been shown in Figure 1. The MRAS block differs from the sensor based methods by eliminating the use of sensors for evaluation of rotor information [15]. The estimated values of speed and angle are obtained and used for dq to $\alpha\beta$ conversion as shown in Figure 3.

MODEL REFERENCE ADAPTIVE SYSTEM

This controller uses a reference model to adapt the available input model according to the error between reference and adjustable models. Hence, it can be said that the output of this model is in terms of reference values [16-18].

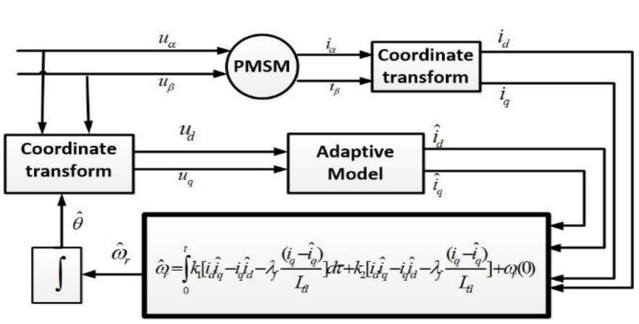

Figure 2. Schematic Block of MRAS scheme

Figure 2 shows the block diagram of an MRAS scheme. It uses two models, reference and adjustable model, and an adaptive mechanism which adapts the present situation and changes the parameters of adjustable model according to the reference model. As these equations are a function of rotor speed ω, the PMSM model and the PMSM motor itself can be treated as the adjustable model and reference model, respectively. The current and voltage values in d-q frame with a selective adaptive mechanism can be used to evaluate the motor speed and rotor position [19-24].

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r \\ \omega_r & -\frac{R_s}{L_s} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} u_d \\ u_q \end{bmatrix} \tag{6}$$

$$A = \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r \\ -\omega_r & \frac{R_s}{L_s} \end{bmatrix}$$

$$i'_d = i_d + \frac{\lambda_f}{L_s} \qquad i'_q = i_q \tag{7}$$

$$u'_d = u_d + R_s\frac{\lambda_f}{L_s} \qquad u'_q = u_q \tag{8}$$

$$\frac{d}{dt}\begin{bmatrix} i'_d \\ i'_q \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \hat{\omega}_r \\ \hat{\omega}_r & -\frac{R_s}{L_s} \end{bmatrix} \begin{bmatrix} \hat{i}'_d \\ \hat{i}'_q \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} u'_d \\ u'_q \end{bmatrix} \tag{9}$$

error can be defined as,

$$e' = i' - \hat{i}' \tag{10}$$

Equation (9) can be rewritten as

$$\frac{d}{dt}\hat{i}' = \hat{A}\hat{i}' + Bu' \tag{11}$$

From the above mention eqn. ω_r can be obtained as[16]

$$\hat{\omega}_r = \int k_1\left[i'_d\hat{i}'_q - i'_q\hat{i}'_d\right]d\tau + k_2\left(i'_d\hat{i}'_q - i'_q\hat{i}'_d\right) + \hat{\omega}_r(0) \tag{12}$$

When k_1 and $k_2 \geq 0$

Replace $i'_d i'_q$ with i_d, i_q we get,

$$\hat{\omega}_r = \int k_1\left| i'_d\hat{i}_q - i'_q\hat{i}_d - \frac{\lambda_f}{L_s}\left(i_q - \hat{i}_q\right)\right| d\tau + k_2\left[i_d\hat{i}_q - i_q\hat{i}_d - \frac{\lambda_f}{L_s}\left(i_q - \hat{i}_q\right)\right] + \hat{\omega}_r(0) \tag{13}$$

Adjustable model variables $\hat{i}'_d$ and $\hat{i}'_q$ and reference model variables (PMSM in this case), i_d and i_q are four inputs for the adaptive mechanism.

RESULTS AND DISCUSSIONS

During this simulation experiment, the speed control of PMSM motor drive has been achieved by using a sensorless method based on MRAS, rotor angle and speed estimation method. PMSM parameters used in this simulation are shown in Table I.

Table I. PMSM Parameters

Parameters	Symbol	Values	Units
Nominal Ref. Speed	*N*	1500	rpm
Stator Resistance	*Rs*	2.8750	Ω
d,q-axis Inductance	*Ld, Lq*	0.0085	mH
Magnetic Flux linkages	*Λ*	0.1750	Wb
Pole-Pair	*P*	4	nos
Rotor Inertia	*J*	0.0010	kgm^2
Friction Co-efficient	*B*	0.000380	Nms

During the analysis, the PMSM motor is made to run in four quadrants. That is in first quadrant, speed and torque references are increased; in second, speed is increased and torque is decreased, in third torque is increased and speed is reduced and in fourth quadrant both speed and torque references are reduced from the initial set references values. The various references values with time are stated as in Table II.

TABLE II. SPEED AND TORQUE REFERENCE VALUES

Reference (sec)	0.0-0.10	0.10-0.15	0.15-0.20	0.20-0.25	0.25-0.30	0.30-0.50
Speed (rpm)	1500	1200	1600		1200	1500
Torque (Nm)	3	4		2		3

During these references values, on the basis of performance of PMSM motor drive, the performances of the speed estimator, MRAS, a sensorless technique have been checked and analyzed. The tracking capability, the static error and the current quality during operation were some of the parameters on the basis of which the analysis has been carried out.

The graphs representing the speed, current and torque responses are shown in Figures 3, 4 and 5, respectively for the above mentioned reference values. It can be seen from speed response that the PMSM drive has shown a good tracking capability irrespective of the torque values. The average steady state error for all reference values is below 1%. The current and torque responses have also been shown in Figures 4 and 5, showing the variations according to the torque reference values.

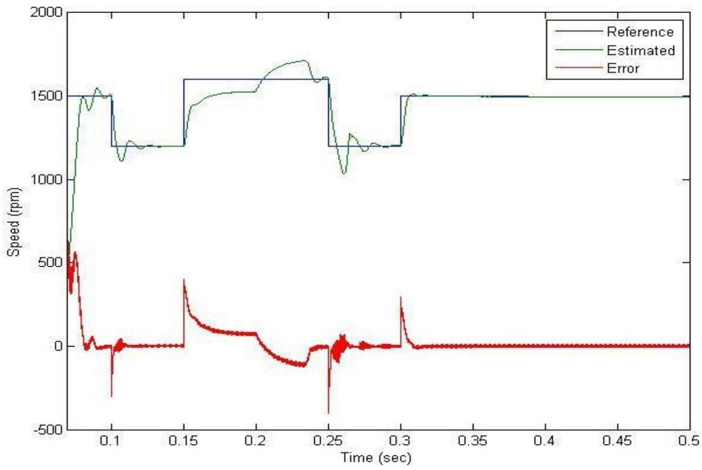

Figure 3. Speed response of MRAS based PMSM drive with reference values shown in Table II.

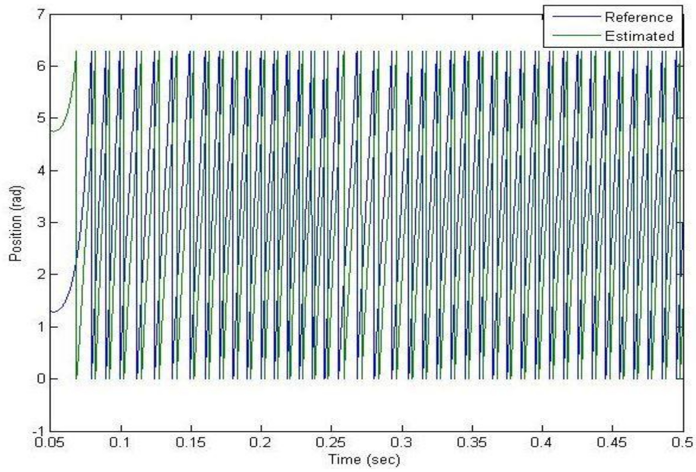

Figure 4. Position response of MRAS based PMSM drive with reference values shown in Table II.

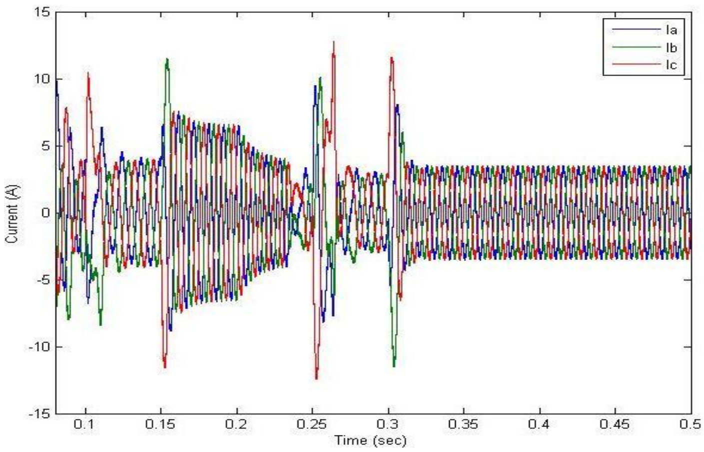

Figure 5. Current response of MRAS based PMSM drive with reference values shown in Table II.

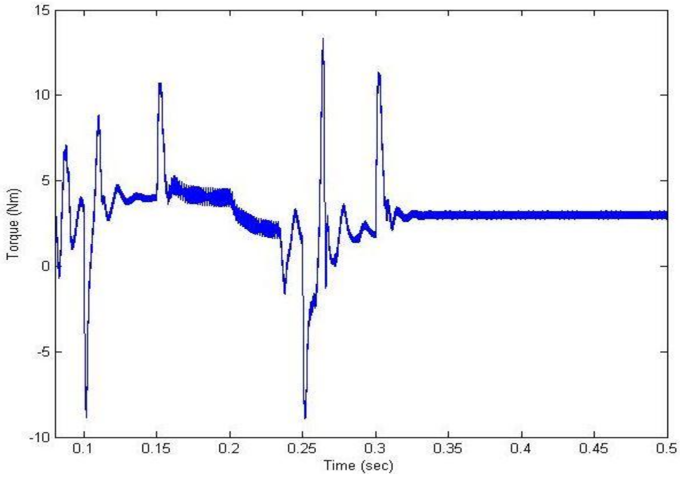

Figure 6. Torque response of MRAS based PMSM drive with reference values shown in Table II.

From Figure 3, it can be seen that speed tracking has some overshoot and delay in beginning due to poor initial parameters of simulation but after 0.3 seconds, model reference adaptive control based technique track the speed variation satisfactorily with some overshoot and less settling time. Figure 4 shows position tracking capability of MRAS with very few ripples.

Similarly, the current response is also not good before 0.3 seconds but after that its spikes are reduced within the limits as shown in Figure 5. The torque variation is larger at the change in speed in beginning but latter these variations are under the limits. From Figure 6, it can be seen that current in all the phases are balanced during the steady state condition. The phase current is different at the sudden change in the speed but these values are less after 0.3 seconds.

Table III shows various performance evaluating parameters. On the basis of these parameters the operation of the MRAS based PMSM drive has been analyzed. The maximum error is approximately 3.70 % which at overloaded condition. During the normal and under-loaded conditions, this error is very small.

TABLE III. VARIOUS PERFORMANCE PARAMETERS FOR MRAS BASED PMSM DRIVE

Performance Parameters	**Values approx..**
Steady State Error (at 1500 rpm, 3 Nm)	0.05%
Steady State Error at overload (at 1600 rpm, 4 Nm ref.)	3.70%
Steady State Error at underload (at 1200 rpm, 2 Nm ref.)	0.01%

CONCLUSION

In this paper, a Model Reference Adaptive System (MRAS), a sensorless estimation technique is implemented for a Permanent Magnet Synchronous Motor (PMSM) drive to evaluate the rotor angle and its speed. The drive performance is observed and analysed using vector control scheme. The current and voltage stator quantities are utilized for this purpose. The estimated values of speed and angle are obtained and used for dq to αβ conversion.The results demonstrate MRAS a promising tool for the purpose in terms of speed tracking capability of drive, position tracking, accuracy, reliability and complexity of the estimation technique.

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